A sustainable approach for the tunnel formwork building method

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Preface

This research marks the culmination of my Master's program in Civil Engineering at Delft University of Technology. Within this program, I specialized in Structural Engineering, focusing on Concrete Structures. Throughout my master's studies, I recognized the growing imperative for sustainability in the construction sector. Having practical experience in the construction field from a previous study, I aimed to contribute to this need through my master's thesis, seeking a topic that could have practical applications in the building sector.

The inspiration for this research came from a conversation with Marco Schuurman, who highlighted the necessity for a sustainable approach to the tunnel formwork building method. Intrigued by the prospect, I conducted a preliminary literature review, confirming that this research aligned perfectly with my aspirations for a master's thesis. This journey has been one of intellectual growth, challenges, and discoveries, and I am privileged to present the outcomes of my research.

I owe a debt of gratitude to my Graduation committee for their unwavering support and encouragement. Their guidance and expertise have been invaluable at every stage of this thesis. My heartfelt thanks to Max, Marco, and Hans for their commitment to academic excellence.

I extend my appreciation to the suppliers and building companies, including BAM, Cugla, and ENCI, for their assistance in providing crucial information.

Finally, I want to express my deepest thanks to my family, especially my mother and sister, my friends, and my colleagues from work (Constructie-adviesbureau S3) for their patience and support throughout the completion of this master thesis.

Lars Verkade
Alphen aan den Rijn, December 2023

Summary

The construction sector plays a significant role in the environment, and concrete structures constitute a substantial portion of this sector. The government is actively seeking ways to reduce the environmental impact of construction activities by promoting a more sustainable approach. In the Netherlands, a considerable number of repetitive cellular residential buildings are constructed using the tunnel formwork building method. Although this method can be enhanced in terms of sustainability by utilizing environmentally friendly cement mixtures, it poses challenges, such as an increase in execution time. This research aims to explore a more sustainable approach to the tunnel formwork building method while devising strategies to maintain the same execution time as before.

The tunnel formwork building method operates with a 24-hour daily execution cycle. During the initial 8 hours, the formwork, reinforcement, and installations are set up, followed by pouring concrete at the end of the day. After 16 hours, the concrete attains sufficient strength for the formwork to be dismantled, allowing it to be placed on the next grid. This approach results in rapid construction, high-quality output, and cost-effectiveness. However, a significant drawback is the reliance on CEM I mixtures, which consist of approximately 100% Portland cement, contributing to substantial greenhouse gas emissions and environmental impact. Blended cement mixtures, such as CEM II and CEM III, offer more environmentally friendly alternatives by incorporating lower percentages of Portland cement blended with fly ash or blast furnace slag. Despite their environmental benefits, these mixtures exhibit a slower strength development, making it challenging to achieve a hardening time of 16 hours.

In pursuit of a dependable and sustainable approach to the tunnel formwork building method that preserves the 24-hour daily cycle, the research question is articulated as follows: "What concrete mixtures and execution strategies can be applied in the Netherlands to diminish the environmental impact of the traditional tunnel formwork building method, utilizing sustainable cement mixtures, while upholding existing advantages in time, cost, and quality?" This research question will guide the exploration of optimal concrete mixtures and execution measures for implementing sustainable cement mixtures within the tunnel formwork building method, while ensuring the continuity of the daily execution cycle.

In addressing this research question, an Excel calculation sheet has been developed. This sheet serves to compute the material costs, shadow costs, and formwork removal time associated with specific modifications in the design, concrete mixture, and additional execution measures for the tunnel formwork building method. The calculation sheet offers flexibility with three grid sizes: 4.5m, 6.0m, and 7.2m. It incorporates various concrete properties, such as the cement mixture (CEM I, CEM II, or CEM III), w/c ratio (0.45 or 0.55), aggregate types (fine and coarse), Blaine value (300 or 400m^2/kg), and admixtures (basic and additional). Additionally, the calculation sheet allows for adjustments in seasonal conditions, with options for summer (20°C) or winter (10°C). The potential additional execution measures include internal heating, external heating, the maturity process, different formwork, and prechamber of the formwork. Users can select the grid size, define the concrete mixture composition, choose additional execution measures, and the calculation sheet will subsequently determine material costs, shadow costs, and formwork removal time. This calculation sheet facilitates the computation of 69 variations, comparing the currently employed cement mixture (CEM I) with two sustainable alternatives (CEM II and CEM III). The analysis encompasses material costs, shadow costs, and execution time. Utilizing the calculation sheet, adjustments in concrete mixtures and execution measures for employing the tunnel formwork building method in both summer and winter conditions are determined for three grid sizes, with the three cement mixtures. The influence of various concrete properties on costs and formwork removal time is derived from literature research and information provided by suppliers in the Netherlands. Strength development and reinforcement calculations adhere to the Eurocode standards.

A comprehensive calculation sheet was developed, drawing on insights gleaned from existing literature and input from experts in the construction field. The sheet was instrumental in generating 69 variations, encompassing various properties of the tunnel formwork building method. Subsequent analysis of

these variations highlighted the significant impact of design modifications, concrete mixture composition, and additional execution measures on the costs and formwork removal time associated with the tunnel formwork building method. The ensuing discussion provides a brief overview of the results pertaining to these three influential properties of the tunnel formwork building method.

With the use of the Eurocode and a literature review the effect of the design of the structure on the costs and striking time can be determined. The material requirements for concrete and reinforcement in a structure are influenced by the properties and dimensions of the structure. Smaller grid sizes necessitate more concrete but require less reinforcement when compared to larger grid sizes. This results in higher material and shadow costs for large grid sizes. When the striking stress remains constant across all grid sizes, the span does not affect the execution time. In scenarios where the striking stress varies, structures with the smallest grid size would exhibit the fastest striking time, given that the smallest grid size corresponds to the lowest striking stress.

The composition of the concrete mixture plays a pivotal role in determining material costs, shadow costs, and execution time. Various parameters within the concrete mixture, including the cement mixture, w/c ratio, aggregate, Blaine value, admixtures, and curing temperature, exert significant influence on these factors. Among these, the cement mixture and w/c ratio stand out as the most influential in determining execution time. Cement mixtures with higher percentages of Portland cement tend to result in faster execution times, albeit with higher material and shadow costs. Additionally, lower w/c ratios, higher Blaine values, the addition of accelerators, and elevated curing temperatures contribute to accelerated execution times. The effect of the concrete properties on the costs and striking time are determined thought the use of a literature review.

With the use of the Eurocode and a literature review the effect of the additional execution measures on the costs and striking time can be determined. Implementation of execution measures, such as internal and external heating, contributes to a reduction in execution time but concurrently leads to an increase in material and shadow costs. Likewise, the integration of measures like the maturity process and the addition of an extra row of struts into the formwork serves to decrease the striking stress, particularly for smaller spans.

In summary, a calculation method has been devised based on the most reliable information available in the literature. A comprehensive study involving 69 variants reveals that it is indeed possible to reduce the environmental impact of the tunnel formwork building method through the incorporation of sustainable cement mixtures. However, this necessitates adjustments in concrete mixtures and the implementation of additional execution measures. During the summer, it is feasible to achieve execution times below 16 hours with sustainable cement mixtures, resulting in reduced costs compared to the current cement mixture. In winter, while execution times below 16 hours are attainable with sustainable cement mixtures, the overall costs are higher than those associated with the current cement mixture. Nevertheless, the environmental benefits of these mixtures outweigh the cost considerations. It's noteworthy that the amount of Portland cement emerges as the most influential factor affecting both costs and formwork removal time. Additionally, this study distinguishes itself by consolidating various properties into a single calculation sheet, a methodology not commonly observed in other research papers.

Nomenclature

Abbreviations

Abbreviation	Definition
TFBM	Tunnel formwork building method
ECI	Environmental Cost Indicator
LCA	Life Cycle Assessment
W/C	Water cement ratio
GGBS	Ground granulated blast furnace slag
UC	Unity check
SLS	Serviceability Limit State
LCA	Ultimate Limit State

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1 Research framework

The initial chapter of the report will describe the research framework. Constructing a research framework requires the formulation of a problem statement, explaining the rationale behind the research, and an exploration of the current state of the topic. This foundational chapter will encompass essential elements such as research questions, objectives, methodology, and an overarching outline of the research study.

1.1. Problem statement

The construction sector plays a significant role in environmental impact, contributing to 32% of global energy consumption [1]. The majority of materials utilized are non-renewable resources, leading to substantial emissions of greenhouse gases and a significant contribution to global warming [2]. According to the European Environment Agency, almost half of all materials entering the global economy are consumed in the construction and maintenance of the built environment, generating approximately 20% of all greenhouse gas emissions [3]. In the Netherlands, 80% of building materials used in utility and residential construction consist of concrete [4]. Consequently, concrete has the most significant environmental impact in the Dutch building sector, making it crucial to explore ways to mitigate this impact.

Approximately 50% of high-rise residential buildings in the Netherlands are constructed using the tunnel formwork building method [5]. This approach, a 16-hour execution process often employed for serial housing projects, involves setting up formwork, including reinforcement and installation facilities, pouring concrete, and removing the formwork after 16 hours. This rapid building process, advantageous in terms of time, cost, and quality, is commonly used for high-rise residential buildings [6]. However, the standard concrete mixture used includes Portland cement, known for its high heat evolution and rapid hardening process, but also for significant greenhouse gas emissions [7]. The production of one ton of Portland cement clinker releases about one ton of carbon dioxide and requires around 4 GJ of energy, contributing to approximately 5% of global carbon dioxide emissions [8, 9]. Blended cement mixtures, where supplementary cementitious material replaces ordinary Portland cement, have been explored as alternatives to reduce CO2 emissions [10].

The question arises: can these alternative mixtures, considered sustainable, meet the 16-hour cycle requirement and other advantageous properties of the tunnel formwork approach? If not, what measures must be taken to achieve a 16-hour building cycle? It is a known principle that concrete structures must reach a specific compressive strength before removing the formwork. In the Netherlands, a common practice dictates that formwork can be removed for load-bearing structures when a compressive strength of 14 MPa is reached. However, it remains unclear where this practice originates and whether a lower compressive strength could be acceptable for structures with smaller spans. The NEN-EN provides some insights into the use of 14 MPa, but questions linger about whether there should be requirements for tensile strength and deflection, or if compressive strength always takes precedence [11].

A concrete structure, cast on-site with a formwork, must achieve a specific compressive strength before the formwork can be removed. In the case of concrete structures employing Portland cement, this critical compressive strength is typically attained after 16 hours, and the determination can be made on-site using a method known as the maturity method [12]. Predicting the compressive strength development of concrete beforehand poses challenges due to various factors influencing the strength development, such as cement type, water content, aggregate properties, admixtures, Blaine value, season, and curing temperature. Formulating a comprehensive formula to predict the compressive strength development of a concrete structure, considering all these diverse properties, proves challenging. Therefore, the question arises: is there an effective approach to predict the development of compressive strength, tensile strength, and deflection in a concrete structure?

1.2. State of the art

The sustainability of construction methods is becoming an increasingly crucial consideration in the face of global environmental challenges. Among these methods, the tunnel formwork building technique has gained prominence for its efficiency in constructing serial high-rise residential buildings. This section presents an overview of current knowledge and research concerning the sustainability aspects of the tunnel formwork method.

The tunnel formwork building method, a 16-hour execution process primarily employed for serial housing projects, has evolved to meet the demand for swift and cost-effective construction. This method produces a monolithic concrete structure, casting walls and floors in a single operation [6]. Currently, the tunnel formwork method predominantly employs CEM I in its concrete mixture due to its rapid hardening properties, enabling the removal of formwork after 16 hours. However, the extensive use of CEM I, mainly composed of Portland cement, poses significant environmental challenges [7].

While numerous studies have explored the tunnel formwork method, emphasizing its time efficiency and cost-effectiveness, a critical gap exists in understanding its environmental sustainability. Existing research predominantly focuses on the method's speed and economic advantages, overlooking its broader ecological impact. The literature review highlights a lack of knowledge regarding the environmental consequences of employing traditional materials, particularly Portland cement, in this construction method. Studies often compare the tunnel formwork building method with other traditional techniques, emphasizing time efficiency and cost-effectiveness [13] [14].

With sustainability taking center stage in construction practices, emerging trends indicate a growing interest in alternative cement mixtures and construction materials. Blended cement mixtures, incorporating supplementary cementitious materials (SCM), have demonstrated the potential to reduce CO2 emissions, offering a promising avenue for sustainable tunnel formwork construction [10].

In conclusion, while the tunnel formwork method has been extensively studied for its speed and economic advantages, a critical evaluation of its sustainability aspects remains notably absent. This study aims to fill this gap by exploring the ecological implications of the tunnel formwork method, providing valuable insights for the construction industry's transition toward more sustainable practices.

1.3. Research objective

The primary objective of this research is to develop an approach for the tunnel formwork building method that effectively reduces the environmental impact of the entire building system. The current concrete mixture used in this method exhibits rapid curing, but unfortunately, it generates a substantial amount of CO2 emissions. To mitigate these emissions, an alternative concrete mixture must be identified. However, it is expected that the use of this alternative mixture may result in longer curing times. Consequently, this research will center on the development of a comprehensive calculation sheet that incorporates key properties of the concrete mixture and execution measures. The aim is to minimize the environmental impact and striking time of the tunnel formwork approach. The calculation sheet must fulfill the following requirements:

- First and foremost the environmental impact should be lower than the current process.
- Secondly the current building cycle of 16 hours needs to be guaranteed as much as possible. If it turns out this is not possible, it needs to be compensated in costs.
- Thirdly the high quality of the building process needs to be guaranteed.
- Lastly the construction costs need to stay as low as possible.

1.4. Research questions

To obtain the research objective, the following main research question is formulated:

What concrete mixtures and execution strategies can be applied in the Netherlands to diminish the environmental impact of the traditional tunnel formwork building method, utilizing sustainable cement mixtures, while upholding existing advantages in time, cost, and quality?

This research concentrates on three primary aspects that impact the costs and execution time of the tunnel formwork building method: the design of the structure, the composition of the concrete mixture, and additional execution measures. Consequently, the main research question can be subdivided into three sub-questions, each with its own set of sub-sub-questions:

1. **What is the impact of the structural dimensions and properties on the material costs, environmental costs (shadow costs), and execution time in the tunnel formwork building method?**
    - What are the current executions processes, requirements, advantages and disadvantages for the tunnel formwork building method?
    - How does the grid size of the tunnel formwork building method influence the material costs, environmental costs (shadow costs), and execution time?
    - What is the function of an environmental cost indicator and what are the LCA-values associated with the components used in the tunnel formwork building method?
2. **What impact does the composition of a concrete mixture have on the material costs, environmental costs (shadow costs), and execution time within the tunnel formwork building method?**
    - What are the properties of the current cement mixture, Portland Cement (CEM I), used in the cold tunnel formwork building method?
    - What are the properties of the PC-fly ash cement for the tunnel formwork building method?
    - What are the properties of the PC-blast furnace cement for the tunnel formwork building method?
    - What specific properties of a concrete mixture affect the hardening time in the context of the tunnel formwork construction building method?
    - In what ways do the various properties of concrete mixtures, including cement mixture, w/c ratio, aggregate size and type, admixtures, Blaine value and curing method, influence the material costs, environmental costs and, execution time of tunnel formwork building method?
3. **How do additional execution measures affect the material costs, environmental costs (shadow costs), and execution time in the tunnel formwork building method?**
    - What are the different internal/external measures that can be taken to decrease the execution time of the tunnel formwork building method while keeping in mind a more environmentally friendly approach?
    - What are the detailed requirements that need to be determined to ensure that the concrete mixture is strong enough for the removal of the tunnel formwork and can these requirements be decreased to increase the striking time?
    - Does a different tunnel formwork have benefits for a more sustainable tunnel formwork building method?
    - In what ways can additional execution measures, such as internal and external measures, a maturity process and a different formwork, influence the material costs, environmental costs and execution time of tunnel formwork building method?

1.5. Research methodology and outline

In order to achieve the research objective and address the research questions, a calculation sheet will be developed to establish a connection between the design of the structure, the concrete mixture and execution measures for the tunnel formwork building method. The research will be divided into three parts, excluding the research framework and final remarks. The first part, which is the literature review, aims to provide background information, which will be used to determine input values for the calculation sheet. The second part will focus on the methodology of the calculation sheet. The final part is the main research, where the analysis of the calculation sheet will be researched. See figure 1.1 for a flowchart of the thesis structure. The following section provides an explanation of the contents and the methods used to obtain results for each part.

Part 1: Research framework. The research framework is meant to give an introduction to the the research. Furthermore a problem statement and the state of the art is given. This first chapter also covers the approach to the research, which includes the research objective, questions, methodology and the outline of the report.

Part 2: Literature review. The literature review for this master thesis will comprehensively cover the background, theory, and current state of several key topics. Firstly, it will delve into the tunnel formwork building method, providing an in-depth explanation of the current execution process. This analysis will identify the requirements, advantages, and disadvantages of this method, which will serve as the foundation for developing a suitable calculation sheet.
Additionally, the literature review will explore the environmental cost indicator (ECI) and conduct a life cycle assessment (LCA). The ECI and LCA will be utilized to compare the existing execution method with the proposed new method, which will be the focus of this research. This portion of the review will shed light on the environmental implications and potential improvements of the proposed method.
Moreover, the literature review will investigate the cement mixtures used in tunnel formwork building. Firstly, it will examine the chemical and mechanical properties of the current cement mixture, which is predominantly Portland cement. Furthermore, the review will explore more sustainable alternatives such as PC-fly ash cement and PC-blast furnace slag cement, providing detailed explanations of their chemical and mechanical properties.
Lastly, the review will analyze the properties of the concrete mixture. Special attention will be given to factors that influence strength development, including the w/c ratio, aggregate type and size, admixtures, Blaine value, and curing temperature. This comprehensive examination will provide valuable insights into optimizing the concrete mixture for tunnel formwork building.
Overall, the literature review will establish a solid foundation for the subsequent research, offering a thorough understanding of the background, theory, and current state of the tunnel formwork building method, environmental cost indicator, cement mixtures, and concrete properties.

Part 3: Methodology of the calculation sheet. This section will focus on developing a comprehensive calculation sheet that incorporates the properties of the structure, concrete mixture, and execution measures. The insights gained from the literature review will be utilized to construct this calculation sheet for the research. The calculation will consider various input values such as the structural properties, concrete mixture design, and additional execution measures. To ensure practical validation, the calculation will be modeled using three different grid sizes.
The design of the concrete mixture in the calculation sheet will encompass factors such as quality, cement mixture, w/c ratio, type of aggregate, admixtures, Blaine value, and curing temperature. Furthermore, the calculation sheet will incorporate four optional execution measures, including internal and external heating, maturity process, and a different formwork. The output values of the calculation sheet will include building costs, environmental costs (shadow costs) and execution time.
To establish a benchmark, calculations will be performed for each grid size using a concrete mixture currently employed in practice. This benchmark will consist out of Portland cement (CEM I 52.5R), a w/c ratio of 0.55, 40% fine aggregate, 60% coarse aggregate, no admixtures, a Blaine value of 300 m^2/kg, a curing temperature of 20°C, and no additional execution measures. Once the benchmark is established, nine variations will be calculated for each sustainable cement type and grid size. These variations will include a base variation and eight variations where parameters such as the w/c ratio, Blaine value, admixtures, season and the four optional execution measures will be modified. For each sustainable cement mixture and grid size two variations are added, one in the summer and winter where applications are made until the striking time is below 16 hours.

At the end of this chapter, hypotheses will be formulated for each variant, providing valuable insights and predictions for the subsequent stages of the research.

Part 4: Analysis of the calculation sheet. The primary objective of this research is to investigate strategies for mitigating the environmental impact associated with the tunnel formwork building method. Part 4 will focus on analyzing the calculation sheet, specifically examining the influence of the concrete mixture and execution measures on material costs, environmental costs (shadow costs) and execution time. Several parameters of the concrete mixture will significantly impact these factors, including the cement mixture, w/c ratio, aggregate type, admixtures, Blaine value, and curing temperature. Additionally, the research will explore the impact of additional execution methods such as internal and external heating, the maturity process, and the use of different formwork on material costs, environmental costs and execution time.
Subsequently, the results obtained from each variant of the calculation will be thoroughly analyzed. This analysis will facilitate the identification of the most optimal option, which can be implemented as an alternative in practice for the tunnel formwork building method.

Part 5: Final remarks. The final remarks are the discussion, conclusion and the recommendation. The discussion will cover the promising aspects of the research. In the conclusion the answers, a summary and the significance of the thesis are given. Lastly, the recommendations for future improvements of the research will be presented.

Additionally, building companies and formwork suppliers will be contacted to gain a deeper understanding of the building method and to obtain their opinions on my research objective and questions.

The following programs and applications will be used for the thesis:

- Overleaf/La Tex for the documentation of the report.
- Excel for the calculation sheet.
- Matrixframe for calculations.

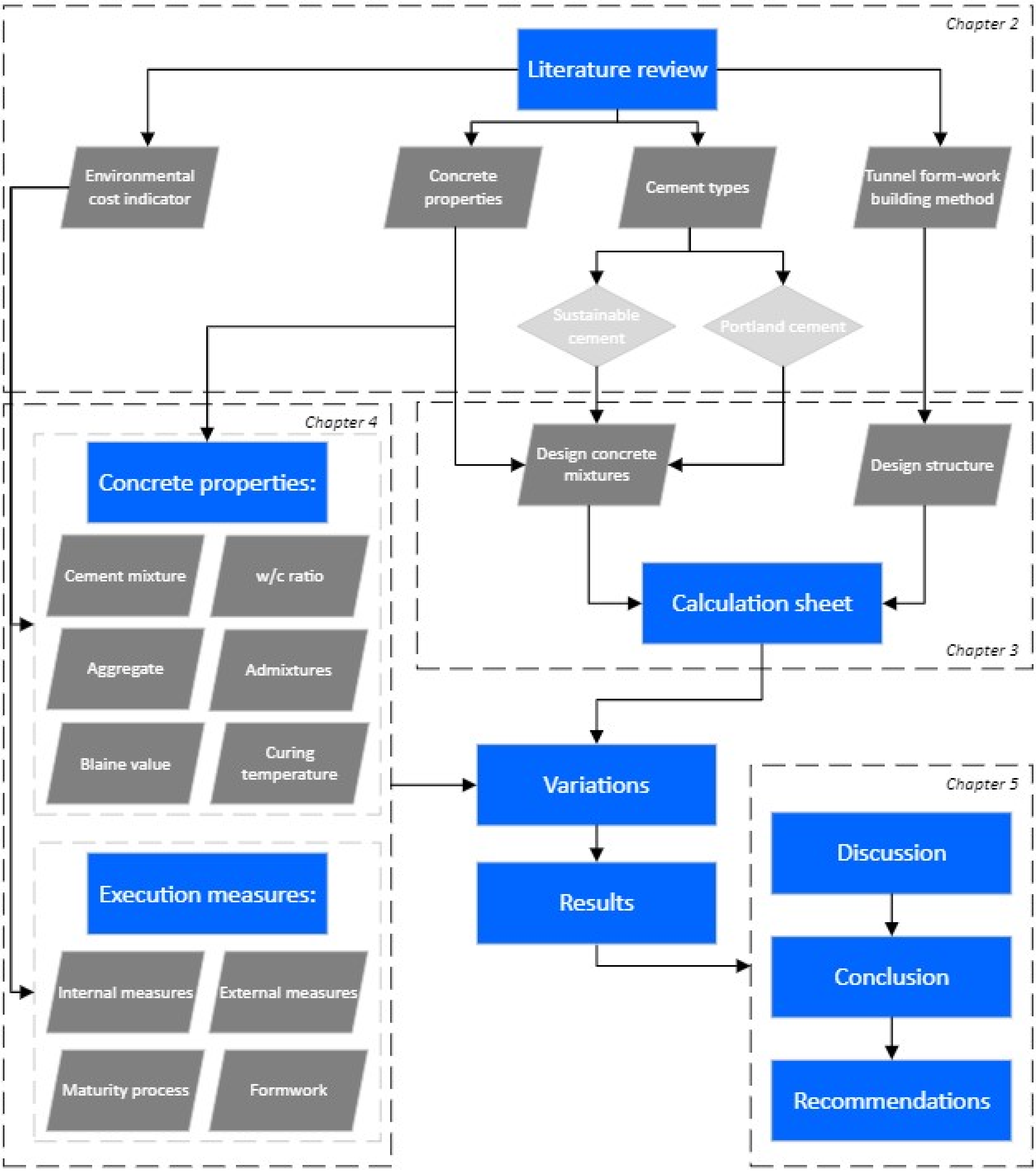


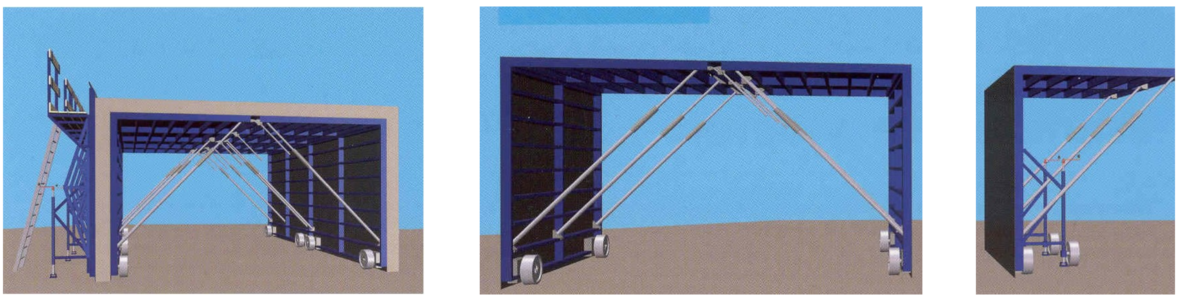
Figure 1.1: Flowchart of the thesis structure

2 Literature review

2.1. Tunnel formwork building method

The tunnel formwork building method is a cast-in-situ reinforced concrete structure comprising of uniform walls and slabs. These walls and slabs are cast in a single pour into a tunnel formwork, resulting in a monolithic cellular structure that enables a fast (a daily cycle), systematic, and high-quality building process. The method is highly repetitive and has an effective load-bearing structure, making it particularly suitable for mass housing and fast building projects that require a lot of repetition [15]. Approximately 50% of high-rise residential buildings in the Netherlands are constructed using the tunnel formwork building method [5]. Klink Bekistingen and Hendriks Stalen Bekistingtechniek are two of the largest suppliers of steel formworks in the Netherlands, capable of delivering formworks ranging from 2 to 9.55 meters in span. The height of these formworks is approximately 2.55 meters. The costs of a formwork are initially high, but is eventually compensated by: the number of repetition, low maintenance costs and fast construction process. Multiple tunnel formworks are used for each project, which will be poured in a single pour. This will result is a uniform structure. A crane is utilized for positioning the formwork, supplying materials, and pouring the concrete. There are three types of formwork applied in the Netherlands:

1. **A full tunnel form** covers the entire depth of a building, which are used for systematic low-rise buildings. For these low-rise buildings with varying grid sizes, a fitting piece is used in the formwork deck. The crane movements required are minimal, but a high lifting capacity is necessary. See figure2.1a
2. **Segmented tunnel forms** are used for structures with varying heights, widths, and depths. The depth of this formwork is either 1.2 or 2.4 meters. These types of formworks provide a lot of adaptability. However, more crane movements are required, but the lifting capacity is lower. See figure 2.1b
3. **A half tunnel form** is utilized when the span is large. Half tunnels provide the opportunity for two-phase formwork removal. After removing the first half, the floor can be partially supported to prevent excessive long-term deflection during hardening. See figure 2.1c



(a) Full tunnel form **(b)** Segmented tunnel form **(c)** Half tunnel form

Figure 2.1: Three types of formworks (source: Stubeco)

2.1.1. Execution process

The execution process of the tunnel formwork building method is a fast and repetitive process that is carried out by specialized contractors. It is essential that the construction workers are adequately trained to optimize coordination between workers and crane movements for maximum productivity. To gain a better understanding of the tunnel formwork building method, a construction site was visited, and photographs were taken. See Figure 2.3 for images of some important details of the process. The execution time follows a daily cycle, see 2.2 for a schematic overview of the execution process. The repetitive steps involved are explained in detail below:

Step 0 involves the construction of the foundation and ground floor, and is named as such because it is not used for the remaining execution cycle. During this step, piles are driven into the ground, foundation beams are constructed, and ground floor slabs are placed. It is crucial to extend the reinforcement through the foundation to connect it to the reinforcement of the walls above. Additionally, it is important to pour the kickers with the foundation, as they are used to position the formwork above. See sub-figure A of figure 2.3 for a photograph of the kickers and starting reinforcement.

Step 1 is the first stage of the cyclical process which involves the placement of formwork, wall and slab reinforcement, and installations. The first step is always done in the morning. It's important that finishing materials, such as internal masonry and insulation materials, are place on the floor below before the formwork is placed. The formwork is lifted by a crane and positioned on top of the kickers. It is comprised of two inverted L-shapes that are bolted at the top and equipped with wheels and jacks to facilitate its accurate placement. The wall reinforcement is then connected to the starter bars located below. It is essential that the wall reinforcement extends above the floor level to enable the attachment of the subsequent wall reinforcement and create a monolithic structure. An end wall formwork is applied to enclose the structure at the end, while continuity strips are installed in the walls and floors where the structure continues. Additionally, the floor reinforcement is placed, and centre ties are applied to prevent the formwork from buckling. See sub-figure B of figure 2.3 for a photograph of the continuity reinforcement. See sub-figure C of figure 2.3 for a photograph of the hole that the centre ties were applied.

Step 2 involves pouring concrete into the formwork. This step is typically conducted in the afternoon. Concrete can be poured using either hoses or a skip, both of which are lifted into place by a crane. It is crucial to pour the walls before the floors to avoid any spillage.

Step 3 of the process involves the hardening of the concrete which takes place during the night. To speed up the hardening process, heaters, insulation, and a fast-hardening cement mixture are used. Further information about accelerating the process can be found in the execution time chapter. The heaters are typically powered by gas, but it is crucial to note that storing gas is prohibited in residential areas. Therefore, alternative power sources such as electricity are used. A photograph of the heaters can be found in sub-figure D of figure 2.3.

Step 4 marks the final stage of the cyclical process, which involves removing the formwork and relocating it to a new position. The crane is used once again to move the formwork. In cases where the grid size is large, a precamber of the slab is applied to normalize its deflection. A photograph of a completed tunnel formwork construction with a prechambered slab can be found in sub-figure E of figure 2.3. Following this step, the cycle begins again with step 1.

The information presented above has been obtained through various sources, including interviews with contractors, on-site visits to the ”Frank is een Binck” project, and my own knowledge on the subject.

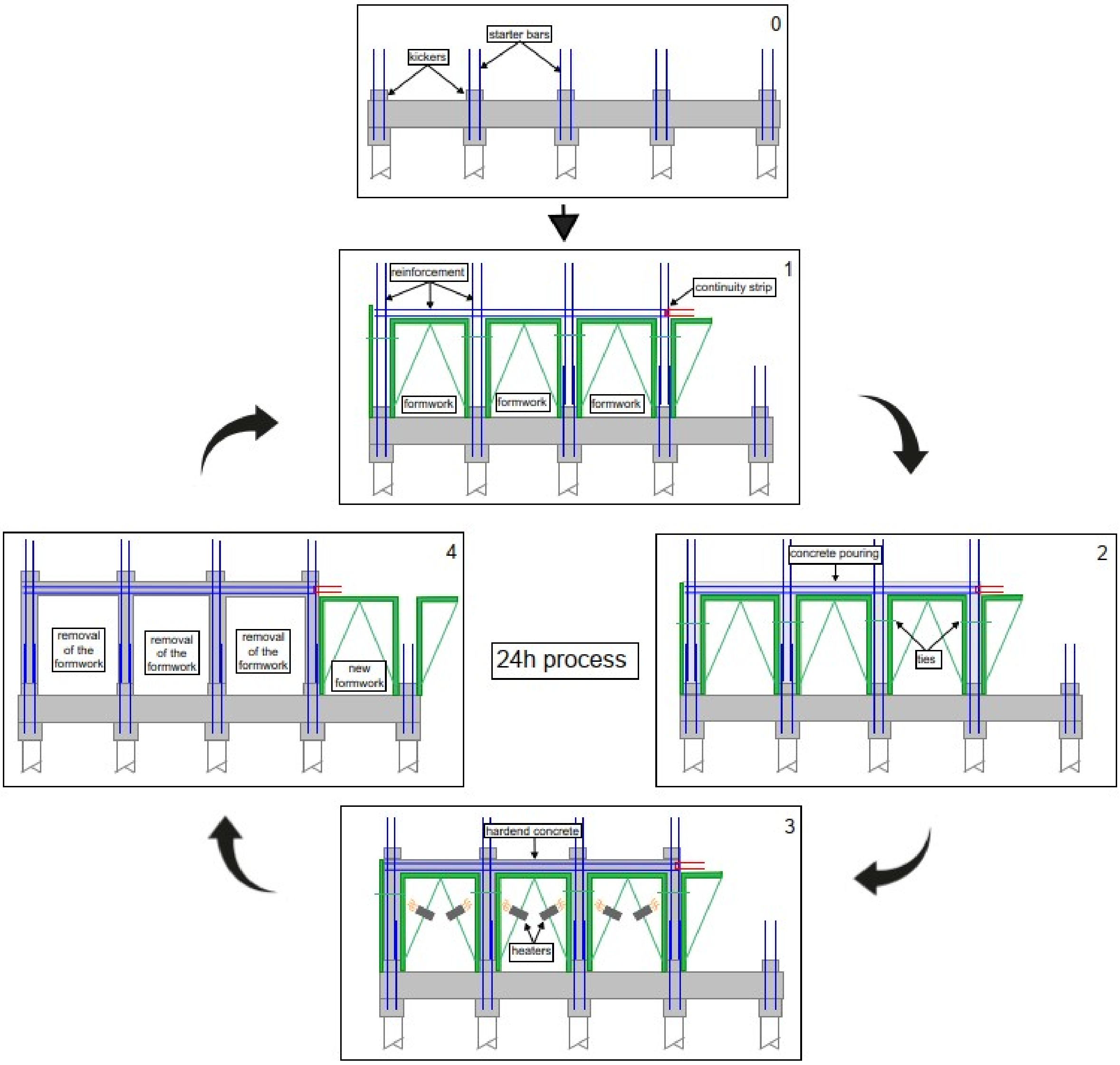


Figure 2.2: A schematic overview of the execution process (source: own drawing)

Figure 2.3: Details of the tunnel formwork building method. A: Kickers + starter bars. B: Continuity strip. C: Ties. D: Heaters. E: Precamber.(source: own photo's)

2.1.2. Execution time

One of the key advantages of the tunnel formwork building method is its fast execution time of only 24 hours per cast (this includes placement of the formwork and reinforcement). However, the hardening time of the concrete is critical, as the formwork is required for the next grid. The rate of heat generation during the hardening process corresponds to the rate of strength gain, and the temperature of the concrete can significantly influence its strength development [16]. According to the NEN-EN 13760 building code, the minimum cube compressive strength required is 14 MPa before the formwork can be removed (more research on the striking stress will be done in chapter 4). To achieve this strength within the 16-hour time frame between casting and the removal of the formwork, several measures can be taken. Below are some of the measures that can be implemented to improve execution time.

Cement mixture:
The type of cement used in a concrete mix plays a critical role in the hardening process. For instance, CEM I, a concrete mix containing Portland cement, has a fast early development due to the large amount of Alite (C3S) present, which leads to high heat evolution [17]. As illustrated in figure 2.4, concrete with Portland cement exhibits faster strength development than, for instance, slag cement mixture (CEM III). More information on the strength development of various cement mixtures will be provided in the cement mixture section of the literature review chapter.

Concrete mixture:
Several parameters can affect the heat evolution and, consequently, the strength development of a concrete mixture. Apart from the cement mixture, these parameters include the w/c ratio, aggregate type and size, admixtures, and curing method. A higher w/c ratio can lead to a greater heat evolution as more water is available to react with the cement [18]. The type and size of the aggregate used can also impact the rate of heat evolution, with larger aggregates absorbing more heat and smaller aggregates providing a higher surface area for reaction (aggregates won't contribute much to the strength development of concrete) [19]. Admixtures such as accelerators can speed up strength development, but they are best used in low temperatures and with a low w/c ratio. The curing method, which is discussed in more detail in the section on applying heat, can also influence strength development. Further research on the parameters of the concrete mixture that influence the strength development is done in section 2.4.

Applying heat:
Applying heat to concrete can accelerate the hardening process by increasing the temperature and thereby speeding up the chemical reactions that occur during curing [20]. There are several ways to apply heat to the concrete structure hot water curing, and heaters [21]. Insulating the formwork can help to retain the heat of the concrete, and insulated cover sheets or cover caps can be used for this purpose. Hot water curing can be done by either applying warm water to the concrete mix or circulating hot water through pipes embedded in the concrete. Heaters can also be attached to the tunnel formwork to heat up the young concrete. The heating process typically involves heating the concrete to a temperature of 50°C to 65°C for the first eight to eleven hours, followed by a cooling period of six to nine hours. This can help to reduce the propagation of cracks [22].

Maturity method (NEN 5970):
The maturity method is used for measuring the strength development of concrete over time. According to Professor Guang Ye the definition of the maturity method is: "A technique for estimating concrete strength that is based on the assumption that samples of a given concrete mixture attain equal strengths if they attain equal values of maturity index". The maturity index is an indicator of maturity that is calculated from the temperature history of the cementitious mixture by using a maturity function. The maturity index has a relation with the strength of concrete. A way to calculate the maturity index is with the use of the Temperature-Time Factor (TTF), see equation 2.1.

$$M(t) = \sum (Ta - To)\Delta t \tag{2.1}$$

In equation 2.1 M(t) stands for the TTF at age t, Ta = average concrete temp during the time interval, To = datum temp and Δt = the time interval. The datum temperature represents a temperature below which no active hydration of cement is considered to take place. The datum temperature depends the type of aggregate, type of admixtures and the temperature of concrete at the time of hardening. The maturity method has several advantages over traditional methods of measuring concrete strength. It is non-destructive, meaning that the concrete can continue to cure and gain strength while being monitored. It is also more accurate than other methods, as it takes into account the effects of temperature on the rate of strength gain. Additionally, it can be used to estimate the strength of in-place concrete, allowing for more efficient scheduling of construction activities.

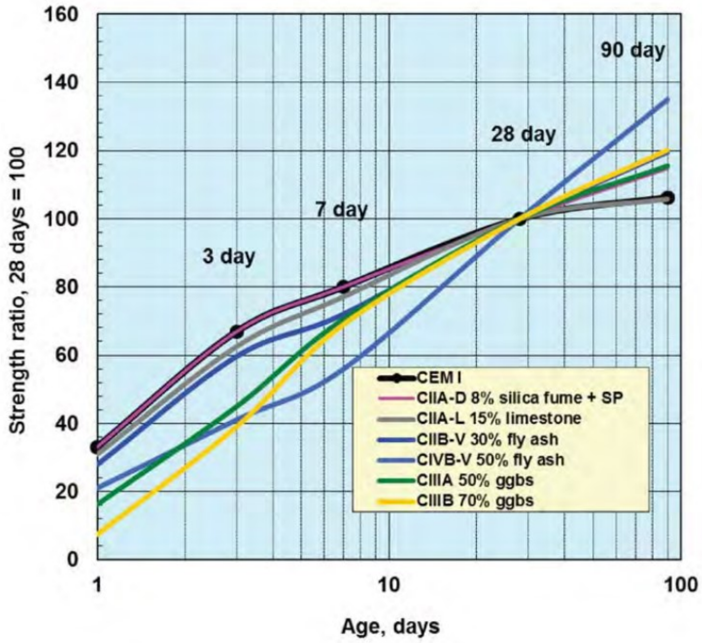


Figure 2.4: Strength development of different types of cement. (source: Chris Clear)

2.1.3. Advantages

The tunnel formwork building method gives multiple advantages as an execution process. The advantages are given below (the advantages are taken form the following sources [13] [7] [23]:

1. **The fast execution time** is the biggest advantage of the tunnel formwork building method. The method allows for a daily cycle of construction, thanks to the quick hardening of the concrete. The repetitive nature of the execution process also contributes to efficient construction. Additionally, the implantation of electrical conduits, water pipes, and gas pipes directly into the formwork can reduce the need for internal finishing work, further streamlining the construction process.
2. **The high quality** of the tunnel formwork building method is due to the prefabricated formwork, which result in consistent and accurate dimensions. The resulting smooth surfaces of the walls and slabs are ideal for finishing work, providing a high-quality and aesthetically pleasing final product.
3. **The costs** of the tunnel formwork building method are much lower compared to traditional construction method. The repetitive nature of the building process and the fast execution time result in reduced labour costs. Additionally, the early completion of the project can lead to cost savings compared to longer construction times associated with traditional methods.
4. **The safety** of the tunnel formwork building method is high. The repetitive nature of the building process reduces the risk of accidents and injuries on the construction site. Additionally, the scaffolding that is attached to the tunnel formwork provides a safe working environment for construction workers. These safety measures ensure that the construction process is carried out in a secure and controlled manner.
5. **The durability and structural integrity** of the tunnel formwork building method are high, due to cellular design.

2.1.4. Disadvantages

The tunnel formwork building method produces also some disadvantages. The disadvantages are given below (the advantages are taken form the following sources [13] [7] [23]:

1. **Limited flexibility:** The tunnel formwork building method is not as flexible as traditional formwork systems, which can be customized to suit different building designs. The method is best suited for buildings with similar floor plans and repetitive grid sizes.
2. **High initial cost:** The initial cost of setting up the tunnel formwork system is high, and it may not be economically viable for small-scale building projects.
3. **Size and safety:** A significant amount of crane movement is required during the construction process as it is needed for almost every step, such as the movement of the formwork and reinforcement, and the pouring of the concrete. This can increase the risk of safety, and in windy weather, the crane may not be able to be used.
4. **Coordination problems** can arise with the tunnel formwork building method due to its tight schedule, leaving no room for errors. It is crucial that coordination is well-planned and executed effectively. In addition, construction workers need to be highly skilled in this building method to ensure successful completion.
5. **Cement mixture (Portland cement):** The tunnel formwork building method requires a fast-hardening cement mixture due to its high execution time, and in practice, Portland cement (CEMI) is often used for the cold tunnel formwork building method. However, the use of Portland cement can result in a high production of carbon dioxide emissions, which has a negative impact on the environment.

2.2. Environmental cost indicator

The aim of this research is to identify an approach for the tunnel formwork building method that can reduce the environmental impact of the building system. To achieve this objective, Life Cycle Assessment (LCA) will be utilized to compare various cement mixtures with each other. LCA will be performed for each execution method, and combinations of cement mixtures and execution methods will be evaluated through LCA calculations.

The environmental impact of a building can be expressed as the environmental impact cost per year, also known as shadow costs. These shadow costs are calculated using the Life Cycle Assessment (LCA) method, which evaluates the environmental impact of a building throughout its entire life cycle [24]. The LCA consists of five stages: the production stage (A1-A3), the construction stage (A4-A5), the use stage (B1-B7), the end-of-life stage (C1-C4), and the re-use and recycle options (D). This research will focus on the product and construction stages, as indicated by the red box in Figure 2.5. So only the ECI information about Module A will be used in the research. This decision was made because the objective of the research is to improve environmental footprint the tunnel formwork building method right now. The use and end-of-life stages will be the same for all variations. The LCA will provide insight into the environmental impacts of different cement mixtures and execution methods, and the shadow costs associated with each option.

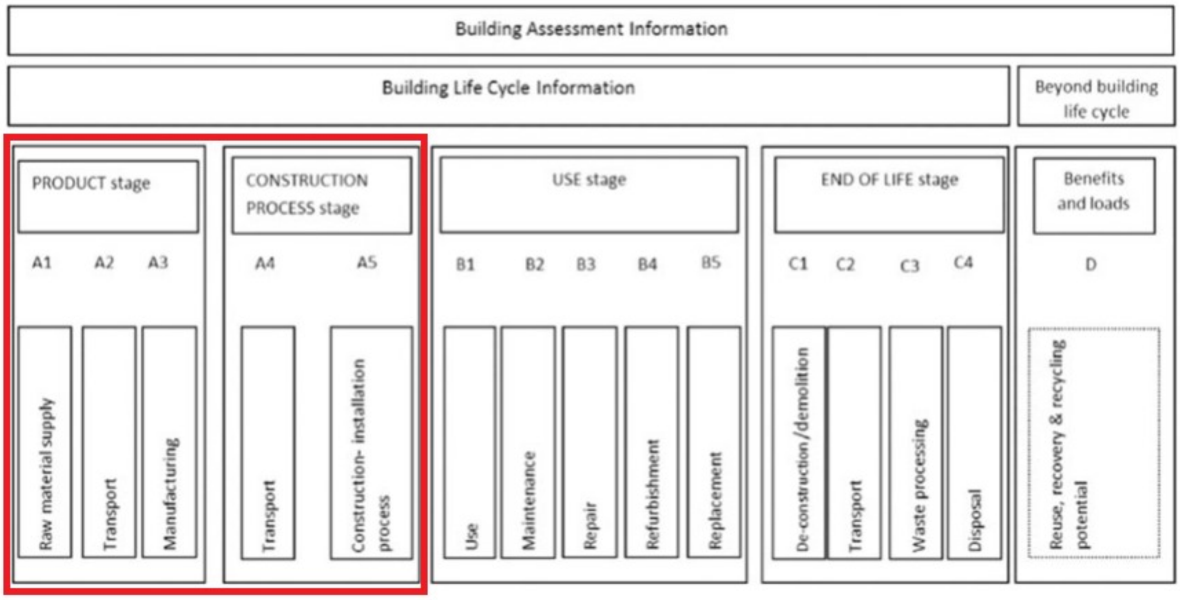


Figure 2.5: LCA overview (source: Henk Jonkers)

The procedure for performing a LCA calculation requires 4 specific steps (ISO 14040 standard):

1. **Goal definition:** The first step in LCA calculation is to define the goal and scope of the assessment. This involves identifying the purpose of the LCA, the process being evaluated, and the boundaries and assumptions of the assessment.
2. **Inventory analysis:**The next step is to conduct an inventory analysis, which involves collecting data on the inputs and outputs of the process being evaluated. This includes data on the raw materials, energy consumption, emissions, waste generation, and other relevant factors associated with each stage of the life cycle.
3. **Impact assessment:** Once the inventory data has been collected, the next step is to assess the environmental impacts associated with the process being evaluated. There are monetary values assigned to impact categories to weigh their environmental impact see table 2.6. In this step the ECI is also calculated, which follows the following steps:
    - The quantity of the input, output, processes and energy are determined.

- Each compound is allocated to a specific input category. See table 2.6 for the impact categories.
- The ECI is calculated, also known as the shadow costs. This is done by multiplying the monatary value times the quantity of the equivalent unit.

4. **Interpretation:** The final step in LCA calculation is to interpret the results of the assessment and draw conclusions about the environmental impacts of the process being evaluated. This involves identifying the key drivers of environmental impact, evaluating the sensitivity of the results to different assumptions and scenarios, and identifying opportunities for improvement and optimization.

Impact category	Abbreviation	Unit	Monetary value (€/unit)
Global Warming Potential	GWP	kg CO_2-eq	0.05 €
Ozone layer Depletion Potential	ODP	kg CFC-11-eq	30.00 €
Human Toxicity Potential	HTP	kg 1.4 DB-eq	0.09 €
Freshwater Aquatic Eco-Toxicity Potential	FAETP	kg 1.4 DB-eq	0.03 €
Marine Aquatic Eco-Toxicity Potential	MAETP	kg 1.4 DB-eq	0.0001 €
Terrestrial Aquatic Eco-Toxicity Potential	TETP	1.4 DB-eq	0.06 €
Photo-chemical Oxidation Potential	POCP	kg C_2H_4	2.00 €
Acidification Potential	AP	kg SO_2-eq	4.00 €
Eutrophication Potential	EP	kg PO_4^3-eq	9.00 €
Abiotic Depletion Potential Fuel	Fuel	kg Sb-eq	0.16 €
Abiotic Depletion Potential Non-Fuel	Non-Fuel	kg Sb-eq	0.16 €

Figure 2.6: Impact categories (source: Henk Jonkers)

2.3. Cement mixtures

This chapter focuses on conducting research on three distinct cement mixtures, namely Portland cement and two blended cement mixtures. The blended cement mixtures consist of Portland cement combined with either fly ash or blast furnace slag. By incorporating these alternative materials, the blended mixtures contain a reduced amount of Portland cement. This reduction in Portland cement content contributes to decreased CO2 emissions and thus also enhances the sustainability aspect. Through this investigation, we aim to evaluate the properties and performance of these cement mixtures in order to promote more sustainable construction practices. The following properties will be researched: manufacturing process, chemical composition, hydration process and strength development. Before the research can be started the different mixtures of cement, oxides and compounds need to be explained. See table 2.7a for the different cement mixtures of cement, see table 2.7b for the different types of oxides, see table 2.7b for the different types of compounds and see figure 2.9 for the nomenclature of cement used in the research.

Type	Name	Notation
I	Portland cement	CEM I
II	PC-slag cement	CEM II/A-S
	PC-pozzolan cement	CEM II/A-P
	PC-fly ash cement	CEM II/A-V
III	Slag cement	CEM III
IV	Pozzolanic cement	CEM IV
V	Composite cement	CEM V

(a) Different cement mixtures (source: P.Kumar Mehta)

Name	Oxide	Abbreviation
Lime	CaO	C
Silica	SiO_2	S
Alumina	Al_2O_3	A
Ferric oxide	Fe_2O_3	F
Magnesia	MgO	M
Sulfurtrioxide	SO_3	$\bar{S}$
Water	H_2O	H

(b) Abbreviations for Oxides (source: P.Kumar Mehta)

Name	Compound	Abbreviation
Alite	$3CaO*SiO_2$	C_3S
Belite	$2CaO*SiO_2$	C_2S
Tricalcium aluminate	$3CaO*Al_2O_3$	C_3A
Tetracalcium aluminoferrite	$4CaO*Al_2O_3*Fe_2O_3$	C_4AF
Gypsum	$CaO*SO_4*H_2O$	$C\bar{S}H_2$

Figure 2.8: Abbreviations for clinker compounds (source: P.Kumar Mehta)

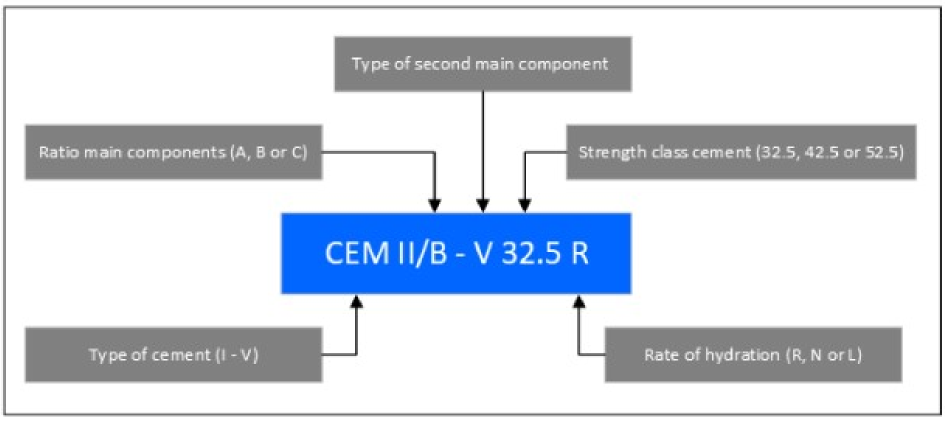


Figure 2.9: Cement nomenclature (own figure, source: P.Kumar Mehta)

2.3.1. Portland cement

Concrete is the second most consumed material by humans, following water. Approximately 12 billion tons of concrete is consumed each year [25]. It is composed of aggregate, which makes up 75% of its composition, as well as cement and water. When water reacts with cement, it forms a glue-like substance that binds the aggregate together, resulting in the formation of concrete. The most commonly used type of cement is Portland cement, with a global annual production of around 4.1 billion tons [26]. In this section, the focus will be on the manufacturing process, chemical composition, hydration process, and strength development of Portland cement.

Manufacturing process

In order to obtain the cement clinkers that are crucial components of concrete, it is necessary to adhere to the following manufacturing process, as outlined in the book "Concrete: Microstructure, Properties and Materials" [27]. See figure 2.10 for an overview of the manufacturing process of Portland cement clinkers.

1. **Quarrying:** The initial stage in the manufacturing process of Portland clinkers involves the extraction of calcium silicates, which serve as the primary constituents of Portland cement. Naturally occurring sources of calcium (CaO) include limestone, chalk, marl, and seashells. Silicate (SiO_2), on the other hand, is found in clay deposits. To facilitate the formation of calcium silicates at lower temperatures, additional substances like alumina, ferric oxide, and alkalis (Al_2O_3 and Fe_2O_3) are added. These materials can also be sourced from clay. In cases where these components are insufficient, raw materials like iron and bauxite are incorporated into the mixture
2. **Mixing and Grinding:** In order to achieve a more reactive and homogeneous mixture, the raw materials undergo a grinding and mixing processes. Grinding the raw materials reduces their particle size, thereby increasing the surface area available for chemical reactions. This enhanced surface area promotes more efficient and thorough reactions. Additionally, the raw materials are carefully mixed in the correct proportions to ensure a homogeneous composition throughout the mixture. This meticulous blending process helps to achieve consistent and uniform properties in the final product.
3. **Burning:** The mixed and ground raw materials are introduced into a rotary kiln, where they are exposed to temperatures reaching approximately 1450°C. These high temperatures trigger chemical reactions that lead to the formation of clinkers, which will be explained in more detail later. There are two main processes employed to produce clinkers: the wet-process and the dry-process. In the wet-process, a slurry is formed by adding 30 to 40% water to the raw materials. This method requires approximately 1400 kcal/kg clinker of fossil fuel energy. On the other hand, the dry-process does not involve the use of water; instead, the mixture of raw materials undergoes preheating. The dry-process requires around 800 kcal/kg clinker of fossil fuel energy. Due to its lower energy consumption, the dry method is favoured by most cement plants.
4. **Milling:** The final stage of the manufacturing process takes place in finish mills, where the cement clinkers are milled into particles smaller than 75 µm. To regulate the early setting and hardening reactions in the cement, gypsum is added. This addition of gypsum helps to control and optimize the cement's setting time and overall strength development.

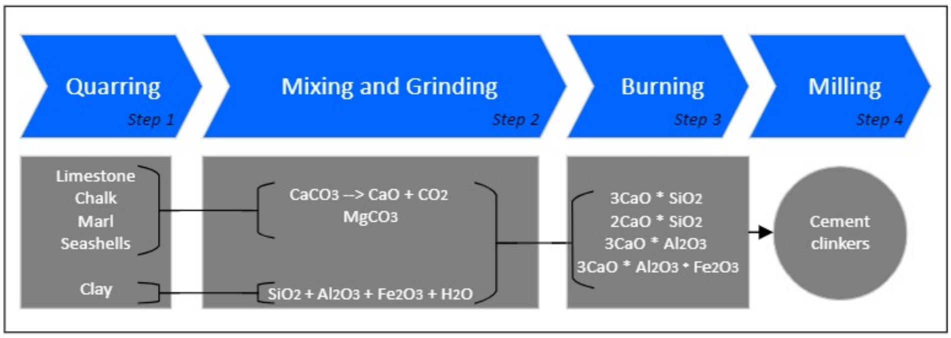


Figure 2.10: Manufacturing process cement clinkers (own figure, source: P.Kumar Mehta)

Chemical composition

The chemical composition of Portland cement has a significant influence on its properties. This composition is determined by the mixture of different oxides. One common method used to calculate the compound composition is by employing the Bogue equations. These equations utilize the oxide percentages present in the mixture to determine the percentages of the four main compounds found in Portland cement: Alite (C_3S), Belite (C_2S), Tricalcium aluminate (C_3A) and Ferrite (C_4AF) [28]. For the specific Bogue equations, see equations 2.2, 2.3, 2.4, and 2.5.

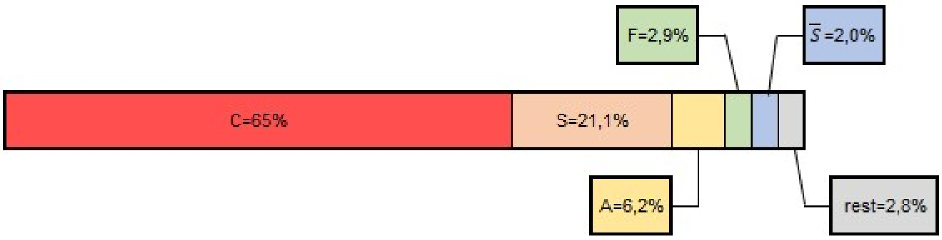
$$\%C_3S = 4.071C - 7.600S - 6.718A - 1.430F - 2.850\bar{S} \tag{2.2}$$

$$\%C_2S = 2.867S - 0.7544C_3S \tag{2.3}$$

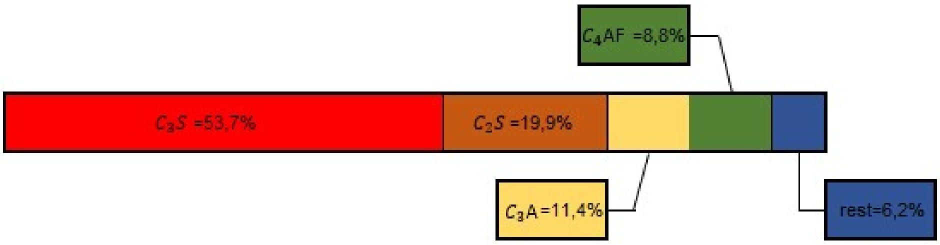
$$\%C_3A = 2.650A - 1.692F \tag{2.4}$$

$$\%C_4AF = 3.043F \tag{2.5}$$

Please note that these equations can only be used if the A/F ratio (ratio of mass in air to mass in fuel) is 0.64 or higher. While the equations provide an estimation and may not be accurate in all cases, they still serve as reliable tools for quickly calculating the percentages of the four main compounds in Portland cement. See Figure 2.11 for the percentages of oxides and compounds in CEM I. It is important to understand that any changes in oxide percentages will have a significant impact on the compound percentages. For instance, if there is a 1% increase in Al_2O_3 and a 1% decrease in Fe_2O_3, the percentages of C_2S and C_3A will decrease by 3.7% and 4.3% respectively.



(a) Percentages of oxides



(b) Percentages of compounds

Figure 2.11: Oxides and compounds of Portland cement (own figure, source: P.Kumar Mehta)

Hydration process

Once the clinkers are manufactured and their composition finalized, the Portland cement is prepared for practical use. Upon coming into contact with water, the hydration process of the cement clinkers commences. In figure 2.12 the five main compounds of Portland are described and their respective hydration products are given. The water-cement ratio plays a crucial role in determining the strength development, hardening time, and workability of the cement, a detailed discussion on this matter will be presented in subsection 2.4. Professor P.Kumar Mehta has outlined the hydration process in five distinct stages:

1. **Dissolution process.** Within the initial hour of the hydration process, the compounds C_3S, C_3A, and C_4AF undergo reactions with the added water. Notably, C_3A and C_4AF exhibit rapid reactivity, and the specific crystalline products formed depend on the presence and quantity of gypsum and AFt. This early stage of hydration is characterized by a significant release of heat.

See equation 2.6 and 2.7 for the reaction of C_3A and C_4AF is there is gypsum present. It will mainly form ettringite ($C_6A\overline{S}_3H_{32}$) and some calcium hydrate (CH).

$$C_3A + 3C\overline{S}H_2 + 26H = C_6A\overline{S}_3H_{32} \tag{2.6}$$

$$C_4AF + 3C\overline{S}H_2 + 30H = C_6A\overline{S}_3H_{32} + CH + FH_3 \tag{2.7}$$

See equation 2.8 and 2.9 for the reaction of C_3A and C_4AF is there is no gypsum present, but AFt ($C_6A\overline{S}_3H_{32}$) is present. It will mainly form Monosulfate ($C_6A\overline{S}H_{12}$) and some calcium hydrate (CH).

$$2C_3A + C_6A\overline{S}_3H_{32} + 4H = C_6A\overline{S}H_{12} \tag{2.8}$$

$$2C_4AF + C_6A\overline{S}_3H_{32} + 12H = C_6A\overline{S}H_{12} + 2CH + 2FH_3 \tag{2.9}$$

See equation 2.10 and 2.11 for the reaction of C_3A and C_4AF is there is no gypsum and no AFt present. It will mainly form Katoite (C_3AH_6) and some calcium hydrate (CH).

$$C_3A + 6H = C_3AH_6 \tag{2.10}$$

$$C_4AF + 6H = C_3AH_6 + CH + FH_3 \tag{2.11}$$

In this first stage C_3A will react with water and form the main hydration products: Calcium silica hydrate (CSH) and calcium hydrate (CH), see equation 2.12

$$C_3S + H = CSH + CH \tag{2.12}$$

2. **Induction period.** Following the initial hour, the pace of the reaction will gradually decelerate over the subsequent two hours. It is crucial to transfer the concrete from the mixing unit into the formwork during this phase. The generation of heat will diminish as the process progresses.
3. **Accelerate stage.** Approximately three hours into the hydration process, the initial setting commences, accompanied by an accelerated reaction rate. At this stage, a significant quantity of hydration products, calcium silicate hydrate (CSH) and calcium hydroxide (CH), are formed. Concurrently, the heat generated during this phase will increase.
4. **Decelerate stage.** After approximately nine hours, the final setting stage initiates, leading to a decrease in the reaction rate. During this phase, a substantial amount of hydration products, calcium silicate hydrate (CSH) and calcium hydroxide (CH), are formed. As the final setting progresses, the heat generated gradually diminishes.
5. **Diffusion stage.** Around 42 hours into the process, the reaction begins to slow down due to diffusion control. It will continue until all cement particles are fully hydrated or until the available water is completely consumed.

Compound	Abbreviation	Percentage	Description	Hydration products
Alite	C_3S	50-70%	Hardens rapidly. Responsible for initial set and early strength.	61% CHS 39% CH
Belite	C_2S	15-25%	Hardens slowly and its effect on strength increases occurs at ages beyond one week.	82% CHS 18% CH
Tricalcium aluminate	C_3A	5-15%	Contributes to strength development in the first few days. It is the first compound to hydrate. The least desirable component because of its high heat generation and its reactiveness with soils and water containing moderate to high sulfate concentrations.	Depents on actual content of gypsum and AFt
Ferrite	C_4AF	5-10%	Lowers clinkering temperature. C4AF contributes very little to strength of concrete even though it hydrates very rapidly.	Depents on actual content of gypsum and AFt
Gypsum	$C\bar{S}H_2$	5-6%	Gypsum is added to Portland cement to slowing down the setting time, preventing flash setting, improving workability, reducing the risk of cracking and shrinkage, and enhancing the strength and durability of the cement.	AFt and CH

Figure 2.12: Main compounds of Portland cement and its hydration products (own figure, source: P.Kumar Mehta)

Strength development

The strength development of Portland cement is influenced by both its chemical composition and the w/c ratio. The w/c ratio plays a significant role in determining the strength development of a Portland cement mixture. Methods for determining the strength development of such mixtures include the Eurocode standards and experimental calculations.
The Eurocode NEN-EN 1992 provides an equation to determine the compressive strength at any given time, as shown in equation 2.13. Here, $f_{cm}(t)$ represents the mean compressive strength of concrete [MPa] at a certain age t [days], f_{cm} represents the mean compressive strength of concrete [MPa] at an age of 28 days, and β is determined using equation 2.14. The coefficient s in the equation depends on the cement mixture and was evaluated by Lerner through research and experiments. For a Portland mixture the value of s=0.161. These experiments utilized CEM I 42.5R and maintained a constant curing temperature of 20°C [29].

$$f_{cm}(t) = \beta_{cc}(t) * f_{cm} \tag{2.13}$$

$$\beta_{cc}(t) = exp(s * (1 - (\frac{28}{t/t_1})^{0.5})) \tag{2.14}$$

Several experiments have been conducted to analyze the compressive strength of Portland cement and understand its strength development. Notable papers, such as those by Castellano [30], Osmanovic [31], Hui [32], and Limbachiya [33], provide valuable insights into the strength development of Portland cement with different water-cement (w/c) ratios. These studies present figures and graphs that illustrate the strength development over time.
To create a comprehensive understanding, compressive strength values from these studies are collected at specific time intervals. A logarithmic curve fit is then derived using these values to plot a graph depicting the compressive strength development. Table 2.13 provides a summary of the different experiments, including the w/c ratio, compressive strength values, curve fit, and R-values (which represent the accuracy of the curve fit, the closer the R-value is to 1, the better the accuracy of the curve fit).
The Fib Bulletin 42, the Eurocode is based on the Fib, so pre-code, and a strength class of C30/37 (f_{cm}=38MPa) are used as references. Graph 2.14 illustrates the compressive strength development over the first 28 days. Notably, it demonstrates that the mixture with the lowest w/c ratio exhibits the most rapid strength development.

Source	Portland	w/c	Days					Curve fit	R
			2	3	7	14	28		
Castellano	100%	0,40	46,10	-	60,20	-	72,10	y = 13,04ln(x) + 32,64	0,992
Osmanovic	100%	0,50	30,00	-	45,27	-	67,68	y = 11,75ln(x) + 24,96	0,993
Castellano	100%	0,50	19,90	-	47,60		60,10	y=10,96ln(x)+21,85	0,971
Hui	100%	0,50		37,22	40,03		51,67	y=9,27ln(x)+22,86	0,992
Limbachiya	100%	0,51	-	32,88	40,00	-	44,44	y=8,26ln(x)+20,91	0,985
FIB Bulletin 42	100%	-	use Formula: $f_{cm}(t) = \beta_{cc}(t) * f_{cm}$						s=0,168

Figure 2.13: Compressive strength development of Portland cement according to experiments and the Fib (own figure, sources: Fib Bulletin 42, Castellano, Osmanovic, Hui and Lambachiya)

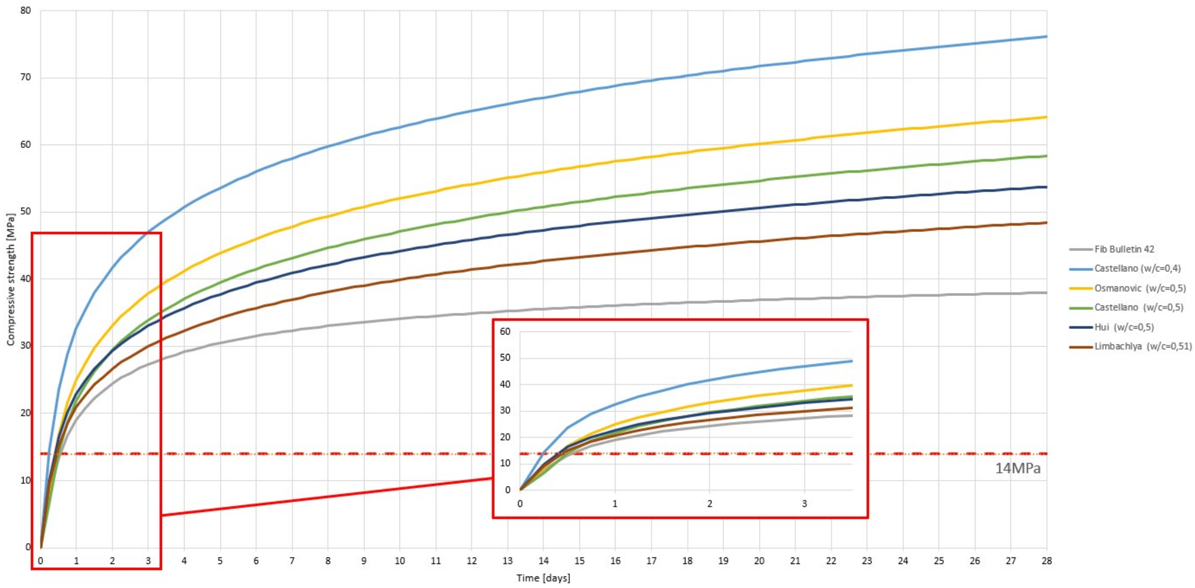


Figure 2.14: Compressive strength development of portland cement according to experiments and the Fib (own figure, sources: Fib Bulletin 42, Castellano, Osmanovic, Hui and Lambachiya)

The NEN-EN 1992-2 standard serves as a reference for assessing the evolution of tensile strength and modulus of elasticity in concrete structures. Tensile strength plays a pivotal role in evaluating the propensity for crack formation, deflection, and the bond interaction between reinforcement and concrete. It's strength development curve closely parallels that of compressive strength, albeit at significantly lower levels. As a result, table 3.1 from NEN-EN 1992 offers valuable insights into determining tensile strength development (to calculate the tensile strength development the characteristic cylinder compressive strength development is needed, see equation 2.15), as illustrated in equation 2.16.
Concurrently, the modulus of elasticity serves as a key parameter for ascertaining the stiffness and deflection behavior of concrete elements. Table 3.1 within the NEN-EN 1992 standard provides a formula that facilitates the determination of modulus of elasticity development, as depicted in equation 2.17.

$$f_{ck}(t) = f_{cm}(t) - 8 \tag{2.15}$$

$$f_{ctm}(t) = 0.30 * f_{ck}(t)^{(2/3)} \tag{2.16}$$

$$E_{cm}(t) = 22000 * (\frac{f_{cm}(t)}{10})^{0.3} \tag{2.17}$$

$f_{ck}(t)$= characteristic cylinder compressive strength in MPa at a certain age t.
$f_{cm}(t)$= Mean cylinder compressive strength in MPa at a certain age t.
$f_{ctm}(t)$= Mean cylinder tensile strength time in MPa at a certain age t.
$E_{cm}(t)$= Mean modulus of elasticity in MPa at a certain age t.

2.3.2. Blended mixture 1: PC-fly ash cement

The first blended mixture that will be researched is the combination of Portland cement with fly ash. For this research CEM II/B-S will be used, which means that 65-76% is Portland cement and 21-35% is fly ash. Fly ash is a byproduct obtained from coal-fired power plants during the combustion process. It is a fine powder that can be used as a supplementary cementitious material in concrete production. The incorporation of fly ash in concrete offers several benefits. Firstly, it improves the workability of the concrete mix, making it easier to handle and place. Secondly, fly ash enhances the long-term strength and durability of concrete by reducing the permeability and increasing resistance to chemical attacks and sulfate attack. Additionally, the use of fly ash in concrete helps in reducing the carbon footprint of the construction industry by utilizing a waste material and reducing the need for Portland cement, which is a major contributor to greenhouse gas emissions. In this section, the focus will be on the manufacturing process, chemical composition, hydration process, and strength development of PC-fly ash cement.

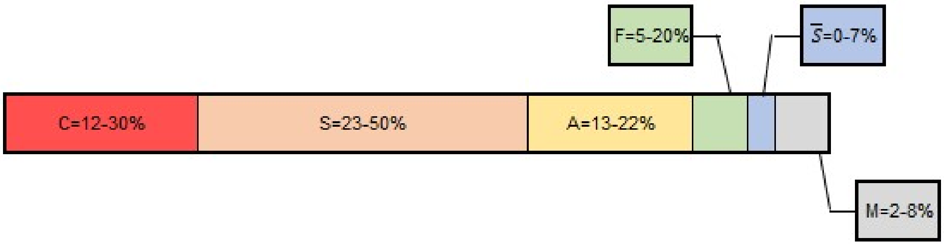
Manufacturing process

PC-fly ash cement is a combination of two primary components: Portland cement and fly ash. While the manufacturing process of Portland cement has been previously discussed, this section will focus on detailing the production of fly ash. Fly ash is predominantly generated as a byproduct from the combustion of coal. As coal burns, it undergoes either complete or partial combustion, leading to the release of gasses and the formation of ash [34]. Specifically, fly ash refers to the fine particles that are carried away by the flue gases and subsequently collected from the exhaust gases using electrostatic precipitators or baghouses. These collection methods effectively capture the fly ash before it is released into the atmosphere. Once collected, fly ash is typically stored in silos or transported to storage facilities. It exists in the form of smooth, solid, glassy spheres that range in size from 0.5 micrometers to 200 micrometers. The composition of fly ash can vary depending on factors such as the type of coal, burning conditions, cooling control, and combustion process. Fly ash can be categorized into two types: C and F. Type C fly ash (high-calcium fly ashes) possesses properties that are both pozzolanic and cementitious. It is produced from the burning of lignite or sub-bituminous coal and must have a total composition of SiO_2, Al_2O_3 and Fe_2O_3 greater than 50%, along with a CaO percentage exceeding 10%. On the other hand, Type F fly ash (low-calcium fly ashes) is solely pozzolanic in nature. It is created from the burning of anthracite or bituminous coal and must have a total composition of SiO_2, Al_2O_3 and Fe_2O_3 greater than 70%, while having a CaO percentage lower than 10% [35].

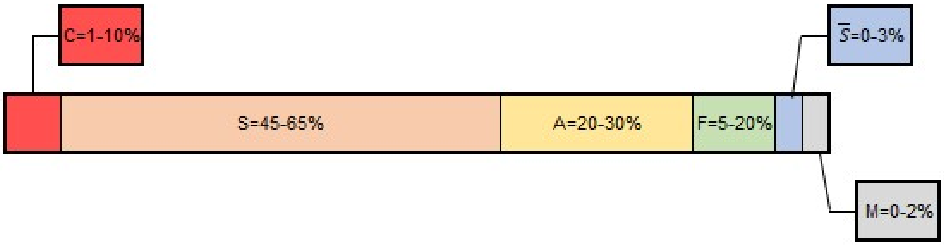
Chemical composition

There are two types of fly ash: high-calcium fly ash and low-calcium fly ash. Figure 2.15a illustrates the oxide percentages found in high-calcium fly ashes, showing a higher presence of calcium. The increased calcium content leads to the formation of more reactive crystalline compounds, such as Tricalcium aluminate (C_3A), calcium sulfate (C$\overline{S}$), and ($C_4A_3\overline{S}$) [27]. On the other hand, Figure 2.15b displays the oxide percentages found in low-calcium fly ashes, indicating a significant amount of silica and alumina. When coal of this type is burned, it generates large amounts of glassy spheres, including quartz (α-SiO_2), sillimanite (AS), and mullite (A_3S_2) [27]. Additionally, Figure 2.16 provides an overview of the global compound percentages in fly ash for both classes. Crystalline compounds make up around 10-30%, aluminosilicate glasses account for 60-85%, and unburnt carbon constitutes approximately 5%.

It's good to know that in the Netherlands there is no distinction between fly ash class C en F. In the Netherlands there is only one classification of fly ash, which is closed to the class C.



(a) Percentages of oxides in fly ash, class C



(b) Percentages of oxides in fly ash, class F

Figure 2.15: Oxides of fly ash (own figure, source: P.Kumar Mehta)

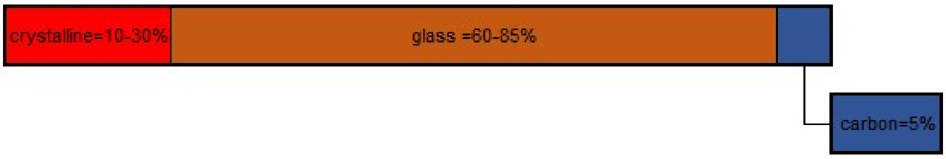


Figure 2.16: Compounds of fly ash (own figure, source: P.Kumar Mehta)

Hydration process

PC-fly ash cement is a blended cement mixture that combines the properties of Portland clinkers and fly ash. When water is added to the mix, the Portland clinkers in PC-fly ash cement react similarly to ordinary Portland cement, resulting in the development of calcium silicate hydrate (CSH) and calcium hydroxide (CH) gel [36]. These hydration products contribute to the strength and durability of the concrete (for a more detailed description, refer to the Portland cement section).
The fly ash in the blend extends the setting time of the cement and reacts with the hydration products of Portland cement to form additional CSH gel. Figure 2.17 provides percentages, a brief description, and hydration products of fly ash. The significant presence of aluminosilicate glasses in fly ash leads to a pozzolanic reaction during hydration. Over time, these glasses react with CH to form additional CSH gel. This reaction results in a longer setting time but ultimately increases the strength and density of the concrete, making it less permeable.
Compared to ordinary Portland cement (OPC), PC-fly ash cement generates less heat during hydration. This reduced heat development helps minimize the risk of setting cracks. Additionally, fly ash has the advantage of providing a ball bearing effect, enhancing the workability of the mixture and reducing the water content required [37].
However, it is important to note that the presence of unburnt carbon in PC-fly ash cement can have varying effects on the hardening process. If the percentage of unburnt carbon is less than 5%, it can contribute to early strength development in concrete. However, an excessive presence (more than 5%) can negatively impact the hardening process by absorbing water and hindering its availability for cement hydration. This can lead to reduced strength, delayed setting, and decreased durability [34].

Category	Name	Abbr.	Percentage	Description	Hydration products
Crystalline compounds:	- Tricalcium aluminate	C_3A	10-30%	See the section about Portland cement	CHS, CH, CAH
	- Calcium sulfate	$C\bar{S}$			
	- Yeelimite	$C_4A_3\bar{S}$			
aluminosilicate glasses:	- Quartz	SiO_2	60-85%	Due to the pozzolanic effect, it will react late with calcium hydrate to form more calcium silicate hydrate and katoite. To give late strength to the concrete.	S + CH = CHS A + CH =CAH
	- Silimanite	AS			
	- Mulite	A_3S_2			
Unburnt carbon:			5%	Below 5% the unburnt carbon contributes to early strength development, Above 5% it can negatively impact the hardening process.	-

Figure 2.17: Main products of fly ash and its hydration products (own figure, source: P.Kumar Mehta)

Strength development

The strength development of PC-fly ash cement is influenced by both its chemical composition and the w/c ratio. The ratio of Portland cement plays a significant role in determining the strength development of a PC-fly ash cement mixture. Methods for determining the strength development of such mixtures include the Fib Bulletin 42 and experimental calculations.

The Fib Bulletin 42 provides an equation to determine the compressive strength at any given time, as shown in equation 2.13. and 2.14. The coefficient s in the equation depends on the cement mixture and was evaluated by Lerner through research and experiments. For a PC-fly ash mixture the value of s=0.367. These experiments utilized CEM I 42.5N and maintained a constant curing temperature of 20°C [29].

Several experiments have been conducted to analyze the compressive strength of PC-fly ash cement and understand its strength development. Notable papers, such as those by Karim [38], McNally [39], and Limbachiya [33], provide valuable insights into the strength development of PC-fly ash cement with different w/c ratios. These studies present figures and graphs that illustrate the strength development over time.

To create a comprehensive understanding, compressive strength values from these studies are collected at specific time intervals. A logarithmic curve fit is then derived using these values to plot a graph depicting the compressive strength development. Table 2.18 provides a summary of the different experiments, including the w/c ratio, compressive strength values, curve fit, and R-values (which represent the accuracy of the curve fit, the closer the R-value is to 1, the better the accuracy of the curve fit).

The FIB Bulletin 42 and a strength class of C30/37 (f_{cm}=38MPa) are used as references. Graph 2.19 illustrates the compressive strength development over the first seven days. Notably, it demonstrates that the mixture with the lowest w/c ratio exhibits the most rapid strength development. It is worth noting that the compressive strength values of McNally, with a w/c ratio of 0.55, exhibit a faster strength development compared to Limbachiya, who utilizes a w/c ratio of 0.50. This can be attributed to the fact that McNally incorporates a higher proportion of Portland cement in their mixture.

Source	Portland	Fly ash	w/c	Days 2	3	7	14	28	Curve fit	R
Karim	85%	15%	0,36	-	-	58,00	65,00	73,50	y = 13,15ln(x) + 30,67	0,999
McNally	65-79%	21-35%	0,45	32,70	-	45,96	49,21	55,84	y = 9,97ln(x) + 24,16	0,996
Limbachiya	65%	35%	0,48	-	26,65	30,47	-	41,83	y = 7,37ln(x) + 17,23	0,995
McNally	65-79%	21-35%	0,55	-	29,09	35,65	40,53	42,80	y = 7,86ln(x) + 19,06	0,998
FIB Bulletin 42	-	-	-	use Formula: $f_{cm}(t) = \beta_{cc}(t) * f_{cm}$						s=0,367

Figure 2.18: Compressive strength development of PC-fly ash cement according to experiments and the Fib (own figure, source: Fib Bulletin 42, Karim, Mcnally and Lambachiya)

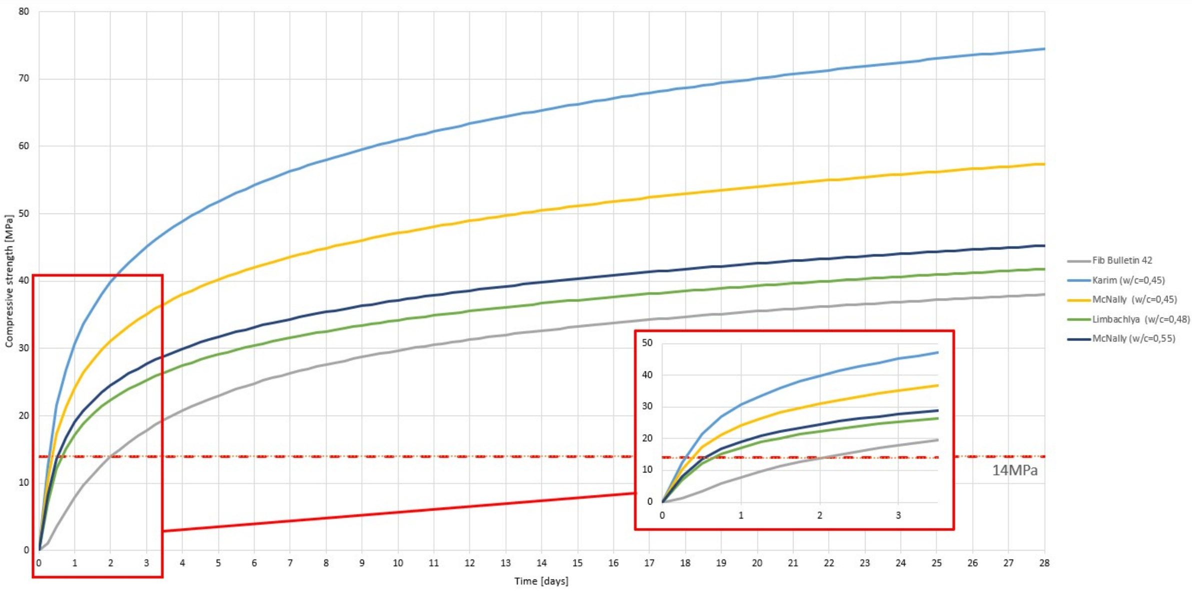


Figure 2.19: Compressive strength development of PC-fly ash cement according to experiments and the Fib (own figure, Fib Bulletin 42, Karim, Mcnally and Lambachiya)

The methodology employed to calculate the development of tensile strength and modulus of elasticity in CEM II mirrors that of CEM I, relying on the NEN-EN 1992-2 standard. For insights into tensile strength development, refer to equation 2.16, while equation 2.17 provides the means to assess the development of modulus of elasticity.

2.3.3. Blended mixture 2: PC-slag cement

The combination of Portland cement with blast furnace slag will be the second blended mixture studied in this research. Specifically, CEM III/B, which consists of 20-34% Portland cement and 66-80% blast furnace slag, will be used.

Blast furnace slag is a byproduct obtained during the iron manufacturing process in blast furnaces. It is commonly utilized as a supplementary cementitious material in concrete production. When finely ground and added to cement mixture, blast furnace slag can improve various properties and offer numerous benefits. These include reduced permeability, low heat production, increased resistance to chloride ingress, and enhanced workability. Incorporating blast furnace slag in concrete is also an environmentally-friendly approach as it reduces the demand for Portland cement, a significant contributor to carbon dioxide emissions. For PC-fly ash cement 25% less Portland cement is used and for PC-slag cement 80% less Portland cement is used. Furthermore, the use of blast furnace slag promotes the efficient utilization of industrial waste materials.

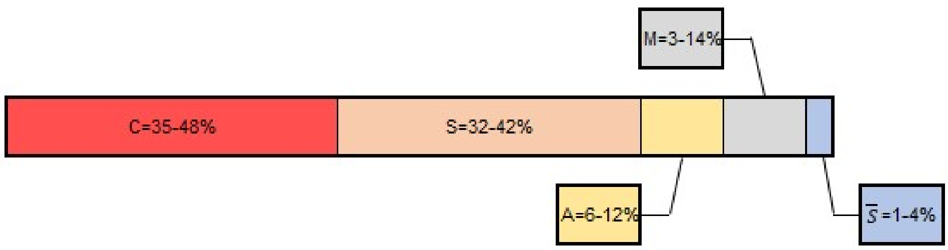
However, it is important to note that there are some disadvantages associated with blast furnace slag, such as longer setting time, slower strength development, higher autogenous shrinkage, and a higher carbonation rate. Nevertheless, overall, the incorporation of blast furnace slag in concrete represents a sustainable practice that offers multiple advantages in terms of performance and environmental impact. This section of the research will focus on the manufacturing process, chemical composition, hydration process, and strength development of PC-blast furnace slag cement.

Manufacturing process

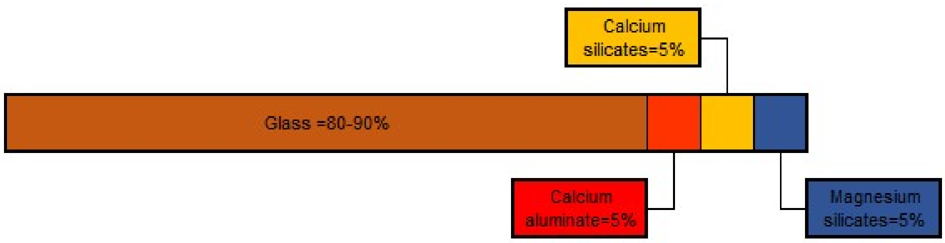
PC-blast furnace slag cement is a composite material consisting of two main components: Portland cement and blast furnace slag. While the manufacturing process of Portland cement has been previously discussed, this section will focus on providing a detailed overview of blast furnace slag production. Blast furnace slag is a byproduct generated during the production of steel and iron. In this process, the blast furnace melts iron ore and coke at a temperature of 1500 degrees Celsius, resulting in the production of iron and slag. The slag is rapidly cooled using water, a process known as granulation, which enhances its reactivity. The granulated blast furnace slag is then finely ground into granular glassy particles, resulting in a product called ground granulated blast furnace slag (GGBS). Subsequently, the GGBS is mixed with Portland cement clinkers and other additives, such as gypsum [40]. It is worth noting that in the Netherlands, the blast furnace slag and Portland cement clinkers are mixed prior to the grinding process [27].

Chemical composition

The chemical composition of blast furnace slag primarily consists of lime (C), silica (S), magnesia (M), and alumina (A), as shown in figure 2.20a. The exact composition of blast furnace slag is influenced by factors such as the ore, fluxing stone, and contamination in the coke supply during the blast furnace process [40].
After the manufacturing process, the main components of blast furnace slag are presented in figure 2.20b. The majority of blast furnace slag is composed of an amorphous glassy material, accounting for approximately 80-90% of its composition. The chemical formula for this glassy blast furnace slag is $C_{7.88}S_{7.39}M_3A$. Crystalline compounds, including calcium silicates (gehlenite), calcium aluminates (tricalcium aluminate), and magnesium silicates (merwinite (Ca*3Mg*2(SiO4))), make up around 5% of the total composition [41] and [42].



(a) Percentages of oxides in blast furnace slag, class C



(b) Percentages of compounds in blast furnace slag

Figure 2.20: Oxides and compounds of blast furnace slag (own figure, source: Melo Neto)

Hydration process

PC-blast furnace slag cement is a blended mixture of Portland clinkers and blast furnace slag designed to combine the beneficial properties of both components. When water is added to the mix, the Portland clinkers in PC-blast furnace slag cement undergo a similar reaction to ordinary Portland cement. This reaction results in the formation of calcium silicate hydrate (CSH) and calcium hydroxide (CH) gel [43],

which contribute to the strength and durability of the concrete (for a more comprehensive explanation, please refer to the Portland cement section).
Figure 2.21 provides information on the percentages, brief descriptions, and hydration products of blast furnace slag. The glassy, amorphous particles of blast furnace slag play a significant role in the pozzolanic reaction. This reaction, involving blast furnace slag ($C_{7.88}S_{7.39}M_3A$), extends the setting time of the cement and interacts with the hydration products of Portland cement, resulting in the formation of CASH gel and hydrotalcite ($M_{4.6}AH$) (as shown in Equation 2.18).

$$C_{7.88}S_{7.39}M_3A + 2.6CH + H = 7.39C_{1.42}SHA_{0.046} + 0.66M_{4.6}AH \tag{2.18}$$

This reaction results in a longer setting time but ultimately increases the strength and density of the concrete, making it less permeable. Compared to ordinary Portland cement (OPC), PC-blast furnace slag cement generates less heat during hydration. This reduced heat development helps minimize the risk of setting cracks. Additionally, blast furnace slag has the advantage of providing a ball bearing effect, enhancing the workability of the mixture and reducing the water content required [40].

Category			Percentage	Description	Hydration products
	Name	Abbr.			
Calcium silicates:	Gehlenite	C_2AS	5%	Improve late strength and durability.	CHS, CH, CAH
Calcium aluminates:	Tricalcium aluminate	C_3A	5%	See the section about Portland cement	CHS, CH, CAH
Magnesium silicates:	Merwinite	-	5%	Improve late strength and durability.	CHS, CH, CAH
Glassy phase:	Blast furnace slag	-	80-90%	Due to the pozzolanic effect, it will react late with calcium hydrate to form CASH gel and hydrotalcite. To give late strength to the concrete.	CASH, MAH

Figure 2.21: Main products of blast furnace slag and its hydration products (own figure, source: Melo Neto)

Strength development

The strength development of PC-blast furnace slag cement is influenced by both its chemical composition and the w/c ratio. The ratio of Portland cement plays a significant role in determining the strength development of a PC-blast furnace cement mixture. Methods for determining the strength development of such mixtures include the Fib Bulletin 42 and experimental calculations.
The Fib Bulletin 42 provides an equation to determine the compressive strength at any given time, as shown in equation 2.13. and 2.14. For PC-blast furnace slag cement no value of s is given, so the Bulletin will not be used for the calculation of the strength development for PC-blast furnace slag cement.
Several experiments have been conducted to analyze the compressive strength of PC-blast furnace slag cement and understand its strength development. Notable papers, such as those by Castellano [30], McNally [39], Osmanovic [31], and O'Rourke [44], provide valuable insights into the strength development of PC-blast furnace slag cement with different water-w/c ratios. These studies present figures and graphs that illustrate the strength development over time.
To create a comprehensive understanding, compressive strength values from these studies are collected at specific time intervals. A logarithmic curve fit is then derived using these values to plot a graph depicting the compressive strength development. Table 2.22 provides a summary of the different experiments, including the w/c ratio, compressive strength values, curve fit, and R-values (which represent the accuracy of the curve fit, the closer the R-value is to 1, the better the accuracy of the curve fit).
Graph 2.23 illustrates the compressive strength development over the first seven days. Notably, it demonstrates that the mixture with the lowest w/c ratio exhibits the most rapid strength development.

Source	Portland	Blast furnace slag	w/c	Days					Curve fit	R
				2	3	7	14	28		
Castellano	20%	80%	0,40	9,20	-	19,30	-	50,80	y=15,89ln(x)-5,1873	0,967
McNally	20-34%	66-80%	0,45	-	26,97	36,63	46,86	48,54	y=10,20ln(x)+16,77	0,973
Osmanovic	20%	76%	0,50	4,42	-	14,67	-	38,75	y=13,09ln(x)-6,766	0,980
O'Rourke	30%	70%	0,50	10,54	-	21,54	-	35,80	y=9,584ln(x)+3,55	0,999
Castellano	20%	80%	0,50	5,00	-	16,30	-	43,60	y=14,72ln(x)-7,658	0,980
McNally	20-34%	66-80%	0,55	-	15,01	28,52	35,45	43,54	y=12,58ln(x)+2,278	0,995

Figure 2.22: Compressive strength development of PC-blast furnace slag cement according to experiments and the Eurocode (own figure, source: Castellano, Mcnally, Osmanovic and O´Rourke)

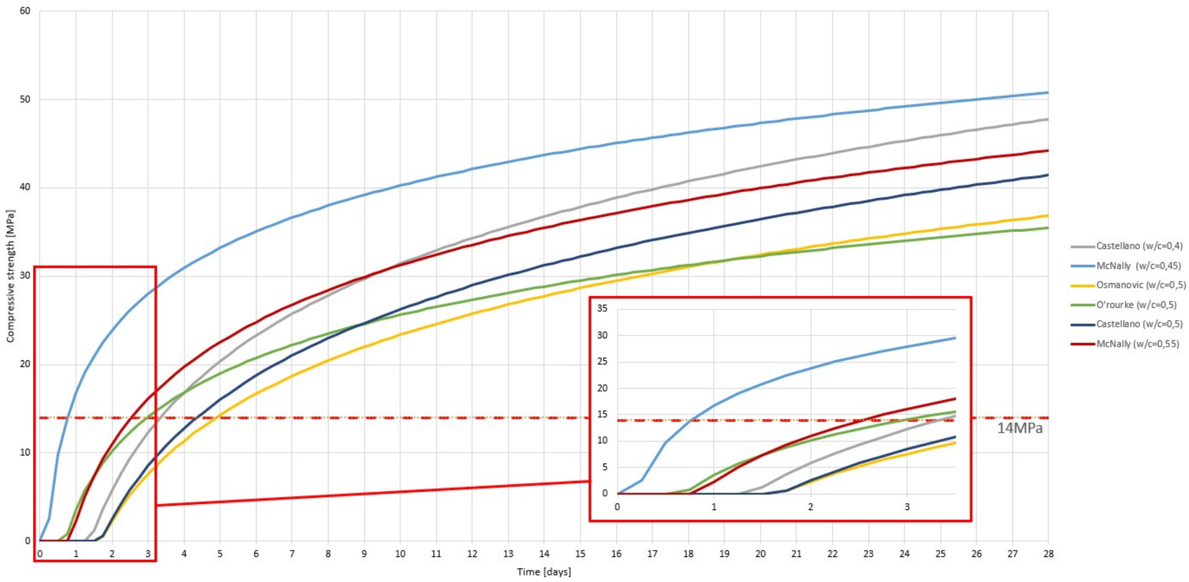


Figure 2.23: Compressive strength development of PC-blast furnace slag cement according to experiments and the Eurocode (own figure, source: Castellano, Mcnally, Osmanovic and O´Rourke)

The methodology employed to calculate the development of tensile strength and modulus of elasticity in CEM II mirrors that of CEM I, relying on the NEN-EN 1992-2 standard. For insights into tensile strength development, refer to equation 2.16, while equation 2.17 provides the means to assess the development of modulus of elasticity.

2.4. Concrete properties

In the upcoming section, the various properties of concrete that have an impact on its hardening time will be researched. The primary focus will be on the early strength of concrete, as this factor determines when the formwork can be safely removed. The quicker we achieve the minimum strength requirement of 14MPa, the sooner the formwork can be dismantled, and used for the next grid. It is important that after 28 days the minimum compressive strength is still achieved. Apart from the cement mixture, there are several other properties that influence the early strength of concrete, including the w/c ratio, aggregate type and size, admixtures, Blaine value and the curing temperature. These factors collectively contribute to the overall hardening time and play a vital role in achieving the desired concrete strength.

2.4.1. Water-cement ratio

The w/c ratio is a significant parameter that greatly impacts the workability, durability, and compressive strength of concrete. Higher w/c ratios enhance workability but compromise durability and strength. This is because an increased w/c ratio provides more water for the hydration process, resulting in greater porosity that subsequently reduces strength and durability.

As the w/c ratio decreases, the thickness of the water layer between unhydrated cement particles in the concrete mixture also decreases. This has two important consequences. Firstly, it brings the cement particles closer together, reducing the need for extensive hydration products to fill voids and bridge open spaces in the paste matrix. Secondly, the reduced water content limits the availability of water for hydration, resulting in a slower rate of the process. Consequently, lower w/c ratios yield more compact and stronger concrete mixtures. For normal strength concrete, the recommended w/c ratio falls between 0.4 and 0.6 [27].

The Fib Bulletin 42 provides an equation to determine the compressive strength at any given time, as shown in equation 2.13. and 2.14. The coefficient s in the equation depends on the w/c ratio and was evaluated by Bergner through research and experiments. Figure 2.24 provides the values of s for different w/c ratios. These experiments utilized CEM I 42.5R and maintained a constant curing temperature of 20°C [29]. Graph 2.25 depicts the relationship between compressive strength and time for different w/c ratios.

In summary, the w/c ratio significantly influences the workability, durability, and compressive strength of concrete. Higher w/c ratios improve workability but compromise durability and strength. Conversely, lower w/c ratios result in more compact and stronger concrete mixtures. The Eurocode NEN-EN 1992 provides an equation to determine compressive strength over time, taking into account the w/c ratio. Experimental research by Bergner has further evaluated the relationship between compressive strength and time for different w/c ratios.

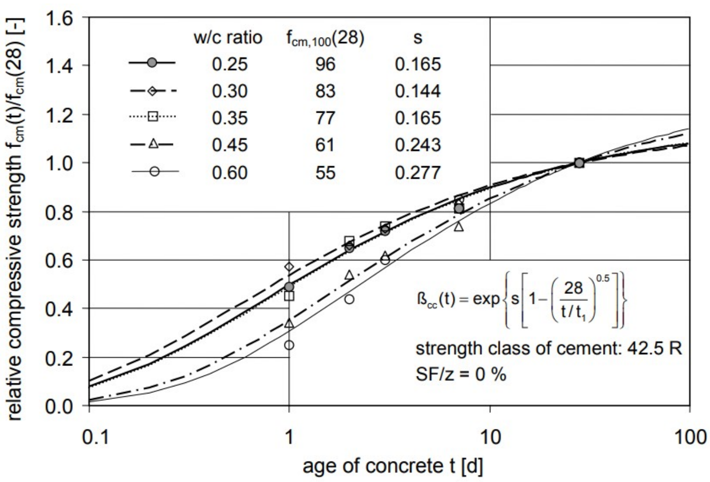


Figure 2.24: S-values for different w/c ratios (source: Fib Bulletin 42)

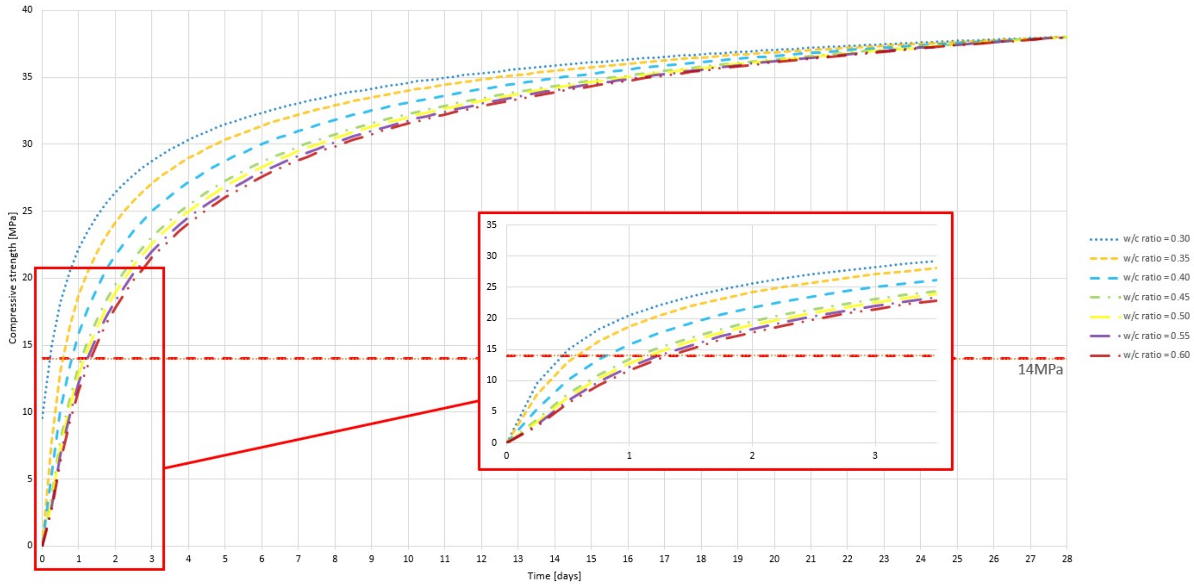


Figure 2.25: Compressive strength development of different w/c ratios (own figure, source: Fib Bulletin 42)

2.4.2. Aggregate type and size

Aggregates, such as sand, gravel, and crushed rocks, make up approximately 75% of concrete composition. While aggregates are often seen as mere filler material, they play a crucial role in enhancing various properties of concrete. Unlike the cement mixture, aggregates are relatively inexpensive and do not undergo complex chemical reactions. However, their significance should not be underestimated. Aggregates contribute to the strength, load-bearing capacity, toughness, hardness, durability, and workability of concrete [27]. Typically, natural mineral aggregates are classified into two divisions, although the addition of petrographic classification can result in three divisions. For the purpose of this research, a division into two classifications will suffice.

1. **Size classification.** The size classification is divided into two: fine or coarse aggregate. Fine aggregate refers to particles smaller than 4mm, such as sand or silt. These fine particles fill the void spaces between the coarse aggregate, resulting in a more compact concrete mix. This compactness increases the strength, particularly when the w/c ratio is lower than 0.5 (see figure 2.26). However, it is important to note that excessive amounts of fine aggregate can lead to increased water demand, which may decrease the strength of the concrete. Typically, fine aggregate content constitutes about 35% to 45% by mass or volume of the total aggregate content [45]. On the other hand, coarse aggregate refers to particles ranging in size from 4mm to 50mm, such as gravel or crushed rocks. It is worth noting that using crushed aggregate typically results in higher compressive strength compared to using uncrushed coarse aggregate [46]. However, when the w/c ratio is high, the size of the aggregate has less influence on the compressive strength ([27], [47] and [48].
2. **Shape and texture classification.** There are five types of shape classifications.
    - Rounded, seashore gravel, which will increase the workability, with around 33% of voids and will lesser the w/c ratio.
    - Irregular, gravel, which will give lower workability due to 37% of voids, but will increase the bond strength.
    - Angular, crushed rocks, which will give lower workability due to 45% of voids, but will increase the compressive strength.
    - Flaky, the thickness is small when compared with the width and length. Should not be used large percentages, because it can easily crack.
    - Elongated, the length is larger than the other two dimensions. Should not be used in large percentages, because it will increase the friction between particles, and in turn will decrease the workability.

In conclusion, the size of the aggregate does have an impact on strength development, particularly when the w/c ratio is low. However, this influence is more significant when the aggregate size is relatively large. It is common practice to use approximately 40% fine aggregate and 60% coarse aggregate in concrete mixes. Additionally, the shape of the aggregate plays a role in the workability of the concrete mixture. In the case of normal strength concrete, aggregates with rounded shapes tend to provide the best workability and can help reduce the required w/c ratio.

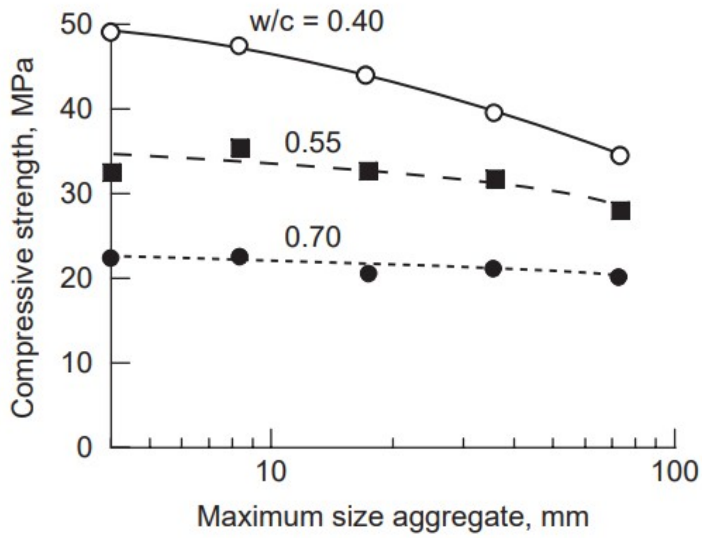


Figure 2.26: Aggregate size vs compressive strength (source: P. Kumar Metha)

2.4.3. Admixtures

Certain materials added to the concrete mixture, known as admixtures, can modify the properties of young concrete. There are several types of admixtures, each serving a specific purpose. In this section, we will provide a brief explanation of two types of admixtures that have an impact on the early compressive strength of concrete. Retarding and air-entraining admixtures, which have different effects on the concrete, will not be discussed extensively here. Retarding admixtures slow down the setting time, while air-entraining admixtures enhance freeze-thaw resistance. Instead, the focus will be on plasticizers and accelerators, which will be explained in detail.

Plasticizers

Water-reducers, also known as plasticizers, also known as polycarboxylate ethers (PCE), are incorporated into concrete mixtures to decrease the w/c ratio while maintaining the same workability as a mixture without admixtures. As previously mentioned, a lower w/c ratio typically results in higher compressive strength for the concrete. Plasticizers operate by influencing the surface charge of cement particles. These particles possess both positive and negative charges. However, plasticizer polymers, which carry negative charges, effectively neutralize the positive charges on the cement surface, leading to an overall negative surface charge. This electrostatic repulsion between negatively charged cement particles causes them to repel each other, creating a dispersing effect that allows for improved water permeation [27].

Numerous studies have demonstrated that the addition of plasticizers can enhance the early compressive strength of concrete. For instance, S. Alsadey conducted a comparison between two concrete mixtures with different w/c ratios and the inclusion of superplasticizers. Figure 2.27 illustrates the compressive strength development with and without superplasticizers, clearly demonstrating that the addition of plasticizers accelerates strength development [49]. Similarly, another research study, presented in the book by P.Kumar Mehta, examined the effect of superplasticizers on the early strength of concrete. The study involved a rapid-hardening Portland cement, cast at room temperature, with varying w/c ratios and superplasticizer contents. The results, depicted in Figure 2.28, further support the conclusion that the addition of superplasticizers enhances early compressive strength.

Superplasticizers also serve to activate concrete mixtures, and as a result, small proportions are consistently integrated into concrete mixtures. The quantity added varies depending on both the temperature and the specific cement mixture in use. For instance, Cugla, a supplier of admixtures in the Netherlands, recommends adding 0.30% of the cement weight for CEM I 52.5R, 0.25% for CEM II/B-S 52.5N, and 0.15% for CEM III/B 42.5N. It's important to note that all these percentages are calculated based on a temperature of 20°C.
In summary, water-reducers, or plasticizers, are utilized in concrete mixtures to activate the concrete mixture, decrease the w/c ratio while maintaining workability. By modifying the surface charge of cement particles, plasticizers enable better water permeation through electrostatic repulsion. Multiple studies have consistently demonstrated that the addition of plasticizers, such as superplasticizers, leads to improved early compressive strength in concrete.

Concrete Mix	Compressive strength in N/mm^2			
	1 day	3 days	7 days	28 days
Control (M) (plain concrete)	15.97	27	36.31	42.22
Control (M1) (plain concrete	12.75	23.23	29.99	35.29
400ml/100 kg of cement (MS1)	16.77	31.16	36.57	42.77
600ml/100 kg of cement (MS2)	20.05	34.18	42.92	44.61
800ml/100 kg of cement (MS3)	20.41	34.38	41.17	46.79
1000ml/100 kg of cement (MS4)	19.78	33.98	40.60	44.21
1200ml/100 kg of cement (MS5)	20.00	32.84	40.70	42.46

Figure 2.27: Superplasticizers vs compr. strength (source: Alsadey)

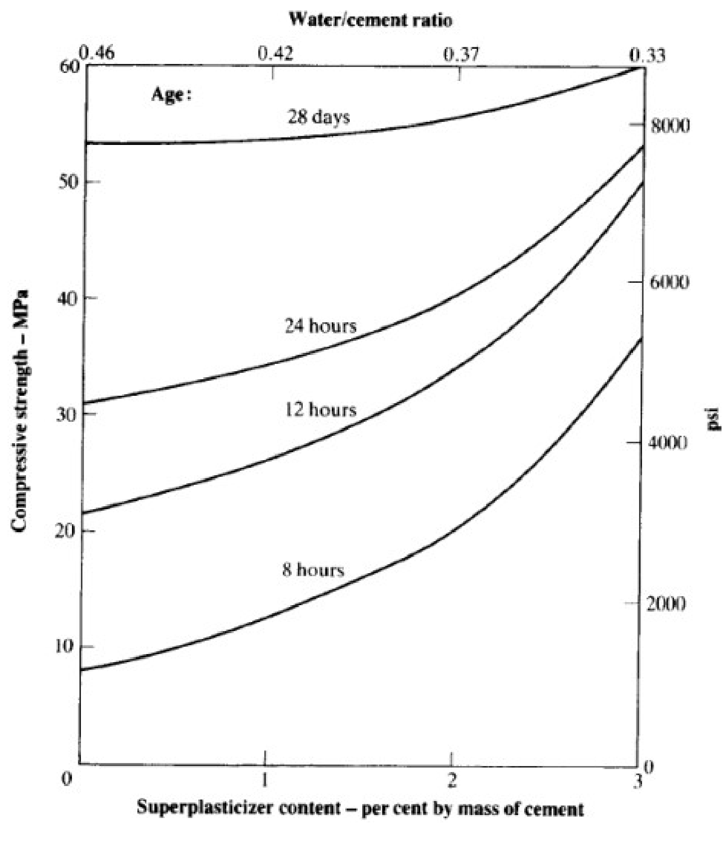


Figure 2.28: Superplasticizers vs compr. strength (source: P.Kumar Mehta)

Accelerators

Accelerator admixtures are commonly employed in the construction industry to expedite the hardening process and promote early strength development in concrete. While various accelerators are available, calcium chloride (CaCl2) was once a popular choice, but it is now avoided due to its adverse effects on reinforcement and its susceptibility to sulfate attacks. Instead, inorganic salt accelerators have emerged as a safe and effective alternative that doesn't harm reinforcement.

These admixtures serve to modify four key properties of Portland cement. First, accelerators hasten the initiation of finishing operations by speeding up the setting time of concrete, allowing for quicker progression to subsequent construction stages. Second, they reduce the required curing time, enabling faster project completion. Additionally, accelerators boost the rate of early strength development, facilitating the earlier removal of formwork. Lastly, they enhance the efficiency of sealing against hydraulic pressure, making them valuable in various construction contexts.[27].

Cugla offers the HA-60 accelerator, which significantly enhances early strength development in concrete mixtures. It primarily consists of inorganic salts, with a maximum nitrate content of 10%. These accelerators can increase compressive strength development by approximately 20% at a temperature of 20°C, with a recommended dosage of around 2% of the cement weight.

In summary, accelerator admixtures play a pivotal role in expediting concrete hardening and early strength development. However, their proper usage, dosage, and consideration of potential drawbacks are crucial to ensure the desired performance and durability of concrete structures.

2.4.4. Blaine value

The fineness of cement plays a crucial role in determining its strength and overall quality. The level of fineness directly affects the rate of strength development, as finer particles have a larger surface area, allowing for faster and more efficient hydration. Improved workability can also be achieved with finer cement particles. However, there is a limit to how fine cement can be ground. This limit is influenced by factors such as high grinding costs and heat generation [50]. Finer particles generate more heat due to their increased surface area and reactivity, which can result in thermal cracking within the concrete.

The Blaine fineness is a measure used to represent the fineness of cement. It quantifies the surface area of a cement clinker, with a higher Blaine fineness indicating finer cement particles. It is important to note that particles larger than 45 µm are challenging to hydrate, and particles larger than 75 µm may never fully hydrate ([51]. A study conducted by Aref M. al-Swaidani demonstrated that higher Blaine fineness correlates with higher compressive strength [52], see figure 2.29.

In conclusion, finer cement, indicated by a higher Blaine value, leads to a more rapid cement reaction and higher compressive strength. Commenly used Blaine values are between 300 m^2/kg or 400 m^2/kg.

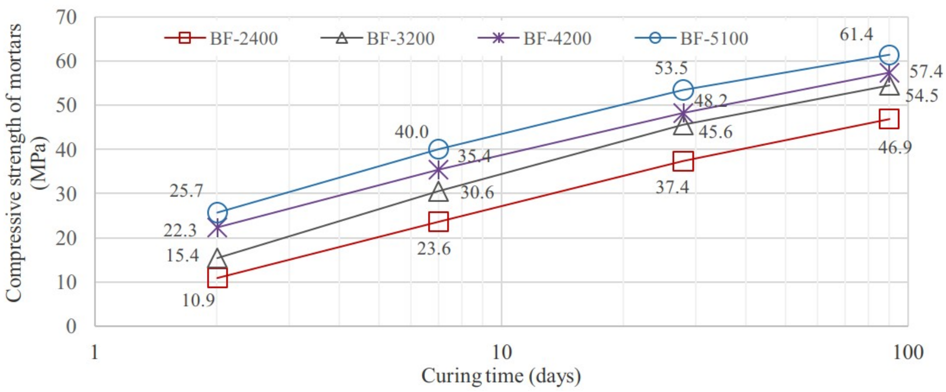


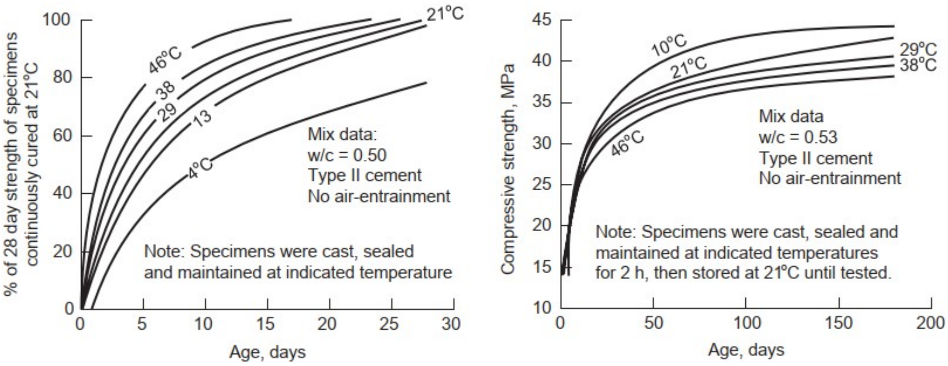
Figure 2.29: Compressive strength over time, for different Blaine fineness's (source: al-Swaidani)

2.4.5. Curing temperature

The compressive strength development of concrete is directly influenced by the curing temperature. There are two ways to understand this relationship.

Firstly, when the concrete is cast and cured at the same temperature, the U.S. Bureau of Reclamation

has found that higher curing temperatures result in higher compressive strength (see Figure 2.30a). This implies that as the temperature increases, the rate of strength development also increases.
Secondly, if the concrete is cast at different temperatures but cured at a constant temperature, Figure 2.30b demonstrates that lower casting temperatures, coupled with normal curing temperatures, lead to higher compressive strengths. The reason behind this is that the lower casting temperature allows for the formation of a more uniform microstructure within the hydrated cement paste [27].
In both cases, it is evident that the curing temperature plays a crucial role in determining the compressive strength of concrete. Higher curing temperatures generally promote faster strength gain, while lower casting temperatures can contribute to a more uniform microstructure and, consequently, higher compressive strengths [53].



(a) Different curing temperatures vs compr. strength **(b)** Different casting temperatures vs compr. strength

Figure 2.30: Graphs of the influence of the curing temperature on the compressive strength (source: U.S. Bureau of Reclamation)

In a study conducted by Pietro Lura in 2001, it was found that higher constant curing temperatures have a positive correlation with increased compressive strength (see Figure 2.31). The research involved the use of three different types of concrete mixtures. Mixture A consisted of CEM I 52.5 R, Mixture B comprised CEM III/B 42.5 LH HS, and Mixture C was a combination of A and B in equal proportions.
The results clearly indicate that as the temperature rises, so does the compressive strength. Moreover, the study reveals that Portland cement exhibits a quicker attainment of higher compressive strength compared to blast furnace slag [54]. This research underscores the significance of curing temperatures in influencing the compressive strength of concrete. Higher temperatures during the curing process contribute to enhanced strength development, while the choice of cement type also plays a role in determining the rate at which the desired strength is achieved.

		Mean cube compressive strength (MPa)						
Mixture	Temperature (°C)	1 day	2 days	3 days	7 days	14 days	28 days	56 days
A	10	–	57.2	65.8	81.7	91.7	97.7	–
	20	53.2	65.1	–	85.9	94.0	99.5	–
	30	55.4	68.5	78.6	92.3	100.1	–	–
	40	66.5	74.2	86.6	92.5[a]	97.0	–	–
B	10	–	5.2[b]	13.1[c]	34.5	51.8	58.9	–
	20	4.9	20.4	32.7	53.8	–	65.9	–
	30	23.6	44.6	50.6	59.6	64.8	–	–
	40	31.8	47.7	53.6	59.4[a]	–	–	69.7
C	10	–	31.1[b]	38.1[c]	57.4	72.2	82.8	–
	20	42	52	58	70	–	82	–
	30	40.7	54.5	63.9	–	84.8	–	–
	40	44.9	65.1	71.4	78.8[a]	79.2	–	–

Figure 2.31: Values of the compressive strength with different curing temperatures (source: Pietro Lura)

2.5. Conclusion

The second chapter has provided the background, the theory and current state for the following topics: the tunnel formwork building method, environmental cost indicator, three cement mixtures (Portland cement, PC-fly ash cement and PC-slag cement) and concrete properties. The cement mixtures and concrete properties that will be used the calculation sheet will be explained in chapter 3. Below a short conclusion of these topics is given.

The tunnel formwork building method offers several advantages, including fast execution time, high quality, cost-effectiveness, safety, and durability. However, there are also limitations, such as limited flexibility in design, high initial costs, coordination challenges, and environmental concerns related to the use of Portland cement. To improve the execution time, measures such as using fast-hardening cement mixtures, optimizing parameters like the w/c ratio and aggregate type, applying heat, and using the maturity method for strength measurement can be implemented. Overall, the tunnel formwork building method is a viable option for efficient construction, particularly for projects that require repetition and speed.

The aim of the research is to reduce the environmental impact of the tunnel formwork building method. By utilizing a LCA, the study will compare different cement mixtures and execution methods, providing valuable insights into their environmental impacts. The focus on the product and construction stages allows for a targeted assessment of key drivers of environmental impact. The LCA calculations will provide shadow costs, enabling a quantitative evaluation of the options. The interpretation of the results will help identify opportunities for improvement and optimization.

Concrete, made up of aggregate, cement, and water, is the second most consumed material in the world, the most used cement mixture is ordinary Portland cement. The manufacturing process involves quarrying raw materials, mixing and grinding them, burning them in a kiln, and milling the resulting clinkers. The chemical composition of Portland cement is determined by the mixture of different oxides, and the Bogue equations can be used to calculate the percentages of the main compounds (Alite, Belite, Tricalcium aluminate and Ferrite). The fineness of cement, measured by its Blaine fineness, affects its strength and quality. The hydration process of cement clinkers occurs in five stages, with the water-cement ratio playing a crucial role. The strength development of Portland cement is influenced by its chemical composition and the water-cement ratio. Several experiments have been conducted to analyze the compressive strength of Portland cement with different water-cement ratios, and it has been found that mixtures with lower ratios exhibit more rapid strength development. Different studies and the Fib bulletin show that CEM I reaches a compressive strength of 14MPa after one day.

Fly ash is a byproduct obtained from coal-fired power plants and has several benefits when incorporated in concrete. It improves workability, enhances long-term strength and durability, and reduces the carbon footprint of the construction industry. Fly ash is produced during the combustion of coal and can be categorized into two types: high-calcium fly ash and low-calcium fly ash. The chemical composition of fly ash affects its properties and reactivity during hydration. PC-fly ash cement is a blended mixture of Portland cement and fly ash, and the hydration process results in the formation of calcium silicate hydrate (CSH) and calcium hydroxide (CH) gel, contributing to concrete strength and durability. The presence of fly ash extends the setting time and reacts with the hydration products of Portland cement to form additional CSH gel. Different studies and the Fib bulletin show that CEM II reaches a compressive strength of 14MPa after two days.

Blast furnace slag is a byproduct of the iron manufacturing process and is commonly used as a supplementary cementitious material. The addition of blast furnace slag to cement mixture improves various properties of concrete, such as reduced permeability, low heat production, increased resistance to chloride ingress, and enhanced workability. Moreover, incorporating blast furnace slag in concrete is environmentally-friendly as it reduces the demand for carbon dioxide emitting Portland cement and promotes the efficient utilization of industrial waste. However, there are some disadvantages associated with blast furnace slag, including longer setting time, slower strength development, higher autogenous shrinkage, and a higher carbonation rate. Different studies and the Fib bulletin show that CEM III reaches a compressive strength of 14MPa after three days.

The focus is primarily on the early strength of concrete, which determines when the formwork can be safely removed. Factors such as the water-cement ratio, aggregate type and size, admixtures, temperature, and curing methods all contribute to the overall hardening time and play a crucial role in achieving the desired concrete strength. The water-cement ratio is a significant parameter that impacts the workability, durability, and compressive strength of concrete. Higher ratios improve workability but compromise durability and strength, as they increase porosity. Lower ratios result in more compact and stronger concrete mixtures. The recommended water-cement ratio for normal strength concrete is between 0.4 and 0.6. Aggregate type and size also affect the strength development of concrete. Fine aggregate, such as sand, fills the void spaces between coarse aggregates, resulting in a more compact mixture and higher strength. However, excessive amounts of fine aggregate can increase water demand and decrease strength. Coarse aggregate, such as gravel or crushed rocks, contributes to strength but has less influence on compressive strength when the water-cement ratio is high. The shape and texture of the aggregates also play a role in workability, with rounded shapes providing the best workability and reducing the required water-cement ratio. Admixtures are materials added to the concrete mixture to modify its properties. Plasticizers, or water-reducers, decrease the water-cement ratio while maintaining workability. They achieve this by modifying the surface charge of cement particles, allowing for better water permeation. Superplasticizers activate the concrete mixture and with high dosages enhance the early compressive strength of concrete. Accelerator admixtures expedite the hardening process and early strength development. They accelerate the chemical reaction between cement and water, leading to faster strength development and earlier formwork removal. The curing temperature also affects the compressive strength of concrete. Higher temperatures during curing promote faster strength gain, while lower casting temperatures can result in a more uniform microstructure and higher compressive strengths.

3 Methodology of the calculation sheet

The third chapter describes the calculation sheet's approach, which will be applied in the fourth chapter's analysis. The computation is created using the data obtained in the literature review part of the preceding chapter. The input and output values of the calculation sheet will be explained in this chapter. Additionally, this chapter will cover the various variations that will be covered in the fourth chapter.

The calculation sheet will be conducted using the following regulations to ensure their practical application:

NEN-EN 1990, Eurocode Basis of structural and geotechnical design.
NEN-EN 1991, Eurocode 1: Actions on structures.
NEN-EN 1992, Eurocode 2: Design of concrete structures.
NEN-EN 1993, Eurocode 3: Design of steel structures.
NEN-EN 1994, Eurocode 4: Design of composite steel and concrete structures.
NEN-EN 13670, Execution of concrete structures.
NEN 8670, Additional regulations to NEN-EN 13670.

A flowchart of the calculation sheet is shown in figure 3.16. The blue parallelogram denotes a manual input value, the green parallelogram denotes a manual allocated (for this project) input value, the light gray rectangle denotes an input value calculated from a manual input value, the blue diamond denotes an optional input value, and the red ellipse denotes an output value.

3.1. Input

The input of the calculation sheet include the following sections: the properties and design of the structure, the design of the concrete mixtures and the additional execution measures.

3.1.1. Properties and design of the structure

To ensure a reliable solution that can be validated in practice, three grid sizes will be modeled. The calculations will be conducted using the following properties, which are the same for all three grid sizes:

- The service class is for new constructions, with Category A, domestic, residential areas, and Category H, roofs accessible for normal maintenance and repair only. The consequence class is CC2/RC2, with a service life of 50 years.
- The variable load for category A is 1.75kN/m^2 in the usage phase and 1.00kN/m^2 in the execution phase
- The load combinations for CC2 are 1.2 for permanent loads and 1.5 for variable loads in the usage phase and 1.0 for both the permanent and variable loads in the execution phase.
- The strength class of the concrete is C30/37.
- The exposure class for concrete inside is XC1.

- The class for the reinforcement is B500A/B500B (both can be used, B500A is mostly used for cross mesh reinforcement and B500B is used for single rebar reinforcement).
- The floor-to-floor height is 2.55 meters plus the height of the floor, as the height of the tunnel formwork is 2.55 meters. According to the dutch Bouwbesluit the minimum required floor-to-floor height is 2.62m, in this research a height of 2.55m will be used, because the height of the tunnel formwork is 2.55m (Klink bekistingen).
- The structural length of the building is 36.00 meters.
- The structural depth of the building is 9.60 meters.
- There are 8 floor levels, including the ground floor.
- The thickness of the walls is in all variants 250mm, with a cross mesh reinforcement of ø6-150 f/b.
- The front and rear facades are cavity walls that consist of an outer layer made of brickwork and a non-load-bearing inner layer of sand-lime bricks, with insulation in between.
- A finishing floor of 70mm is applied on the concrete floor, which has a weight of 1.40kN/m^2.
- Partions walls of 1.00kN/m^2 are added to the variable floor load.
- The stability of the building is not being considered as it is not the focus of the research. A stabilizing structure has been placed on the right side of the building.
- The fire resistance of the structure is 90 minutes, as the building height exceeds 21 meters.

Three grid sizes will be analyzed: a small grid size of 4.5m, a medium grid size of 6.0m, and a large grid size of 7.2m. This will ensure a trustworthy solution that can be confirmed in practice. These grid sizes were selected because they all precisely fit within the 36-meter length. For example, a grid size of 4.5 meters will result in 8 grids for each floor (see figure 3.1), a grid size of 6.0 meters will result in 6 grids for each floor (see figure 3.2), and a grid size of 7.2 meters will result in 5 grids for each floor (see figure 3.3). Many of the structure's dimensions depend on the grid size, such as the floor thickness and reinforcement, amount of grids and the total volume of concrete used.

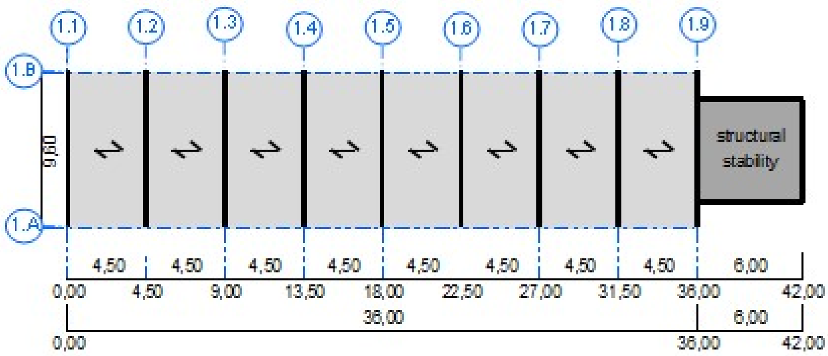


Figure 3.1: Floor plan grid size: 4.5m (own figure)

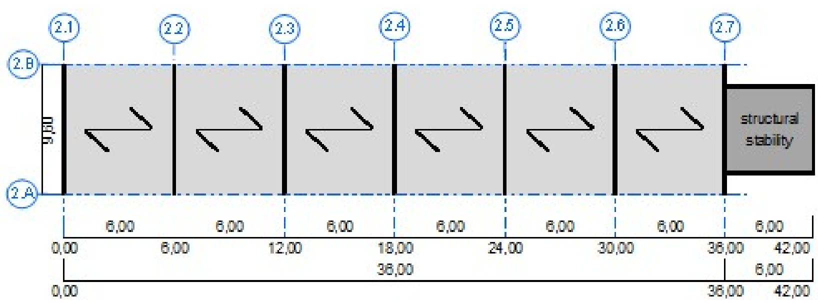


Figure 3.2: Floor plan grid size: 6.0m (own figure)

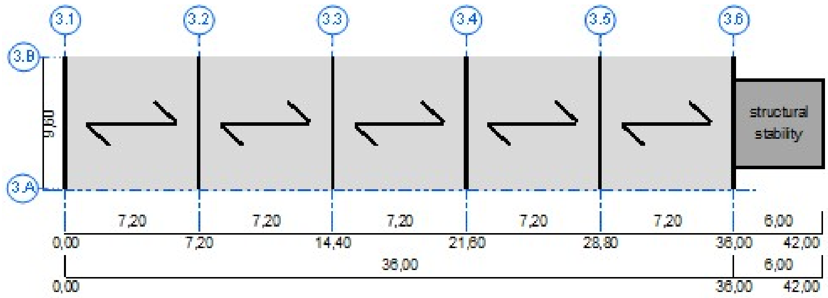


Figure 3.3: Floor plan grid size: 7.2m (own figure)

The floor thickness remains consistent across all grid sizes, measuring 250mm (excluding the finishing floor). This dimension is established based on structural considerations and to meet the minimum requirements for fire safety and sound insulation. In order to determine the maximum top and bottom moments in the floor, a rule of thumb is employed. Given the numerous fields, it is established that the maximum top moment is situated above the second support, while the maximum bottom moment is located in the middle of the first field. The maximum top moment is calculated using equation 3.1, while the maximum bottom moment is calculated using equation 3.2. These moments are then utilized to ascertain the required amount of reinforcement, in accordance with the NEN-EN 1992-1-1+C2-2011 standards. Based on this calculation, a specific cross mesh is selected for application in both the top and bottom regions of the floor. If the required amount of reinforcement exceeds the capacity of the chosen cross mesh, additional reinforcement is added, where needed. The total amount of reinforcement, considering both the floor and wall reinforcement, can then be determined. It is important to note that the total amount of reinforcement mentioned does not include auxiliary reinforcement, hairpins, or cutting losses.
In order to maintain a consistent U.C. value, the reinforcement for each grid size is carefully calculated. For a grid size of 4.50m, a cross mesh of ø8-150 is applied at both the top and bottom, resulting in a U.C. of 0.88 at the top and 0.65 at the bottom. Similarly, for grid sizes of 6.00m, a cross mesh of ø10-150 is used at the top and bottom. This configuration yields a U.C. of 1.02 at the top and 0.74 at the bottom for a grid size of 6.00m. For a grid size of 7.20m, a cross mesh of ø12-150 is used at the top and bottom. This configuration yields a U.C. of 1.03 at the top and 0.75 at the bottom for a grid size of 7.20m. The extra reinforcement due to the deflection will be determined in chapter 4.

$$M_{ed,top} = 0.1055 * Q_{ed} * L_{span} \tag{3.1}$$

$$M_{ed,bottom} = 0.0780 * Q_{ed} * L_{span} \tag{3.2}$$

Figure 3.4 illustrates the graphical representation of the input values pertaining to the properties and design of the structure on the calculation sheet. The blue values indicate manually inputted data, while the green values represent manual input values that remain constant throughout the course of this research thesis.

x.1 Input

x.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	Variable safety factor:	1,50

x.1.2 Design of the structure

Grid size [m¹]	Amount of levels (incl. GF)	Level height [m¹]	Total length [m¹]	Total depth [m¹]	Total height [m¹]	Amount of grids	Floor thickness [mm¹]	Wall thickness [mm¹]	Total volume [m³]
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:										Execution phase:	
	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)		6,25 kN/m²
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	Reinforcement:	B500	Exposure class:	XC1

Floor Reinforcement: TOP

M_{Ed} [kNm¹/m¹]	$A_{s;req}$ [mm²/m¹]	Applied Reinforcement base	Applied Reinforcement additional	$A_{s;prov}$ [mm²/m¹]	U.C.
50,5	531	Ø 10 - 150		524	1,01

Floor Reinforcement: BOTTOM

M_{Ed} [kNm¹/m¹]	$A_{s;req}$ [mm²/m¹]	Applied Reinforcement base	Applied Reinforcement additional	$A_{s;prov}$ [mm²/m¹]	U.C.
37,4	390	Ø 10 - 150		524	0,74

Wall Reinforcement v/a:	Ø 6 - 150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	45456	kg
Amount of wall reinforcement applied	=	9132	kg
Total Amount of reinforcement applied	=	54588	kg

(without auxiliary reinforcement, hairpins and cuttings losses)

Figure 3.4: Visible representation of the input values related to the properties and design of the structure. (own figure, taken from the calculation sheet)

3.1.2. Design of the concrete mixture

The design of the concrete mixture relies on several input parameters, including the cement mixture, w/c ratio, aggregate type, admixtures, Blaine value, and curing temperature. Figure 3.5 provides a visual representation of these input values within the calculation sheet, highlighting blue values as manually inputted data and green values as constant inputs throughout this research thesis. The right side of Figure 3.5 features a percentage bar that dynamically adjusts based on the chosen Portland cement type. The density of concrete is 2500kg/m^3, the percentages of each component are calculated. With these percentages the weight (kg) per cube (m^3) of concrete are calculated for each component.
Three cement mixtures are available: CEM I 52.5R (100% Portland cement), CEM II/B-V 42.5N (65% Portland cement and 35% fly ash), and CEM III/B 42.5N (20% Portland cement and 80% fly ash). These options were selected due to their prevalence in the Netherlands and their significant differences in environmental costs. The total amount of cement is calculated as 100% minus the percentage of aggregate and water.
The w/c ratio is represented by two values in the calculation sheet: 0.45 and 0.55, which are commonly used and yield different results in terms of execution time. The total amount of water depends on the w/c ratio and the percentage of aggregate, as shown in equation 3.3.

$$\%_{water} = (100 - W/C)/(1 + 1/\%_{aggregate}) \tag{3.3}$$

Throughout this thesis, the total amount of aggregate remains constant at 75% for all variants, with 40% representing fine aggregate and 60% representing coarse aggregate. Both river and sea aggregates can be chosen for the fine and coarse aggregate, each resulting in different shadow costs.
Admixtures can be classified into two main categories: basic admixtures and additional admixtures.

Basic admixtures primarily comprise superplasticizers, and the recommended percentages vary depending on the type of cement mixture. For CEM I 52.5R, a dosage of 0.30% of the cement weight is advised, while for CEM II/B-S 52.5N, 0.25% is recommended, and for CEM III/B 42.5N, 0.15% is suggested. As for the additional admixtures, there are two options to consider: one is to omit the use of admixtures altogether, while the other involves incorporating accelerators like HA-60, which is offered by Cugla. To achieve the desired results, it is recommended to use 2% of the cement weight of accelerators for each type of cement mixture.
The Blaine value offers two choices: 300m^2/kg or 400m^2/kg. A Blaine value of 300m^2/kg is most commonly used and 400m^2/kg is a relatively high Blaine value, which will decrease the execution time.
The curing temperature will vary based on the season during which the structure is constructed and the additional execution methods. In most cases, the structure is built during the summer, resulting in a curing temperature of 20°C. However, for one variation of each grid size and sustainable cement mixture, the construction will take place in the winter, leading to a curing temperature of 10°C.
See figure 3.6, 3.7, 3.8, 3.9 and 3.10 for the global warming potential and environmental cost indicator for the five different concrete mixtures used in this research.

x.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	Accelerator HA60	2	8,06	**
Blaine value	400m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	60°C	-	-	***

* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

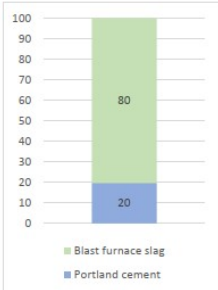


Figure 3.5: Visible representation of the input values related to the design of the concrete mixture. (own figure, taken from the calculation sheet)

Component	kg per m³ concrete	GWP kg*CO2/kg	ECI €/kg	GWP kg*CO2/m³	ECI €/m³
CEM I 52.5R	403	0,82	0,0606	330,46	24,42
Water	222	0,00034	0	0,08	0
Sand	750	0,0029	0,000455	2,18	0,34
Gravel	1125	0,0011	0,0000844	1,24	0,09
Total	2500	-	-	**333,95**	**24,86**

Figure 3.6: GWP and ECI for CEM I 52.5R w/c=0.55 (own figure, source: Henk Jonkers)

Component	kg per m³ concrete	GWP kg*CO2/kg	ECI €/kg	GWP kg*CO2/m³	ECI €/m³
CEM II/B-S 52.5N	431	0,53	0,0395	228,43	17,02
Water	194	0,00034	0	0,07	0
Sand	750	0,0029	0,000455	2,18	0,34
Gravel	1125	0,0011	0,0000844	1,24	0,09
Total	2500	-	-	**231,91**	**17,46**

Figure 3.7: GWP and ECI for CEM II/B-S 52.5N w/c=0.45 (own figure, source: Henk Jonkers)

Component	kg per m^3 concrete	GWP $kg*CO2/kg$	ECI €/kg	GWP $kg*CO2/m^3$	ECI €/m^3
CEM II/B-S 52.5N	403	0,53	0,0395	213,59	15,92
Water	222	0,00034	0	0,08	0
Sand	750	0,0029	0,000455	2,18	0,34
Gravel	1125	0,0011	0,0000844	1,24	0,09
Total	2500	-	-	**217,08**	**16,35**

Figure 3.8: GWP and ECI for CEM II/B-S 52.5N w/c=0.55 (own figure, source: Henk Jonkers)

Component	kg per m^3 concrete	GWP $kg*CO2/kg$	ECI €/kg	GWP $kg*CO2/m^3$	ECI €/m^3
CEM III/B 42.5N	431	0,18	0,0134	77,58	5,78
Water	194	0,00034	0	0,07	0
Sand	750	0,0029	0,000455	2,18	0,34
Gravel	1125	0,0011	0,0000844	1,24	0,09
Total	2500	-	-	**81,06**	**6,21**

Figure 3.9: GWP and ECI for CEM III/B 42.5N w/c=0.45 (own figure, source: Henk Jonkers)

Component	kg per m^3 concrete	GWP $kg*CO2/kg$	ECI €/kg	GWP $kg*CO2/m^3$	ECI €/m^3
CEM III/B 42.5N	403	0,18	0,0134	72,54	5,40
Water	222	0,00034	0	0,08	0
Sand	750	0,0029	0,000455	2,18	0,34
Gravel	1125	0,0011	0,0000844	1,24	0,09
Total	2500	-	-	**76,03**	**5,84**

Figure 3.10: GWP and ECI for CEM III/B 42.5N w/c=0.55 (own figure, source: Henk Jonkers)

3.1.3. Additional execution methods

The additional execution methods encompass five options, namely: no additional execution methods, internal heating, external heating, maturity process, and formwork. The impact of these methods will be explained in Chapter Four. There is also the option to use a precamber of the formwork, if this option is used the extra precamber height is 10mm. Figure 3.11 visually presents these additional execution methods within the calculation sheet.

x.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Internal heating	Internal heating used, the internal curing temperature will increase to 50°C.	50°C
External heating	External heating used, the curing temperature will increase with 60°C.	60°C
Maturity process	The maturity method is used. New stresses will develop, the minimum compressive strength is:	12,8 MPa
Formwork	An extra support is applied, in the middle of each grid. New stresses will develop, the minimum compressive strength is:	9,2 Mpa

Precamber:	Yes	Extra precamber height:	10 mm

Figure 3.11: Visible representation of the input values related to the additional execution methods. (own figure, taken from the calculation sheet)

3.2. Output

The output of the calculation sheet include the following sections: the material and shadow costs and the execution time. The output values will change as the input values are changed.

3.2.1. Material and shadow costs

To determine the material and shadow costs, it is imperative to first calculate the quantities of the materials integrated into the concrete mixture. These quantities form the basis for subsequently computing the material and shadow costs. For a visual representation of this calculation process, please refer to Figure 3.12 in the accompanying calculation sheet.
Furthermore, for a detailed breakdown of the material costs per unit, consult Figure 3.13, and for the shadow costs per unit, refer to Figure 3.15. It is essential to note, however, that these values are provided as approximate estimates by relevant companies and should not be employed in practical applications. The actual costs are highly contingent on various factors such as project scale, geographical location, and ambient temperature. For the purpose of this research, these parameters have not been incorporated into the calculations.

x.2 Output

x.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	84139	68994,27	€ 65.208,00	€ 5.100,78
	Blast furnace slag	322,6	336557	6394,59		€ 518,07
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 4.890,60	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 13.899,60	€ 99,09
Water	Tap water	222	231383	78,67	€ 347,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	0,60	631	454,35	€ 946,57	€ 58,21
Additional admixtures	Accelerator HA60	8,1	8414	6058,03355	€ 21.034,84	€ 776,19
Heating	Propaan gas - fossil	-	2838	1705,67807	€ 7.805,54	€ 365,09
Extra grinding costs		-	-	68994,27	€ 12.620,90	€ 5.100,78
				238123	€ 195.008,33	€ 21.271,04
					€ 216.279,36	

Figure 3.12: Visible representation of the output values related to material and shadow costs. (own figure, taken from the calculation sheet)

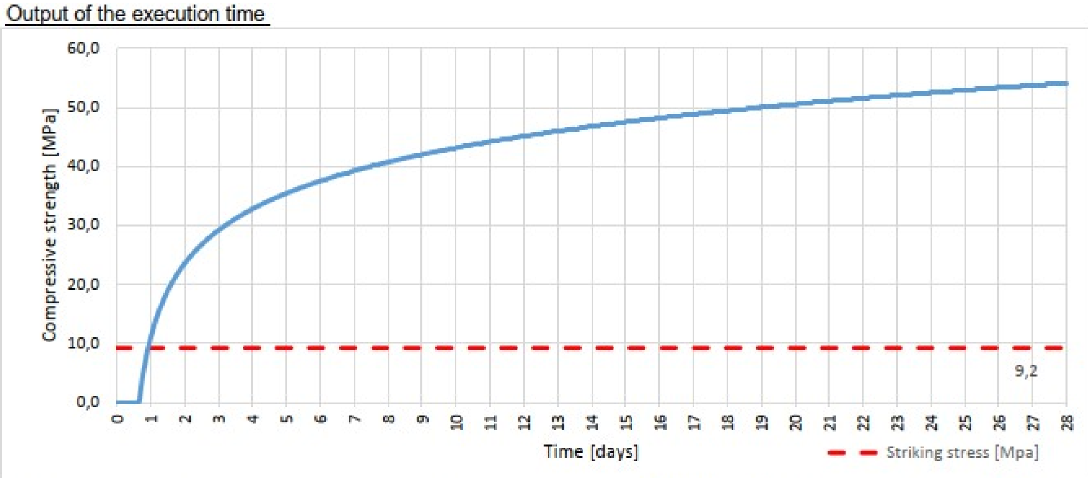
Material	Value	Unit	Source
CEM I 52.5R	170,00	€/ton	ENCI
CEM II/B-S 52.5N	160,00	€/ton	ENCI
CEM III/B 42.5N	155,00	€/ton	ENCI
Cross mesh ø8-150 (floor)	4651,55	€/floor	Betonstaal.nl
Cross mesh ø10-150 (floor)	6889,70	€/floor	Betonstaal.nl
Cross mesh ø6-150 (wall)	1876,80	€/wall	Betonstaal.nl
Bar ø8, L=6,00m	2,95	€/bar	Betonstaal.nl
Bar ø10, L=6,00m	4,50	€/bar	Betonstaal.nl
Bar ø12, L=6,00m	6,55	€/bar	Betonstaal.nl
Bar ø16, L=6,00m	11,65	€/bar	Betonstaal.nl
Bar ø20, L=6,00m	18,35	€/bar	Betonstaal.nl
Sand	10,00	€/m3	Cementbouw.nl
Gravel	22,50	€/m3	Cementbouw.nl
Water	1,50	€/m3	Cementbouw.nl
Superplasticizer	1,50	€/m3	Cugla
Accelerator HA60	2,50	€/kg	Cugla
Propane gas	2,75	€/kg	Antargaz.nl

Figure 3.13: Material costs (own figure, sources see figure)

3.2.2. Execution time

The calculation sheet's output, which will depict the execution time, will include a graph illustrating the compressive cylinder strength development over time. Additionally, it will compute the minimum compressive stress, tensile stress, and E-modulus to determine which of these factors is the critical stress, dictating the formwork removal time. This critical stress will guide the assessment of the striking time. Figure 3.14 provides a visual representation of the execution time's output. The method for calculating the minimum striking stress and time will be elaborated upon in Chapter 4.

x.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	9,2	Mpa. Which is reached after	23,0	hours
The formwork can be removed when a tensile strength of	0,04	Mpa. Which is reached after	22,0	hours
The formwork can be removed is the deflection is less than	13	mm. Which is reached after	16,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	23,0	hours

Figure 3.14: Visible representation of the output values related to execution time. (own figure, taken from the calculation sheet)

Impact category:		(GWP)	(ODP)	(HT)	(FAETP)	(MAETP)	(TETP)	(POCP)	(AP)	(EP)	fuel (ADf)	non fuel (ADnf)	TOTAL [€/kg]
Unit:		kg CO2 eq	kg CFC-11 eq	kg 1,4-DB eq	kg 1,4-DB eq	kg 1,4-DB eq	kg 1,4-DB eq	kg C2H4 eq	kg SO2 eq	kg PO42- eq	kg Sb eq	kg Sb eq	
Raw materials:	Monetary value:	0,05	30	0,09	0,03	0,0001	0,06	2	4	9	0,16	0,16	
CEM I NL	kg	8,20E-01	5,20E-09	5,00E-02	6,90E-04	5,10E+00	6,80E-04	2,10E-04	2,70E-03	3,60E-04	5,70E-04	6,70E-07	6,062296E-02
Blast Furnace Slag (GGBFS)	kg	1,90E-02	1,10E-09	3,60E-03	4,60E-06	2,00E+00	2,70E-06	1,00E-06	5,80E-06	1,40E-06	1,70E-04	7,60E-10	1,539333E-03
Fly ash from coal	kg	3,30E-03	2,60E-10	6,70E-04	2,10E-05	2,10E-01	7,40E-06	1,20E-06	1,50E-05	3,50E-06	2,30E-05	8,50E-10	3,449619E-04
Sand, river 0-4mm	kg	2,90E-03	3,10E-10	1,90E-03	3,10E-05	2,00E-01	1,10E-05	2,30E-06	1,80E-05	4,20E-06	2,00E-05	1,30E-09	4,551995E-04
Sand, sea 0-4mm	kg	1,10E-02	1,30E-09	8,00E-03	1,30E-04	7,40E-01	2,30E-05	1,00E-05	7,90E-05	1,80E-05	7,40E-05	3,40E-09	1,859160E-03
Sand, crushed 0-4mm	kg	9,00E-03	5,70E-10	4,30E-03	5,40E-05	5,50E-01	3,20E-05	3,10E-06	2,90E-05	6,10E-06	6,90E-05	1,90E-08	1,083700E-03
Crushed recycled 0-4mm	kg	2,00E-03	3,00E-10	3,30E-04	1,60E-05	1,00E-01	2,80E-06	6,90E-07	3,00E-06	5,20E-07	1,40E-05	5,10E-10	1,606571E-04
Gravel, river >4mm	kg	1,10E-03	1,70E-10	1,60E-04	8,40E-06	5,20E-02	7,00E-07	3,60E-07	1,40E-06	2,30E-07	7,10E-06	1,20E-10	8,442512E-05
Gravel, sea >4mm	kg	1,10E-02	1,30E-09	7,90E-03	1,30E-04	7,30E-01	2,00E-05	1,00E-05	7,90E-05	1,80E-05	7,20E-05	3,10E-09	1,848659E-03
Gravel, crushed >4mm	kg	6,20E-03	6,80E-10	1,70E-02	8,90E-05	4,40E-01	1,70E-05	7,10E-06	5,70E-05	1,30E-05	4,30E-05	3,10E-09	2,253791E-03
Crushed recycled >4mm	kg	1,10E-03	1,10E-10	7,20E-04	1,10E-05	6,80E-02	5,60E-06	8,30E-07	6,70E-06	1,50E-06	7,00E-06	7,70E-10	1,703494E-04
Superplasticizer (PCE)	kg	7,20E-01	9,60E-08	8,20E-02	3,00E-02	9,10E+00	3,60E-04	1,40E-03	9,70E-03	4,60E-04	8,10E-03	0,00E+00	9,225048E-02
Accelerator HA60	kg	7,20E-01	9,60E-08	8,20E-02	3,00E-02	9,10E+00	3,60E-04	1,40E-03	9,70E-03	4,60E-04	8,10E-03	0,00E+00	9,225048E-02
Tap water	kg	3,40E-04	1,60E-11	8,30E-05	1,30E-06	2,20E-02	1,50E-06	1,10E-07	8,00E-07	1,40E-07	2,70E-06	2,60E-10	3,191152E-05
Surface / well water	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,000000E+00
Reinforcement	kg	1,50E+00	6,00E-08	5,50E-01	1,80E-02	5,00E+01	2,70E-02	1,20E-03	5,10E-03	7,00E-04	1,30E-02	1,10E-06	1,628420E-01
Propaan gas - fossil	kg	6,01E-01	4,71E-07	3,80E-01	3,09E-02	2,60E+02	2,65E-03	3,78E-04	6,84E-03	5,95E-04	2,44E-02	8,14E-07	1,286247E-01

Figure 3.15: Shadow costs (own figure, source: Henk Jonkers)

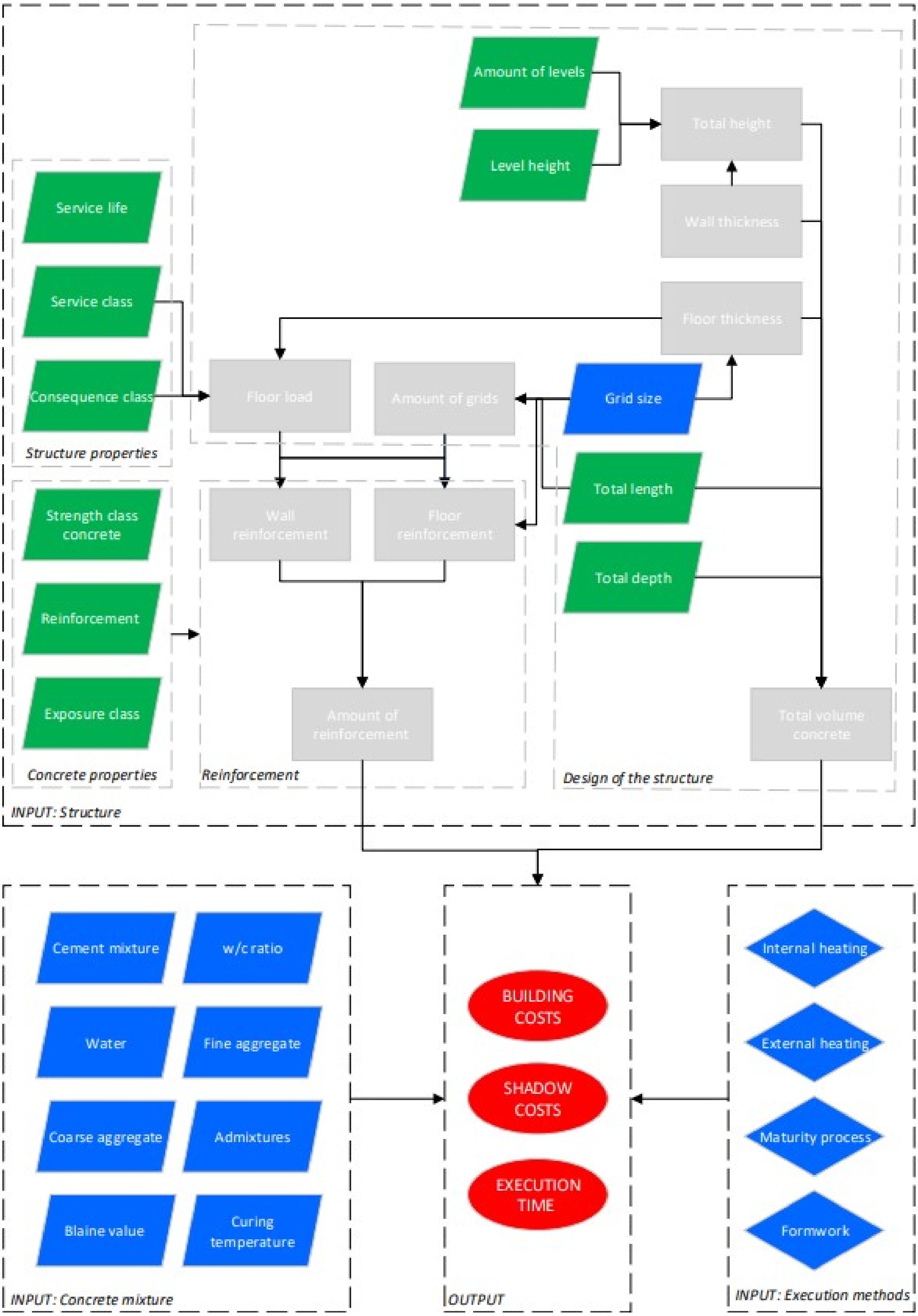


Figure 3.16: Flowchart of the calculation sheet. The blue parallelogram denotes a manual input value, the green parallelogram denotes a manual allocated (for this project) input value, the light gray rectangle denotes an input value calculated from a manual input value, the blue diamond denotes an optional input value, and the red ellipse denotes an output value. (own figure)

3.3. Variants

As previously mentioned, the research will encompass three different grid sizes, each with three distinct cement mixtures. To validate the findings against current practice standards, it is essential to establish a benchmark. This benchmark will consist out of Portland cement (CEM I 52.5R), a w/c ratio of 0.55, 40% fine aggregate, 60% coarse aggregate, no additional admixtures, a Blaine value of 300m2/kg, a curing temperature of 20°C, and no additional execution measures. Once the benchmark has been defined, nine variations will be computed for each sustainable cement type and grid size. These variations will encompass a base variation and eight others where parameters such as the w/c ratio (variation a), Blaine value (variation b), admixtures (variation c), season (variation d) and four optional execution measures (variations e-h) will be adjusted accordingly. Finally, two additional variations will be investigated for each grid size and sustainable cement mixture. These variations include a summer variant (variation s) with the required adjustments to achieve an execution time of 16 hours and a winter variant (variation w) with the necessary modifications to attain the same 16-hour execution time.

3.4. Hypothesis

The dimensions of the grid have a direct impact on the quantity of reinforcement incorporated into the structure. A larger grid size naturally entails a greater amount of reinforcement, whereas a smaller grid size results in a comparatively lower quantity of reinforcement. However, it's important to note that since the overall structural length remains consistent across all scenarios, a structure featuring a reduced grid density is likely to exhibit a correspondingly decreased total volume of concrete. This correlation between grid size and concrete volume arises from the influence of grid dimensions on the spacing and distribution of reinforcement elements within the structure.

Variations involving CEM I 52.5R are expected to yield the fastest execution time, followed by CEM II/B-S 52.5N, with CEM III/B 42.5N likely having the slowest execution time. This expectation is rooted in the composition of these cement types. CEM I contains the highest proportion of Portland cement (approximately 100%), resulting in rapid strength development. Conversely, CEM II (65% Portland) and CEM III (20% Portland) are anticipated to exhibit slower strength development due to their lower Portland cement content. Material and shadow costs are also expected to be lower for CEM II and CEM III mixtures compared to CEM I, as Portland cement is costlier and has a larger environmental footprint.

As discussed in the literature review, concrete mixtures with lower w/c ratios tend to exhibit enhanced strength development. Thus, a mixture with a w/c ratio of 0.45 is expected to demonstrate faster strength development than one with a w/c ratio of 0.55. However, lower w/c ratios will result in higher material and shadow costs, as cement is more expensive and has a greater environmental impact than water.

Finer cement particles, indicated by a higher Blaine value, are anticipated to lead to faster strength development. Consequently, a mixture with a Blaine value of 400 m^2/kg is expected to outperform one with a Blaine value of 300 m^2/kg in terms of strength development. A higher Blaine value will affect material and shadow costs, due to extra grinding costs.

Superplasticizers are standard additives used to control the concrete mix's workability in response to ambient temperature. In contrast, accelerators are employed to expedite strength development. The inclusion of accelerators is likely to result in faster strength development but will increase material and shadow costs.

Higher curing temperatures are expected to accelerate strength development in concrete. So a structure built in the summer will have a faster execution time then an structure built in the winter. Internal and external heating measures are likely to expedite strength development, though they will also raise material and shadow costs.

The existing requirement for formwork removal is contingent on the concrete mixture reaching a compressive strength of 14 MPa. If this requirement can be lowered, it may be possible to remove the formwork earlier, which would benefit CEM II and CEM III mixtures.

The addition of an extra row of supports in the middle of each grid size is expected to significantly reduce stresses, potentially allowing for earlier formwork removal. This adjustment could be advantageous for CEM II and CEM III mixtures.

Variation	Grid-size	Wall thickness	Floor thickness	Reinforcement	Volume	Cement mixture	PC [%]	FA [%]	BFS [%]	w/c ratio	Fine aggregate	Coarse aggregate	Blaine value	Basic Admixtures	Additional Admixtures	Season	Additional execution method
Variation_1	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM I 52.5R	100	0	0	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,3%	None	Summer	None
Variation_2	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,25%	None	Summer	None
Variation_2a	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM II/B-S 52.5N	65	35	0	0,45	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,25%	None	Summer	None
Variation_2b	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	$400m^2/kg$	Superplasticizer (PCE) 0,25%	None	Summer	None
Variation_2c	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,25%	Accelerator HA60 2%	Summer	None
Variation_2d	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,25%	None	Winter	None
Variation_2e	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,25%	None	Summer	Internal heating
Variation_2f	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,25%	None	Summer	External heating
Variation_2g	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,25%	None	Summer	Maturity process
Variation_2h	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,25%	None	Summer	Formwork
Variation_3	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM III/B 42.5N	20	0	80	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,15%	None	Summer	None
Variation_3a	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM III/B 42.5N	20	0	80	0,45	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,15%	None	Summer	None
Variation_3b	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM III/B 42.5N	20	0	80	0,55	40%	60%	$400m^2/kg$	Superplasticizer (PCE) 0,15%	None	Summer	None
Variation_3c	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM III/B 42.5N	20	0	80	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,15%	Accelerator HA60 2%	Summer	None
Variation_3d	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,15%	None	Winter	None
Variation_3e	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM III/B 42.5N	20	0	80	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,15%	None	Summer	Internal heating
Variation_3f	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM III/B 42.5N	20	0	80	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,15%	None	Summer	External heating
Variation_3g	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM III/B 42.5N	20	0	80	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,15%	None	Summer	Maturity process
Variation_3h	4,50m	250mm	250mm	$335mm^2/m^1$	$1144m^3$	CEM III/B 42.5N	20	0	80	0,55	40%	60%	$300m^2/kg$	Superplasticizer (PCE) 0,15%	None	Summer	Formwork

Figure 3.17: Variations with a grid size of 4.50m (own figure)

Variation	Grid-size	Wall thickness	Floor thickness	Reinforcement	Volume	Cement mixture	PC [%]	FA [%]	BFS [%]	w/c ratio	Fine aggregate	Coarse aggregate	Blaine value	Basic Admixtures	Additional Admixtures	Season	Additional execution method
Variation_4	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM I 52.5R	100	0	0	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,3%	None	Summer	None
Variation_5	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,25%	None	Summer	None
Variation_5a	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM II/B-S 52.5N	65	35	0	0,45	40%	60%	300m²/kg	Superplasticizer (PCE) 0,25%	None	Summer	None
Variation_5b	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	400m²/kg	Superplasticizer (PCE) 0,25%	None	Summer	None
Variation_5c	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,25%	Accelerator HA60 2%	Summer	None
Variation_5d	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,25%	None	Winter	None
Variation_5e	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,25%	None	Summer	Internal heating
Variation_5f	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,25%	None	Summer	External heating
Variation_5g	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,25%	None	Summer	Maturity process
Variation_5h	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,25%	None	Summer	Formwork
Variation_6	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM III/B 42.5N	20	0	80	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,15%	None	Summer	None
Variation_6a	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM III/B 42.5N	20	0	80	0,45	40%	60%	300m²/kg	Superplasticizer (PCE) 0,15%	None	Summer	None
Variation_6b	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM III/B 42.5N	20	0	80	0,55	40%	60%	400m²/kg	Superplasticizer (PCE) 0,15%	None	Summer	None
Variation_6c	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM III/B 42.5N	20	0	80	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,15%	Accelerator HA60 2%	Summer	None
Variation_6d	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,15%	None	Winter	None
Variation_6e	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM III/B 42.5N	20	0	80	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,15%	None	Summer	Internal heating
Variation_6f	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM III/B 42.5N	20	0	80	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,15%	None	Summer	External heating
Variation_6g	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM III/B 42.5N	20	0	80	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,15%	None	Summer	Maturity process
Variation_6h	6,00m	250mm	250mm	524mm²/m¹	1044m³	CEM III/B 42.5N	20	0	80	0,55	40%	60%	300m²/kg	Superplasticizer (PCE) 0,15%	None	Summer	Formwork

Figure 3.18: Variations with a grid size of 6.00m (own figure)

Variation	Grid-size	Wall thickness	Floor thickness	Reinforcement	Volume	Cement mixture	PC [%]	FA [%]	BFS [%]	w/c ratio	Fine aggregate	Coarse aggregate	Blaine value	Basic Admixtures	Additional Admixtures	Season	Additional execution method
Variation_7	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM I 52.5R	100	0	0	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,3%	None	Summer	None
Variation_8	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,25%	None	Summer	None
Variation_8a	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM II/B-S 52.5N	65	35	0	0,45	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,25%	None	Summer	None
Variation_8b	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	400m^2/kg	Superplasticizer (PCE) 0,25%	None	Summer	None
Variation_8c	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,25%	Accelerator HA60 2%	Summer	None
Variation_8d	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,25%	None	Winter	None
Variation_8e	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,25%	None	Summer	Internal heating
Variation_8f	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,25%	None	Summer	External heating
Variation_8g	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,25%	None	Summer	Maturity process
Variation_8h	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,25%	None	Summer	Formwork
Variation_9	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM III/B 42.5N	20	0	80	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,15%	None	Summer	None
Variation_9a	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM III/B 42.5N	20	0	80	0,45	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,15%	None	Summer	None
Variation_9b	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM III/B 42.5N	20	0	80	0,55	40%	60%	400m^2/kg	Superplasticizer (PCE) 0,15%	None	Summer	None
Variation_9c	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM III/B 42.5N	20	0	80	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,15%	Accelerator HA60 2%	Summer	None
Variation_9d	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM II/B-S 52.5N	65	35	0	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,15%	None	Winter	None
Variation_9e	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM III/B 42.5N	20	0	80	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,15%	None	Summer	Internal heating
Variation_9f	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM III/B 42.5N	20	0	80	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,15%	None	Summer	External heating
Variation_9g	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM III/B 42.5N	20	0	80	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,15%	None	Summer	Maturity process
Variation_9h	7,20m	250mm	250mm	785mm^2/m^1	993m^3	CEM III/B 42.5N	20	0	80	0,55	40%	60%	300m^2/kg	Superplasticizer (PCE) 0,15%	None	Summer	Formwork

Figure 3.19: Variations with a grid size of 7.20m (own figure)

4

Analysis of the calculation sheet

The fourth and final main chapter will analyse the effect of the concrete properties and additional execution measures on the material costs, shadow costs and execution time. After the effects of these properties are analysed, the results of the variants are calculated with the help of the calculation sheet.

4.1. Effect of the concrete properties

First the effect of the concrete properties on the material costs, shadow costs and execution time will be discussed. The effect of the following properties will be analysed: cement mixture, w/c ratio, Aggregate, admixtures and curing temperature.

4.1.1. Cement mixture and w/c ratio

The first two properties of the concrete mixture are discussed together, as they exert the most significant influence on material costs, shadow costs, and execution time. According to the literature review, the cement mixture with the highest proportion of Portland cement exhibits the swiftest strength development. Similarly, the w/c ratio plays a vital role, with lower ratios correlating to faster strength development.

The following cement mixtures will be used: CEM I 52.5R, CEM II/B-S 52.5N and CEM III/B 42.5N. The choice of CEM I 52.5R is rooted in its exceptional strength development, achieved through the utilization of 100% Portland cement. The reason for using CEM II/B-S 52.5N is because it has the least amount of Portland cement (compared to CEM II/A) and thus will decrease the material and shadow costs. CEM II/B-S 52.5N has the fastest strength development (CEM II/B-S 52.5R does not exist for CEM II). The reason for using CEM III/B 42.5N is because it has the least amount of Portland cement (compared to CEM III/A) and thus will decrease the material and shadow costs. CEM III/B 42.5N has the fastest strength development (CEM III/B 52.5R and CEM III/B 42.5R does not exist for CEM III).

The Betonpocket provides an equation that combines the cement type and w/c ratio to calculate the mean compressive cube strength over time, as seen in equation 4.1. This calculation necessitates three coefficients denoted as a, b, and c available from the Betonpocket and contingent upon the cement type used. Additionally, the nominal strength (N_n) of the cement mixture, furnished by ENCI, is a requisite input. The curing temperature is 20°C.

Figure 4.1 illustrates the cement mixtures alongside their corresponding w/c ratios employed in the research. Utilizing the coefficients and nominal strength, one can calculate the mean compressive cube strength ($f_{cm,cube(n)}$). This, in turn, facilitates the construction of a curve fit capable of determining the compressive cube strength at any given point in time. It is important to note that the mean compressive cube strength must be converted to obtain the mean compressive cylinder strength (f_{cm}), as per equation 4.2 (a value of 0.81 is used, because a concrete class of C30/37 is used in this research, 30 divived by 37 is 0.81).

$$f_{cm,cube(n)} = a * N_n + \frac{b}{wc} - c \tag{4.1}$$

$$f_{cm} = f_{cm,cube} * 0.81 \tag{4.2}$$

Cement mixture	w/c	Coefficients			Nn [MPa]			fcm,cube [MPa]			Curve fit	R
		a	b	c	0 days	2 days	28 days	0 days	2 days	28 days		
CEM I 52.5R	0,55	0,85	33	62	0	30,00	52,5	0	23,50	42,63	fcm,c=6,47ln(t)+20,30	0,997
CEM II/B-S 52.5N	0,45	0,85	33	62	0	20,00	52,5	0	28,33	55,96	fcm,c=10,47ln(t)+21,08	1,000
CEM II/B-S 52.5N	0,55	0,85	33	62	0	20,00	52,5	0	15,00	42,63	fcm,c=10,47ln(t)+7,74	1,000
CEM III/B 42.5N	0,45	0,75	18	30	0	10,00	42,5	0	17,50	41,88	fcm,c=9,24ln(t)+11,10	1,000
CEM III/B 42.5N	0,55	0,75	18	30	0	10,00	42,5	0	10,23	34,60	fcm,c=9,24ln(t)+3,83	1,000

Figure 4.1: Mean compressive cube strength development due to the cement mixture and w/c ratio, according to the Betonpocket(own figure).

The curve fit depicted in Figure 4.1 are integrated into the calculation sheet. The impact of cement mixture and w/c ratio on execution time is explained, highlighting that a mixture rich in Portland cement yields the fastest compressive strength development. Conversely, regarding material and shadow costs, the reverse relationship holds true: a mixture with less Portland cement results in lower material and shadow costs, as illustrated in figure 3.13 and figure 3.15.

4.1.2. Aggregate

The impact of aggregates on execution time is deemed negligible and, as such, will not be incorporated into the calculation sheet. In all variants considered, aggregates constitute 75% of the total concrete weight. This 75% is further divided into 40% fine aggregate (sand) and 60% coarse aggregate (gravel). Various types of sand can serve as aggregate, including river sand, sea sand, crushed sand, and crushed recycled sand. Similarly, different options exist for gravel. The choice of aggregate type carries implications for environmental impact, with recycled aggregate having the lowest impact, followed by river aggregate. Sea aggregate ranks highest in terms of environmental impact, followed by crushed aggregate. For this research, river aggregate is selected due to its availability in the Netherlands.

4.1.3. Admixtures

There are two categories of admixtures that can be incorporated into concrete mixtures: basic admixtures and additional admixtures. Basic admixtures, exemplified by PCE (superplasticizers), are a fundamental component of concrete mixes, with the precise quantity depending on the specific cement blend in use. However, it's important to note that these basic admixtures do not exert any influence on the development of compressive strength.
On the other hand, additional admixtures, such as accelerators (applied in variation C), can significantly impact compressive strength development. When applied in concrete mixtures cured at temperatures of 20°C or higher, accelerators enhance compressive strength by approximately 20%. Moreover, at curing temperatures ranging from 5°C to 20°C, they contribute to a 30% improvement in concrete strength development. These percentage figures are sourced from the product information for HA-60 accelerators provided by Cugla. Typically, a dosage equivalent to around 2% of the cement weight is recommended for accelerators.
It's worth noting that the use of admixtures can have cost implications, affecting both material costs and associated expenses. PCEs tend to be more cost-effective compared to accelerators, and their shadow costs are generally in the same range. Furthermore, it's essential to consider that as the number of admixtures used increases, both material and shadow costs are likely to rise accordingly.

4.1.4. Blaine value

The Blaine value impacts the fineness of cement, with higher Blaine values corresponding to greater fineness in the cement particles. Enhanced fineness leads to a more rapid development of strength, as

elaborated in chapter 2. The influence of the Blaine value on strength development is derived from various research papers. In the case of the two sustainable cement mixtures, an examination is conducted to understand how the percentage increase varies when the Blaine value is raised from 300m^2/kg to 400m^2/kg. Notably, our research omits an investigation into the Blaine value's effect on CEM I, as all CEM I variants in this study maintain a standard Blaine value of 300m^2/kg.
Chindaprasirt's research delves into the Blaine value's impact on Portland fly ash cement mixtures. This specific research employs a blend of 60% Portland cement and 40% fly ash, coupled with a water-to-cement ratio of 0.46. For these mixtures, two variants are explored: one with a fly ash fineness of 300m^2/kg and another with a fineness of 390m^2/kg. Compressive strengths are measured at 3, 7, and 28 days, allowing for the creation of two curve fits, as depicted in figure 4.2. These curve fits facilitate the determination of strength development for the two mixtures, along with the calculation of the associated percentage increase. A Portland-fly ash cement mixture boasting a Blaine value of 390m^2/kg exhibits a 20% accelerated strength development compared to its counterpart with a Blaine value of 300m^2/kg. It is important to note that Chindaprasirt's research varies in terms of fly ash fineness, uses a single water-to-cement ratio, and deploys a Blaine value different from our research's Blaine value of 400m^2/kg. Nonetheless, the findings from Chindaprasirt's study remain pertinent, suggesting that an increase in Blaine value can enhance the strength development by 20% in mixtures employing CEM II [55].
Öner's study delves into the influence of the Blaine value on Portland blast furnace slag cement mixtures. This particular research incorporates a blend consisting of 50% Portland cement and 50% fly ash, with a water-to-cement ratio set at 0.50. Two distinct variations are investigated: one with a fineness of 300m^2/kg for the Portland blast furnace slag cement and another with a fineness of 400m^2/kg. Compressive strength measurements are taken at 2, 7, and 28 days, allowing for the generation of two curve fits, as illustrated in figure 4.2. These curve fits facilitate the assessment of strength development for both mixtures, as well as the calculation of the associated percentage increase. Notably, a Portland blast furnace slag cement mixture possessing a Blaine value of 400m^2/kg demonstrates a remarkable 40% increase in strength development when compared to its counterpart with a Blaine value of 300m^2/kg. It is worth highlighting that Öner's research deviates in terms of employing a single water-to-cement ratio and a lower percentage of blast furnace slag, which stands at 50%, as opposed to our research utilizing 80% BFS. Nonetheless, the outcomes from Öner's investigation remain relevant, a 40% improvement in strength development with an increased Blaine value in mixtures utilizing CEM III [56].

Source	Cement mixture			w/c	Blaine value	Days				Curve fit	R
	PC	FA	BFS			2	3	7	28		
Chindaprasirt	60%	40%	-	0,46	300 m2/kg	-	11,50	20,50	30,50	y=8,38ln(x)+3,02	0,988
Chindaprasirt	60%	40%	-	0,46	390 m2/kg	-	15,50	23,00	38,50	y=10,38ln(x)+3,60	0,996
Öner	50%	-	50%	0,50	300 m2/kg	5,60	-	13,40	30,80	y=9,60ln(x)-2,51	0,965
Öner	50%	-	50%	0,50	400 m2/kg	8,90	-	19,10	42,30	y=12,73ln(x)-1,90	0,964

Figure 4.2: Strength development of cement mixtures with different Blaine values (own figure, source: Chindaprasirt and Öner).

The impact of a higher Blaine value carries significant implications for both material costs and shadow costs. Elevating the Blaine value leads to an increase in grinding costs, a factor that cannot be overlooked due to its substantial expense. In the context of this research, if the Blaine value is 400m^2/kg, additional costs come into play. These additional costs are hypothetical, amounting to €30 per ton of cement used in terms of material costs and €0.0128 per kg in shadow costs. It is worth noting that these figures are purely theoretical, as they are conjured for the purpose of this study. In practice, such specific cost increments resulting from a higher Blaine value remain undocumented due to the lack of available information on the subject.

4.1.5. Curing temperature

The curing temperature plays a pivotal role in influencing the strength development of concrete structures. Higher curing temperatures lead to a swifter progression in strength compared to lower curing temperatures, as explained in chapter 2. There are two principal approaches for assessing the impact of curing temperature on strength development. The first method involves the use of the maturity method (NEN 5970), which gauges strength development over time in conjunction with heat generation. This method necessitates the establishment of a graphical relationship between compressive strength and maturity. The maturity of concrete, however, is contingent on a multitude of intricate factors, which extend beyond the scope of this research.
An alternative way to assess the influence of curing temperature is provided by Equation B.10 from NEN-EN 1992-2. This equation calculates the corrected age of the prevailing curing temperature, as indicated in equation 4.3. The resulting value can then be incorporated into equation 4.4. Using this Beta value, one can compute the compressive strength at different curing temperatures, see equation 4.5. The benchmark temperature for equation 4.5 is set at 20°C. For example, if the curing temperature is 10°C, the compressive strength at 1 day for both 20°C and 10°C will be calculated. The effect of curing temperature is determined by dividing the compressive strength at 10°C by that at 20°C. This value quantifies the influence of curing temperature. It's essential to note that the equation's nature is exponential. As the compressive strength approaches 0 days, the value diverges further from 1, whereas as it approaches 28 days, the value tends to converge towards 1. In this research, we will adopt the NEN-EN method to assess the impact of curing temperature on strength development.

$$t_T = exp(-((\frac{4000}{273 + T\Delta t_i}) - 13.65)) * \Delta t_i \tag{4.3}$$

$$\beta_{cc}(t_T) = exp(s * (1 - (\frac{28}{t_T})^{0.5})) \tag{4.4}$$

$$f_{cm}(t_T) = \beta_{cc}(t_T) * f_{cm} \tag{4.5}$$

Where:
t_T= corrected age of the curing temperature.
$T\Delta t_i$= temperature during period Δt_i.
Δt_i= time period in days.
$\beta_{cc}(t_T)$= Beta factor for a given temperature.
s= Coefficient dependent on the cement mixture, s=0.20 for CEM II/B-S 52.5N and s=0.25 for CEM III/B 42.5N.
$f_{cm}(t_T)$= mean compressive cylinder strength for a given temperature.

Two options are available for controlling the curing temperature: 10°C, which is applicable when the structure is constructed in winter, and 20°C, which is suitable for summer construction. The curing temperature is dependent on the additional execution measures. In cases where internal heating measures are applied, the curing temperature can rise to 50°C. Alternatively, external heating measures can elevate the curing temperature to 60°C.
If the curing temperature is 10°C the calculated strength development in equation 4.2 will exponentially change from 0.24*f_{cm} (at 1 hour of strength) to 1*f_{cm} (at 28 days of strength). If the curing temperature is 20°C the calculated strength development in equation 4.2 will exponentially change from 1*f_{cm} (at 1 hour of strength) to 1*f_{cm} (at 28 days of strength). If the curing temperature is 50°C the calculated strength development in equation 4.2 will exponentially change from 11.43*f_{cm} (at 1 hour of strength) to 1*f_{cm} (at 28 days of strength). If the curing temperature is 50°C the calculated strength development in equation 4.2 will exponentially change from 18.24*f_{cm} (at 1 hour of strength) to 1*f_{cm} (at 28 days of strength). These value changes are for CEM II, the value changes for CEM III are higher because the s-value is higher.

4.2. Effect of the execution measures

Lastly the effect of the additional execution measures on the material costs, shadow costs and execution time will be discussed. The effect and influence of the following execution measures will be analysed: Internal and external heating measures, the maturity process and the formwork.

4.2.1. Internal measures

To reduce the construction time and thereby minimizing the formwork striking duration, two internal execution measures can come into play: pouring concrete with hot water and implementing internal heating within the concrete structure. In this research, we will solely delve into the latter measure, as pouring with hot water primarily affects the initial hours following concrete placement, with some mixtures taking an extended period to attain the requisite strength.

Internal heating of the concrete structure involves the placement of plastic conduits within the formwork of floors and walls before concrete pouring. This method allows the curing temperature to be elevated to 50°C. Throughout this study, the curing temperature will be maintained at a constant 50°C, ensuring a consistent heat evolution. While this may not strictly align with practical scenarios, it simplifies the analysis. The effect of raising the curing temperature to 50°C on strength development is explored in the section addressing the influence of curing temperature. The process of heating a concrete structure in this manner is referred to as ”hot casting.” To facilitate this process, insulation sheets made of PE with a 6mm thickness are utilized around the tunnel formwork.

Propane gas is the chosen heating source for the concrete structure. To ascertain material and shadow costs, it is imperative to calculate the quantity of propane gas required to heat the concrete structure to 50°C and maintain it at this temperature. equation 4.6 provides insight into the energy needed to raise the concrete structure's temperature from the ambient temperature to 50°C. Despite insulation measures, there remains an hourly energy loss to the surrounding environment, as captured by equation 4.7. This hourly energy loss must be continually compensated by additional energy input. The concrete structure is heated for a duration of 10 hours, allowing time for it to cool down before formwork removal. Equation 4.8 aids in determining the requisite amount of propane gas to attain and sustain the concrete structure at 50°C.

$$E_{con} = V_{con} * \rho_{con} * C_{con} * \Delta T \tag{4.6}$$

$$Q_{loss,con} = \frac{A_{con} * \Delta T}{R_{con} + R_{PE}} * 3,6 \tag{4.7}$$

$$M_p = \frac{E_{con} + Q_{loss,con} * t}{E_p} \tag{4.8}$$

Where:
E_{con}= Energy required to heat up the concrete structure [kJ].
V_{con}= The total volume of the concrete structure [m^3].
ρ_{con}= The density of concrete = 2500 [kg/m^3].
C_{con}= The heat capacity of concrete = 0.879 [kJ/kg*°C].
ΔT= The temperature difference [°C].
$Q_{loss,con}$= The energy loss of concrete each hour [kJ/h].
A_{con}= The area of concrete [m^2].
R_{con}= Thermal resistance of concrete R=d/k -> R=0.25/1.33=0.19 [$m^2 * °C/W$].
R_{PE}= Thermal resistance of PE-sheets R=d/k -> R=0.006/0.04=0.15 [$m^2 * °C/W$].
M_p= Amount of propane gas needed [kg].
E_p= Energy content propane gas [kJ/kg].

To calculate the material and shadow costs associated with heating the structure to 50°C, multiply the amount of propane gas required by the respective material and shadow cost rates. Refer to figure 3.13 and figure 3.15 for detailed cost figures. It's important to note that the expenses related to the plastic conduits are not included in these calculations.

4.2.2. External measures

An alternative approach to expedite construction involves external measures, specifically external heating. This process entails the use of heaters within the tunnel formwork to warm the internal airspace, the region between the walls and floors, as illustrated in Figure 2.3D depicting the heaters. Similar to internal heating, external heating also constitutes a hot casting method, necessitating the application of insulation sheets around the formwork. For the purpose of this study, we maintain a consistent curing temperature at 60°C to ensure uniform heat evolution, despite this divergence from practical scenarios, which simplifies our analysis.
The influence of elevating the curing temperature to 60°C on strength development is explored within the section addressing the impact of curing temperature. Propane gas is the chosen heating source for the space inside the tunnel. To assess the material and shadow costs, it is crucial to compute the quantity of propane gas needed to raise the internal tunnel space temperature to 60°C and sustain it at this level. Equation 4.9 provides a formula used to calculate the energy required to elevate the air temperature inside the tunnel from the ambient level to 60°C.
To account for heat loss, which can occur via the side walls (constructed of concrete and insulation) or through the front and back (comprised of PE-insulation sheets only), Equation 4.10 provides two distinct equations. The hourly energy loss necessitates continuous compensation through additional energy input. The space inside the tunnel is subjected to heating for a period of 10 hours, allowing sufficient time for it to gradually cool down before the removal of the formwork. Equation 4.11 assists in determining the requisite amount of propane gas essential to achieve and sustain the desired temperature of 60°C within the tunnel.

$$E_{sp} = V_{sp} * \rho_{air} * C_{air} * \Delta T \tag{4.9}$$

$$Q_{loss,sp} = \frac{A_{con} * \Delta T}{R_{con} + R_{PE}} * 3,6..or..Q_{loss,sp} = \frac{A_{PE} * \Delta T}{R_{PE}} * 3,6 \tag{4.10}$$

$$M_p = \frac{E_{sp} + Q_{loss,sp} * t}{E_p} \tag{4.11}$$

Where:
E_{sp}= Energy required to heat up the space inside the tunnel [kJ].
V_{sp}= The total volume of the space inside the tunnel [m^3].
ρ_{air}= The density of air inside the tunnel = 1.293 [kg/m^3].
C_{air}= The heat capacity of air = 1.006 [kJ/kg*°C].
ΔT= The temperature difference [°C].
$Q_{loss,sp}$= The energy loss of space inside the tunnel each hour [kJ/h].
A_{con}= The area of concrete [m^2].
A_{PE}= The area of PE-insulation sheet [m^2].
R_{con}= Thermal resistance of concrete R=d/k -> R=0.25/1.33=0.19 [$m^2 * °C/W$].
R_{PE}= Thermal resistance of PE-sheets R=d/k -> R=0.006/0.04=0.15 [$m^2 * °C/W$].
M_p= Amount of propane gas needed [kg].
E_p= Energy content propane gas [kJ/kg].

To calculate the material and shadow costs associated with heating the space inside the tunnel to 60°C, multiply the amount of propane gas required by the respective material and shadow cost rates. Refer to figure 3.13 and figure 3.15 for detailed cost figures.

4.2.3. Maturity process

This section will delve into the minimum stress required in concrete for formwork removal. In the Netherlands, a common rule of thumb suggests that formwork can be removed once a mean compressive cube strength ($f_{cm,cube}$) of 14 MPa is achieved. However, it's worth noting that this rule of thumb lacks traceability in any official code and may have been erroneously carried over from previous standards. Table 1 of NEN 8670 specifies the minimum value of $f_{cm,cube}$ that must be attained before formwork removal, as depicted in Figure 4.3. It's important to emphasize that the NEN 8670 standard exclusively provides the mean cube compressive strength. However, in this research, the mean cylinder strength is adopted as the determining factor for the timing of formwork removal. Equation 4.2 outlines the required calculation to transform the mean cube strength into the mean cylinder strength. It's worth noting that, conventionally, a mean cube strength is employed on the construction site. Interestingly, NEN 8670 also allows engineers to calculate the compressive strength value, provided that the mean compressive cube strength is validated at three separate locations using the maturity process outlined in NEN 5970.

Strength class	Mean cube compressive strength fcm,cube [MPa]	Mean cylinder compressive strength fcm [MPa]
C12/15	15	12
C20/25	25	20
C30/37	37	29,6
C35/45	45	36
C45/55	55	44
C55/67	67	53,6

Figure 4.3: Minimum values of the mean compressive cube strength for the removal of the formwork (NEN 8670).

To determine the minimum required stress, several key properties must be verified: the mean compressive cylinder strength, the minimum tensile strength, the minimum modulus of elasticity and the maximum deflection shouldn't be reached.

First, we begin by calculating the minimum mean compressive cylinder strength. This calculation necessitates two crucial parameters: the provided reinforcement ($A_s, prov$) and the moment ($M_{ed,SLS}$) following the removal of the formwork. The determination of the provided reinforcement is detailed in Chapter 3, while $M_{ed,SLS}$ is calculated based solely on the dead weight of the concrete floor. Note that in the execution phase exists out of a single field, and not out of multiple fields as in the use phase. So the moment is calculated as follows: $M_{ed,SLS} = 1/8 * q_{ep} * L^2$. It's essential to note that the reinforcement should not yield in this stage, so the calculation should be elastic. To calculate the elastic stress of the reinforcement, we assume that the distance between the concrete force and reinforcement force, 0.9 times the d is, see equation 4.12. With the assumed elastic stress of the reinforcement, force equilibrium can be achieved. In a concrete floor, achieving force equilibrium between the compressive strength of the concrete and the tensile strength of the reinforcement is essential. This equilibrium enables the calculation of the minimum design value of concrete compressive strength ($f_{cd,min}$). Refer to Figure 4.4 for a visual representation of the force equilibrium within the concrete floor, and equations 4.13, 4.14, and 4.15 for the calculations leading to the determination of the minimum design value of concrete compressive strength. These formulas are all sourced from NEN-EN 1992-2.

To arrive at the minimum mean compressive cylinder strength of concrete, utilized to ascertain the strength required for formwork removal, we employ equations 4.16 and 4.17.

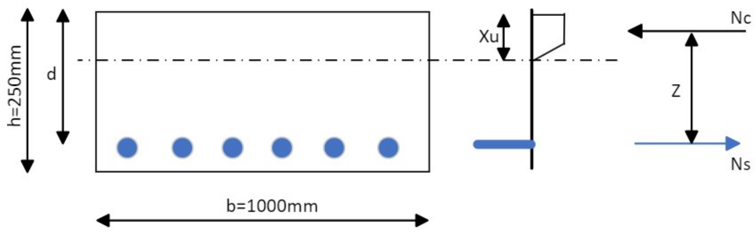


Figure 4.4: Drawing of the equilibrium of the forces inside a concrete floor(own figure).

$$\sigma_{yd,el} = \frac{M_{ed,SLS}}{A_{s,prov} * 0.9 * d} \tag{4.12}$$

$$M_{ed,SLS} = A_{s,prov} * \sigma_{yd,el} * (d - \beta * X_u) - - > X_u = \frac{d - \frac{M_{ed,SLS}}{A_{s,prov} * \sigma_{yd,el}}}{\beta} \tag{4.13}$$

$$X_{u,max} = KX_{u,max} * d - - > X_{u,max} = ((1 - x)/1.25(0.6 + 1.4/\epsilon_{cu3})) * d \tag{4.14}$$

$$N_s = N_c - - > A_{s,prov} * \sigma_{yd,el} = \alpha * X_u * f_{cd,min} * b - - > f_{cd,min} = \frac{A_{s,prov} * \sigma_{yd,el}}{\alpha * X_u * b} \tag{4.15}$$

$$f_{ck,min} = f_{cd,min} * 1.5 \tag{4.16}$$

$$f_{cm,min} = f_{ck,min} + 8 \tag{4.17}$$

Where:
$M_{ed,SLS}$= Moment right after the removal of the formwork [Nmm].
$A_{s,prov}$= Provided amount of reinforcement [mm^2] .
$\sigma_{yd,el}$= Elastic strength of the reinforcement [N/mm^2].
d= Effective height d=h-c-ø/2 [mm].
β= Parameter needed for the calculation of X_u: 0.39.
α= Parameter needed for the calculation of X_u: 0.75.
X_u= Height of the compressive zone [mm].
X_u, max= Maximum height of the compressive zone [mm].
X= Parameter needed for the calculation of X_u, max: 0.44.
ϵ_{cu3}= Relative shortening of the concrete according to table 3.1 in the NEN-EN 1992.
N_c= Normal force of the concrete [N].
N_s= Normal force of the reinforcement [N].
$f_{cd,min}$= Design value of concrete compressive strength [MPa].
$f_{ck,min}$= Characteristic compressive cylinder strength of concrete [MPa].
$f_{ck,min}$= Mean compressive cylinder strength of concrete [MPa].

Upon removal of the formwork, the concrete structure must exhibit sufficient stiffness to withstand the maximum permissible deflection, as stipulated in the NEN-EN 1992. Specifically, the deflection of the floor should not exceed 0.001 times the span, right after the removal of the formwork. This deflection is contingent upon the evolution of the E-modulus of the concrete and the development of cracks within the floor. Utilizing a deflection calculation, it becomes feasible to determine the minimum required stiffness for the structure. Formwork removal is permissible when the deflection, for the first time, falls below 0.001 times the span.
Before embarking on the assessment of deflection development over time, certain assumptions need to be made. The first assumption is that right after the removal of the formwork the load is short-term, which implies that there is no creep in the floor. The second assumption pertains to the floor's existence in both uncracked (I) and cracked (II) stages. The third and fourth assumptions revolve around the tensile strength and E-modulus of the concrete, evolving over time in accordance with equations 2.16

and 2.17. There is no creep so the effective E-modulus of concrete is the E-modulus development over time, see equation 4.18. The last assumption is that right after the removal of the formwork, there will be no shrinkage.
Furthermore, the development of the ratio between the E-modulus of steel and concrete ($\alpha_e(t)$, 4.19), the reinforcement ratio (ρ_1, 4.20), the compressive height of the concrete ($x(t)$, 4.21), the magnification of the tensile strength ($f_{ctm,fl}(t)$, 4.22), the cracking moment ($M_{cr}(t)$, 4.23), the bending moment according to the frequent load combination, which is the same as the $M_{ed,SLS}$ (M_{eqp}, 4.24), and the distribution factor ($\zeta(t)$, 4.25) can be calculated over time. Note that ρ_1 and M_{eqp} remain constant and do not vary with time. It is worth noting that the distribution factor includes tension stiffening (β), which is set at 0.5 for this research. When the cracking moment exceeds the bending moment due to the load, the distribution factor becomes zero, and crack development is prevented.
Once all these variables are calculated, it becomes feasible to determine the development of stiffness in both the uncracked and cracked stages over time, as outlined in equations 4.26 and 4.27. This paves the way for the determination of the total stiffness of the concrete floor ($EI_{I+II}(t)$), as indicated in equation 4.28. Consequently, the deflection of the floor resulting from both the load and creep can be ascertained using equation 4.29. Importantly, the deflection decreases as the execution time progresses. It's crucial to emphasize that these formulas are sourced from NEN-EN 1992-2.

$$E_{c,eff}(t) = E_{cm}(t) \tag{4.18}$$

$$\alpha_e(t) = \frac{E_s}{E_{c,eff}(t)} \tag{4.19}$$

$$\rho_1 = \frac{A_{s,prov}}{b * d} \tag{4.20}$$

$$x(t) = -\alpha_e(t) * \rho_1 + \sqrt{(\alpha_e(t) * \rho_1)^2 + 2 * (\alpha_e(t) * \rho_1)} * d \tag{4.21}$$

$$f_{ctm,fl}(t) = (1.6 - h) * f_{ctm}(t) \tag{4.22}$$

$$M_{cr}(t) = 1/6 * b * h^2 * f_{ctm,fl}(t) \tag{4.23}$$

$$M_{eqp} = 1/8 * (q_g + q_q) * L^2 \tag{4.24}$$

$$\zeta(t) = 1 - \beta * (\frac{M_{cr}(t)}{M_{eqp}})^2 \tag{4.25}$$

$$EI_I(t) = (\frac{1 + 3 * \alpha_e(t) * \rho_1}{1 + \alpha_e(t) * \rho_1}) * E_{c,eff}(t) * 1/12 * b * h^3 \tag{4.26}$$

$$EI_{II}(t) = 6 * (\frac{d}{h})^3 * (\frac{x(t)}{d})^2 * (1 - 1/3 * \frac{x(t)}{d}) * E_{c,eff}(t) * 1/12 * b * h^3 \tag{4.27}$$

$$EI_{I+II}(t) = EI_I(t) * (1 - \zeta(t)) + EI_{II}(t) * \zeta(t) \tag{4.28}$$

$$w_{I+II}(t) = \frac{5 * M_{eqp} + L^2}{48 * EI_{I+II}(t)} \tag{4.29}$$

Where:
$E_{c,eff}(t)$= Effective E-modulus development of concrete over time [MPa].
$E_{cm}(t)$= E-modulus development of concrete over time [MPa].
$\alpha_e(t)$= Ratio between the E-modulus of steel and concrete development of time.
E_s= E-modulus of steel 210000 [MPa].
ρ_1= Reinforcement ratio.
$x_(t)$= Compressive zone of the concrete development over time [mm].

$f_{ctm,fl}(t)$= Magnification of the tensile strength [MPa].
$M_{cr}(t)$= Cracking moment development over time [Nmm].
M_{eqp}= Bending moment according to the frequent load combination [Nmm].
$\zeta(t)$= Distribution factor development over time.
β= Tension stiffening 0.5.
$EI_I(t)$= Stiffness on the uncracked concrete development over time [Nmm^2].
$EI_{II}(t)$= Stiffness on the cracked concrete development over time [Nmm^2].
$EI_{I+II}(t)$= Stiffness on the uncracked and cracked concrete development over time [Nmm^2].
$w_{I+II}(t)$= Deflection due to the load and creep [mm].

The overall deflection development over time, denoted as $w_{tot}(t)$, encompasses the deflection resulting only from both the load, because the deflection right after the removal of the formwork is needed, so creep and shrinkage do no play a role. The critical point at which the deflection, for the first time, falls below 0.001 times the span indicates the opportune moment for the removal of the tunnel's formwork. Subsequently, the critical E-modulus of the concrete is determined. In this deflection calculation, two pivotal factors stand out: the span and the reinforcement ratio. Larger spans necessitate an increased amount of reinforcement to effectively mitigate deflection.

$$w_{tot}(t) = w_{I+II}(t) \tag{4.30}$$

To establish the minimum required tensile strength, it is essential that the crack width exceeds a specific threshold. This calculation hinges on four critical parameters: the provided reinforcement ($A_{s,prov}$), the required reinforcement ($A_{s,req}$), the moment ($M_{ed,SLS}$), and the bending moment according to the frequent load combination (M_{eqp}). The determination of both provided and required reinforcement is outlined in Chapter 3 (Note that again the reinforcement should not yield, so the elastic reinforcement stress, as in 4.12, should be used for the ($A_{s,prov}$) and($A_{s,req}$)). M_{eqp} is computed in equation 4.31 with a permanent load (q_g) of only the dead weight of the concrete floor and a variable load (q_q) of 0 kN/m. The modulus of elasticity of the concrete is the minimum value that is calculated when the deflection is less than 0,001 times the span. For the detailed calculations leading to the determination of the minimum tensile strength of concrete, please refer to Equations 4.32 and 4.33. All these formulas are sourced from NEN-EN 1992.

$$M_{eqp} = 1/8 * q_g * L^2 + 0.5 * (1/8 * q_q * L^2) = M_{ed,SLS} \tag{4.31}$$

$$\sigma_s = \frac{A_{s,req}}{A_{s,prov}} * \frac{M_{eqp}}{M_{ed,SLS}} * \sigma_{yd,el} = \frac{A_{s,req}}{A_{s,prov}} * \sigma_{yd,el} \tag{4.32}$$

$$\epsilon_{sm} - \epsilon_{cm} = 0.6 * \frac{\sigma_s}{E_s} -> \frac{\sigma_s - k_t * \frac{f_{ctm,min}}{P_{p,eff}} * (1 + \alpha_e(t) * P_{p,eff})}{E_s}) = 0.6 * \frac{\sigma_s}{E_s} -> f_{ctm,min} = \frac{\frac{0.4 * \sigma_s * P_{p,eff}}{k_t}}{1 + \alpha_e(t) * P_{p,eff}} \tag{4.33}$$

Where:
ϵ_{sm}= Mean relative shortening of the reinforcement.
ϵ_{cm}= Mean relative shortening of the concrete.
σ_s= Reinforcement stress in the SLS [MPa] .
k_t= 0.4 (long term load).
$P_{p,eff}$=$A_{s,prov}/A_{c,eff}$.
$A_{c,eff}$= Effective area= $b * (2.5 * (h - d))$.
E_s=Modulus of elasticity of steel 210000 [MPa].
$\alpha_{e,t}$=$E_s/E_{c,t}$.
$f_{ctm,min}$= Minimum value of the tensile strength of the concrete [MPa].

After conducting various calculations, it becomes evident that the mean compressive cylinder strength of concrete is the critical parameter in most scenarios. However, when dealing with larger spans, the primary concern shifts to deflection. In cases where the grid size is 6.0m or 7.2m, deflection becomes a critical factor, necessitating the addition of extra reinforcement. An alternative approach to mitigate deflection is to precamber the formwork. When this option is implemented, the formwork is precambered by 10mm, resulting in that the deflection should not reach 0.001 time the span plus 10mm. For a span of 6.0m with precambering, no additional reinforcement is required. However, for a span of 7.2m, the base reinforcement of ø12-150mm proves insufficient. To address this, extra reinforcement of ø10-150mm is applied, achieving a unity check of 0.44.

4.2.4. Formwork

Another approach to expedite the construction process involves the utilization of an alternative formwork system. This formwork incorporates a row of struts positioned in the middle of the span. In contrast to the current single-piece formwork, this modified formwork comprises three components: two inverted L-frames and a central row of struts. Upon the removal of the formwork, the row of struts will be retained for approximately 7 days, at which point the concrete structure will have attained sufficient strength to support their removal. This adaptation is expected to accelerate the overall construction timeline. For an illustrative representation of the new formwork, please refer to Figure 4.5.

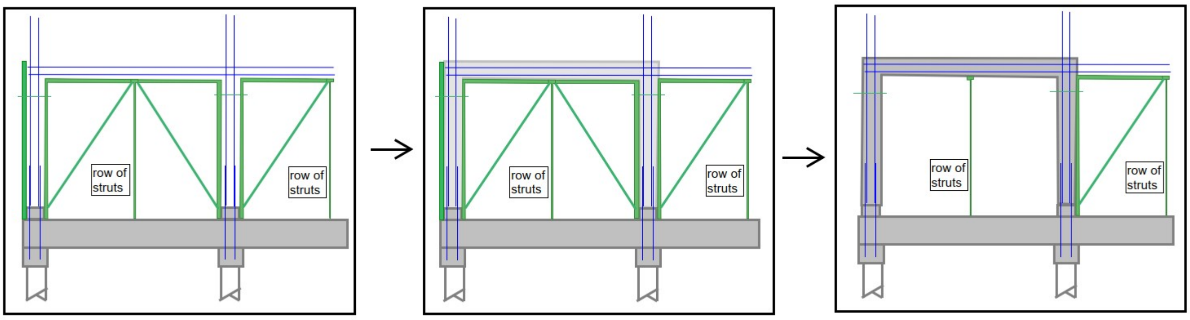


Figure 4.5: Formwork with an extra row of struts at mid span (own figure).

It's crucial to emphasize that the introduction of the additional row of struts will involve the Maturity Process calculations discussed in the preceding section. These calculations are performed using half of the span. The span size significantly affects the bending moment within the floor and, consequently, the deflection. With the implementation of an extra row of struts, there is no requirement for supplementary reinforcement in spans of 6.0m and 7.2m. Furthermore, there are no additional material or shadow costs associated with the inclusion of an extra row of struts.

4.3. Results of the variants

As previously mentioned, there are a total of 23 variants per grid size, resulting in 69 variants in total. The calculation sheet provides information for each variant, including material costs, shadow costs, global warming potential, and the time required for removing the formwork. Please refer to Figure 4.7 for the results of the 4.5m grid-size variants, Figure 4.8 for the 6.0m grid-size variants, and Figure 4.9 for the 7.2m grid-size variants. These results are compared to benchmark variants, which consist of Portland cement and one of the sustainable cement mixtures. In these figures, green values indicate that a variant has a more favorable impact than the benchmark, while red values signify a less favorable impact.

The material costs, shadow costs, and global warming potential are calculated per square meter (m^2). Each variant corresponds to a total floor area of 9.6m by 36m, with 8 floors, resulting in 2764.8 square meters (m^2). For material and shadow costs per square meter, please consult Figure 4.10 for 4.5m grid-size variants, Figure 4.14 for 6.0m grid-size variants, and Figure 4.18 for 7.2m grid-size variants. The shadow costs apart per square meter is presented in Figure 4.11 for 4.5m grid-size variants, Figure 4.15 for 6.0m grid-size variants, and Figure 4.19 for 7.2m grid-size variants. The global warming potential per square meter is presented in Figure 4.12 for 4.5m grid-size variants, Figure 4.16 for 6.0m grid-size variants, and Figure 4.20 for 7.2m grid-size variants. Additionally, Figure 4.13, Figure 4.17, and Figure 4.21 depict the striking time for all variants with a span of 4.5m, 6.0m, and 7.2m, respectively.

The figures reveal that concrete mixtures incorporating CEM I 52.5R exhibit higher material costs, shadow costs, and GWP compared to those using CEM II/B-S 52.5N and CEM III/B 42.5N. Furthermore, mixtures with CEM II/B-S 52.5N demonstrate higher costs and GWP than those with CEM III/B 42.5N. This trend is attributed to the varying amounts of Portland cement used, with CEM I 52.5R employing the highest quantity, followed by CEM II/B-S 52.5N, and CEM III/B 42.5N utilizing the least. As the span increases, material costs, shadow costs, and GWP also rise due to additional floor reinforcement for larger spans. Conversely, concrete mixtures incorporating CEM I 52.5R exhibit a considerably faster striking time compared to those with CEM II/B-S 52.5N and CEM III/B 42.5N, a characteristic attributed to the higher amount of Portland cement used. Notably, the striking time remains consistent for CEM I 52.5R at 16 hours, regardless of span increase. For CEM II/B-S 52.5N (60 hours) and CEM III/B 42.5N (104 hours), striking times remain unchanged for all spans.For the exact values for the material costs, shadow costs and GWP for the benchmark values refer to figure 4.10, 4.14 and 4.18.

A decrease in the w/c ratio from 0.55 to 0.45 results in increased material costs, shadow costs, and GWP for both CEM II/B-S 52.5N and CEM III/B 42.5N across all spans, in comparison to their respective benchmarks. It's noteworthy that, despite higher material costs, the shadow costs and GWP remain significantly lower than the benchmark variant CEM I 52.5R. As the span increases, the differences in costs and GWP between benchmark and decreased w/c ratio variants lessen. For CEM II/B-S 52.5N the striking time decreases from 60 hours to 17 hours and for CEM III/B 42.5N the striking time decreases from 104 hours to 47 hours for all spans.

Similarly, an increase in the Blaine value from 300m^2/kg to 400m^2/kg raises material costs, shadow costs, and GWP for both CEM II/B-S 52.5N and CEM III/B 42.5N across all spans compared to the benchmark of that cement type.. This is due to heightened grinding costs associated with the increased Blaine value. The material costs remain higher than the benchmark variant CEM I 52.5R, while shadow costs and GWP stay lower. For CEM II/B-S 52.5N the striking time decreases from 60 hours to 46 hours and for CEM III/B 42.5N the striking time decreases from 104 hours to 61 hours for all spans.

The addition of accelerators increases material costs, shadow costs, and GWP for both CEM II/B-S 52.5N and CEM III/B 42.5N across all spans compared to their benchmarks. Despite higher material costs, the shadow costs and GWP are lower than the benchmark variant CEM I 52.5R. The striking time decreases with the addition of accelerators, showcasing faster reactions between cement and water. For CEM II/B-S 52.5N the striking time decreases from 60 hours to 46 hours and for CEM III/B 42.5N the striking time decreases from 104 hours to 76 hours for all spans.

Building in winter (10°C) instead of summer (20°C) results in no change in material costs, shadow costs, and GWP for all variations. However, the striking time increases for both CEM II/B-S 52.5N and CEM III/B 42.5N, reaching 80 hours and 140 hours, respectively, for the winter variations.

Heating the concrete structure increases material costs, shadow costs, and GWP for both CEM II/B-S 52.5N and CEM III/B 42.5N across all spans compared to their benchmarks. External heating generates less impact than internal heating. Internal heating needs more propane gas so has higher material costs, shadow costs and GWP than external heating. For CEM II/B-S 52.5N, the striking time decreases to 34 hours with internal heating and 31 hours with external heating. For CEM III/B 42.5N, the striking time decreases to 55 hours with internal heating and 49 hours with external heating.

If the maturity process is selected as an additional execution measure, the material costs, shadow costs, and GWP will remain unchanged compared to the benchmark variants of CEM II/B-S 52.5N and CEM III/B 42.5N. This is because the maturity process is implemented on the construction site and, as such, does not alter the material costs, shadow costs, or GWP. The maturity process involves calculating the minimum stress at which the formwork can be removed, thereby influencing the striking time. Smaller spans exhibit faster striking times than larger spans. For CEM II/B-S 52.5N, the striking time decreases from 60 hours to 42 hours, and for CEM III/B 42.5N, it decreases from 104 hours to 69 hours for a span of 4.5m. Similarly, for a span of 6.0m, the striking time decreases from 60 hours to 52 hours for CEM II/B-S 52.5N and from 104 hours to 88 hours for CEM III/B 42.5N. The striking time remains unchanged at 60 hours for CEM II/B-S 52.5N and 104 hours for CEM III/B 42.5N for a span of 7.2m.

If formwork is chosen as an additional execution measure, the material costs, shadow costs, and GWP will not differ from the benchmark variants of CEM II/B-S 52.5N and CEM III/B 42.5N. Similar to the maturity process, formwork is implemented on the construction site and does not affect the material costs, shadow costs, or GWP. The formwork involves adding an extra row of struts in the middle of the span, resulting in a smaller span and faster striking times. Lower spans exhibit faster striking times than larger spans. For CEM II/B-S 52.5N, the striking time decreases from 60 hours to 32 hours, and for CEM III/B 42.5N, it decreases from 104 hours to 51 hours for a span of 4.5m. Likewise, for a span of 6.0m, the striking time decreases from 60 hours to 34 hours for CEM II/B-S 52.5N and from 104 hours to 55 hours for CEM III/B 42.5N. For a span of 7.2m, the striking time decreases from 60 hours to 36 hours for CEM II/B-S 52.5N and from 104 hours to 59 hours for CEM III/B 42.5N.

In the last two variations for each sustainable cement mixture and span, procedures are applied to achieve striking times below 16 hours in summer and winter. The w/c ratio is reduced from 0.55 to 0.45 for both CEM II/B-S 52.5N and CEM III/B 42.5N in all seasons. In summer, the maturity process is added for smaller spans, while an extra row of struts is needed for larger spans. In winter, accelerators and external heating are commonly required. Notably, despite higher material costs in summer or winter for both CEM II/B-S 52.5N and CEM III/B 42.5N, shadow costs and GWP remain lower than the benchmark variant CEM I 52.5R. See figure 4.6 for the procedures applied for the summer and winter variation to reach a striking time below 16 hours.

Variant	Span	Cement type	Season	Change parameters	Striking time
2s	4,50m	**CEM II/B-S 52.5N**	Summer	w/c ratio to 0.45, Maturity Process	12 hours
2w	4,50m	**CEM II/B-S 52.5N**	Winter	w/c ratio to 0.45, Accelerators, Maturity Process	16 hours
3s	4,50m	**CEM III/B 42.5N**	Summer	w/c ratio to 0.45, Maturity Process, EH	13 hours
3w	4,50m	**CEM III/B 42.5N**	Winter	w/c ratio to 0.45, Accelerators, MP, EH	11 hours
5s	6,00m	**CEM II/B-S 52.5N**	Summer	w/c ratio to 0.45, Maturity Process	15 hours
5w	6,00m	**CEM II/B-S 52.5N**	Winter	w/c ratio to 0.45, Formwork	16 hours
6s	6,00m	**CEM III/B 42.5N**	Summer	w/c ratio to 0.45, Maturity Process, EH	14 hours
6w	6,00m	**CEM III/B 42.5N**	Winter	w/c ratio to 0.45, Formwork, EH	14 hours
8s	7,20m	**CEM II/B-S 52.5N**	Summer	w/c ratio to 0.45, Formwork	11 hours
8w	7,20m	**CEM II/B-S 52.5N**	Winter	w/c ratio to 0.45, Accelerators, Formwork	14 hours
9s	7,20m	**CEM III/B 42.5N**	Summer	w/c ratio to 0.45, Formwork, EH	12 hours
9w	7,20m	**CEM III/B 42.5N**	Winter	w/c ratio to 0.45, Accelerators, Formwork, EH	11 hours

Figure 4.6: Procedures for the summer and winter variations to reach a striking time below 16 hours (own figure).

Variation	Grid-size	Cement mixture	Changed parameter	Material costs: Total Costs	Material costs: costs [€/m²]	Material costs: Difference i.r.t. Variation 1	Material costs: Difference i.r.t. Variation x	Shadow costs: Total Costs	Shadow costs: costs [€/m²]	Shadow costs: Difference i.r.t. Variation 1	Shadow costs: Difference i.r.t. Variation x	Global warming potential: Total kg*CO2/kg	Global warming potential: GWP [kgCO2/m²]	Global warming potential: Difference i.r.t. Variation 1	Global warming potential: Difference i.r.t. Variation x	Striking stress [Mpa]	Striking time: Time [hours]	Striking time: Difference i.r.t. Variation 1	Striking time: Difference i.r.t. Variation x
1	4,50m	CEM I 52.5R	None	€ 149.742,26	€ 54,16	-	-	€ 35.247,52	€ 12,75	-	-	4,44E+05	160,76	-	-	14	16,0	-	-
2	4,50m	CEM II/B-S 52.5N	Cement mixture	€ 144.783,67	€ 52,37	-3,31%	-	€ 25.494,81	€ 9,22	-27,67%	-	3,12E+05	113,01	-29,70%	-	14	60,0	275,00%	-
2a	4,50m	CEM II/B-S 52.5N	W/C ratio: 0.45	€ 149.992,77	€ 54,25	0,17%	3,60%	€ 26.758,49	€ 9,68	-24,08%	4,96%	3,29E+05	119,18	-25,87%	5,45%	14	17,0	6,25%	-71,67%
2b	4,50m	CEM II/B-S 52.5N	Blaine value: 400m²/kg	€ 158.621,60	€ 57,37	5,93%	9,56%	€ 31.087,45	€ 11,24	-11,80%	21,94%	3,88E+05	140,37	-12,68%	24,21%	14	46,0	187,50%	-23,33%
2c	4,50m	CEM II/B-S 52.5N	Admixture: Accelerator	€ 167.846,89	€ 60,71	12,09%	15,93%	€ 26.345,85	€ 9,53	-25,25%	3,34%	3,19E+05	115,41	-28,21%	2,13%	14	46,0	187,50%	-23,33%
2d	4,50m	CEM II/B-S 52.5N	Season: Winter	€ 144.783,67	€ 52,37	-3,31%	0,00%	€ 25.494,81	€ 9,22	-27,67%	0,00%	3,12E+05	113,01	-29,70%	0,00%	14	80,0	400,00%	33,33%
2e	4,50m	CEM II/B-S 52.5N	AEM: Internal heating	€ 149.292,11	€ 54,00	-0,30%	3,11%	€ 25.705,68	€ 9,30	-27,07%	0,83%	3,13E+05	113,37	-29,48%	0,32%	14	34,0	112,50%	-43,33%
2f	4,50m	CEM II/B-S 52.5N	AEM: External heating	€ 148.654,44	€ 53,77	-0,73%	2,67%	€ 25.675,85	€ 9,29	-27,16%	0,71%	3,13E+05	113,32	-29,51%	0,27%	14	31,0	93,75%	-48,33%
2g	4,50m	CEM II/B-S 52.5N	AEM: Maturity process	€ 144.783,67	€ 52,37	-3,31%	0,00%	€ 25.494,81	€ 9,22	-27,67%	0,00%	3,12E+05	113,01	-29,70%	0,00%	10,7	42,0	162,50%	-30,00%
2h	4,50m	CEM II/B-S 52.5N	AEM: Formwork	€ 144.783,67	€ 52,37	-3,31%	0,00%	€ 25.494,81	€ 9,22	-27,67%	0,00%	3,12E+05	113,01	-29,70%	0,00%	8,7	32,0	100,00%	-46,67%
2s	4,50m	CEM II/B-S 52.5N	Combinations,best results in the summer	€ 149.992,77	€ 54,25	0,17%	3,60%	€ 26.758,49	€ 9,68	-24,08%	4,96%	3,29E+05	119,18	-25,87%	5,45%	10,7	12,0	-25,00%	-80,00%
2w	4,50m	CEM II/B-S 52.5N	Combinations,best results in the winter	€ 174.646,57	€ 63,17	16,63%	20,63%	€ 27.668,22	€ 10,01	-21,50%	8,52%	3,37E+05	121,74	-24,27%	7,73%	10,7	16,0	0,00%	-73,33%
3	4,50m	CEM III/B 42.5N	Cement mixture	€ 141.785,45	€ 51,28	-5,31%	-	€ 13.381,15	€ 4,84	-62,04%	-	1,48E+05	53,67	-66,61%	-	14	104,0	550,00%	-
3a	4,50m	CEM III/B 42.5N	W/C ratio: 0.45	€ 146.787,78	€ 53,09	-1,97%	3,53%	€ 13.809,41	€ 4,99	-60,82%	3,20%	1,54E+05	55,74	-65,33%	3,86%	14	47,0	193,75%	-54,81%
3b	4,50m	CEM III/B 42.5N	Blaine value: 400m²/kg	€ 155.623,38	€ 56,29	3,93%	9,76%	€ 18.973,79	€ 6,86	-46,17%	41,79%	2,24E+05	81,03	-49,59%	50,98%	14	61,0	281,25%	-41,35%
3c	4,50m	CEM III/B 42.5N	Admixture: Accelerator	€ 164.848,67	€ 59,62	10,09%	16,27%	€ 14.232,18	€ 5,15	-59,62%	6,36%	1,55E+05	56,08	-65,12%	4,48%	14	76,0	375,00%	-26,92%
3d	4,50m	CEM II/B-S 52.5N	Season: Winter	€ 141.785,45	€ 51,28	-5,31%	0,00%	€ 13.381,15	€ 4,84	-62,04%	0,00%	1,48E+05	53,67	-66,61%	0,00%	14	140,0	775,00%	34,62%
3e	4,50m	CEM III/B 42.5N	AEM: Internal heating	€ 146.293,89	€ 52,91	-2,30%	3,18%	€ 13.592,02	€ 4,92	-61,44%	1,58%	1,49E+05	54,03	-66,39%	0,66%	14	55,0	243,75%	-47,12%
3f	4,50m	CEM III/B 42.5N	AEM: External heating	€ 145.656,22	€ 52,68	-2,73%	2,73%	€ 13.562,19	€ 4,91	-61,52%	1,35%	1,49E+05	53,98	-66,42%	0,57%	14	49,0	206,25%	-52,88%
3g	4,50m	CEM III/B 42.5N	AEM: Maturity process	€ 141.785,45	€ 51,28	-5,31%	0,00%	€ 13.381,15	€ 4,84	-62,04%	0,00%	1,48E+05	53,67	-66,61%	0,00%	10,7	69,0	331,25%	-33,65%
3h	4,50m	CEM III/B 42.5N	AEM: Formwork	€ 141.785,45	€ 51,28	-5,31%	0,00%	€ 13.381,15	€ 4,84	-62,04%	0,00%	1,48E+05	53,67	-66,61%	0,00%	8,7	51,0	218,75%	-50,96%
3s	4,50m	CEM III/B 42.5N	Combinations,best results in the summer	€ 150.658,55	€ 54,49	0,61%	4,06%	€ 13.990,45	€ 5,06	-60,31%	4,55%	1,55E+05	56,05	-65,13%	4,43%	10,7	13,0	-18,75%	-87,50%
3w	4,50m	CEM III/B 42.5N	Combinations,best results in the winter	€ 176.280,04	€ 63,76	17,72%	21,75%	€ 14.945,45	€ 5,41	-57,60%	11,69%	1,62E+05	58,69	-63,49%	9,35%	10,7	11,0	-31,25%	-89,42%

Figure 4.7: Results from the calculation sheet for the variants with a span of 4.5m (own figure).

Variation	Grid-size	Cement mixture	Changed parameter	Material costs: Total Costs	Material costs: costs [€/m²]	Material costs: Difference i.r.t. Variation 1	Material costs: Difference i.r.t. Variation x	Shadow costs: Total Costs	Shadow costs: costs [€/m²]	Shadow costs: Difference i.r.t. Variation 1	Shadow costs: Difference i.r.t. Variation x	Global warming potential: Total kg*CO2/kg	Global warming potential: GWP [kgCO2/m²]	Global warming potential: Difference i.r.t. Variation 1	Global warming potential: Difference i.r.t. Variation x	Striking stress [Mpa]	Striking time: Time [hours]	Striking time: Difference i.r.t. Variation 1	Striking time: Difference i.r.t. Variation x
4	6,00m	CEM I 52.5R	None	€ 155.482,54	€ 56,24	-	-	€ 34.972,23	€ 12,65	-	-	4,31E+05	156,03	-	-	14	16,0	-	-
5	6,00m	CEM II/B-S 52.5N	Cement mixture	€ 150.960,05	€ 54,60	-2,91%	-	€ 26.077,26	€ 9,43	-25,43%	-	3,11E+05	112,48	-27,91%	-	14	60,0	275,00%	-
5a	6,00m	CEM II/B-S 52.5N	W/C ratio: 0.45	€ 155.711,02	€ 56,32	0,15%	3,15%	€ 27.229,81	€ 9,85	-22,14%	4,42%	3,27E+05	118,10	-24,31%	5,00%	14	17,0	6,25%	-71,67%
5b	6,00m	CEM II/B-S 52.5N	Blaine value: 400m²/kg	€ 163.580,95	€ 59,17	5,21%	8,36%	€ 31.178,04	€ 11,28	-10,85%	19,56%	3,80E+05	137,44	-11,92%	22,18%	14	46,0	187,50%	-23,33%
5c	6,00m	CEM II/B-S 52.5N	Admixture: Accelerator	€ 171.994,88	€ 62,21	10,62%	13,93%	€ 26.853,45	€ 9,71	-23,21%	2,98%	3,17E+05	114,68	-26,51%	1,95%	14	46,0	187,50%	-23,33%
5d	6,00m	CEM II/B-S 52.5N	Season: Winter	€ 150.960,05	€ 54,60	-2,91%	0,00%	€ 26.077,26	€ 9,43	-25,43%	0,00%	3,11E+05	112,48	-27,91%	0,00%	14	80,0	400,00%	33,33%
5e	6,00m	CEM II/B-S 52.5N	AEM: Internal heating	€ 155.071,98	€ 56,09	-0,26%	2,72%	€ 26.269,59	€ 9,50	-24,88%	0,74%	3,12E+05	112,81	-27,70%	0,29%	14	34,0	112,50%	-43,33%
5f	6,00m	CEM II/B-S 52.5N	AEM: External heating	€ 154.653,66	€ 55,94	-0,53%	2,45%	€ 26.250,02	€ 9,49	-24,94%	0,66%	3,12E+05	112,78	-27,72%	0,26%	14	31,0	93,75%	-48,33%
5g	6,00m	CEM II/B-S 52.5N	AEM: Maturity process	€ 150.960,05	€ 54,60	-2,91%	0,00%	€ 26.077,26	€ 9,43	-25,43%	0,00%	3,11E+05	112,48	-27,91%	0,00%	12,8	52,0	225,00%	-13,33%
5h	6,00m	CEM II/B-S 52.5N	AEM: Formwork	€ 150.960,05	€ 54,60	-2,91%	0,00%	€ 26.077,26	€ 9,43	-25,43%	0,00%	3,11E+05	112,48	-27,91%	0,00%	9,2	34,0	112,50%	-43,33%
5s	6,00m	CEM II/B-S 52.5N	Combinations,best results in the summer	€ 155.711,02	€ 56,32	0,15%	3,15%	€ 27.229,81	€ 9,85	-22,14%	4,42%	3,27E+05	118,10	-24,31%	5,00%	12,8	15,0	-6,25%	-75,00%
5w	6,00m	CEM II/B-S 52.5N	Combinations,best results in the winter	€ 155.711,02	€ 56,32	0,15%	3,15%	€ 27.229,81	€ 9,85	-22,14%	4,42%	3,27E+05	118,10	-24,31%	5,00%	9,2	16,0	0,00%	-73,33%
6	6,00m	CEM III/B 42.5N	Cement mixture	€ 148.225,52	€ 53,61	-4,67%	-	€ 15.028,99	€ 5,44	-57,03%	-	1,61E+05	58,36	-62,60%	-	14	104,0	550,00%	-
6a	6,00m	CEM III/B 42.5N	W/C ratio: 0.45	€ 152.787,90	€ 55,26	-1,73%	3,08%	€ 15.419,58	€ 5,58	-55,91%	2,60%	1,67E+05	60,25	-61,39%	3,24%	14	47,0	193,75%	-54,81%
6b	6,00m	CEM III/B 42.5N	Blaine value: 400m²/kg	€ 155.623,38	€ 56,29	0,09%	4,99%	€ 20.129,76	€ 7,28	-42,44%	33,94%	2,30E+05	83,32	-46,60%	42,76%	14	61,0	281,25%	-41,35%
6c	6,00m	CEM III/B 42.5N	Admixture: Accelerator	€ 169.260,36	€ 61,22	8,86%	14,19%	€ 15.805,18	€ 5,72	-54,81%	5,16%	1,67E+05	60,56	-61,19%	3,75%	14	76,0	375,00%	-26,92%
6d	6,00m	CEM II/B-S 52.5N	Season: Winter	€ 148.225,52	€ 53,61	-4,67%	0,00%	€ 15.028,99	€ 5,44	-57,03%	0,00%	1,61E+05	58,36	-62,60%	0,00%	14	140,0	775,00%	34,62%
6e	6,00m	CEM III/B 42.5N	AEM: Internal heating	€ 152.337,45	€ 55,10	-2,02%	2,77%	€ 15.221,31	€ 5,51	-56,48%	1,28%	1,62E+05	58,69	-62,39%	0,56%	14	55,0	243,75%	-47,12%
6f	6,00m	CEM III/B 42.5N	AEM: External heating	€ 151.919,13	€ 54,95	-2,29%	2,49%	€ 15.201,75	€ 5,50	-56,53%	1,15%	1,62E+05	58,66	-62,41%	0,50%	14	49,0	206,25%	-52,88%
6g	6,00m	CEM III/B 42.5N	AEM: Maturity process	€ 148.225,52	€ 53,61	-4,67%	0,00%	€ 15.028,99	€ 5,44	-57,03%	0,00%	1,61E+05	58,36	-62,60%	0,00%	12,8	88,0	450,00%	-15,38%
6h	6,00m	CEM III/B 42.5N	AEM: Formwork	€ 148.225,52	€ 53,61	-4,67%	0,00%	€ 15.028,99	€ 5,44	-57,03%	0,00%	1,61E+05	58,36	-62,60%	0,00%	9,2	55,0	243,75%	-47,12%
6s	6,00m	CEM III/B 42.5N	Combinations,best results in the summer	€ 156.481,51	€ 56,60	0,64%	5,57%	€ 15.592,34	€ 5,64	-55,42%	3,75%	1,67E+05	60,54	-61,20%	3,74%	12,8	14,0	-12,50%	-86,54%
6w	6,00m	CEM III/B 42.5N	Combinations,best results in the winter	€ 157.404,91	€ 56,93	1,24%	6,19%	€ 15.635,53	€ 5,66	-55,29%	4,04%	1,68E+05	60,62	-61,15%	3,86%	12,8	14,0	-12,50%	-86,54%

Figure 4.8: Results from the calculation sheet for the variants with a span of 6.0m (own figure).

Variation	Grid-size	Cement mixture	Changed parameter	Material costs: Total Costs	Material costs: costs [€/m²]	Material costs: Difference i.r.t. Variation 1	Material costs: Difference i.r.t. Variation x	Shadow costs: Total Costs	Shadow costs: costs [€/m²]	Shadow costs: Difference i.r.t. Variation 1	Shadow costs: Difference i.r.t. Variation x	Global warming potential: Total kg*CO2/kg	Global warming potential: GWP [kgCO2/m²]	Global warming potential: Difference i.r.t. Variation 1	Global warming potential: Difference i.r.t. Variation x	Striking stress [Mpa]	Striking time: Time [hours]	Striking time: Difference i.r.t. Variation 1	Striking time: Difference i.r.t. Variation x
7	7,20m	CEM I 52.5R	None	€ 175.806,48	€ 63,59	-	-	€ 37.890,04	€ 13,70	-	-	4,53E+05	163,85	-	-	14	16,0	-	-
8	7,20m	CEM II/B-S 52.5N	Cement mixture	€ 171.502,04	€ 62,03	-2,45%	-	€ 29.423,94	€ 10,64	-22,34%	-	3,38E+05	122,40	-25,30%	-	14	60,0	275,00%	-
8a	7,20m	CEM II/B-S 52.5N	W/C ratio: 0.45	€ 176.023,94	€ 63,67	0,12%	2,64%	€ 30.520,91	€ 11,04	-19,45%	3,73%	3,53E+05	127,75	-22,03%	4,37%	14	17,0	6,25%	-71,67%
8b	7,20m	CEM II/B-S 52.5N	Blaine value: 400m²/kg	€ 183.514,42	€ 66,38	4,38%	7,00%	€ 34.278,78	€ 12,40	-9,53%	16,50%	4,04E+05	146,15	-10,80%	19,40%	14	46,0	187,50%	-23,33%
8c	7,20m	CEM II/B-S 52.5N	Admixture: Accelerator	€ 191.522,68	€ 69,27	8,94%	11,67%	€ 30.162,70	€ 10,91	-20,39%	2,51%	3,44E+05	124,49	-24,02%	1,70%	14	46,0	187,50%	-23,33%
8d	7,20m	CEM II/B-S 52.5N	Season: Winter	€ 171.502,04	€ 62,03	-2,45%	0,00%	€ 29.423,94	€ 10,64	-22,34%	0,00%	3,38E+05	122,40	-25,30%	0,00%	14	80,0	400,00%	33,33%
8e	7,20m	CEM II/B-S 52.5N	AEM: Internal heating	€ 175.415,71	€ 63,45	-0,22%	2,28%	€ 29.606,99	€ 10,71	-21,86%	0,62%	3,39E+05	122,71	-25,11%	0,25%	14	34,0	112,50%	-43,33%
8f	7,20m	CEM II/B-S 52.5N	AEM: External heating	€ 175.107,07	€ 63,33	-0,40%	2,10%	€ 29.592,55	€ 10,70	-21,90%	0,57%	3,39E+05	122,68	-25,12%	0,23%	14	31,0	93,75%	-48,33%
8g	7,20m	CEM II/B-S 52.5N	AEM: Maturity process	€ 171.502,04	€ 62,03	-2,45%	0,00%	€ 29.423,94	€ 10,64	-22,34%	0,00%	3,38E+05	122,40	-25,30%	0,00%	14	60,0	275,00%	0,00%
8h	7,20m	CEM II/B-S 52.5N	AEM: Formwork	€ 171.022,04	€ 61,86	-2,72%	-0,28%	€ 28.293,05	€ 10,23	-25,33%	-3,84%	3,28E+05	118,63	-27,60%	-3,08%	9,7	36,0	125,00%	-40,00%
8s	7,20m	CEM II/B-S 52.5N	Combinations,best results in the summer	€ 175.543,94	€ 63,49	-0,15%	2,36%	€ 29.390,03	€ 10,63	-22,43%	-0,12%	3,43E+05	123,98	-24,33%	1,29%	9,7	11,0	-31,25%	-81,67%
8w	7,20m	CEM II/B-S 52.5N	Combinations,best results in the winter	€ 196.945,32	€ 71,23	12,02%	14,84%	€ 30.179,74	€ 10,92	-20,35%	2,57%	3,49E+05	126,21	-22,97%	3,11%	9,7	14,0	-12,50%	-76,67%
9	7,20m	CEM III/B 42.5N	Cement mixture	€ 168.899,35	€ 61,09	-3,93%	-	€ 18.908,35	€ 6,84	-50,10%	-	1,96E+05	70,89	-56,74%	-	14	104,0	550,00%	-
9a	7,20m	CEM III/B 42.5N	W/C ratio: 0.45	€ 173.241,76	€ 62,66	-1,46%	2,57%	€ 19.280,12	€ 6,97	-49,12%	1,97%	2,01E+05	72,69	-55,64%	2,54%	14	47,0	193,75%	-54,81%
9b	7,20m	CEM III/B 42.5N	Blaine value: 400m²/kg	€ 180.911,74	€ 65,43	2,90%	7,11%	€ 23.763,20	€ 8,59	-37,28%	25,68%	2,62E+05	94,64	-42,24%	33,51%	14	61,0	281,25%	-41,35%
9c	7,20m	CEM III/B 42.5N	Admixture: Accelerator	€ 188.920,00	€ 68,33	7,46%	11,85%	€ 19.647,12	€ 7,11	-48,15%	3,91%	2,02E+05	72,97	-55,46%	2,94%	14	76,0	375,00%	-26,92%
9d	7,20m	CEM II/B-S 52.5N	Season: Winter	€ 168.899,35	€ 61,09	-3,93%	0,00%	€ 18.908,35	€ 6,84	-50,10%	0,00%	1,96E+05	70,89	-56,74%	0,00%	14	140,0	775,00%	34,62%
9e	7,20m	CEM III/B 42.5N	AEM: Internal heating	€ 172.813,03	€ 62,50	-1,70%	2,32%	€ 19.091,40	€ 6,91	-49,61%	0,97%	1,97E+05	71,20	-56,55%	0,44%	14	55,0	243,75%	-47,12%
9f	7,20m	CEM III/B 42.5N	AEM: External heating	€ 172.504,38	€ 62,39	-1,88%	2,13%	€ 19.076,97	€ 6,90	-49,65%	0,89%	1,97E+05	71,17	-56,56%	0,40%	14	49,0	206,25%	-52,88%
9g	7,20m	CEM III/B 42.5N	AEM: Maturity process	€ 168.899,35	€ 61,09	-3,93%	0,00%	€ 18.908,35	€ 6,84	-50,10%	0,00%	1,96E+05	70,89	-56,74%	0,00%	14	104,0	550,00%	0,00%
9h	7,20m	CEM III/B 42.5N	AEM: Formwork	€ 168.419,35	€ 60,92	-4,20%	-0,28%	€ 17.777,47	€ 6,43	-53,08%	-5,98%	1,86E+05	67,12	-59,03%	-5,31%	9,7	59,0	268,75%	-43,27%
9s	7,20m	CEM III/B 42.5N	Combinations,best results in the summer	€ 176.366,79	€ 63,79	0,32%	4,42%	€ 18.317,85	€ 6,63	-51,66%	-3,12%	1,91E+05	69,20	-57,76%	-2,38%	9,7	12,0	-25,00%	-88,46%
9w	7,20m	CEM III/B 42.5N	Combinations,best results in the winter	€ 198.669,43	€ 71,86	13,00%	17,63%	€ 19.149,72	€ 6,93	-49,46%	1,28%	1,98E+05	71,50	-56,36%	0,87%	9,7	11,0	-31,25%	-89,42%

Figure 4.9: Results from the calculation sheet for the variants with a span of 7.2m (own figure).

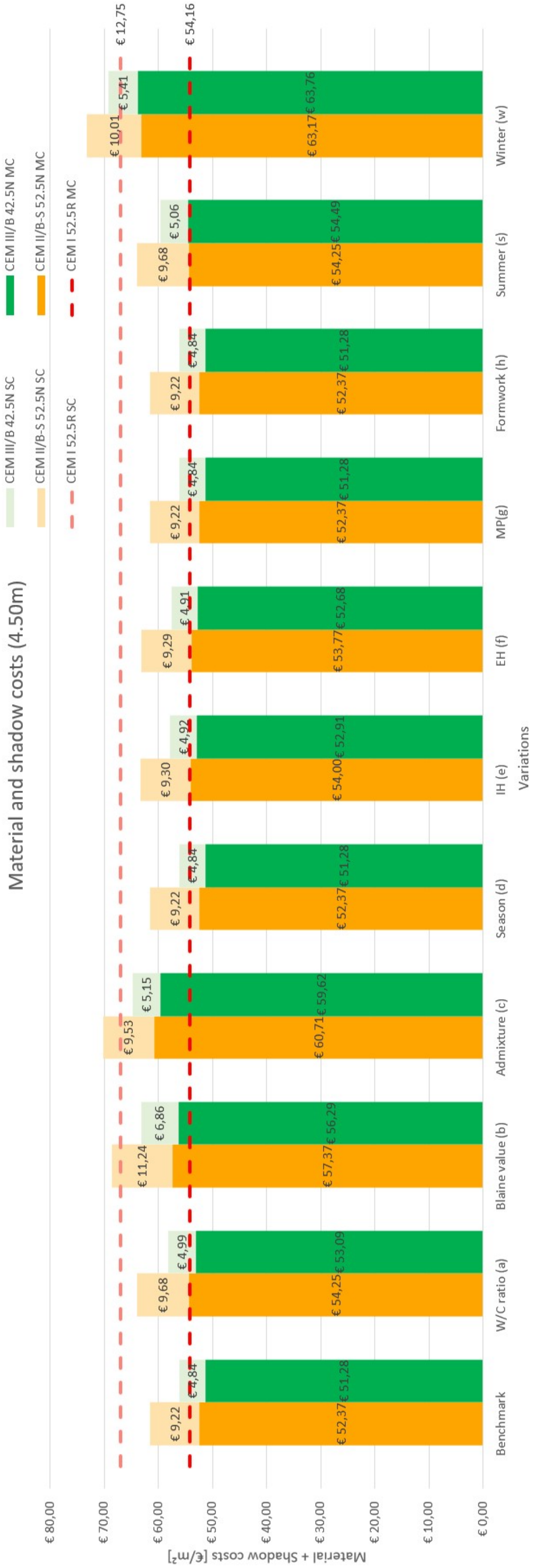


Figure 4.10: Results of the material costs and shadow costs from the calculation sheet for the variants with a span of 4.5m (own figure).

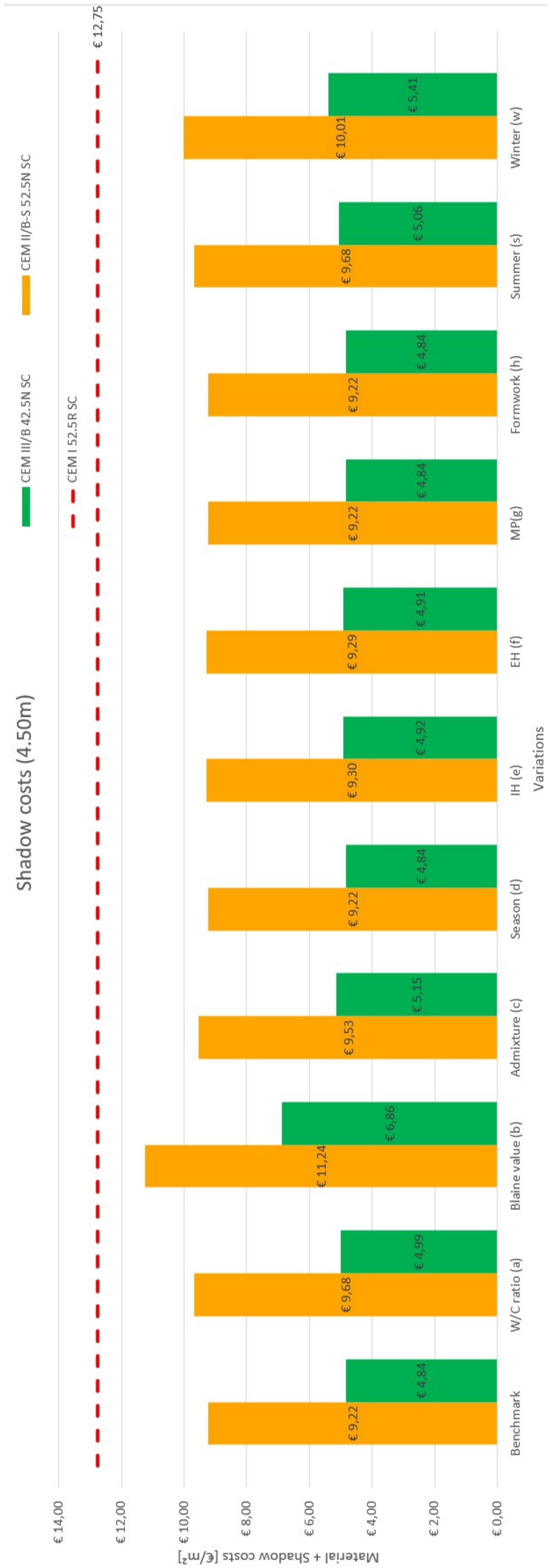


Figure 4.11: Results of the shadow costs from the calculation sheet for the variants with a span of 4.5m (own figure).

Figure 4.12: Results GWP from the calculation sheet for the variants with a span of 4.5m (own figure).

Figure 4.13: Results of the striking time from the calculation sheet for the variants with a span of 4.5m (own figure).

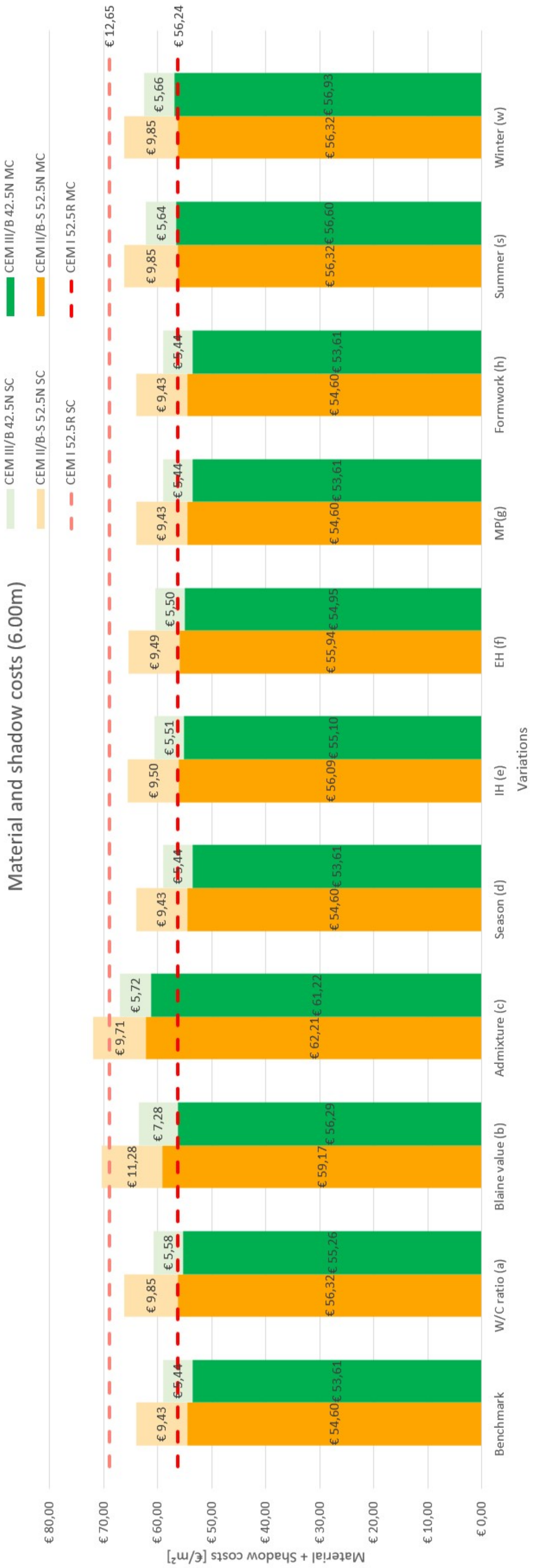


Figure 4.14: Results of the material costs and shadow costs from the calculation sheet for the variants with a span of 6.0m (own figure).

Figure 4.15: Results of the shadow costs from the calculation sheet for the variants with a span of 6.0m (own figure).

Figure 4.16: Results GWP from the calculation sheet for the variants with a span of 6.0m (own figure).

Figure 4.17: Results of the striking time from the calculation sheet for the variants with a span of 6.0m (own figure).

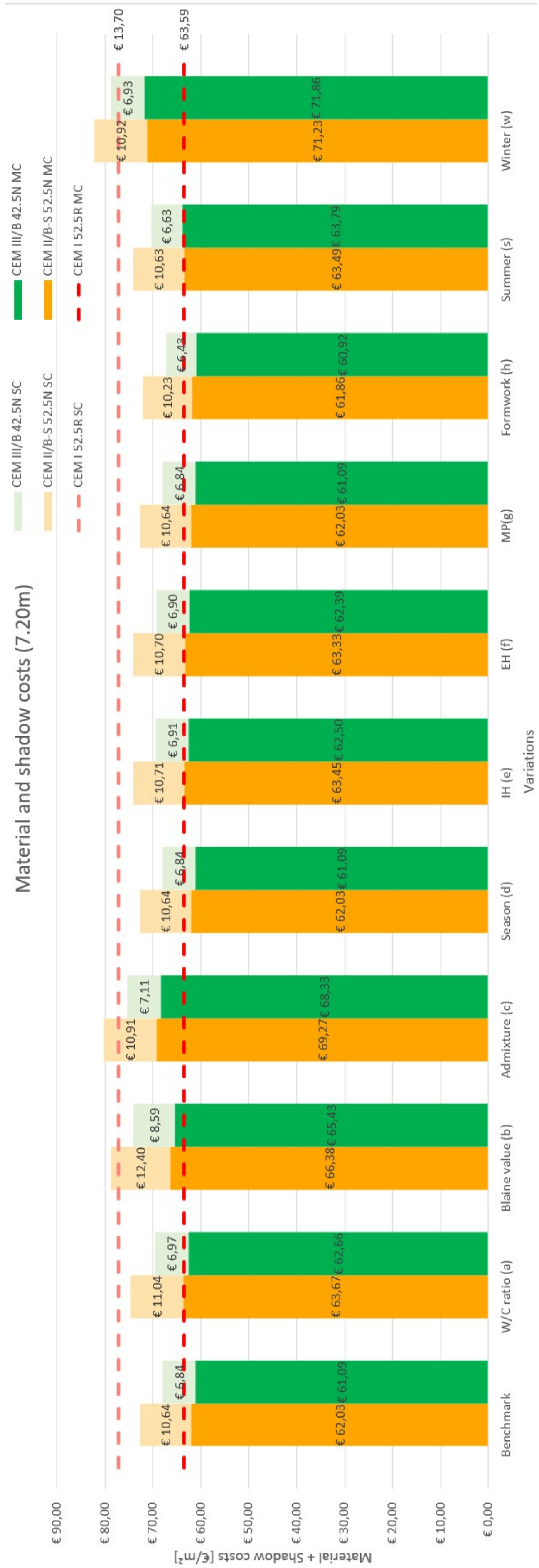


Figure 4.18: Results of the material costs and shadow costs from the calculation sheet for the variants with a span of 7.2m (own figure).

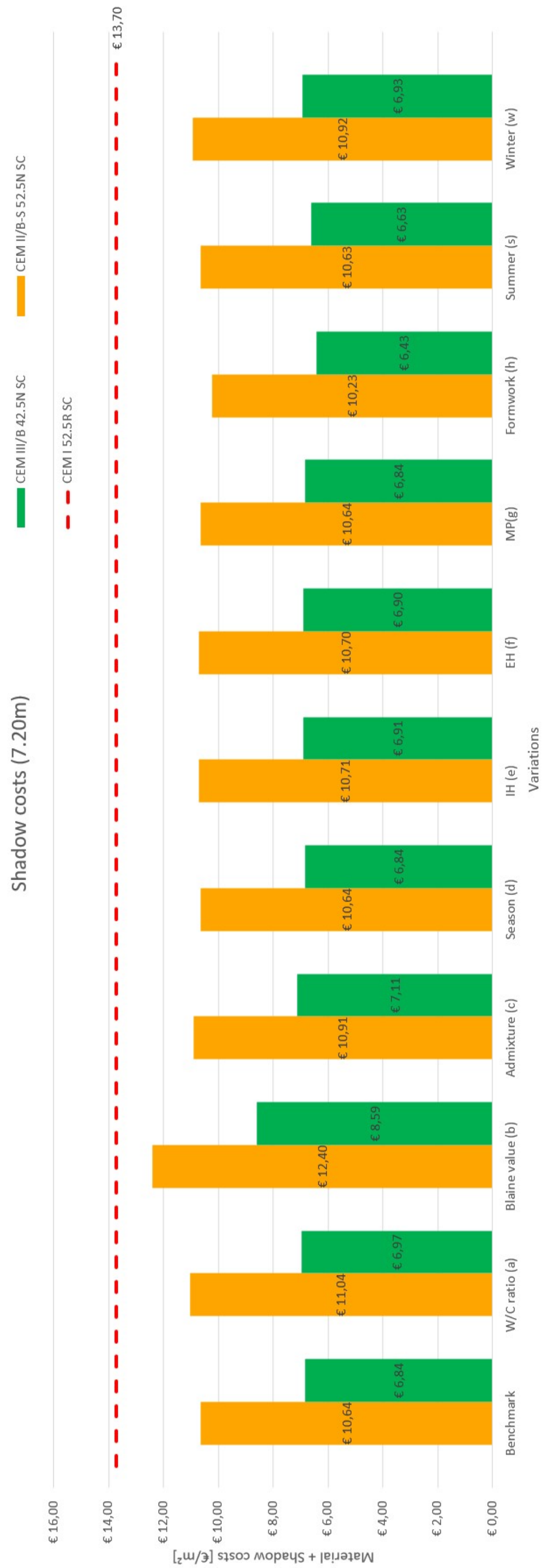


Figure 4.19: Results of the shadow costs from the calculation sheet for the variants with a span of 7.2m (own figure).

Figure 4.20: Results GWP from the calculation sheet for the variants with a span of 7.2m (own figure).

Figure 4.21: Results of the striking time from the calculation sheet for the variants with a span of 7.2m (own figure).

5 Discussion, conclusions and recommendations

This master's thesis has developed a calculation sheet aimed at determining a sustainable approach to the tunnel formwork building method. The calculation sheet provides estimates for material costs, shadow costs, global warming potential (GWP), and striking time for specific structures and concrete mixtures. This chapter will offer insights into the research process, starting with a discussion of the input values of the calculation sheet. Subsequently, the results will be examined, followed by the conclusions of the thesis. Lastly, the chapter will provide recommendations for future research.

5.1. Discussion

This section will discuss two primary parts of the research: the input parameters and the output results of the calculation sheet. Initially, the various input choices will be explained, encompassing the structural design, floor thickness, cement mixtures, w/c ratios, Blaine value, maturity process, formwork, cost-related values and workability. Subsequently, the focus will shift to an in-depth discussion of the output results generated by the calculation sheet.

5.1.1. Input parameters

This research utilizes a straightforward rectangular box structure excluding balconies and accessibility features, with a basic stabilizing structure on the side. It's important to note that in practical applications, these characteristics must be realized, necessitating a more detailed examination of how they impact the tunnel formwork building method, along with its implications on material costs, shadow costs, and execution time. To ensure a robust comparison across different grid sizes, certain variables remain consistent. Specifically, the floor thickness and concrete strength class are kept constant. While thinner floor thicknesses for lower grid sizes could potentially reduce material and shadow costs, maintaining a minimum thickness of 250mm is essential for sound insulation and fire resistance (thought better floor finishing can also solve these requirements). Despite the possibility of lowering the concrete strength class for structures with smaller grid sizes, the decision is made to maintain uniformity for a more accurate comparison between variations.

This study employs three distinct cement mixtures: CEM I 52.5R, CEM II/B-S 52.5N, and CEM III/B 42.5N. The selection of CEM I 52.5R is based on its outstanding strength development, achieved through the use of 100% Portland cement, making it a widely used benchmark in current practices. CEM II/B-S 52.5N is chosen for its lower Portland cement content (compared to CEM II/A), leading to a reduction in material and shadow costs. Additionally, CEM II/B-S 52.5N exhibits the fastest strength development, surpassing CEM II/B-S 52.5R, which does not exist for CEM II. The rationale for utilizing CEM III/B 42.5N is its lower Portland cement content (compared to CEM III/A), resulting in decreased material and shadow costs. CEM III/B 42.5N also boasts the fastest strength development among its counterparts (CEM III/B 52.5R and CEM III/B 42.5R, which do not exist for CEM III). This research prioritizes sustainable cement mixtures with minimal Portland cement to minimize environmental impact.

Notably, geopolymer concrete, which entirely excludes Portland cement, is not considered due to its novelty, necessitating further research.

This research employs two distinct w/c ratios: 0.55, corresponding to the benchmark variations, and 0.45, representing a new value aimed at reducing the striking time. While w/c ratios of 0.5 and 0.4 could be alternative options, the decision to utilize 0.55 and 0.45 is deliberate. These values, less commonly found in research papers, offer an opportunity for novel results. If w/c ratios of 0.5 and 0.4 were chosen, material and shadow costs would rise due to increased cement usage, counterbalanced by a reduction in striking time. The selected ratios provide a distinctive approach, introducing new insights into the relationship between w/c ratios, material costs, shadow costs, and striking time.

This research considers Blaine values of 300 m^2/kg for the benchmark variations and 400 m^2/kg as the new value, aimed at reducing the striking time. Limited research papers delve into the impact of the Blaine value on material costs and shadow costs. It is evident that an increase in the Blaine value leads to enhanced strength development, resulting in a decrease in striking time. The influence of the Blaine value is highly dependent on the concrete mixture's composition, involving the type of cement mixture and w/c ratio. While this research draws insights from previous studies on the impact of an increased Blaine value, it acknowledges that the properties of the concrete mixture in those studies may not precisely match those used in this research. These studies provide the closest approximation to the concrete mixture employed here. Although the results may not be conclusive, they indicate that the Blaine value affects the strength development of concrete. Notably, the specific impacts on material costs, shadow costs, and Global Warming Potential (GWP) resulting from an increase in Blaine values from 300 m^2/kg to 400 m^2/kg are not documented in existing research papers. These values are introduced for the purpose of this study, and it is essential to recognize that practical cost increments due to a higher Blaine value lack documentation due to limited available information. Despite potential limitations, this study highlights a correlation between increased Blaine values and elevated material costs, shadow costs, and GWP, attributed to higher grinding costs.

The maturity process serves as an additional execution measure, involving the pre-determination of the minimum required compressive strength, tensile strength, and deflection. On-site, strength is assessed using the maturity method after 16 hours. The equations utilized to establish the minimum required compressive strength, tensile strength, and deflection are sourced from the Eurocodes. However, certain assumptions are made in this research: only the dead weight of the floor is considered, with no variable load applied (moment right after the removal of the formwork); the reinforcement should not yield; short-term loading is assumed (no creep and shrinkage); analyses include uncracked and cracked phases, and calculations are based on the mean compressive cylinder strength. While most assumptions align with theoretical principles, practical variations may occur. In this study, calculations are performed using the mean compressive cylinder strength, consistent with common research practices. It's essential to note that, in practical on-site applications, the mean compressive cube strength is measured. Therefore, caution is advised, and calculated values in this research's calculation sheet should be adjusted to reflect the mean compressive cube strength if employed in practice.

This master's thesis contains limited research regarding the utilization of a different formwork, incorporating an additional row of struts in the middle of the span. The research done merely states that when this supplementary execution measure is applied, the span of the structure is halved. Logically, this suggests a reduced need for reinforcement to accommodate deflection, and the required compressive strength is lower because the moment right after the removal of the formwork is diminished. However, there is a notable absence in this research addressing how this extra row of struts will be implemented and what impact it will have on the tunnel formwork. Furthermore, there is no consideration given to extra material or execution costs associated with the application of this additional row of struts.

The input values for material costs in this study are sourced from suppliers in the Netherlands. It's crucial to emphasize that these figures are approximate estimates provided by relevant companies and are not intended for practical applications. The actual costs are highly variable, influenced by factors such as project scale, geographical location, and ambient temperature. However, when comparing these values to similar research, the costs per square meter align closely. This similarity extends to the shadow costs and GWP, where the values utilized in this research, obtained from Henk Jonkers' lecture and a couple of years old, can be reasonably considered accurate. It's worth noting that this study does not factor in labor costs, equipment costs, and transport costs.

This master thesis does not address the workability of the variations in the calculation sheet. Here's a brief overview of the workability for the different variations. The type of cement mixture has no impact on the workability of the concrete mixture. An increase in the w/c ratio leads to a decrease in workability because less water results in a less workable concrete mixture. The aggregate type remains constant for all variations, thus having no effect on workability. An increase in the Blaine value corresponds to a decrease in the workability of the concrete mixture. The addition of admixtures increases workability. Heating measures involve the use of propane gas, necessitating extra precautions and subsequently decreasing workability. For the maturity process, on-site maturity tests reduce workability. The use of an extra row of struts involves more on-site actions, which in turn decreases workability.

5.1.2. Output results

When comparing the benchmark variations for the three cement mixtures and the three grid sizes, it is evident that, across all benchmark variations, 90% of the material costs consist of cement and reinforcement costs. This alignment with practical observations is notable, especially when considering that smaller grid sizes exhibit a higher proportion of cement costs to reinforcement costs (50% to 40%), while larger grid sizes show the opposite trend with more reinforcement costs than cement costs (40% to 50%). This discrepancy is attributed to the increased need for reinforcement in larger grid sizes. In all benchmark variations, approximately 100% of the shadow costs result from cement and reinforcement. Specifically, for all spans using CEM I 52.5R, cement shadow costs outweigh reinforcement shadow costs. However, as the amount of Portland cement used decreases, reinforcement becomes relatively more environmentally impactful than cement. These findings align with similar results found in other research papers on the same subject.

Reducing the water-to-cement (w/c) ratio lowers the execution time, but concurrently increases material costs, shadow costs, and the global warming potential (GWP). This is logical because a lower w/c ratio, achieved by using more cement, reduces execution time but escalates the associated costs and environmental impact. Similarly, an increase in the Blaine value decreases execution time due to enhanced strength development, but it results in higher material costs, shadow costs, and GWP due to increased grinding expenses to achieve finer cement particles. The use of accelerators decreases execution time but leads to higher material costs, shadow costs, and GWP, as reflected in the results. Conversely, a decrease in curing temperature increases execution time while maintaining the material costs, shadow costs, and GWP. This aligns with the understanding that lower temperatures slow down the chemical reaction between water and cement. Conversely, an increase in curing temperature reduces execution time. Monitoring the strength development of a concrete structure allows for earlier removal of the formwork. The introduction of an extra row of struts reduces the span by half, minimizing deflection and accelerating the attainment of the minimum required compressive and tensile strength.

5.2. Conclusions

The primary objective of this research is to develop an approach for the tunnel formwork building method that effectively reduces the environmental impact of the entire building system. To reach this objective a comprehensive calculation sheet that incorporates key properties of the concrete mixture and execution measures is made. The aim is to minimize the environmental impact and striking time of the tunnel formwork approach. The main research question to reach this objective is as follows:

What concrete mixtures and execution strategies can be implemented in the Netherlands to reduce the environmental impact of the traditional tunnel formwork building method, through the use of sustainable cement mixtures, while also maintaining the current time, cost, and quality advantages?

To answer this research question and reach the objective of this research, the sub-question for each part of the research needs to be answered first.

5.2.1. Sub research questions

What is the impact of the structural dimensions and properties on the material costs, environmental costs (shadow costs), and execution time in the tunnel formwork building method?

The section discusses the significance of understanding the tunnel formwork building method and LCA to assess the impact of structure dimensions and properties on material costs, shadow costs, and execution time. The tunnel formwork method offers advantages like rapid execution and cost-effectiveness but has limitations such as design inflexibility and environmental concerns related to Portland cement. Strategies to improve execution time involve using fast-hardening cement and optimizing parameters. The research aims to mitigate the environmental impact by employing LCA to compare cement mixtures and execution methods. The calculation sheet considers three grid sizes with consistent dimensions but varying floor reinforcement. The largest grid incurs the highest costs, primarily from materials. The environmental impact varies, with the largest grid having the highest GWP. Interestingly, a smaller grid size with more reinforcement can be more environmentally sustainable than a larger one with more concrete. Consistent striking stress ensures uniform striking times across all grid sizes.

What impact does the composition of a concrete mixture have on the material costs, environmental costs (shadow costs), and execution time within the tunnel formwork building method?

The composition of concrete mixtures significantly influences material costs, shadow costs, and execution time. The study compared ordinary Portland cement (CEM I 52.5R) with sustainable alternatives (CEM II/B-S 52.5N and CEM III/B 42.5N), revealing the latter's slower but environmentally friendlier strength development. CEM I 52.5R is the most expensive, with the highest shadow costs and GWP. Conversely, CEM III/B 42.5N boasts the lowest material costs, shadow costs, and GWP, highlighting its economic and environmental advantages.

Various properties, including cement mixture, w/c ratio, Blaine value, accelerators, and curing temperature, play vital roles in strength development. Changes in the w/c ratio exhibit pronounced effects, especially in mixtures with higher Portland cement content. Alterations in the Blaine value also impact striking time, more significantly in mixtures with lower Portland cement content. Accelerators influence striking time uniformly across different mixtures. Temperature differences do impact the hardening speed of various cement mixtures.

The study emphasizes the significance of understanding these properties for optimizing the concrete mixture's environmental and economic performance. The findings contribute valuable insights for the construction industry, aiding in the selection of sustainable alternatives with cost-effective and environmentally friendly outcomes.

How do additional execution measures affect the material costs, environmental costs (shadow costs), and execution time in the tunnel formwork building method?

The tunnel formwork building method is significantly influenced by additional execution measures, including internal and external heating, the maturity process, and alterations to the formwork. Internal heating, achieved through plastic conduits, and external heating, utilizing heaters attached to the formwork, both reduce striking time by about 45-50%, with internal heating incurring higher costs. The maturity process, evaluating strength development without added costs, results in varied striking time reductions. Choosing the formwork option, with an extra row of struts, significantly reduces striking time across grid sizes without extra costs. These measures provide crucial insights for optimizing the tunnel formwork method for efficiency and cost-effectiveness.

5.2.2. Main research questions

What concrete mixtures and execution strategies can be applied in the Netherlands to diminish the environmental impact of the traditional tunnel formwork building method, utilizing sustainable cement mixtures, while upholding existing advantages in time, cost, and quality?

In conclusion, a calculation method has been devised based on the most reliable information available in the literature. A comprehensive study involving 69 variants reveals that it is indeed possible to reduce the environmental impact of the tunnel formwork building method through the incorporation of sustainable cement mixtures. However, this necessitates adjustments in concrete mixtures and the implementation of additional execution measures. During the summer, it is feasible to achieve execution times below 16 hours with sustainable cement mixtures, resulting in reduced costs compared to the current cement mixture. In winter, while execution times below 16 hours are attainable with sustainable cement mixtures, the overall costs are higher than those associated with the current cement mixture. Nevertheless, the environmental benefits of these mixtures outweigh the cost considerations. It's noteworthy that the amount of Portland cement emerges as the most influential factor affecting both costs and formwork removal time. Additionally, this study distinguishes itself by consolidating various properties into a single calculation sheet, a methodology not commonly observed in other research papers.

5.3. Recommendations

This study involves the development of a calculation sheet aimed at evaluating the material costs, shadow costs, and execution time associated with adopting a sustainable approach to the tunnel formwork building method. To enhance the comprehensiveness of the analysis, certain additions can be incorporated into the calculation sheet, to provide a more refined overview of the sustainable aspects related to the tunnel formwork building method.

- *Floor thickness*
  In this study, the floor thickness is maintained at 250mm for all grid sizes, although it is not essential for smaller grid sizes like 4.5m. Reducing the floor thickness would result in decreased material costs and shadow costs, contributing to a more sustainable approach. This adjustment would also accentuate the differences between grid sizes.

- *Strength class concrete*
  In this study, the strength class of the concrete is standardized at C30/37 for all grid sizes, which may not be essential for smaller grid sizes like 4.5m. Lowering the strength class of the concrete would result in reduced material costs and shadow costs, contributing to a more sustainable approach. This adjustment would also emphasize the distinctions between grid sizes.

- *Wall reinforcement*
  It is assumed that, for all variations, the reinforcement in the wall consists of a cross mesh ø6-150mm at the front and back. However, this may not be necessary due to the minimal bending moment in the wall that can be adequately supported by the concrete. Reinforcement is primarily required at the points where the wall connects with the floor to establish a connection between these two elements.

- *Geopolymer binder*
  All the cement mixtures employed in this study utilize Portland cement, the production of which is known to have significant environmental implications. An alternative to mixtures incorporating Portland cement is a Geopolymer binder, an inorganic binder that utilizes aluminosilicate materials. Geopolymer concrete is recognized for its potential benefits, including lower carbon dioxide emissions compared to traditional cement production, along with enhanced resistance to chemical corrosion and fire. Therefore, it would be valuable to explore the incorporation of geopolymer concrete in the tunnel formwork building method and assess its impact on achieving a more sustainable approach.

- *Blaine value*
  The data pertaining to the Blaine value utilized in this study is derived from previous research papers. However, a potential limitation lies in the fact that the concrete mixtures employed in those papers differ from the ones used in this research, potentially yielding different results. Additionally, there was a lack of supplementary information regarding the additional grinding costs associated with increasing the Blaine value. Consequently, conducting dedicated research to precisely investigate the impact of a higher Blaine value on material costs, shadow costs, and execution time would be beneficial.

- *Weather conditions*
  Weather conditions, including temperature, humidity, precipitation, and wind, play a role in the strength development of concrete. While temperature has been considered in this research, the impact of other conditions, such as humidity, precipitation, and wind, has not been explored. It would be valuable to investigate how these factors affect the tunnel formwork building method.

- *Electrical heating*
  In this study, propane gas is employed for the heating process. However, using a gas tank onsite introduces potential safety concerns. A safer alternative for heating the concrete structure involves the use of electrical heating.

- *Additional costs*
  This research considers material and shadow costs but excludes additional expenses like transport costs, building costs, and labor costs. It would be advantageous to incorporate these cost

factors into the calculation sheet to obtain a comprehensive overview of the total costs associated with the tunnel formwork building method.

- *Formwork*
  The investigation into the formwork with an additional row of struts in the middle of the span is rudimentary. It is merely mentioned that the new formwork will consist of three parts: two upside-down L-shaped formwork pieces combined with a row of struts in the middle. Further research can be conducted on this novel formwork, covering aspects such as its fabrication, placement, removal, and associated costs.
- *Duration of the formwork*
  This study investigates Which measures needs to be taken to keep the striking time of the formwork below 16 hours. By keeping the formwork in place for a longer period, more formwork constructions become necessary, but with potentially fewer additional implications on the concrete mixture and execution measures. The key question is how such an extension will affect costs and execution time. This approach may present an alternative method towards achieving sustainability in tunnel formwork building method.

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A

Appendix A: Explanation and verification calculation sheet

In Appendix A, the initial section provides a detailed explanation of the necessary steps to calculate material costs, shadow costs, and execution time using the calculation sheet. This is followed by a manual calculation process intended to serve as a verification method for the accuracy of the calculations made on the sheet.

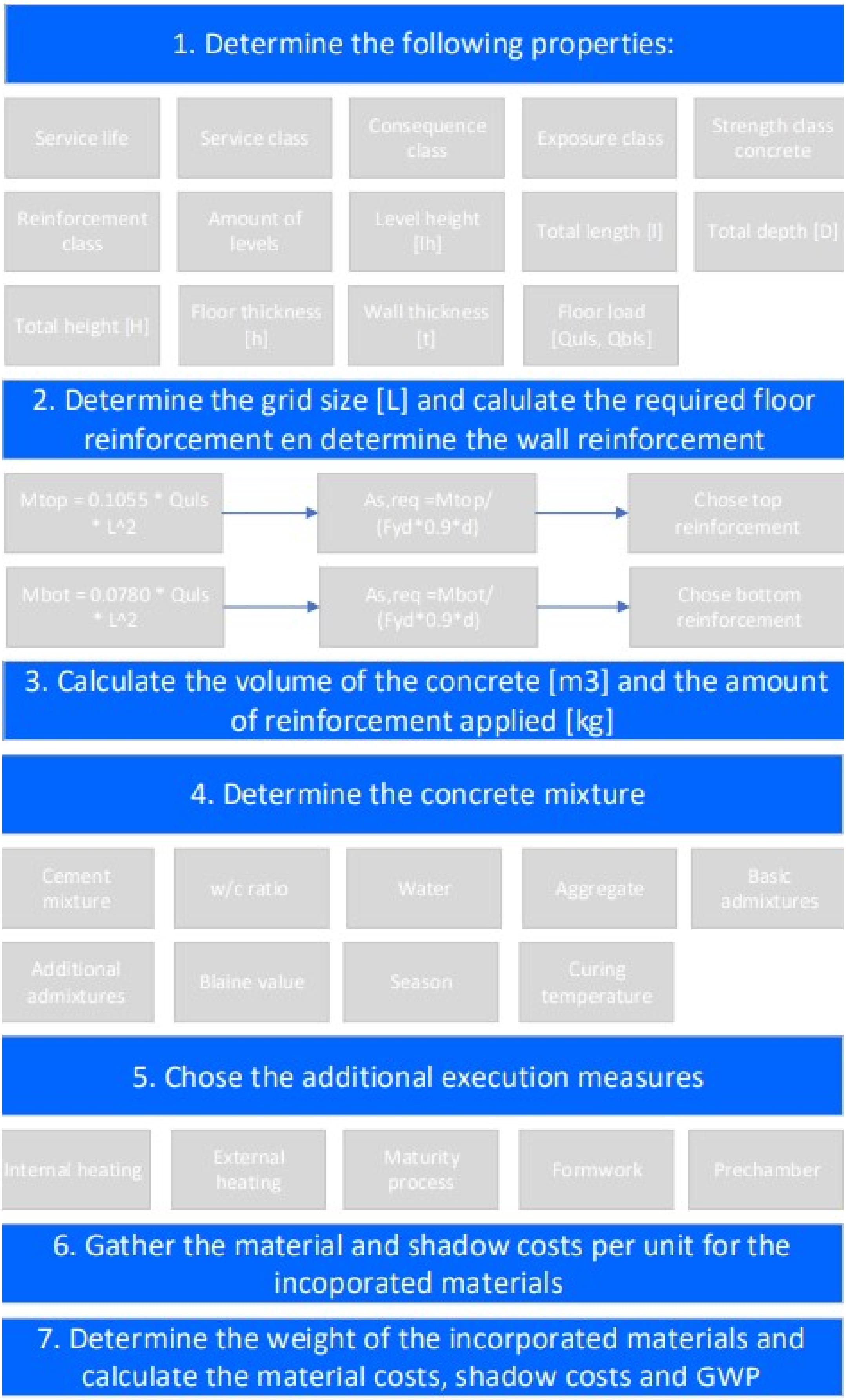


Figure A.1: Steps of the calculation sheet part 1 (own figure).

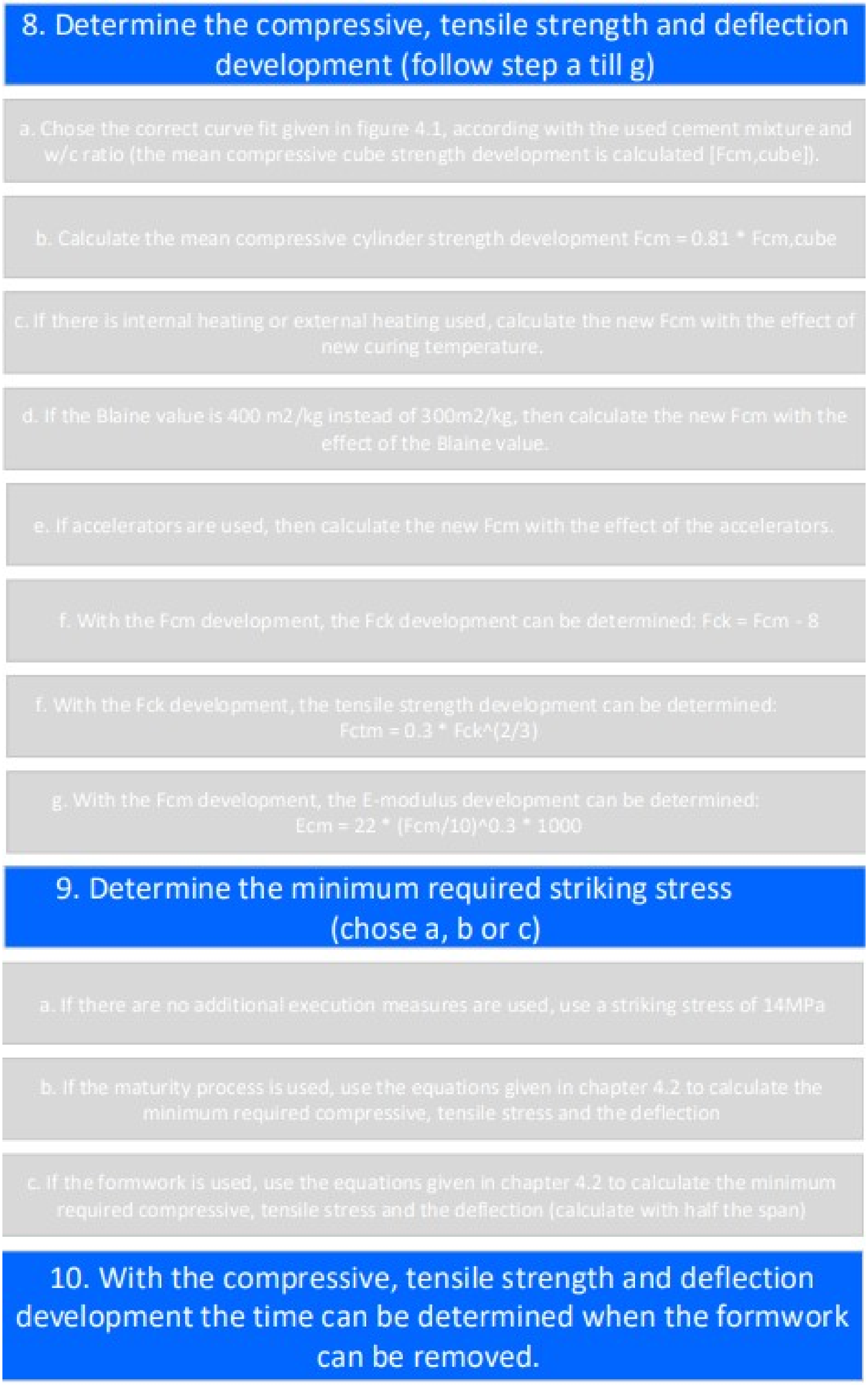


Figure A.2: Steps of the calculation sheet part 2 (own figure).

To validate the calculation sheet, variation 9w is employed, and an assessment is made of the compressive strength, tensile strength, and deflection after an 11 hour period.

Step 1: Determine the following parameters
The initial step involves determining the properties and designing the structure. Refer to Figure A.3 for the specific properties of variation 9w. It is crucial to highlight that the permanent and variable safety factors of CC2 are 1.2 and 1.5, respectively. The calculation of the floor load during the usage phase (Q_{ULS}) utilizes Equation A.1, while the calculation of the floor load during the execution phase (Q_{BLS}) relies on Equation A.2. In these equations, dw represents the dead weight of the floor, ff denotes the floor finish, and vl corresponds to the variable load.

$$Q_{ULS} = 1.2*(dw+ff)+1.5*(vl+partions)-->Q_{ULS} = 1.2*(25*0.25+1.40)+1.5*(1.75+1.00) = 13.305kN/m^2 \tag{A.1}$$

$$Q_{SLS} = 1.0*dw+1.0*vl-->Q_{SLS} = 1.0*(25*0.25)+1.0*0 = 6.25kN/m^2 \tag{A.2}$$

Service class	Category A	Reinforcement class	B500	Total height	H=22,96
Consequence class	Class CC2/RC2	Amount of levels	al=8	Floor thickness	h=250mm
Service life	Class 3: 50 years	Level height	lh=2,55m	Wall thickness	t=250mm
Exposure class	XC1	Total length	l=36m	Floor load (Quls)	13,305 kN/m2
Strength class concrete	C30/37	Total depth	d=9,6m	Floor load (Qbls)	6,25 kN/m2

Figure A.3: Properties of variation 9w (own figure).

Step 2: Determine the grid size [L] and calculate the required floor reinforcement and determine the wall reinforcement
A grid size of 7.20 meters is used for variation 9w. The number of grids can be calculated using the formula: n=l/L = 36/7.2 = 5. To determine the floor reinforcement, it is necessary to calculate the bending moment at the top ($M_{ed,top}$) and bottom ($M_{ed,bot}$) of the floor during the usage phase, as outlined in equations A.3 and A.4, respectively.

$$M_{ed,top} = 0.1055*Q_{ULS}*L^2-->M_{ed,top} = 0.1055*13.305*7.2^2 = 72.767kNm^1/m^1 \tag{A.3}$$

$$M_{ed,bot} = 0.078*Q_{ULS}*L^2-->M_{ed,bot} = 0.078*13.305*7.2^2 = 53.799kNm^1/m^1 \tag{A.4}$$

Utilizing the calculated bending moments, the necessary amount of reinforcement required at the top ($A_{s,req,top}$) and bottom ($A_{s,req,bot}$) of the floor can be determined. Refer to Equations A.5, A.6, A.7, and A.8 for the detailed calculations of the required reinforcement. The outcomes for variation 9w are presented in Figure A.4.

$$A_{s,req} = \frac{N_c}{f_yd} \tag{A.5}$$

$$N_c = \frac{M_{ed}*10^6}{z} \tag{A.6}$$

$$z = d-(X_u*\beta) \tag{A.7}$$

$$X_u = \frac{(d - \sqrt{d^2 - (\frac{4*\beta*M_{ed}*10^6}{\alpha*b*f_{cd}}}))}{2*\beta} \tag{A.8}$$

Location	Med [kNm]	d [mm]	α	β	b [mm]	fcd [Mpa]	fyd [Mpa]	Xu [mm]	z [mm]	Nc [kN]	As,req [mm²]
Top	72,7666	224	0,75	0,39	1000	20	435	22,5414	215,209	338,121	777,2892885
Bottom	53,799	224	0,75	0,39	1000	20	435	16,4847	217,571	247,271	568,439218

Figure A.4: required amount of reinforcement of variation 9w (own figure).

The next step involves determining the reinforcement for the floor. A cross mesh of ø12-150mm is chosen as the floor reinforcement, providing a reinforcement area ($A_{s,prov,floor}$) of 754mm^2. This choice yields a unity check of 1.03 for the top and 0.75 for the bottom. Reinforcement to address deflection will be calculated at a later stage. For the wall reinforcement, a practical approach involves adding a cross reinforcement of ø6-150mm (188mm^2) to the front and back ($A_{s,prov,wall}$).

Step 3: Calculate the volume of the concrete and the amount of reinforcement applied

The volume of the concrete, V_{con}, is calculated using Equation A.9, and the weight of the reinforcement is determined by Equation A.10. The density of the reinforcement is 7850kg/m^3.

$$V_{con} = h*l*d*al+(H-h*av)*t*d*(n+1)-->V_{con} = 0.25*9.6*36*8+(22.96-0.25*8)*0.25*9.6*(5+1) = 993.02m^3 \tag{A.9}$$

$$W_{rein} = A_{s,prov,floor}*l*d*al*4/1000000*7850+A_{s,prov,wall}*H*d*(n+1)*4/1000000*7850 = 73284kg \tag{A.10}$$

Step 4: Determine the concrete mixture

Variation 9w represents a cement mixture of CEM III/B 42.5N with a w/c ratio of 0.45. It incorporates standard aggregate, basic admixtures, and an additional admixture in the form of accelerators. The mixture features a Blaine value of 300m^2/kg, undergoes curing at a temperature of 60°C, and is constructed during the winter season. For a comprehensive overview of the concrete properties, please refer to Figure A.5. The detailed explanation of the percentage and weight calculations for each component will be provided in step 7.

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,65	**
Additional admixtures	Accelerator HA60	2	8,62	**
Blaine value	300m²/kg	-	-	
Sesaon	Winter	-	-	
Curing temperature	60°C	-	-	***

* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

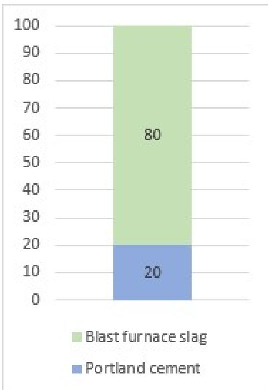


Figure A.5: The concrete properties of variation 9w (own figure).

Step 5: Chose the additional execution measures
In the case of variation 9w, two additional execution measures are implemented: the use of formwork and external heating. An additional row of struts will be introduced in the middle of the span, eliminating the need for precambering. Consequently, no supplementary bottom reinforcement is required to address deflection. The external heating is incorporated to elevate the curing temperature to 60°C.

Step 6: Gather the material and shadow costs per unit for the Incorporated materials.
The material and shadow costs are gathered from 3.13 and 3.15, respectively, and are illustrated in Figure A.6 for variation 9w.

Step 7: Determine the weight of the incorporated materials and calculate the material costs, shadow costs and GWP.
The density of concrete is 2500 kg/m^3, allowing for the calculation of the weight per unit volume for each constituent material incorporated into the concrete. Within the concrete mixture, 75% constitutes aggregate, resulting in 1875kg/m^3 of aggregate. Of this aggregate, 40% is fine aggregate (750kg/m^3), and 60% is coarse aggregate (1125kg/m^3). The remaining 25% of the concrete mixture comprises water and cement. The w/c ratio determines the quantities of water and cement, with a ratio of 0.45 yielding 17.2% cement (431 kg/m^3) and 7.8% water (194kg/m^3). Basic and additional admixtures have a minimal impact on the concrete density. Superplasticizers use 0.15% of the cement (0.65kg/m^3), and accelerators use 2% of the cement (8.62kg/m^3). The Blaine value, season, and curing temperature do not affect the concrete weight. However, due to the use of external heating, the curing temperature increases to 60°C, employing propane gas in the process. This influences the material costs, shadow costs, and GWP. Refer to equations A.11, A.12, and A.13 for the calculation of the required weight of propane gas, considering a temperature difference of 50°C. Figure A.6 provides an overview of the total material costs, shadow costs, and GWP for variation 9w. It's worth noting that material costs for sand, gravel, and water are calculated based on volume, while the remaining material costs are calculated based on weight.

$$E_{sp} = V_{sp} * \rho_{air} * C_{air} * \Delta T - - > 6805.44 * 1.393 * 1.006 * 50 = 476842.89kJ \tag{A.11}$$

$$Q_{loss,sp} = (\frac{2 * lh * L * \Delta T}{R_{PE}} + \frac{d * L * \Delta T}{R_{PE} + R_{con}} + \frac{2 * lh * L * \Delta T}{R_{PE} + R_{con}} + \frac{d * L * \Delta T}{R_{con}} + \frac{(n-1) * lh * d * \Delta T}{+R_{con}}) * 3.6 = 7493528.17kJ/h \tag{A.12}$$

$$M_p = \frac{E_{sp} + Q_{loss,sp} * t}{E_p} - - > \frac{476842.89 + 7493528 * 10}{46000} = 1611.51kg \tag{A.13}$$

Material	kg/m³ concrete	Volume [m3]	Weight [kg]	gwp[kg*CO2/kg]	MC [€/unit]	SC [€/kg]	GWP [kg*CO2]	Material costs [€]	Shadow costs [€]
Portland cement	86,2	-	85606	0,82	155,00	0,06062	70196,61	66344,29	5189,67
Blast furnace slag	344,8	-	342422	0,019		0,00154	6506,02		527,10
Rein-forcement	-	-	73284	1,5	See 3,2	0,16284	109926,00	92304,80	11933,71
Sand	750,0	297,907	744768	0,0029	10,00	0,00046	2159,83	2979,07	339,02
Gravel	1125,0	446,861	1117152	0,0011	22,50	8,4E-05	1228,87	10054,37	94,32
Water	194,0	77,4559	192612	0,00034	1,50	3,2E-05	65,49	116,18	6,15
Super-plasticizers	0,6	-	642	0,72	1,50	0,09225	462,27	963,06	59,23
Accelerator	8,6	-	8561	0,72	2,50	0,09225	6163,60	21401,38	789,72
Propane gas	-	-	1638,65	0,601	2,75	0,12862	984,83	4506,29	210,77
							197694	198669,44	19149,67

Figure A.6: The amounts and material costs, shadow costs and GWP of variation 9w (own figure).

Step 8: Determine the compressive strength, tensile strength and E-modulus development.
The initial step involves calculating the compressive cube strength at 11 hours, utilizing CEM III/B 42.5N and a w/c ratio of 0.45, as outlined in Equation A.14.

$$f_{cm,cube}(t) = 9.2363*\ln(t)+11.098-->f_{cm,cube}(11) = 9.2363*\ln(11/24)+11.098 = 3.892MPa \quad \text{(A.14)}$$

With the compressive cube strength the compressive cylinder strength at 11 hours can be calculated, see equation A.15.

$$f_{cm}(t) = f_{cm,cube}(t) * 0.81 --> f_{cm}(11) = 3.892 * 0.81 = 3.153MPa \quad \text{(A.15)}$$

External heating is employed, causing the curing temperature to elevate from the base of 20°C to 60°C. The initial step involves calculating the compressive strength at 11 hours at 20°C, utilizing equations A.16, A.17, and A.18. Simultaneously, the compressive strength at 11 hours at 60°C must be determined using equations A.19, A.20, and A.21. These values serve as the basis for calculating the percentage increase when the curing temperature rises from 20°C to 60°C, as per equation A.22. Subsequently, the new compressive cylinder strength is computed, taking into account the influence of the higher curing temperature, as detailed in equation A.23.

$$t_T = exp(-((\frac{4000}{273+T\Delta t_i})-13.65))*\Delta t_i-->t_{20} = exp(-(\frac{4000}{273+20})-13.65)*(11/24) = 0.457 \quad \text{(A.16)}$$

$$\beta_{cc}(t_T) = exp(s*(1-(\frac{28}{t_T})^{0.5}))-->\beta_{cc}(t_{20}) = exp(0.25*(1-(\frac{28}{0.457})^{0.5})) = 0.182 \quad \text{(A.17)}$$

$$f_{cm}(t_T) = \beta_{cc}(t_T) * f_{cm} --> f_{cm}(t_{20}) = 0.182 * 38 = 6.901MPa \quad \text{(A.18)}$$

$$t_T = exp(-((\frac{4000}{273+T\Delta t_i})-13.65))*\Delta t_i-->t_{60} = exp(-(\frac{4000}{273+60})-13.65)*(11/24) = 2.358 \quad \text{(A.19)}$$

$$\beta_{cc}(t_T) = exp(s*(1-(\frac{28}{t_T})^{0.5}))-->\beta_{cc}(t_{60}) = exp(0.25*(1-(\frac{28}{2.358})^{0.5})) = 0.543 \quad \text{(A.20)}$$

$$f_{cm}(t_T) = \beta_{cc}(t_T) * f_{cm} --> f_{cm}(t_{60}) = 0.543 * 38 = 20.617MPa \quad \text{(A.21)}$$

$$\%T = \frac{f_{cm}(t_{60})}{f_{cm}(t_{20})} --> \%T = \frac{20.61}{6.901} = 2.987 \quad \text{(A.22)}$$

$$f_{cm}(t,T) = f_{cm}(t) * \%T --> f_{cm}(11,60) = 3.153 * 2.987 = 9.418MPa \quad \text{(A.23)}$$

The Blaine value does not increase from 300m^2/kg to 400m^2/kg in variation 9w, so the compressive cylinder strength will not further increase.

The inclusion of accelerators in variation 9w leads to a 20% increase in the compressive cylinder strength, as indicated by Equation A.24. This elevated value represents the maximum compressive cylinder strength achievable for variation 9w.

$$f_{cm}(t,T,acc) = f_{cm}(t,T) * 1.20 --> f_{cm}(11,60,acc) = 9.418 * 1.2 = 11.302MPa \quad \text{(A.24)}$$

With the maximum compressive cylinder strength at 11 hours for variation 9w, the characteristic cylinder compressive strength can be calculated, see equation A.25

$$f_{ck}(t) = f_{cm}(t,T,acc) - 8 --> f_{ck}(11) = 11.302 - 8 = 3.302MPa \quad \text{(A.25)}$$

With the maximum characteristic cylinder compressive strength at 11 hours for variation 9w, the tensile strength can be calculated, see equation A.26

$$f_{ctm}(t) = 0.30 * f_{ck}(t)^{(2/3)} --> f_{ctm}(11) = 0.30 * 3.302^{(2/3)} = 0.665MPa \tag{A.26}$$

With the maximum compressive cylinder strength at 11 hours for variation 9w, the E-modulus can be calculated, see equation A.27

$$E_{cm}(t) = 22 * (\frac{f_{cm}(t)}{10})^{0.3} --> E_{cm}(11) = 22000 * (\frac{11.302}{10})^{0.3} = 22822.82MPa \tag{A.27}$$

Step 9: Determine the minimum required striking stress.
The decision to use formwork as an additional execution measure prompts the application of equations in Chapter 4.2 to determine the minimum required compressive strength, tensile strength, and deflection at 11 hours, calculated with half the total span due to the extra row of struts. Refer to Equation A.33 for the minimum mean compressive cylinder strength, Equation A.45 for the minimum deflection, and Equation A.47 for the minimum tensile strength for variation 9w at 11 hours. It's crucial to acknowledge that the values of the tensile strength and deflection (E-modulus) on the calculation sheet have lower values, as the minimum required values are achieved earlier than 11 hours.

$$M_{ed,SLS} = 1/8 * Q_{SLS} * (0.5 * L)^2 --> M_{ed,SLS} = 1/8 * 6.25 * (0.5 * 7.2)^2 = 10.125kNm^1/m^1 \tag{A.28}$$

$$\sigma_{yd,el} = \frac{M_{ed,SLS}}{A_{s,prov} * 0.9 * d} --> \sigma_{yd,el} = \frac{10.125 * 10^6}{754 * 0.9 * 224} = 66.61MPa \tag{A.29}$$

$$X_u = \frac{d - \frac{M_{ed,SLS}}{A_{s,prov} * \sigma_{yd,el}}}{\beta} --> X_u = \frac{224 - \frac{10.125 * 10^6}{754 * 66.91}}{0.39} = 57.6mm \tag{A.30}$$

$$f_{cd,min} = \frac{A_{s,prov} * \sigma_{yd,el}}{\alpha * X_u * b} --> f_{cd,min} = \frac{754 * 66.61}{0.75 * 57.6 * 1000} = 1.163MPa \tag{A.31}$$

$$f_{ck,min} = f_{cd,min} * 1.5 --> f_{ck,min} = 1.163 * 1.5 = 1.744MPa \tag{A.32}$$

$$f_{cm,min} = f_{ck,min} + 8 --> f_{cm,min} = 1.744 + 8 = 9.744MPa \tag{A.33}$$

$$E_{c,eff}(t) = E_{cm}(t) --> E_{c,eff}(11) = 22822.82MPa \tag{A.34}$$

$$\alpha_e(t) = \frac{E_s}{E_{c,eff}(t)} --> \alpha_e(11) = \frac{210000}{22822.82} = 9.201 \tag{A.35}$$

$$\rho_1 = \frac{A_{s,prov}}{b * d} --> \rho_1 = \frac{754}{1000 * 224} = 0.00337 \tag{A.36}$$

$$x(11) = -9.201 * 0.00337 + \sqrt{(9.201 * 0.00337)^2 + 2 * (9.201 * 0.00337)} * 224 = 56.149mm \tag{A.37}$$

$$f_{ctm,fl}(t) = (1.6 - h) * f_{ctm}(t) --> f_{ctm,fl}(t) = (1.6 - 0.25) * 0.665 = 0.898MPa \tag{A.38}$$

$$M_{cr}(t) = 1/6 * b * h^2 * f_{ctm,fl}(t) --> M_{cr}(11) = 1/6 * 1000 * 250^2 * 0.898/1000000 = 9.352kNm \tag{A.39}$$

$$M_{eqp} = 1/8 * (q_g + q_q) * L^2 = M_{ed,SLS} = 10.125kNm^1/m^1 \tag{A.40}$$

$$\zeta(t) = 1 - \beta * (\frac{M_{cr}(t)}{M_{eqp}})^2 --> \zeta(11) = 1 - 0.5 * (\frac{9.352}{10.125})^2 = 0.573 \tag{A.41}$$

$$EI_I(11) = (\frac{1 + 3 * 9.201 * 0.00337}{1 + 9.201 * 0.00337}) * 22822.82 * 1/12 * 1000 * 250^3 = 3.15 * 10^13 Nmm^2 \tag{A.42}$$

$$EI_{II}(11) = 6 * (\frac{224}{250})^3 * (\frac{56.149}{224})^2 * (1 - 1/3 * \frac{56.149}{224}) * 22822.82 * 1/12 * 1000 * 250^3 = 7.39 * 10^12 Nmm^2 \tag{A.43}$$

$$EI_{I+II}(11) = 3.15 * 10^13 * (1 - 0.573) + 7.39 * 10^12 * 0.573 = 1.77 * 10^12 Nmm^2 \tag{A.44}$$

$$w_{I+II}(t) = \frac{5 * M_{eqp} + L^2}{48 * EI_{I+II}(t)} - - > w_{I+II}(t) = \frac{5 * 10.125 + (0.5 * 7.2)^2}{48 * 1.77 * 10^12} = 0.773mm \tag{A.45}$$

$$\sigma_s = \frac{A_{s,req}}{A_{s,prov}} * \sigma_{yd,el} - - > \sigma_s = \frac{568.44}{754} * 66.61 = 50.22MPa \tag{A.46}$$

$$f_{ctm,min} = \frac{\frac{0.4 * \sigma_s * P_{p,eff}}{k_t}}{1 + \alpha_e(t) * P_{p,eff}} - - > f_{ctm,min} = \frac{\frac{0.4 * 50.22 * 0.013}{0.4}}{1 + 9.201 * 0.013} = 0.583MPa \tag{A.47}$$

Step 10: Verification of the striking stress.
Step 8 involves the calculation of the compressive strength, tensile strength, and E-modulus at 11 hours for variation 9w. These calculated values must surpass those obtained in step 9. The verification of the E-modulus is conducted through the deflection. As demonstrated in equations A.48, A.49, and A.50, all values calculated in step 8 exceed those computed in step 9. Consequently, the formwork can be removed after 11 hours following the concrete pouring process.

$$f_{cm}(t, T, acc) > f_{cm,min} - - > 11.302 > 9.744MPa \tag{A.48}$$

$$f_{cm}(t, T, acc) > f_{ctm,min} - - > 0.665 > 0.583MPa \tag{A.49}$$

$$0.001 * (0.5 * L) > w_{I+II}(t) - - > 3.2 > 0.773mm \tag{A.50}$$

B

Appendix B: Calculation sheet variants

1 Variation 1

1.1 Input

1.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

1.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m^1]	(incl. GF)	[m^1]	[m^1]	[m^1]	[m^1]		[mm^1]	[mm^1]	[m^3]
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25	kN/m²
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement		$A_{s;prov}$	U.C.
[kNm^1/m^1]	*[mm^2/m^1]*	*base*	*additional*	*[mm^2/m^1]*	
28,4	294	Ø 8 - 150		335	0,88

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement		$A_{s;prov}$	U.C.
[kNm^1/m^1]	*[mm^2/m^1]*	*base*	*additional*	*[mm^2/m^1]*	
21,0	216	Ø 8 - 150		335	0,65

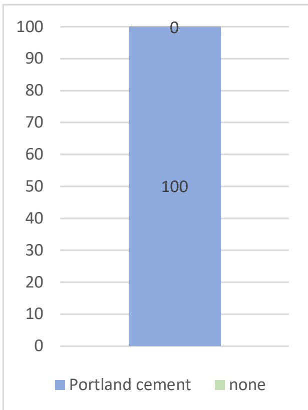
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

1.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM I 52.5R	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,3	1,21	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

1.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

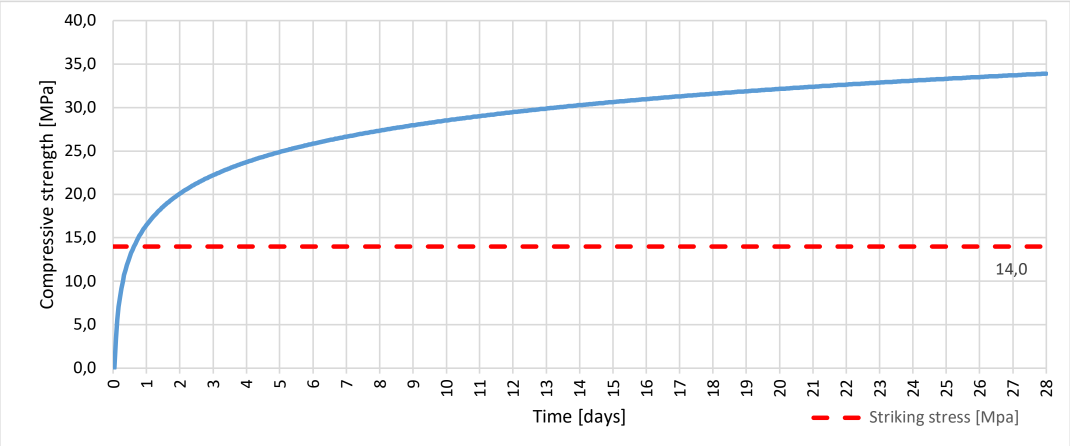
Precamber:	No		Extra precamber height:	0 mm

1.2 Output

1.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	403,2	461265	378236,90	€ 78.414,97	€ 27.963,22
	none					
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	1,21	1384	996,33	€ 2.075,69	€ 127,66
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				444473	€ 149.742,26	€ 35.247,52
					€ 184.989,78	

1.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	16,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	6,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	9,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	16,0	hours

2 Variation 2

2.1 Input

2.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

2.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement		As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*	*additional*	*[mm²/m¹]*	
28,4	294	Ø 8 - 150		335	0,88

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement		As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*	*additional*	*[mm²/m¹]*	
21,0	216	Ø 8 - 150		335	0,65

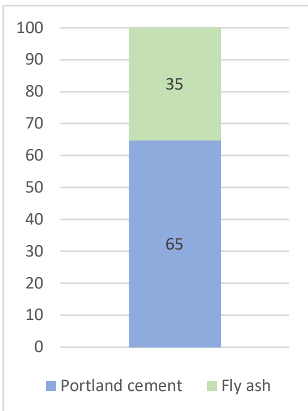
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

2.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

2.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

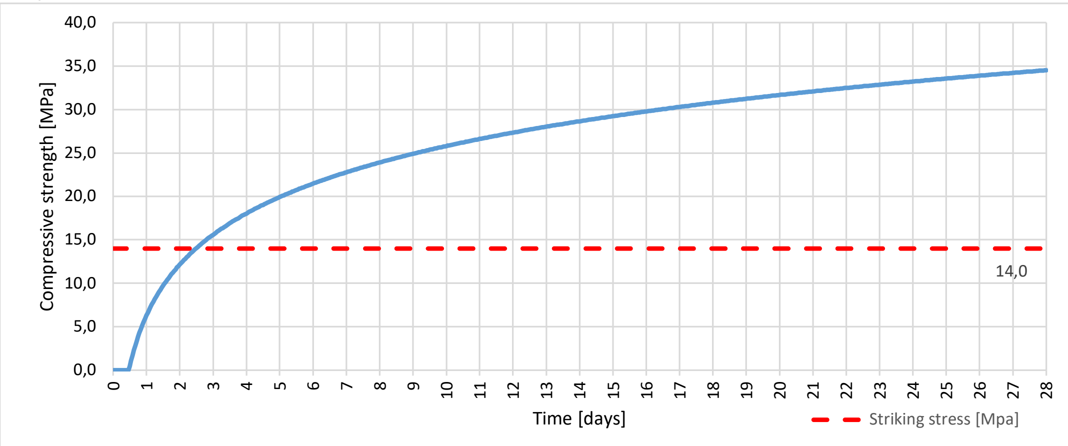
Precamber:	No	Extra precamber height:	0 mm

2.2 Output

2.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	299822	245853,99	€ 73.802,32	€ 18.176,09
	Fly ash	141,1	161443	532,76		€ 55,69
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	1,01	1153	830,28	€ 1.729,74	€ 106,38
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				312457	€ 144.783,67	€ 25.494,81
					€ 170.278,47	

2.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after		60,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after		32,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after		42,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after		60,0	hours

2 Variation 2a

2.1 Input

2.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

2.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25	kN/m²
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
28,4	294	Ø	8	-	150			335	0,88

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
21,0	216	Ø	8	-	150			335	0,65

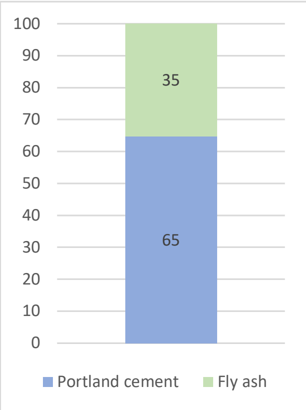
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

2.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,08	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

2.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

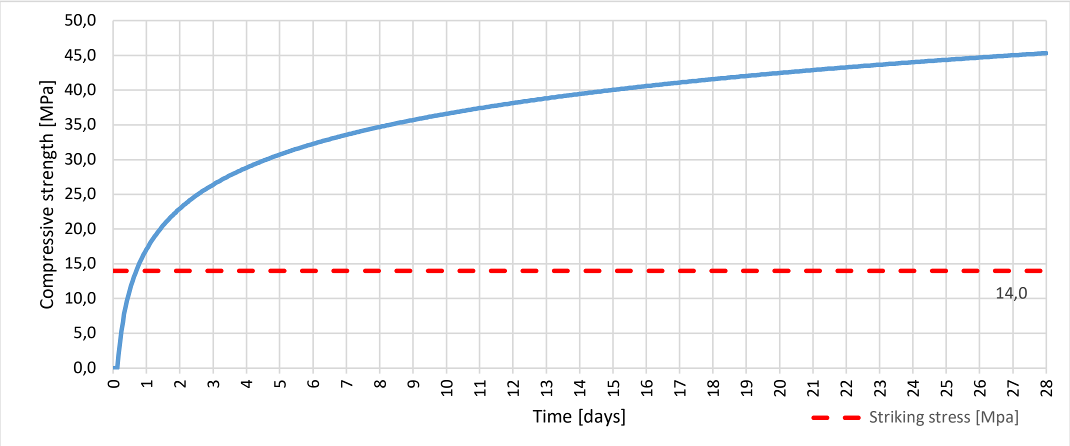
Precamber:	No	Extra precamber height:	0	mm

2.2 Output

2.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	280,2	320499	262809,43	€ 78.892,14	€ 19.429,62
	Fly ash	150,9	172577	569,50		€ 59,53
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	194	221884	75,44	€ 133,84	€ 7,08
Basic admixtures	Superplasticizer (PCE)	1,08	1233	887,54	€ 1.849,03	€ 113,72
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				329495	€ 149.992,77	€ 26.758,49
					€ 176.751,27	

2.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	17,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	9,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	12,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	17,0	hours

2 Variation 2b

2.1 Input

2.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

2.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
28,4	294	Ø	8	-	150			335	0,88

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
21,0	216	Ø	8	-	150			335	0,65

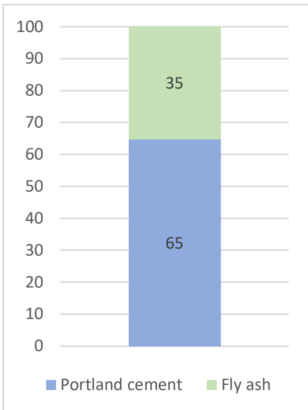
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

2.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	400m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

2.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

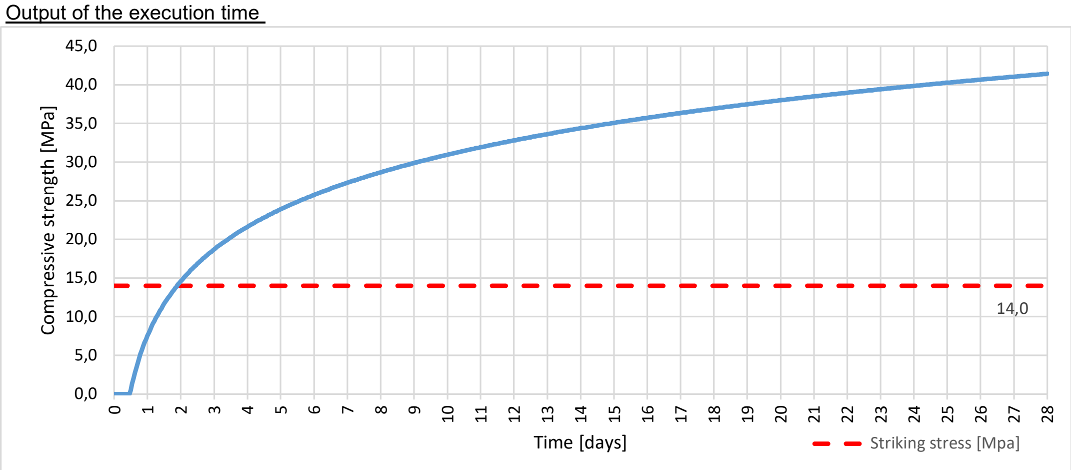
Precamber:	No	Extra precamber height:	0 mm

2.2 Output

2.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	299822	245853,99	€ 73.802,32	€ 18.176,09
	Fly ash	141,1	161443	532,76		€ 55,69
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	1,01	1153	830,28	€ 1.729,74	€ 106,38
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-	75647,38	€ 13.837,94	€ 5.592,64
				388104	€ 158.621,60	€ 31.087,45
					€ 189.709,05	

2.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	46,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	27,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	34,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	46,0	hours

2 Variation 2c

2.1 Input

2.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

2.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement					As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
28,4	294	Ø	8	-	150		335	0,88

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement					As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
21,0	216	Ø	8	-	150		335	0,65

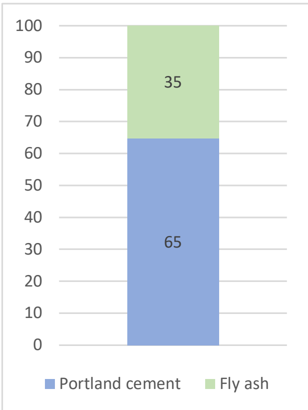
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

2.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	Accelerator HA60	2	8,06	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

2.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

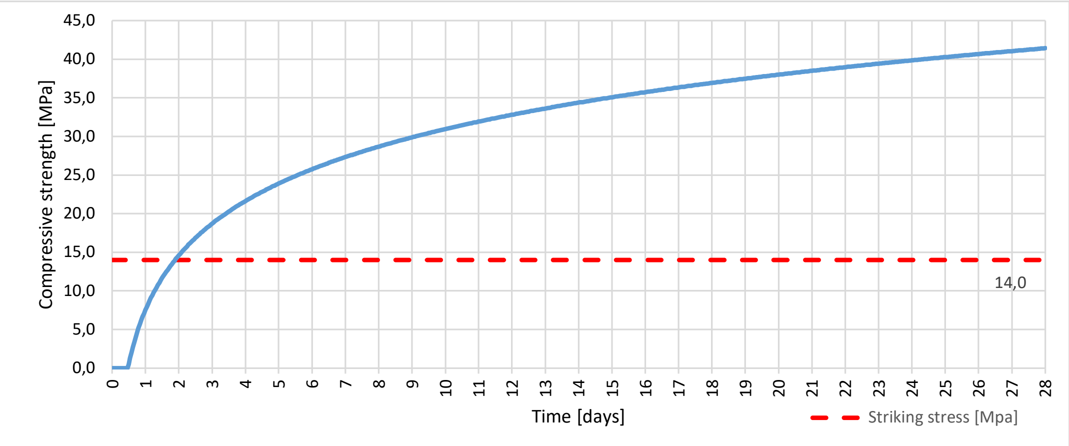
Extra precamber height:	0 mm

2.2 Output

2.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	299822	245853,99	€ 73.802,32	€ 18.176,09
	Fly ash	141,1	161443	532,76		€ 55,69
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	1,01	1153	830,28	€ 1.729,74	€ 106,38
Additional admixtures	Accelerator HA60	8,1	9225	6642,20903	€ 23.063,23	€ 851,04
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				319099	€ 167.846,89	€ 26.345,85
					€ 194.192,74	

2.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	46,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	27,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	34,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	46,0	hours

2 Variation 2d

2.1 Input

2.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

2.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	p_g	=	6,25 +	1,40 =	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	p_q	=	1,75 +	1,00 =	2,75	kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement					$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
28,4	294	Ø	8	-	150		335	0,88

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement					$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
21,0	216	Ø	8	-	150		335	0,65

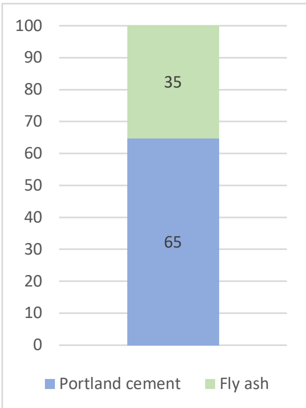
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

2.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Winter	-	-	
Curing temperature	10°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

2.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

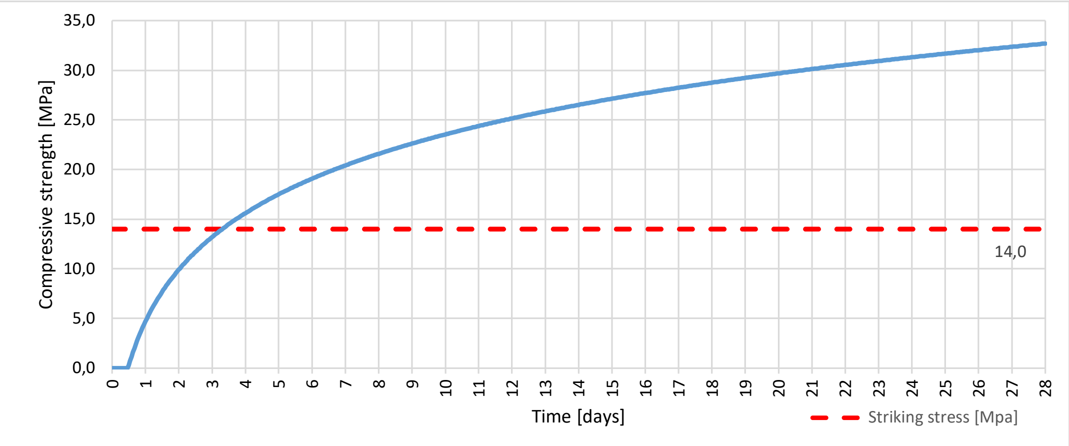
Extra precamber height:	0 mm

2.2 Output

2.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	299822	245853,99	€ 73.802,32	€ 18.176,09
	Fly ash	141,1	161443	532,76		€ 55,69
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	1,01	1153	830,28	€ 1.729,74	€ 106,38
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				312457	€ 144.783,67	€ 25.494,81
					€ 170.278,47	

2.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	80,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	40,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	55,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	80,0	hours

2 Variation 2e

2.1 Input

2.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

2.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement						$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
28,4	294	Ø	8	-	150			335	0,88

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement						$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
21,0	216	Ø	8	-	150			335	0,65

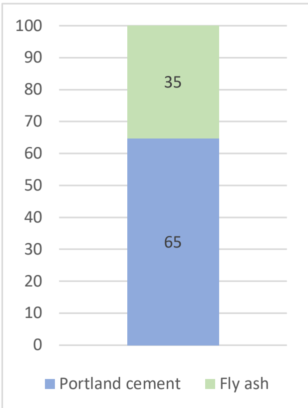
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

2.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	50°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

2.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Internal heating	Internal heating used, the internal curing temperature will increase to 50°C.	50°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

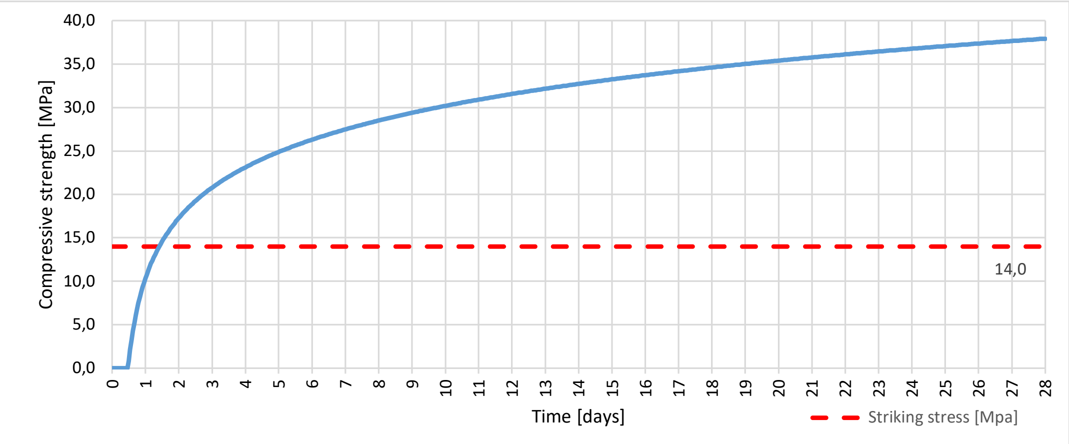
Precamber:	No	Extra precamber height:	0 mm

2.2 Output

2.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	299822	245853,99	€ 73.802,32	€ 18.176,09
	Fly ash	141,1	161443	532,76		€ 55,69
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	1,01	1153	830,28	€ 1.729,74	€ 106,38
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1639	985,191687	€ 4.508,44	€ 210,87
Extra grinding costs		-	-			
				313442	€ 149.292,11	€ 25.705,68
					€ 174.997,79	

2.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	34,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	21,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	26,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	34,0	hours

2 Variation 2f

2.1 Input

2.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

2.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement					$A_{s;prov}$	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional	[mm²/m¹]	
28,4	294	Ø	8	-	150		335	0,88

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement					$A_{s;prov}$	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional	[mm²/m¹]	
21,0	216	Ø	8	-	150		335	0,65

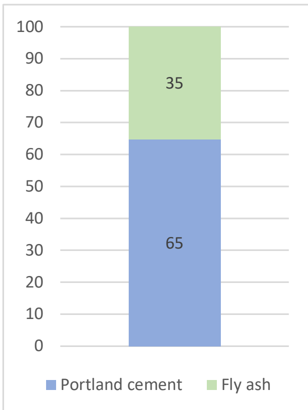
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

2.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	60°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

2.1.4 Additional execution methods

Additional execution method:	Explanation	New value
External heating	External heating used, the curing temperature will increase with 60°C.	60°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

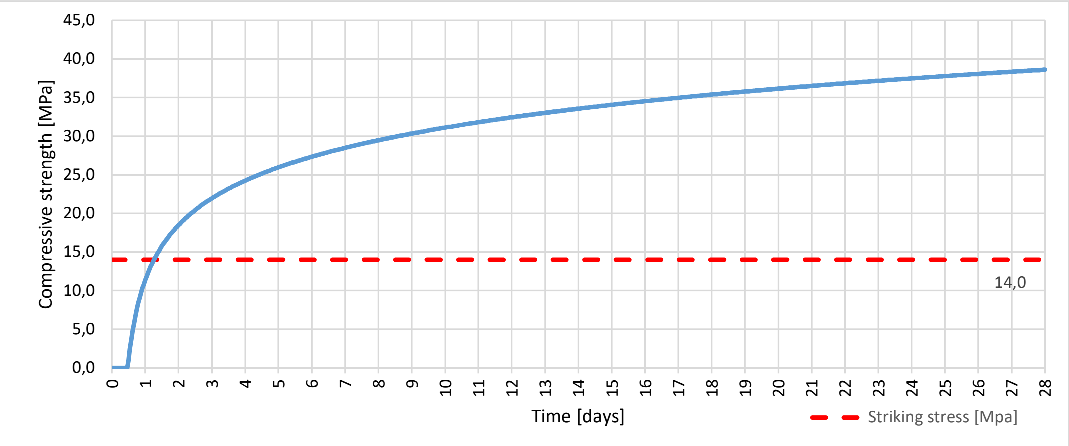
Extra precamber height:	0 mm

2.2 Output

2.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	299822	245853,99	€ 73.802,32	€ 18.176,09
	Fly ash	141,1	161443	532,76		€ 55,69
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	1,01	1153	830,28	€ 1.729,74	€ 106,38
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1408	845,846543	€ 3.870,77	€ 181,05
Extra grinding costs		-	-			
				313303	€ 148.654,44	€ 25.675,85
					€ 174.330,29	

2.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	31,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	20,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	24,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	31,0	hours

2 Variation 2g

2.1 Input

2.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

2.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25	kN/m²
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement						$A_{s;prov}$	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional		[mm²/m¹]	
28,4	294	Ø	8	-	150			335	0,88

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement						$A_{s;prov}$	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional		[mm²/m¹]	
21,0	216	Ø	8	-	150			335	0,65

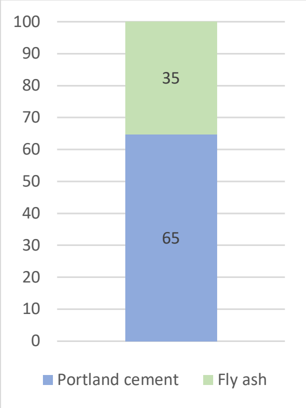
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

2.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

2.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Maturity process	The maturity method is used. New stresses will develop, the minimum compressive strength is:	10,68 MPa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

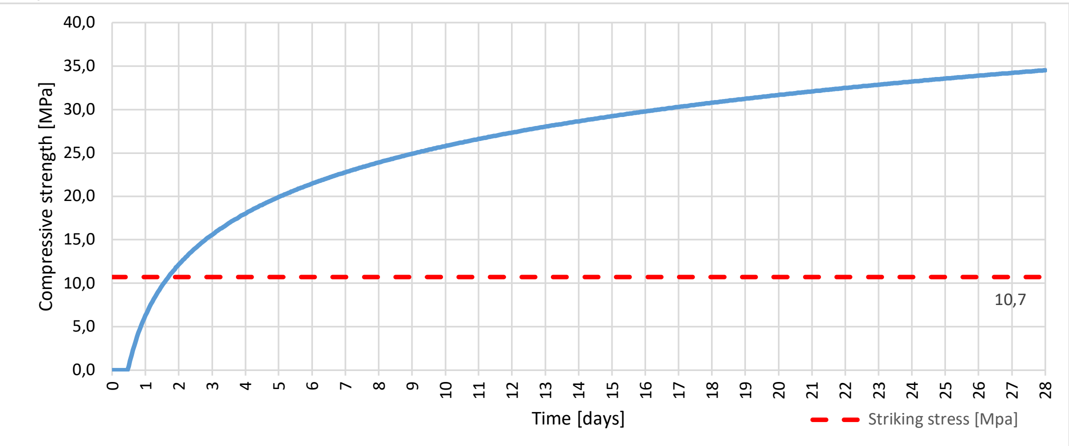
Extra precamber height:	0 mm

2.2 Output

2.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	299822	245853,99	€ 73.802,32	€ 18.176,09
	Fly ash	141,1	161443	532,76		€ 55,69
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	1,01	1153	830,28	€ 1.729,74	€ 106,38
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				312457	€ 144.783,67	€ 25.494,81
					€ 170.278,47	

2.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	10,7	Mpa. Which is reached after		41,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after		32,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after		42,0	hours
The determining valiation is the	Deflection	. So the formwork can be removed after		42,0	hours

2 Variation 2h

2.1 Input

2.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

2.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement						$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
28,4	294	Ø	8	-	150			335	0,88

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement						$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
21,0	216	Ø	8	-	150			335	0,65

Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

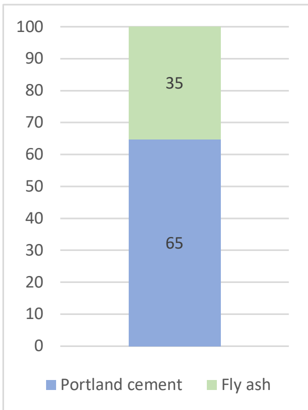
Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

2.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***

* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.



2.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Formwork	An extra support is applied, in the middle of each grid. New stresses will develop, the minimum compressive strength is:	8,67 Mpa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

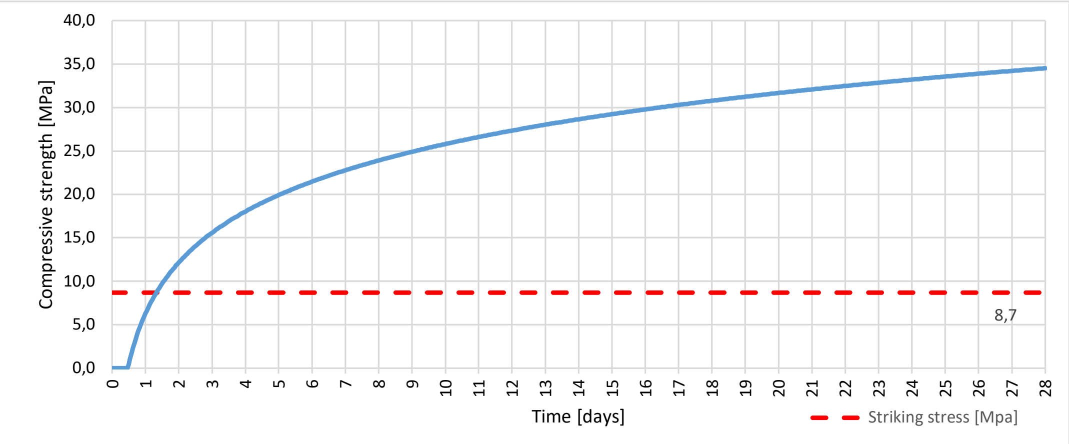
Precamber:	No	Extra precamber height:	0 mm

2.2 Output

2.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	299822	245853,99	€ 73.802,32	€ 18.176,09
	Fly ash	141,1	161443	532,76		€ 55,69
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	1,01	1153	830,28	€ 1.729,74	€ 106,38
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				312457	€ 144.783,67	€ 25.494,81
					€ 170.278,47	

2.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	8,7	Mpa. Which is reached after	32,0	hours
The formwork can be removed when a tensile strength of	0,02	Mpa. Which is reached after	30,0	hours
The formwork can be removed is the deflection is less than	2,25	mm. Which is reached after	12,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	32,0	hours

2 Variation 2s

2.1 Input

2.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

2.1.2 Design of the structure

Grid size [m¹]	Amount of levels (incl. GF)	Level height [m¹]	Total length [m¹]	Total depth [m¹]	Total height [m¹]	Amount of grids	Floor thickness [mm¹]	Wall thickness [mm¹]	Total volume [m³]
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	p_g	=	6,25 +	1,40 =	7,65 kN/m²	(dead weight + finishing floor)		**Execution phase:**	6,25 kN/m²
	p_q	=	1,75 +	1,00 =	2,75 kN/m²	(variable load + partitions)			1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed} [kNm¹/m¹]	$A_{s;req}$ [mm²/m¹]	Applied Reinforcement base	Applied Reinforcement additional	$A_{s;prov}$ [mm²/m¹]	U.C.
28,4	294	Ø 8 - 150		335	0,88

Floor Reinforcement: BOTTOM

M_{Ed} [kNm¹/m¹]	$A_{s;req}$ [mm²/m¹]	Applied Reinforcement base	Applied Reinforcement additional	$A_{s;prov}$ [mm²/m¹]	U.C.
21,0	216	Ø 8 - 150		335	0,65

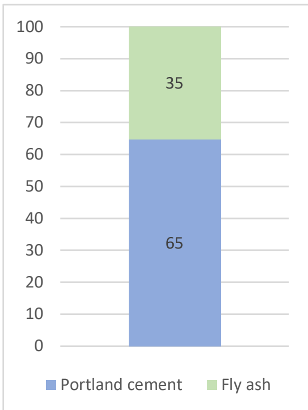
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

2.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,08	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

2.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Maturity process	The maturity method is used. New stresses will develop, the minimum compressive strength is:	10,68 MPa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

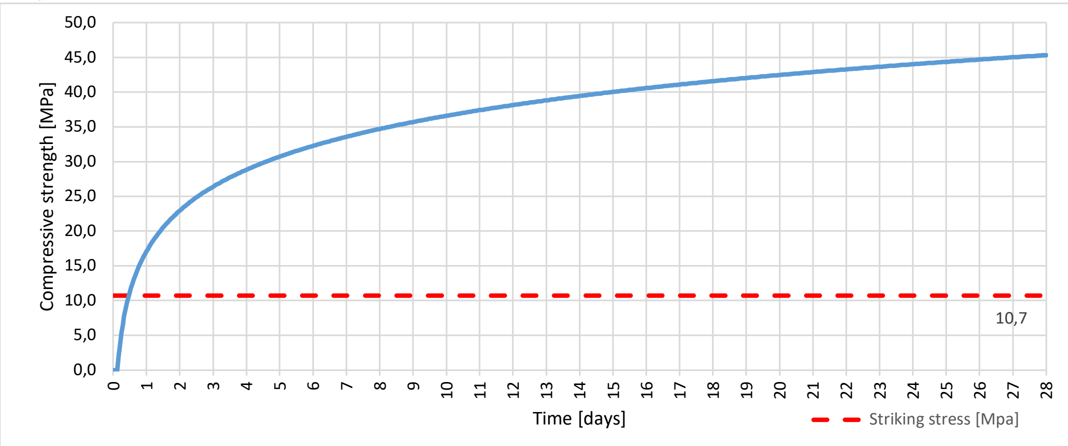
Precamber:	No	Extra precamber height:	0 mm

2.2 Output

2.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	280,2	320499	262809,43	€ 78.892,14	€ 19.429,62
	Fly ash	150,9	172577	569,50		€ 59,53
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	194	221884	75,44	€ 133,84	€ 7,08
Basic admixtures	Superplasticizer (PCE)	1,08	1233	887,54	€ 1.849,03	€ 113,72
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				329495	€ 149.992,77	€ 26.758,49
					€ 176.751,27	

2.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	10,7	Mpa. Which is reached after	12,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	9,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	12,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	12,0	hours

2 Variation 2w

2.1 Input

2.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

2.1.2 Design of the structure

Grid size [m^1]	Amount of levels (incl. GF)	Level height [m^1]	Total length [m^1]	Total depth [m^1]	Total height [m^1]	Amount of grids	Floor thickness [mm^1]	Wall thickness [mm^1]	Total volume [m^3]
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	p_g = 6,25 + 1,40 = 7,65 kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	p_q = 1,75 + 1,00 = 2,75 kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed} [kNm^1/m^1]	$A_{s;req}$ [mm^2/m^1]	Applied Reinforcement base	Applied Reinforcement additional	$A_{s;prov}$ [mm^2/m^1]	U.C.
28,4	294	Ø 8 - 150		335	0,88

Floor Reinforcement: BOTTOM

M_{Ed} [kNm^1/m^1]	$A_{s;req}$ [mm^2/m^1]	Applied Reinforcement base	Applied Reinforcement additional	$A_{s;prov}$ [mm^2/m^1]	U.C.
21,0	216	Ø 8 - 150		335	0,65

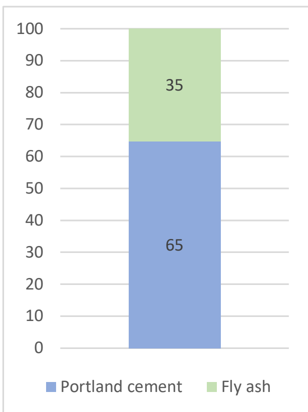
Wall Reinforcement v/a: Ø 6 - 150 = 188 mm^2/m^1

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

2.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,08	**
Additional admixtures	Accelerator HA60	2	8,62	**
Blaine value	300m²/kg	-	-	
Sesaon	Winter	-	-	
Curing temperature	10°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

2.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Maturity process	The maturity method is used. New stresses will develop, the minimum compressive strength is:	10,68 MPa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

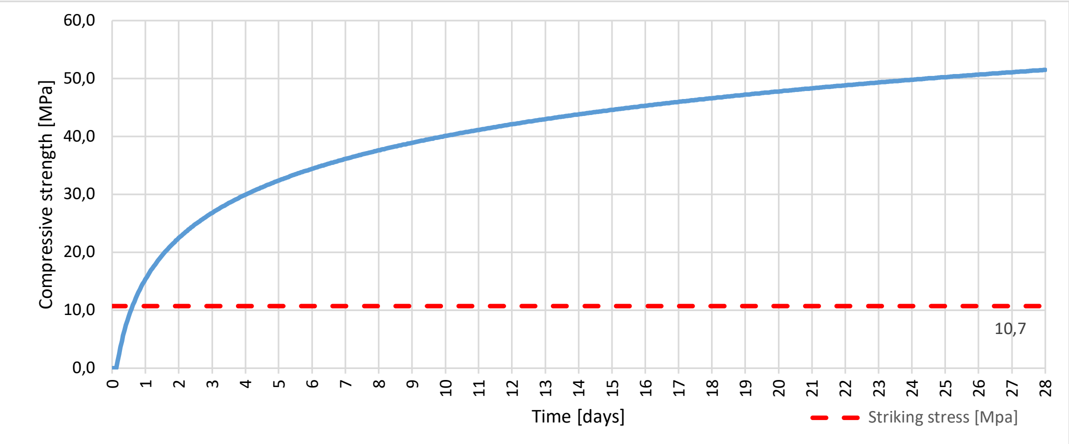
Extra precamber height:	0 mm

2.2 Output

2.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	280,2	320499	262809,43	€ 78.892,14	€ 19.429,62
	Fly ash	150,9	172577	569,50		€ 59,53
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	194	221884	75,44	€ 133,84	€ 7,08
Basic admixtures	Superplasticizer (PCE)	1,08	1233	887,54	€ 1.849,03	€ 113,72
Additional admixtures	Accelerator HA60	8,6	9862	7100,29241	€ 24.653,79	€ 909,73
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				336596	**€ 174.646,57**	**€ 27.668,22**
					€ 202.314,79	

2.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	10,7	Mpa. Which is reached after	15,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	12,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	16,0	hours
The determining valiation is the	Deflection	. So the formwork can be removed after	16,0	hours

3 Variation 3

3.1 Input

3.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

3.1.2 Design of the structure

Grid size [m¹]	Amount of levels (incl. GF)	Level height [m¹]	Total length [m¹]	Total depth [m¹]	Total height [m¹]	Amount of grids	Floor thickness [mm¹]	Wall thickness [mm¹]	Total volume [m³]
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed} [kNm¹/m¹]	$A_{s;req}$ [mm²/m¹]	Applied Reinforcement base				Applied Reinforcement additional	$A_{s;prov}$ [mm²/m¹]	U.C.
28,4	294	Ø	8	-	150		335	0,88

Floor Reinforcement: BOTTOM

M_{Ed} [kNm¹/m¹]	$A_{s;req}$ [mm²/m¹]	Applied Reinforcement base				Applied Reinforcement additional	$A_{s;prov}$ [mm²/m¹]	U.C.
21,0	216	Ø	8	-	150		335	0,65

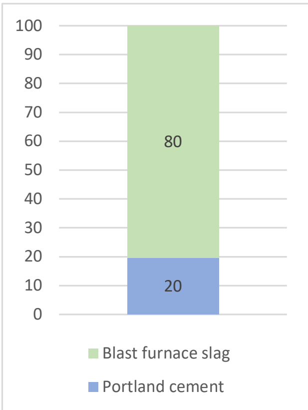
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

3.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

3.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

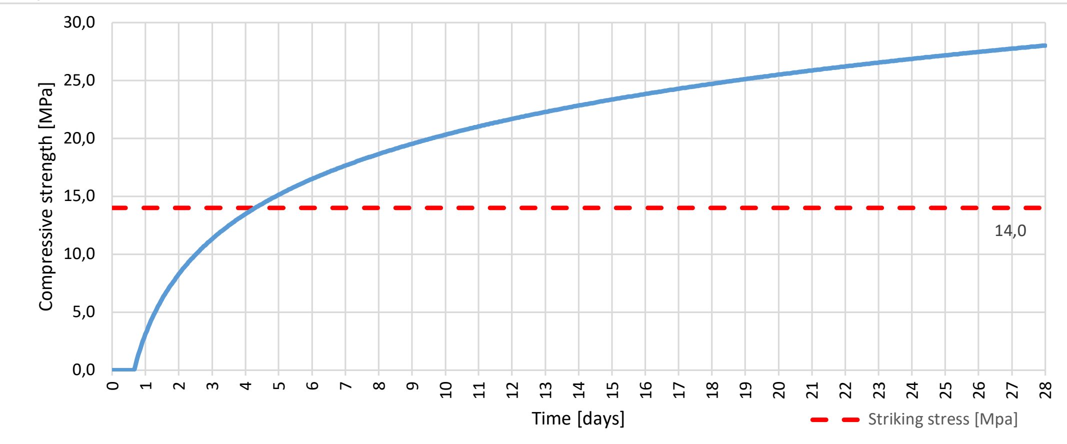
Precamber:	No		Extra precamber height:	0 mm

3.2 Output

3.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	92253	75647,38	€ 71.496,00	€ 5.592,64
	Blast furnace slag	322,6	369012	7011,22		€ 568,03
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	0,60	692	498,17	€ 1.037,85	€ 63,83
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				148397	€ 141.785,45	€ 13.381,15
					€ 155.166,59	

3.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	104,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	50,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	69,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	104,0	hours

3 Variation 3a

3.1 Input

3.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

3.1.2 Design of the structure

Grid size [m¹]	Amount of levels (incl. GF)	Level height [m¹]	Total length [m¹]	Total depth [m¹]	Total height [m¹]	Amount of grids	Floor thickness [mm¹]	Wall thickness [mm¹]	Total volume [m³]
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd [kNm¹/m¹]	As;req [mm²/m¹]	Applied Reinforcement base				Applied Reinforcement additional	As;prov [mm²/m¹]	U.C.
28,4	294	Ø	8	-	150		335	0,88

Floor Reinforcement: BOTTOM

MEd [kNm¹/m¹]	As;req [mm²/m¹]	Applied Reinforcement base				Applied Reinforcement additional	As;prov [mm²/m¹]	U.C.
21,0	216	Ø	8	-	150		335	0,65

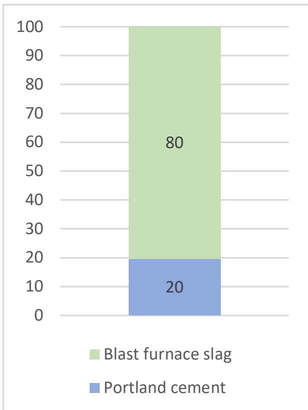
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

3.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,65	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

3.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

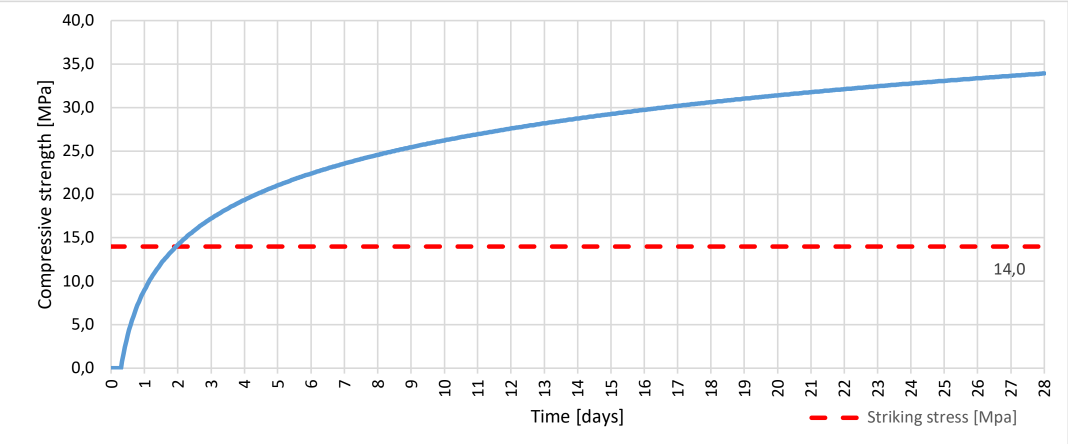
Extra precamber height:	0 mm

3.2 Output

3.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	86,2	98615	80864,44	€ 76.426,76	€ 5.978,34
	Blast furnace slag	344,8	394461	7494,75		€ 607,21
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	194	221884	75,44	€ 133,84	€ 7,08
Basic admixtures	Superplasticizer (PCE)	0,65	740	532,52	€ 1.109,42	€ 68,23
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				154121	€ 146.787,78	€ 13.809,41
					€ 160.597,19	

3.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	47,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	23,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	32,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	47,0	hours

3 Variation 3b

3.1 Input

3.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

3.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:									
	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	
	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement							$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*		*base*			*additional*			*[mm²/m¹]*	
28,4	294	Ø	8	-	150				335	0,88

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement							$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*		*base*			*additional*			*[mm²/m¹]*	
21,0	216	Ø	8	-	150				335	0,65

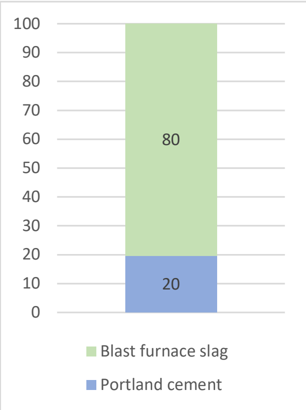
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

3.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	400m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

3.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

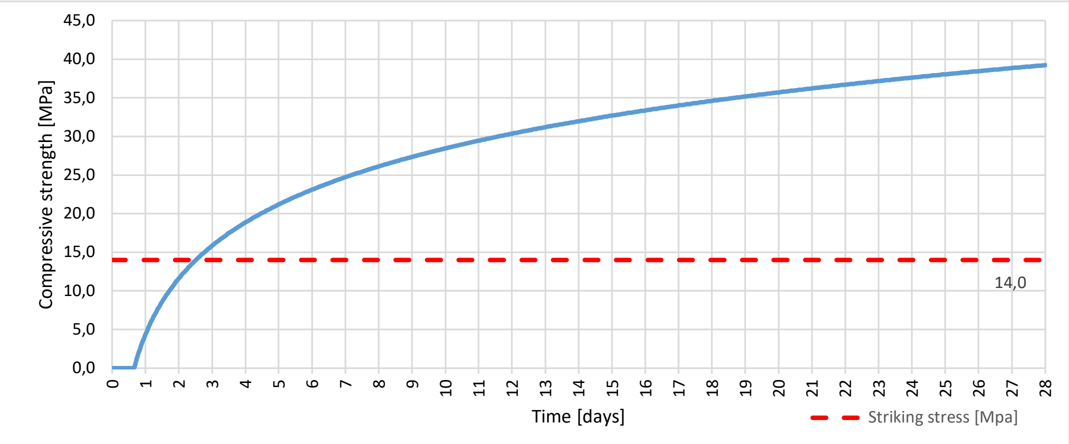
Extra precamber height:	0 mm

3.2 Output

3.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	92253	75647,38	€ 71.496,00	€ 5.592,64
	Blast furnace slag	322,6	369012	7011,22		€ 568,03
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	0,60	692	498,17	€ 1.037,85	€ 63,83
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-	75647,38	€ 13.837,94	€ 5.592,64
				224044	€ 155.623,38	€ 18.973,79
					€ 174.597,17	

3.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	61,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	36,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	46,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	61,0	hours

3 Variation 3c

3.1 Input

3.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

3.1.2 Design of the structure

Grid size [m¹]	Amount of levels (incl. GF)	Level height [m¹]	Total length [m¹]	Total depth [m¹]	Total height [m¹]	Amount of grids	Floor thickness [mm¹]	Wall thickness [mm¹]	Total volume [m³]
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	pg	=	6,25 +	1,40 =	7,65 kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	pq	=	1,75 +	1,00 =	2,75 kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd [kNm¹/m¹]	As;req [mm²/m¹]	Applied Reinforcement base				Applied Reinforcement additional	As;prov [mm²/m¹]	U.C.
28,4	294	Ø	8	-	150		335	0,88

Floor Reinforcement: BOTTOM

MEd [kNm¹/m¹]	As;req [mm²/m¹]	Applied Reinforcement base				Applied Reinforcement additional	As;prov [mm²/m¹]	U.C.
21,0	216	Ø	8	-	150		335	0,65

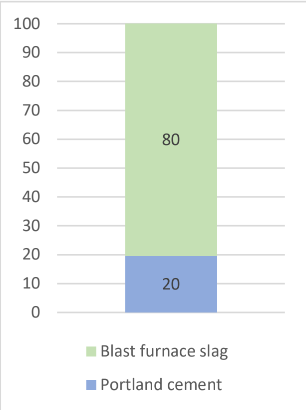
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

3.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	Accelerator HA60	2	8,06	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

3.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

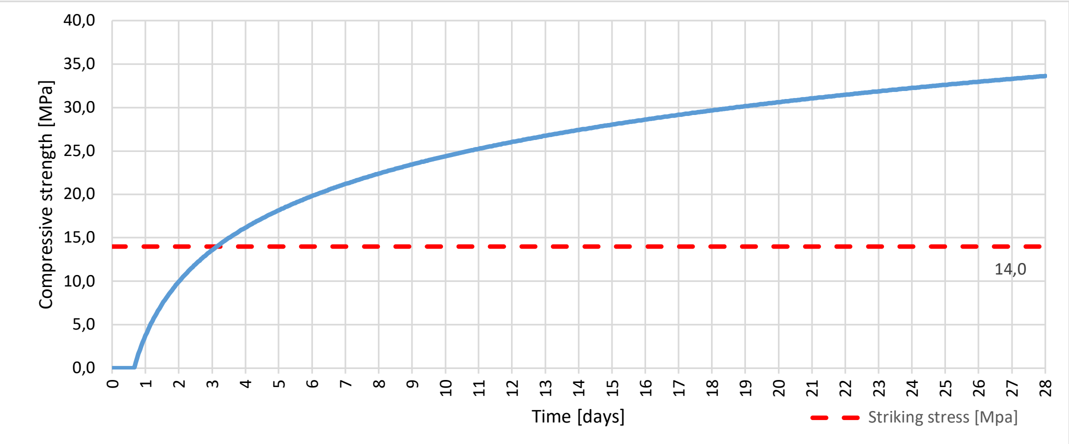
Precamber:	No	Extra precamber height:	0 mm

3.2 Output

3.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	92253	75647,38	€ 71.496,00	€ 5.592,64
	Blast furnace slag	322,6	369012	7011,22		€ 568,03
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	0,60	692	498,17	€ 1.037,85	€ 63,83
Additional admixtures	Accelerator HA60	8,1	9225	6642,20903	€ 23.063,23	€ 851,04
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				155039	€ 164.848,67	€ 14.232,18
					€ 179.080,86	

3.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after		76,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after		41,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after		54,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after		76,0	hours

3 Variation 3d

3.1 Input

3.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

3.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement					$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
28,4	294	Ø	8	-	150		335	0,88

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement					$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
21,0	216	Ø	8	-	150		335	0,65

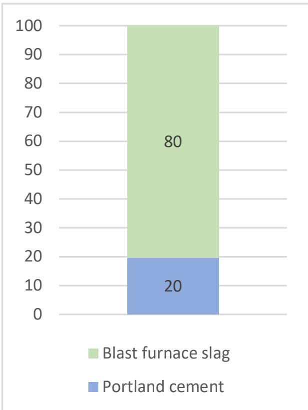
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

3.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Winter	-	-	
Curing temperature	10°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

3.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

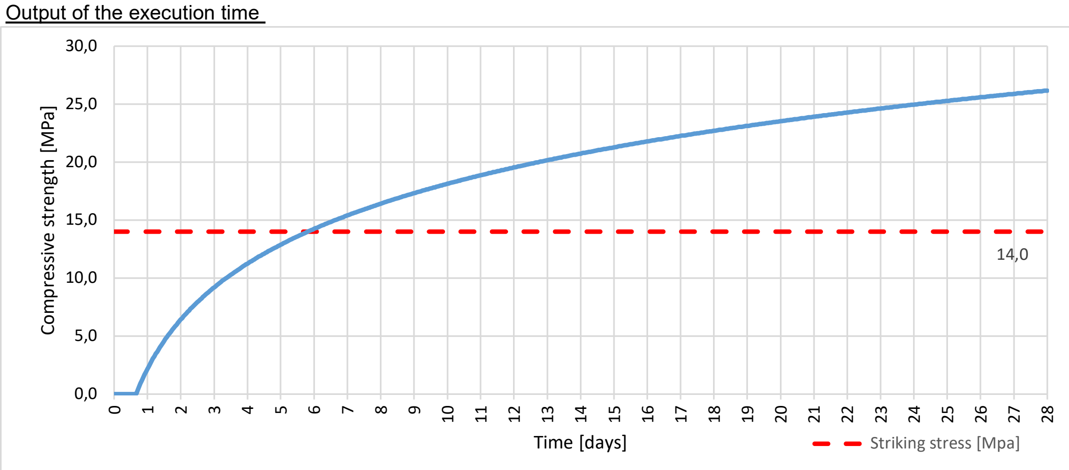
Precamber:	No		Extra precamber height:	0 mm

3.2 Output

3.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	92253	75647,38	€ 71.496,00	€ 5.592,64
	Blast furnace slag	322,6	369012	7011,22		€ 568,03
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	0,60	692	498,17	€ 1.037,85	€ 63,83
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				148397	€ 141.785,45	€ 13.381,15
					€ 155.166,59	

3.2.2 Output of the execution time



The formwork can be removed when a compressive strength of		14,0	Mpa. Which is reached after	140,0	hours
The formwork can be removed when a tensile strength of		0,18	Mpa. Which is reached after	65,0	hours
The formwork can be removed is the deflection is less than		4,5	mm. Which is reached after	92,0	hours
The determining valiation is the	Compressive strength		. So the formwork can be removed after	140,0	hours

3 Variation 3e

3.1 Input

3.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

3.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25	kN/m²
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional		[mm²/m¹]	
28,4	294	Ø	8	-	150			335	0,88

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional		[mm²/m¹]	
21,0	216	Ø	8	-	150			335	0,65

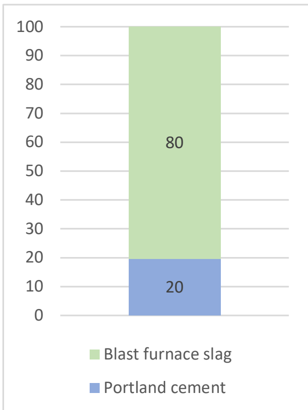
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

3.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	50°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

3.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Internal heating	Internal heating used, the internal curing temperature will increase to 50°C.	50°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

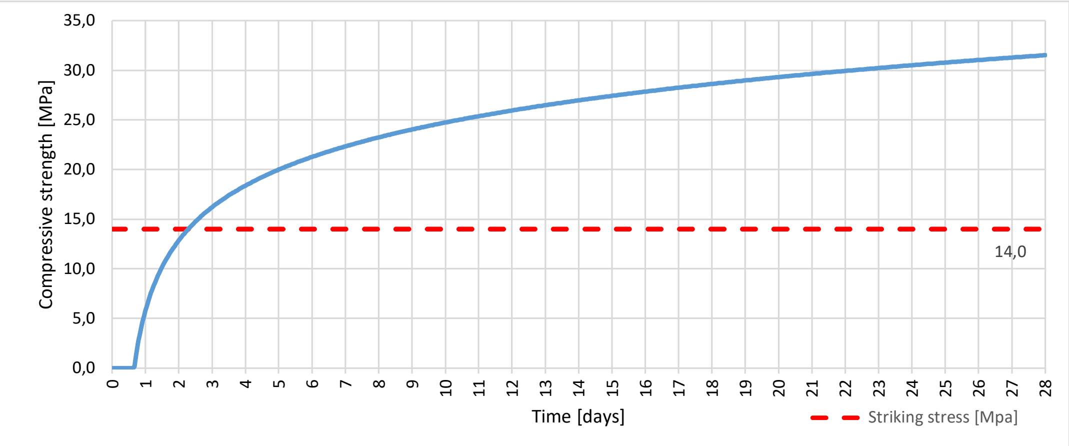
Precamber:	No		Extra precamber height:	0 mm

3.2 Output

3.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	92253	75647,38	€ 71.496,00	€ 5.592,64
	Blast furnace slag	322,6	369012	7011,22		€ 568,03
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	0,60	692	498,17	€ 1.037,85	€ 63,83
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1639	985,191687	€ 4.508,44	€ 210,87
Extra grinding costs		-	-			
				149382	€ 146.293,89	€ 13.592,02
					€ 159.885,91	

3.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	55,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	31,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	39,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	55,0	hours

3 Variation 3f

3.1 Input

3.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

3.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement					As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base			additional		[mm²/m¹]	
28,4	294	Ø	8	-	150		335	0,88

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement					As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base			additional		[mm²/m¹]	
21,0	216	Ø	8	-	150		335	0,65

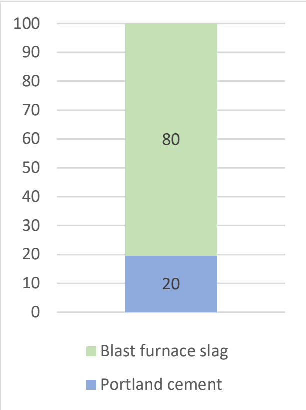
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

3.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	60°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

3.1.4 Additional execution methods

Additional execution method:	Explanation	New value
External heating	External heating used, the curing temperature will increase with 60°C.	60°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

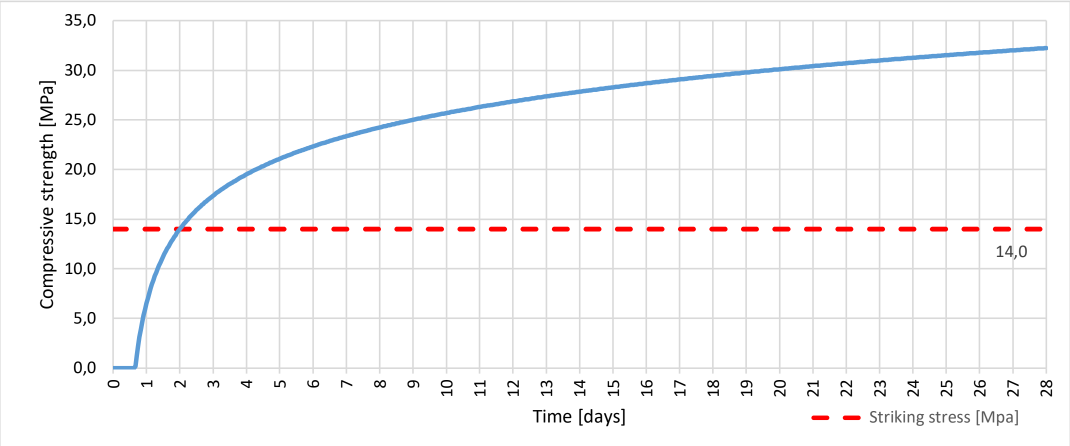
Precamber:	No	Extra precamber height:	0 mm

3.2 Output

3.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	92253	75647,38	€ 71.496,00	€ 5.592,64
	Blast furnace slag	322,6	369012	7011,22		€ 568,03
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	0,60	692	498,17	€ 1.037,85	€ 63,83
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1408	845,846543	€ 3.870,77	€ 181,05
Extra grinding costs		-	-			
				149242	**€ 145.656,22**	**€ 13.562,19**
					€ 159.218,41	

3.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	49,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	29,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	35,0	hours
The determining valiation is the **Compressive strength**		. So the formwork can be removed after	49,0	hours

3 Variation 3g

3.1 Input

3.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

3.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement					As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
28,4	294	Ø	8	-	150		335	0,88

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement					As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
21,0	216	Ø	8	-	150		335	0,65

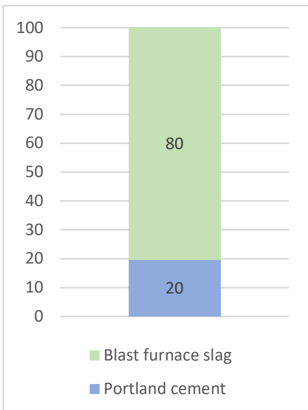
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

3.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

3.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Maturity process	The maturity method is used. New stresses will develop, the minimum compressive strength is:	10,68 MPa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

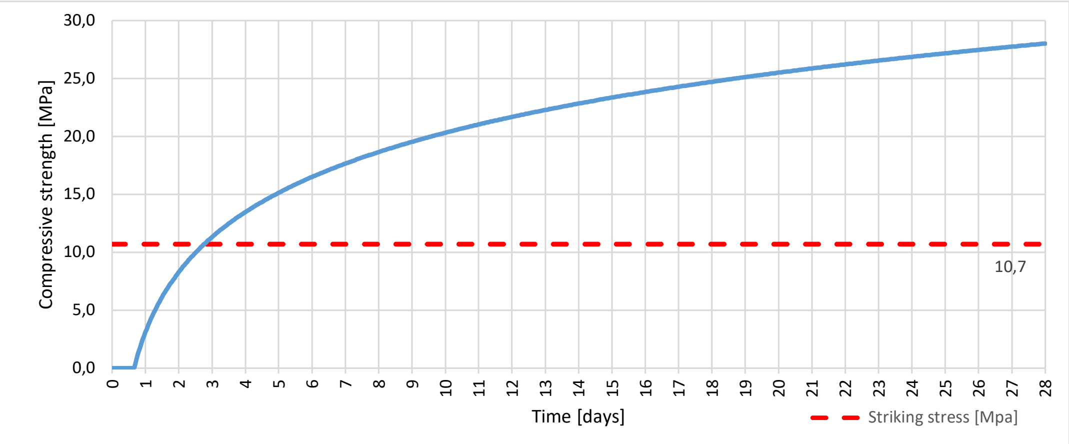
Extra precamber height:	0 mm

3.2 Output

3.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	92253	75647,38	€ 71.496,00	€ 5.592,64
	Blast furnace slag	322,6	369012	7011,22		€ 568,03
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	0,60	692	498,17	€ 1.037,85	€ 63,83
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				148397	€ 141.785,45	€ 13.381,15
					€ 155.166,59	

3.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	10,7	Mpa. Which is reached after	67,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	50,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	69,0	hours
The determining valiation is the	Deflection	. So the formwork can be removed after	69,0	hours

3 Variation 3h

3.1 Input

3.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

3.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25	kN/m²
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement					As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
28,4	294	Ø	8	-	150		335	0,88

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement					As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
21,0	216	Ø	8	-	150		335	0,65

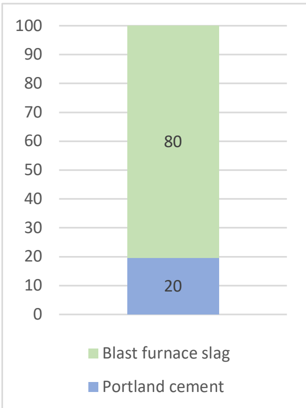
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

3.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

3.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Formwork	An extra support is applied, in the middle of each grid. New stresses will develop, the minimum compressive strength is:	8,67 Mpa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

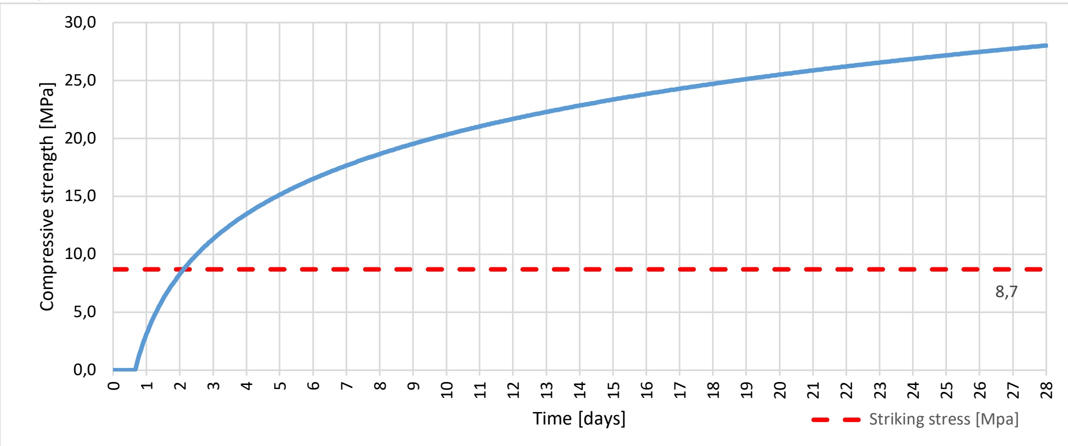
Precamber: **No** **Extra precamber height:** **0 mm**

3.2 Output

3.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	92253	75647,38	€ 71.496,00	€ 5.592,64
	Blast furnace slag	322,6	369012	7011,22		€ 568,03
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	222	253695	86,26	€ 133,84	€ 8,10
Basic admixtures	Superplasticizer (PCE)	0,60	692	498,17	€ 1.037,85	€ 63,83
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				148397	**€ 141.785,45**	**€ 13.381,15**
					€ 155.166,59	

3.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	**8,7**	Mpa. Which is reached after		**51,0**	hours
The formwork can be removed when a tensile strength of	**0,01**	Mpa. Which is reached after		**47,0**	hours
The formwork can be removed is the deflection is less than	**2,25**	mm. Which is reached after		**16,0**	hours
The determining valiation is the	**Compressive strength**	. So the formwork can be removed after		**51,0**	hours

3 Variation 3s

3.1 Input

3.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

3.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	pg	=	6,25 +	1,40 =	7,65 kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25	kN/m²
	pq	=	1,75 +	1,00 =	2,75 kN/m²	(variable load + partitions)		1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement					As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
28,4	294	Ø	8	-	150		335	0,88

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement					As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
21,0	216	Ø	8	-	150		335	0,65

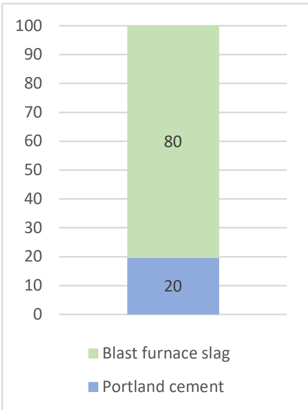
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

3.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,65	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	60°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

3.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Maturity process	The maturity method is used. New stresses will develop, the minimum compressive strength is:	10,68 MPa
External heating	External heating used, the curing temperature will increase with 60°C.	60°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

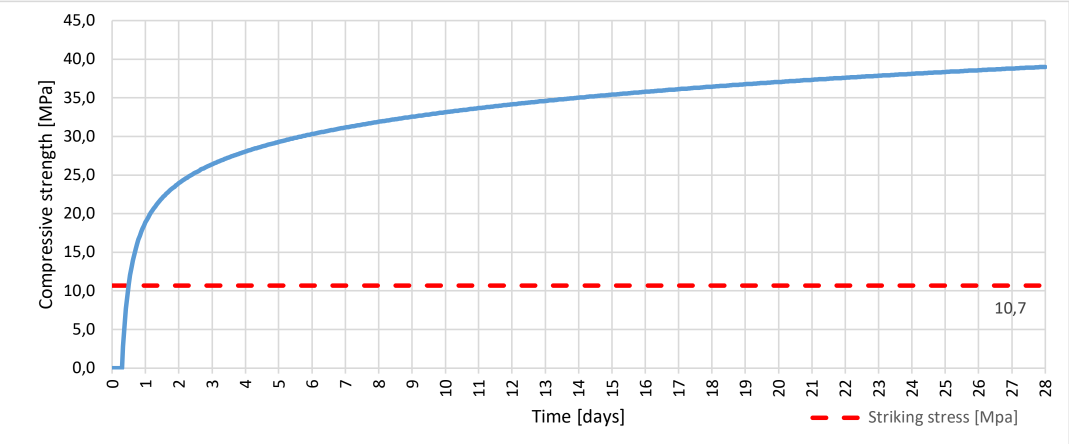
Extra precamber height:	0 mm

3.2 Output

3.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	86,2	98615	80864,44	€ 76.426,76	€ 5.978,34
	Blast furnace slag	344,8	394461	7494,75		€ 607,21
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	194	221884	75,44	€ 133,84	€ 7,08
Basic admixtures	Superplasticizer (PCE)	0,65	740	532,52	€ 1.109,42	€ 68,23
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1408	845,846543	€ 3.870,77	€ 181,05
Extra grinding costs		-	-			
				154966	€ 150.658,55	€ 13.990,45
					€ 164.649,01	

3.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	10,7	Mpa. Which is reached after	12,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	11,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	13,0	hours
The determining valiation is the	Deflection	. So the formwork can be removed after	13,0	hours

3 Variation 3w

3.1 Input

3.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

3.1.2 Design of the structure

Grid size [m¹]	Amount of levels (incl. GF)	Level height [m¹]	Total length [m¹]	Total depth [m¹]	Total height [m¹]	Amount of grids	Floor thickness [mm¹]	Wall thickness [mm¹]	Total volume [m³]
4,50	8	2,55	36,00	9,60	22,96	8	250	250	1143,94

Floor load:	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed} [kNm¹/m¹]	$A_{s;req}$ [mm²/m¹]	Applied Reinforcement base				Applied Reinforcement additional	$A_{s;prov}$ [mm²/m¹]	U.C.
28,4	294	Ø	8	-	150		335	0,88

Floor Reinforcement: BOTTOM

M_{Ed} [kNm¹/m¹]	$A_{s;req}$ [mm²/m¹]	Applied Reinforcement base				Applied Reinforcement additional	$A_{s;prov}$ [mm²/m¹]	U.C.
21,0	216	Ø	8	-	150		335	0,65

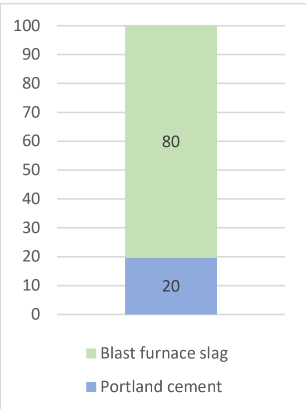
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**29092**	**kg**
Amount of wall reinforcement applied	=	**11741**	**kg**
Total Amount of reinforcement applied	=	**40833**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

3.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,65	**
Additional admixtures	Accelerator HA60	2	8,62	**
Blaine value	300m²/kg	-	-	
Sesaon	Winter	-	-	
Curing temperature	60°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

3.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Maturity process	The maturity method is used. New stresses will develop, the minimum compressive strength is:	10,68 MPa
External heating	External heating used, the curing temperature will increase with 60°C.	60°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

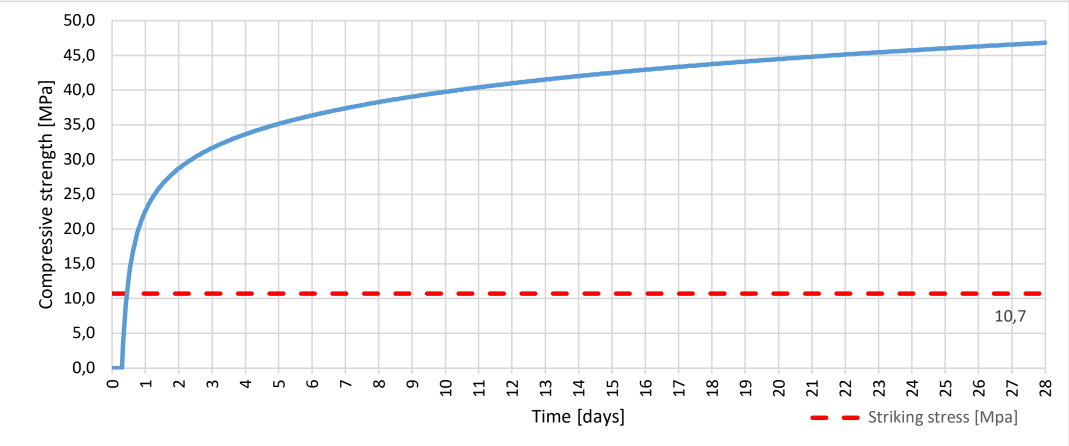
Extra precamber height:	0 mm

3.2 Output

3.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	86,2	98615	80864,44	€ 76.426,76	€ 5.978,34
	Blast furnace slag	344,8	394461	7494,75		€ 607,21
Reinforcement		7850 kg/m³	40833	61249,80	€ 54.103,60	€ 6.649,36
Aggregate	FA= Sand, river 0-4mm	750	857952	2488,06	€ 3.431,81	€ 390,54
	CA= Gravel, river >4mm	1125	1286928	1415,62	€ 11.582,35	€ 108,65
Water	Tap water	194	221884	75,44	€ 133,84	€ 7,08
Basic admixtures	Superplasticizer (PCE)	0,65	740	532,52	€ 1.109,42	€ 68,23
Additional admixtures	Accelerator HA60	8,6	9862	7100,29241	€ 24.653,79	€ 909,73
Heating	Propaan gas - fossil	-	1759	1057,30818	€ 4.838,46	€ 226,31
Extra grinding costs		-	-			
				162278	€ 176.280,04	€ 14.945,45
					€ 191.225,48	

3.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	10,7	Mpa. Which is reached after	11,0	hours
The formwork can be removed when a tensile strength of	0,18	Mpa. Which is reached after	10,0	hours
The formwork can be removed is the deflection is less than	4,5	mm. Which is reached after	11,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	11,0	hours

4 Variation 4

4.1 Input

4.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

4.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement					As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
50,5	531	Ø	10	-	150		524	1,01

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement					As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
37,4	390	Ø	10	-	150		524	0,74

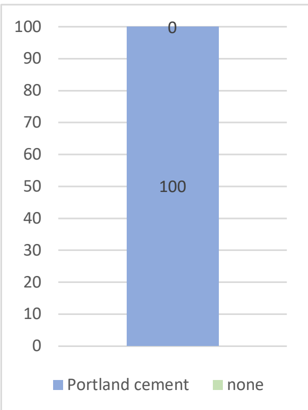
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

4.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM I 52.5R	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,3	1,21	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

4.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

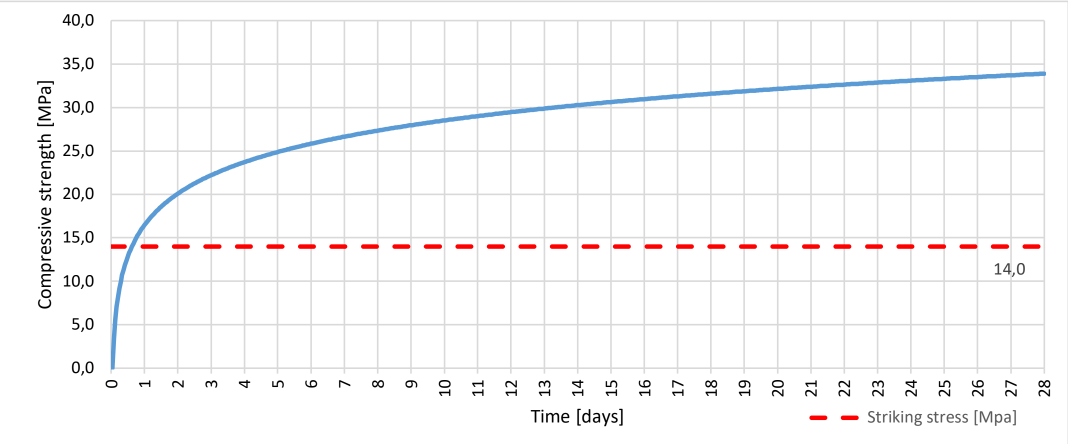
Precamber: Yes   **Extra precamber height:** 10 mm

4.2 Output

4.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	403,2	420697	344971,35	€ 71.518,45	€ 25.503,89
	none					
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	1,21	1262	908,71	€ 1.893,14	€ 116,43
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				431401	€ 155.482,54	€ 34.972,23
					€ 190.454,77	

4.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	16,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	7,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	9,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	16,0	hours

5 Variation 5

5.1 Input

5.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

5.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	pg =	6,25 +	1,40 =	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	pq =	1,75 +	1,00 =	2,75	kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement				$A_{s;prov}$	U.C.
[kNm¹/m¹]	[mm²/m¹]	base			additional	[mm²/m¹]	
50,5	531	Ø	10	-	150	524	1,01

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement				$A_{s;prov}$	U.C.
[kNm¹/m¹]	[mm²/m¹]	base			additional	[mm²/m¹]	
37,4	390	Ø	10	-	150	524	0,74

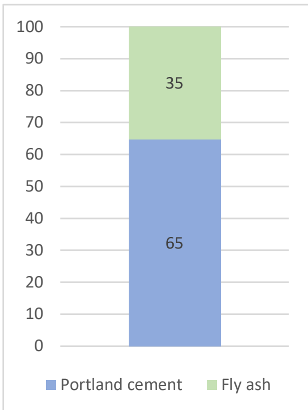
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

5.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

5.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

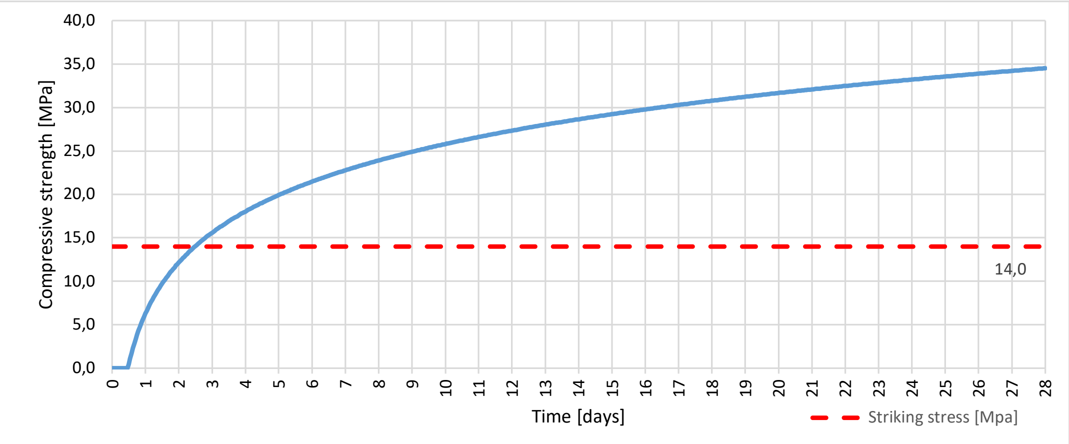
Precamber:	Yes	Extra precamber height:	10	mm

5.2 Output

5.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	273453	224231,38	€ 67.311,48	€ 16.577,53
	Fly ash	141,1	147244	485,90		€ 50,79
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	1,01	1052	757,25	€ 1.577,61	€ 97,02
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				310996	€ 150.960,05	€ 26.077,26
					€ 177.037,31	

5.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	60,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	35,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	43,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	60,0	hours

5 Variation 5a

5.1 Input

5.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

5.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement						$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
50,5	531	Ø	10	-	150			524	1,01

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement						$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
37,4	390	Ø	10	-	150			524	0,74

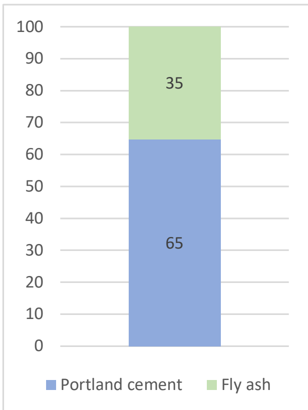
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

5.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,08	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

5.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

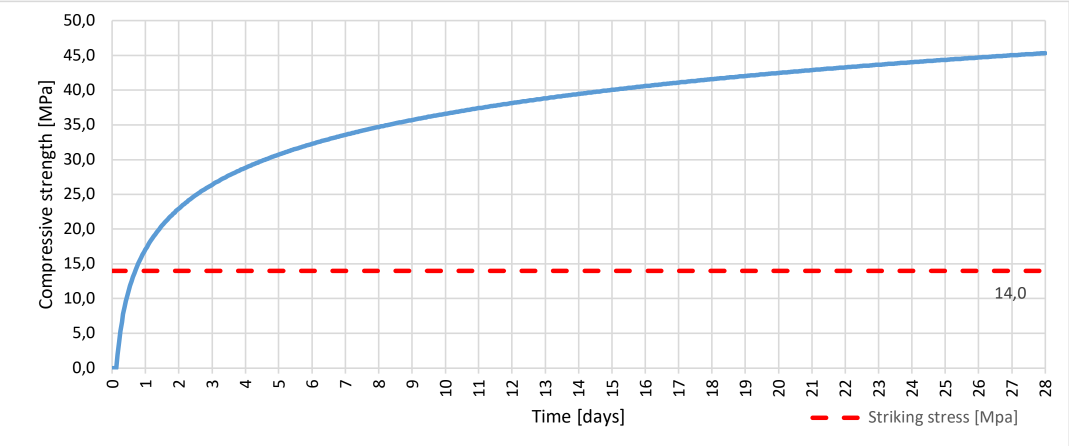
Precamber:	Yes	Extra precamber height:	10	mm

5.2 Output

5.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	280,2	292312	239695,61	€ 71.953,66	€ 17.720,80
	Fly ash	150,9	157399	519,42		€ 54,30
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	194	202370	68,81	€ 122,07	€ 6,46
Basic admixtures	Superplasticizer (PCE)	1,08	1124	809,48	€ 1.686,41	€ 103,71
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				326536	€ 155.711,02	€ 27.229,81
					€ 182.940,83	

5.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	17,0	hours
The formwork can be removed when a tensile strength of	0,36	Mpa. Which is reached after	10,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	13,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	17,0	hours

5 Variation 5b

5.1 Input

5.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	Variable safety factor:	1,50

5.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:									
	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	
	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	Reinforcement:	B500	Exposure class:	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement				As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base			additional	[mm²/m¹]	
50,5	531	Ø	10	-	150	524	1,01

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement				As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base			additional	[mm²/m¹]	
37,4	390	Ø	10	-	150	524	0,74

Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

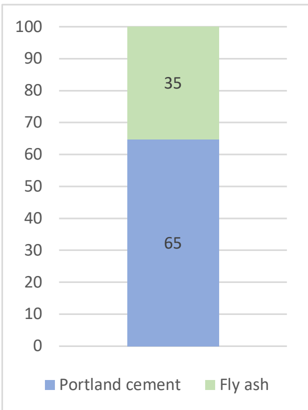
Amount of floor reinforcement applied	=	45456	kg
Amount of wall reinforcement applied	=	9132	kg
Total Amount of reinforcement applied	=	54588	kg

(without auxiliary reinforcement, hairpins and cuttings losses)

5.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	400m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***

* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.



5.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

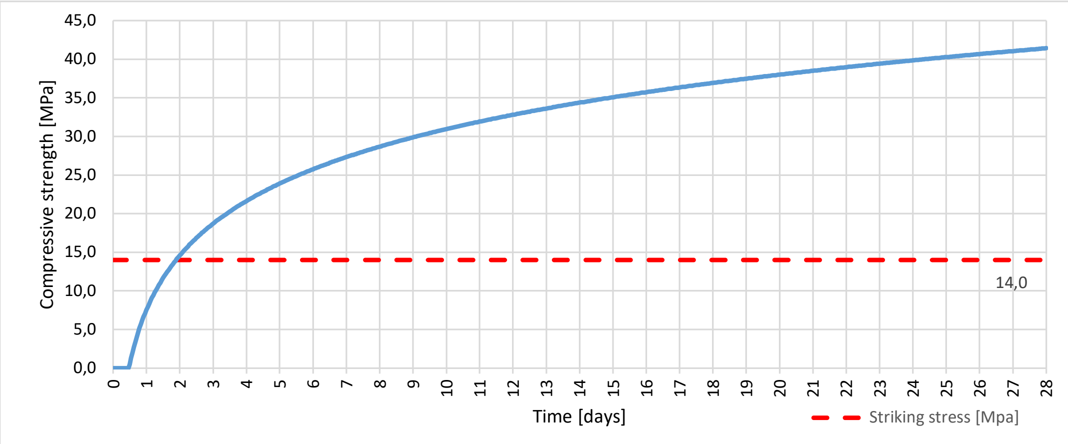
Precamber:	Yes	Extra precamber height:	10 mm

5.2 Output

5.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	273453	224231,38	€ 67.311,48	€ 16.577,53
	Fly ash	141,1	147244	485,90		€ 50,79
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	1,01	1052	757,25	€ 1.577,61	€ 97,02
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-	68994,27	€ 12.620,90	€ 5.100,78
				379990	€ 163.580,95	€ 31.178,04
					€ 194.758,99	

5.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	46,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	29,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	35,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	46,0	hours

5 Variation 5c

5.1 Input

5.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

5.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement		As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*	*additional*	*[mm²/m¹]*	
50,5	531	Ø 10 - 150		524	1,01

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement		As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*	*additional*	*[mm²/m¹]*	
37,4	390	Ø 10 - 150		524	0,74

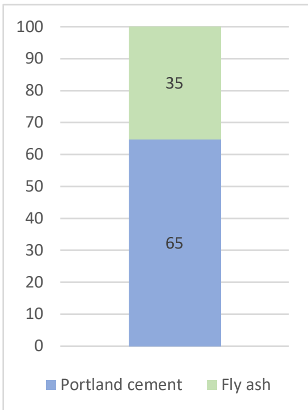
Wall Reinforcement v/a:	Ø 6 - 150	=	188	mm²/m¹	

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

5.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	Accelerator HA60	2	8,06	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

5.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

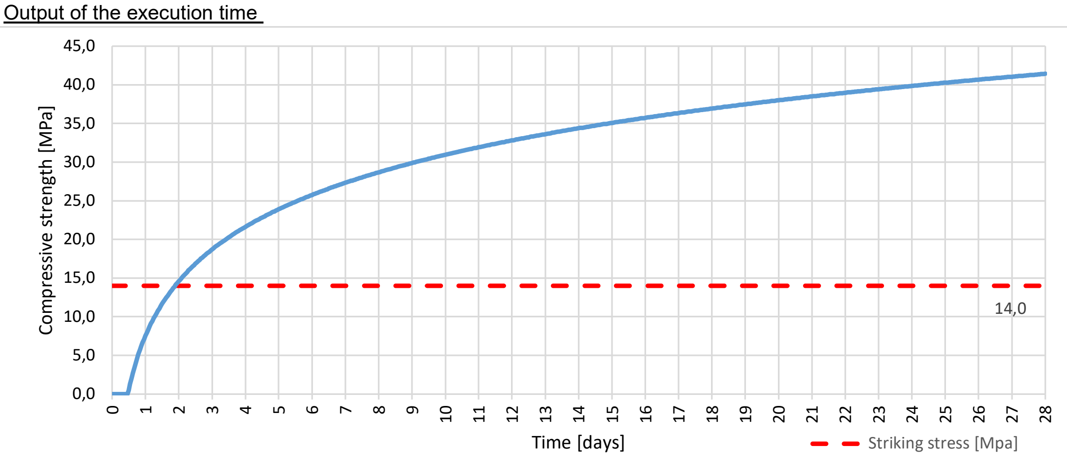
Precamber:	Yes	Extra precamber height:	10 mm

5.2 Output

5.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	273453	224231,38	€ 67.311,48	€ 16.577,53
	Fly ash	141,1	147244	485,90		€ 50,79
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	1,01	1052	757,25	€ 1.577,61	€ 97,02
Additional admixtures	Accelerator HA60	8,1	8414	6058,03355	€ 21.034,84	€ 776,19
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				317054	€ 171.994,88	€ 26.853,45
					€ 198.848,34	

5.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	46,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	29,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	35,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	46,0	hours

5 Variation 5d

5.1 Input

5.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

5.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement		As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*	*additional*	*[mm²/m¹]*	
50,5	531	Ø 10 - 150		524	1,01

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement		As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*	*additional*	*[mm²/m¹]*	
37,4	390	Ø 10 - 150		524	0,74

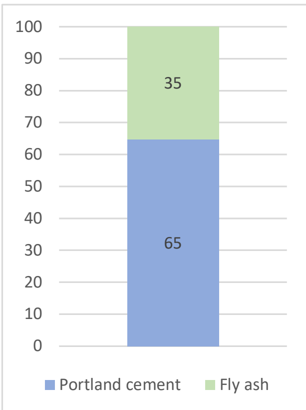
Wall Reinforcement v/a: Ø 6 - 150 = 188 mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

5.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Winter	-	-	
Curing temperature	10°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

5.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

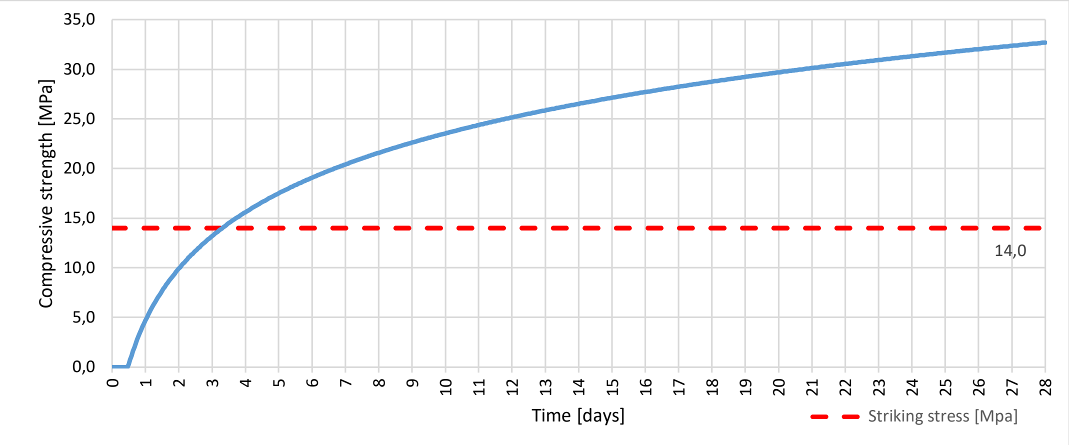
Precamber:	Yes		Extra precamber height:	10 mm

5.2 Output

5.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	273453	224231,38	€ 67.311,48	€ 16.577,53
	Fly ash	141,1	147244	485,90		€ 50,79
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	1,01	1052	757,25	€ 1.577,61	€ 97,02
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				310996	€ 150.960,05	€ 26.077,26
					€ 177.037,31	

5.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	80,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	45,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	57,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	80,0	hours

5 Variation 5e

5.1 Input

5.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

5.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement							$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*			*[mm²/m¹]*	
50,5	531	Ø	10	-	150				524	1,01

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement							$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*			*[mm²/m¹]*	
37,4	390	Ø	10	-	150				524	0,74

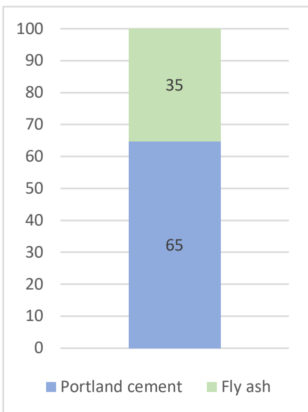
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

5.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	50°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

5.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Internal heating	Internal heating used, the internal curing temperature will increase to 50°C.	50°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	Yes

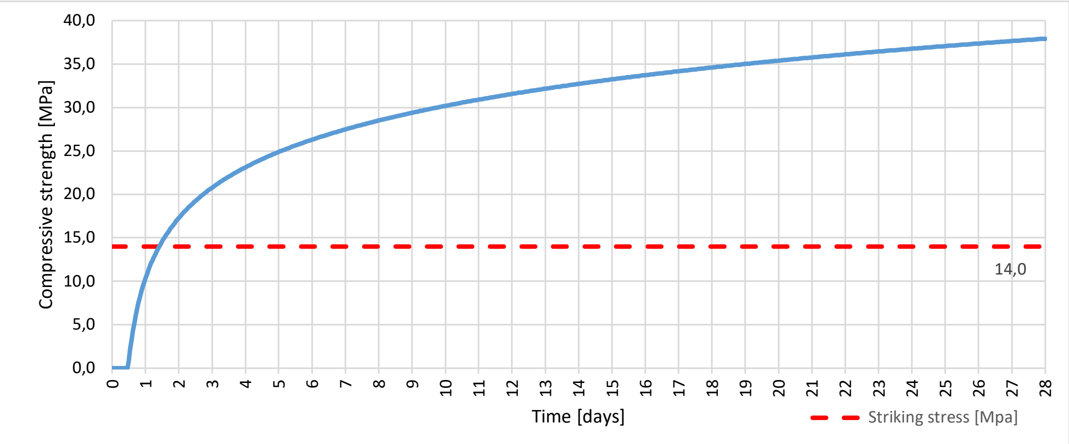
Extra precamber height:	10 mm

5.2 Output

5.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	273453	224231,38	€ 67.311,48	€ 16.577,53
	Fly ash	141,1	147244	485,90		€ 50,79
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	1,01	1052	757,25	€ 1.577,61	€ 97,02
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1495	898,545087	€ 4.111,93	€ 192,33
Extra grinding costs		-	-			
				311894	€ 155.071,98	€ 26.269,59
					€ 181.341,57	

5.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after		34,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after		22,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after		26,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after		34,0	hours

5 Variation 5f

5.1 Input

5.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

5.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
50,5	531	Ø	10	-	150			524	1,01

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
37,4	390	Ø	10	-	150			524	0,74

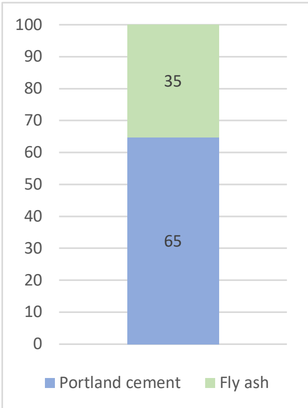
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

5.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	60°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

5.1.4 Additional execution methods

Additional execution method:	Explanation	New value
External heating	External heating used, the curing temperature will increase with 60°C.	60°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

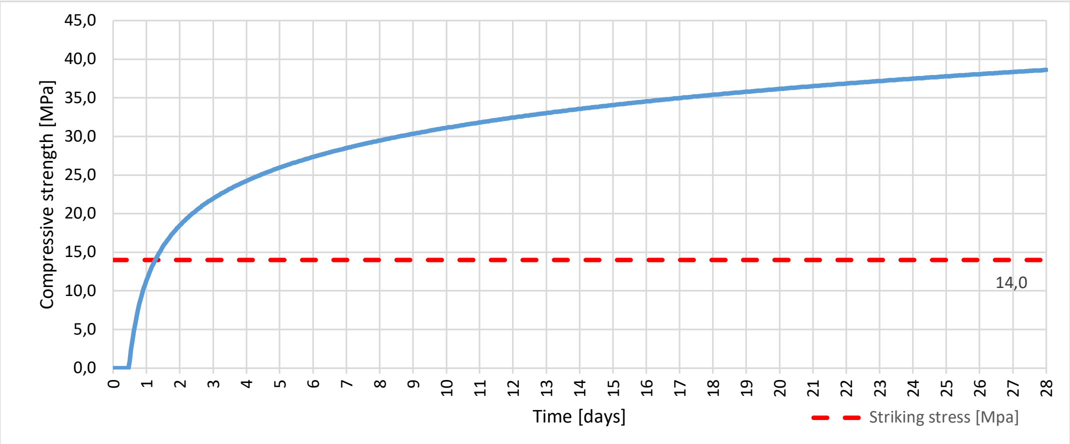
Precamber:	Yes		Extra precamber height:	10 mm

5.2 Output

5.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	273453	224231,38	€ 67.311,48	€ 16.577,53
	Fly ash	141,1	147244	485,90		€ 50,79
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	1,01	1052	757,25	€ 1.577,61	€ 97,02
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1343	807,13298	€ 3.693,61	€ 172,76
Extra grinding costs		-	-			
				311803	€ 154.653,66	€ 26.250,02
					€ 180.903,68	

5.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	31,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	21,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	24,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	31,0	hours

5 Variation 5g

5.1 Input

5.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

5.1.2 Design of the structure

Grid size [m¹]	Amount of levels (incl. GF)	Level height [m¹]	Total length [m¹]	Total depth [m¹]	Total height [m¹]	Amount of grids	Floor thickness [mm¹]	Wall thickness [mm¹]	Total volume [m³]
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd [kNm¹/m¹]	As;req [mm²/m¹]	Applied Reinforcement base				Applied Reinforcement additional	As;prov [mm²/m¹]	U.C.
50,5	531	Ø	10	-	150		524	1,01

Floor Reinforcement: BOTTOM

MEd [kNm¹/m¹]	As;req [mm²/m¹]	Applied Reinforcement base				Applied Reinforcement additional	As;prov [mm²/m¹]	U.C.
37,4	390	Ø	10	-	150		524	0,74

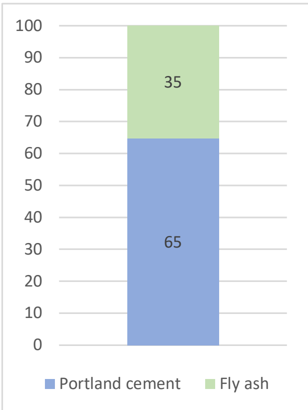
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

5.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

5.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Maturity process	The maturity method is used. New stresses will develop, the minimum compressive strength is:	12,8 MPa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

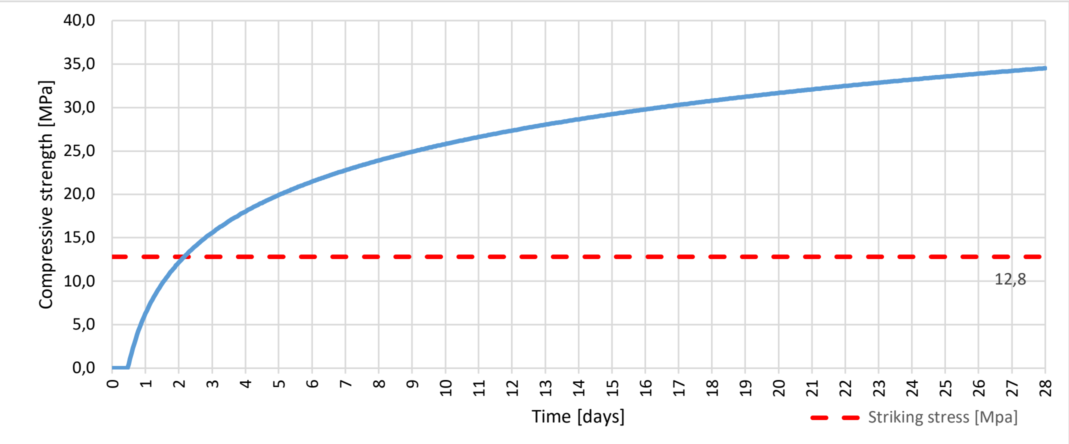
Precamber:	Yes	Extra precamber height:	10 mm

5.2 Output

5.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	273453	224231,38	€ 67.311,48	€ 16.577,53
	Fly ash	141,1	147244	485,90		€ 50,79
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	1,01	1052	757,25	€ 1.577,61	€ 97,02
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				310996	€ 150.960,05	€ 26.077,26
					€ 177.037,31	

5.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	12,8	Mpa. Which is reached after	52,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	35,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	43,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	52,0	hours

5 Variation 5h

5.1 Input

5.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

5.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement							$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*			*[mm²/m¹]*	
50,5	531	Ø	10	-	150				524	1,01

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement							$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*			*[mm²/m¹]*	
37,4	390	Ø	10	-	150				524	0,74

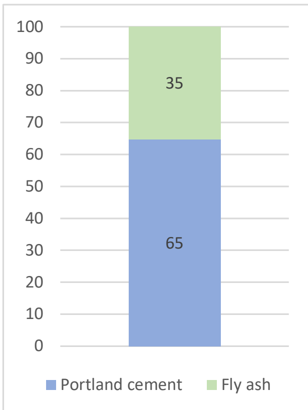
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

5.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

5.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Formwork	An extra support is applied, in the middle of each grid. New stresses will develop, the minimum compressive strength is:	9,2 Mpa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	Yes

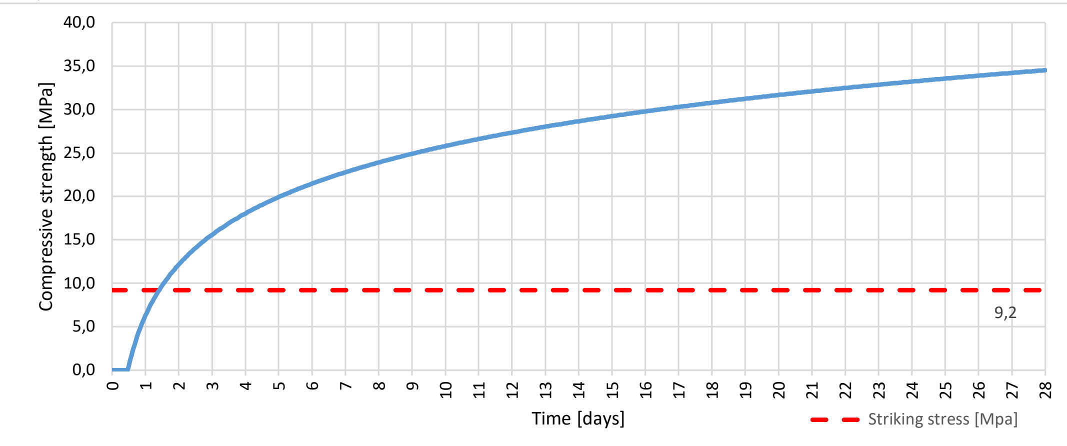
Extra precamber height:	10 mm

5.2 Output

5.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	273453	224231,38	€ 67.311,48	€ 16.577,53
	Fly ash	141,1	147244	485,90		€ 50,79
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	1,01	1052	757,25	€ 1.577,61	€ 97,02
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				310996	€ 150.960,05	€ 26.077,26
					€ 177.037,31	

5.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	9,2	Mpa. Which is reached after	34,0	hours
The formwork can be removed when a tensile strength of	0,04	Mpa. Which is reached after	30,0	hours
The formwork can be removed is the deflection is less than	13	mm. Which is reached after	12,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	34,0	hours

5 Variation 5s

5.1 Input

5.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

5.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement					$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
50,5	531	Ø	10	-	150		524	1,01

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement					$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
37,4	390	Ø	10	-	150		524	0,74

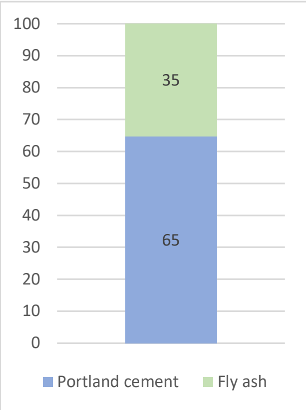
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

5.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,08	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

5.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Maturity process	The maturity method is used. New stresses will develop, the minimum compressive strength is:	12,8 MPa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

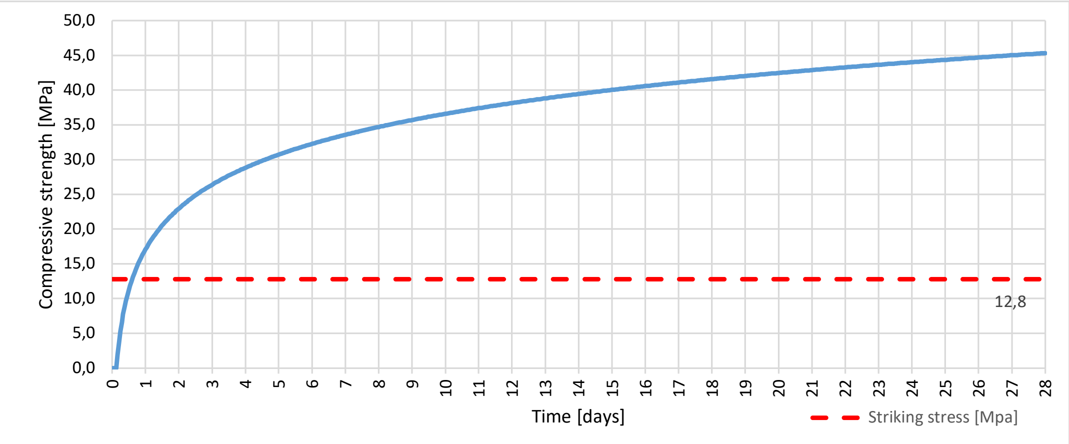
Precamber:	Yes	Extra precamber height:	10 mm

5.2 Output

5.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	280,2	292312	239695,61	€ 71.953,66	€ 17.720,80
	Fly ash	150,9	157399	519,42		€ 54,30
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	194	202370	68,81	€ 122,07	€ 6,46
Basic admixtures	Superplasticizer (PCE)	1,08	1124	809,48	€ 1.686,41	€ 103,71
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				326536	€ 155.711,02	€ 27.229,81
					€ 182.940,83	

5.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	12,8	Mpa. Which is reached after	15,0	hours
The formwork can be removed when a tensile strength of	0,36	Mpa. Which is reached after	10,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	13,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	15,0	hours

5 Variation 5w

5.1 Input

5.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

5.1.2 Design of the structure

Grid size [m¹]	Amount of levels (incl. GF)	Level height [m¹]	Total length [m¹]	Total depth [m¹]	Total height [m¹]	Amount of grids	Floor thickness [mm¹]	Wall thickness [mm¹]	Total volume [m³]
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)	

Execution phase:	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd [kNm¹/m¹]	As;req [mm²/m¹]	Applied Reinforcement base					Applied Reinforcement additional	As;prov [mm²/m¹]	U.C.
50,5	531	Ø	10	-	150			524	1,01

Floor Reinforcement: BOTTOM

MEd [kNm¹/m¹]	As;req [mm²/m¹]	Applied Reinforcement base					Applied Reinforcement additional	As;prov [mm²/m¹]	U.C.
37,4	390	Ø	10	-	150			524	0,74

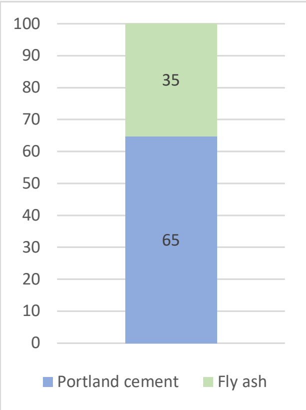
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

5.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,08	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Winter	-	-	
Curing temperature	10°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

5.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Formwork	An extra support is applied, in the middle of each grid. New stresses will develop, the minimum compressive strength is:	9,2 Mpa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

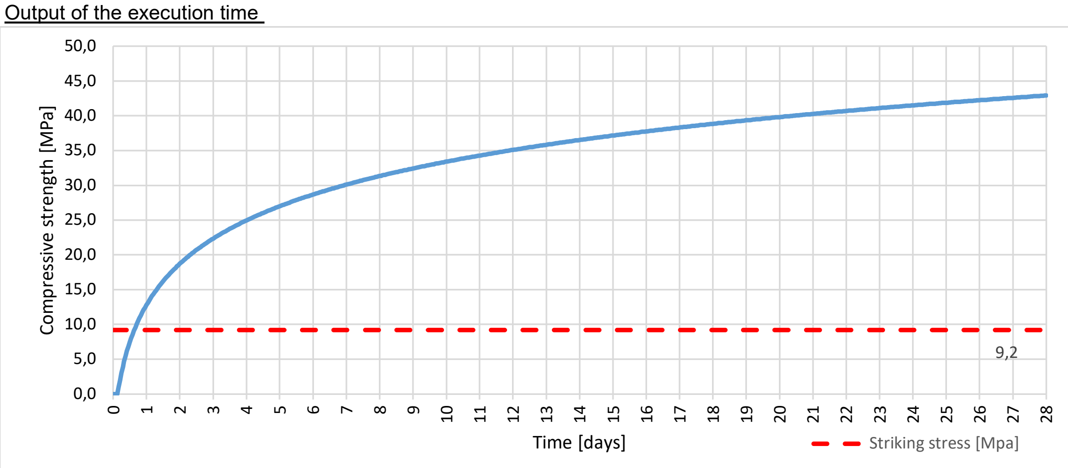
Precamber:	Yes	Extra precamber height:	10 mm

5.2 Output

5.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	280,2	292312	239695,61	€ 71.953,66	€ 17.720,80
	Fly ash	150,9	157399	519,42		€ 54,30
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	194	202370	68,81	€ 122,07	€ 6,46
Basic admixtures	Superplasticizer (PCE)	1,08	1124	809,48	€ 1.686,41	€ 103,71
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				326536	€ 155.711,02	€ 27.229,81
					€ 182.940,83	

5.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	9,2	Mpa. Which is reached after	16,0	hours
The formwork can be removed when a tensile strength of	0,05	Mpa. Which is reached after	14,0	hours
The formwork can be removed is the deflection is less than	13	mm. Which is reached after	4,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	16,0	hours

6 Variation 6

6.1 Input

6.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

6.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	pg	=	6,25	+	1,40	=	7,65 kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25	kN/m²
	pq	=	1,75	+	1,00	=	2,75 kN/m²	(variable load + partitions)		1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement							$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*			*[mm²/m¹]*	
50,5	531	Ø	10	-	150				524	1,01

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement							$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*			*[mm²/m¹]*	
37,4	390	Ø	10	-	150				524	0,74

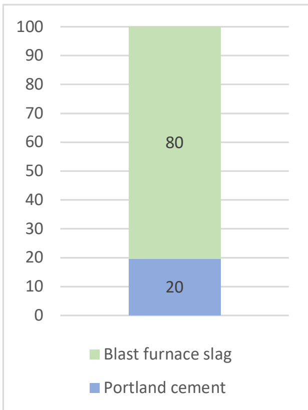
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

6.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

6.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

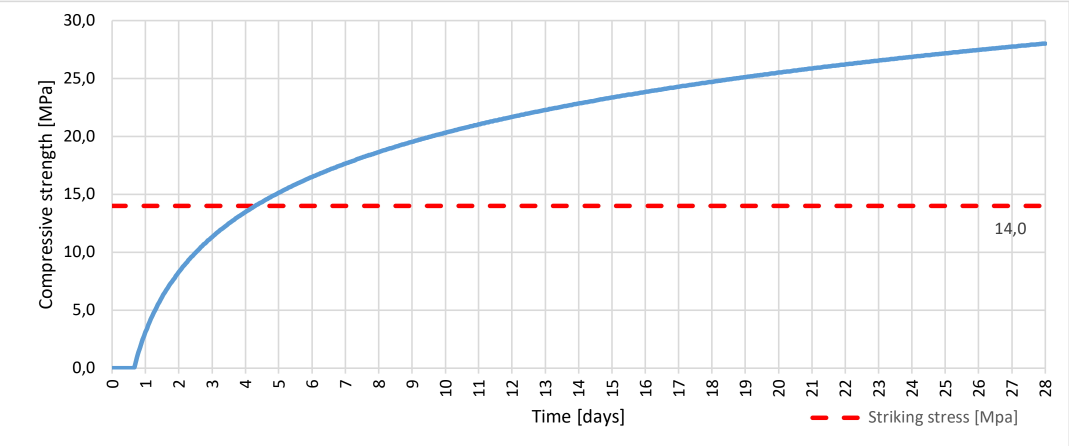
Precamber:	Yes		Extra precamber height:	10 mm

6.2 Output

6.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	84139	68994,27	€ 65.208,00	€ 5.100,78
	Blast furnace slag	322,6	336557	6394,59		€ 518,07
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	0,60	631	454,35	€ 946,57	€ 58,21
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				161365	€ 148.225,52	€ 15.028,99
					€ 163.254,50	

6.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	104,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	55,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	71,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	104,0	hours

6 Variation 6a

6.1 Input

6.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

6.1.2 Design of the structure

Grid size [m¹]	Amount of levels (incl. GF)	Level height [m¹]	Total length [m¹]	Total depth [m¹]	Total height [m¹]	Amount of grids	Floor thickness [mm¹]	Wall thickness [mm¹]	Total volume [m³]
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	pg	=	6,25	+	1,40	=	7,65 kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25	kN/m²
	pq	=	1,75	+	1,00	=	2,75 kN/m²	(variable load + partitions)		1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd [kNm¹/m¹]	As;req [mm²/m¹]	Applied Reinforcement base				additional	As;prov [mm²/m¹]	U.C.
50,5	531	Ø	10	-	150		524	1,01

Floor Reinforcement: BOTTOM

MEd [kNm¹/m¹]	As;req [mm²/m¹]	Applied Reinforcement base				additional	As;prov [mm²/m¹]	U.C.
37,4	390	Ø	10	-	150		524	0,74

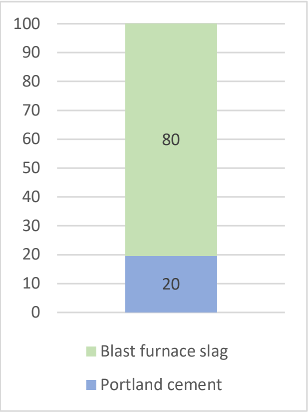
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

6.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,65	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

6.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

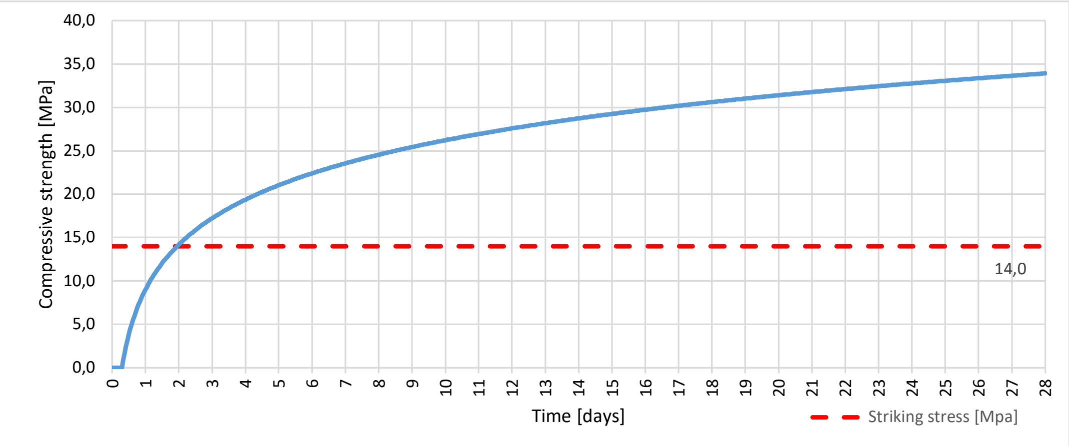
Precamber:	Yes	Extra precamber height:	10 mm

6.2 Output

6.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	86,2	89942	73752,50	€ 69.705,10	€ 5.452,55
	Blast furnace slag	344,8	359768	6835,60		€ 553,80
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	194	202370	68,81	€ 122,07	€ 6,46
Basic admixtures	Superplasticizer (PCE)	0,65	675	485,69	€ 1.011,85	€ 62,23
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				166585	€ 152.787,90	€ 15.419,58
					€ 168.207,48	

6.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	47,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	25,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	33,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	47,0	hours

6 Variation 6b

6.1 Input

6.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

6.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement							$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*			*[mm²/m¹]*	
50,5	531	Ø	10	-	150				524	1,01

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement							$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*			*[mm²/m¹]*	
37,4	390	Ø	10	-	150				524	0,74

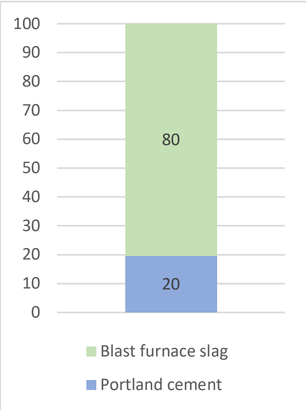
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

6.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	400m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

6.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

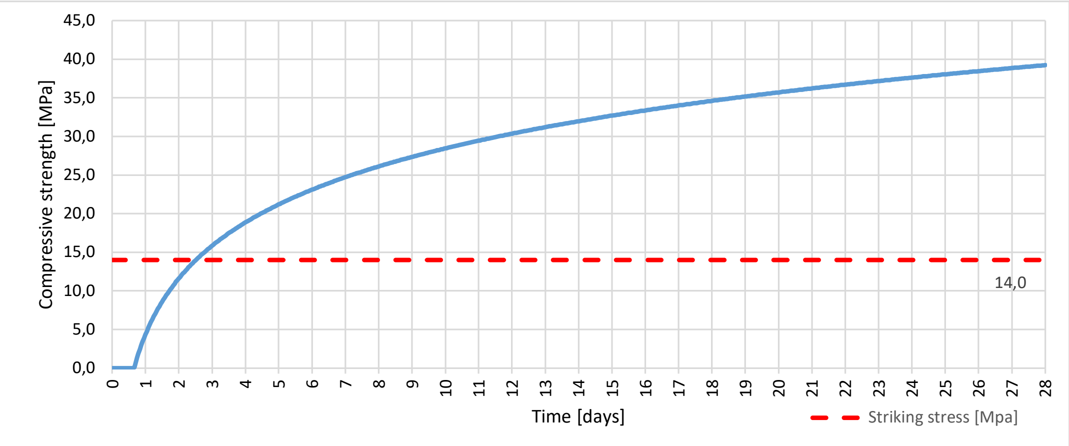
Precamber:	Yes		Extra precamber height:	10 mm

6.2 Output

6.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	84139	68994,27	€ 65.208,00	€ 5.100,78
	Blast furnace slag	322,6	336557	6394,59		€ 518,07
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	0,60	631	454,35	€ 946,57	€ 58,21
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-	68994,27	€ 12.620,90	€ 5.100,78
				230359	€ 160.846,42	€ 20.129,76
					€ 180.976,18	

6.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	61,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	39,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	47,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	61,0	hours

6 Variation 6c

6.1 Input

6.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

6.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)	

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement							As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional			[mm²/m¹]	
50,5	531	Ø	10	-	150				524	1,01

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement							As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional			[mm²/m¹]	
37,4	390	Ø	10	-	150				524	0,74

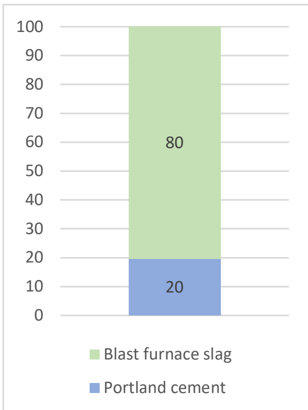
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

6.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	Accelerator HA60	2	8,06	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

6.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

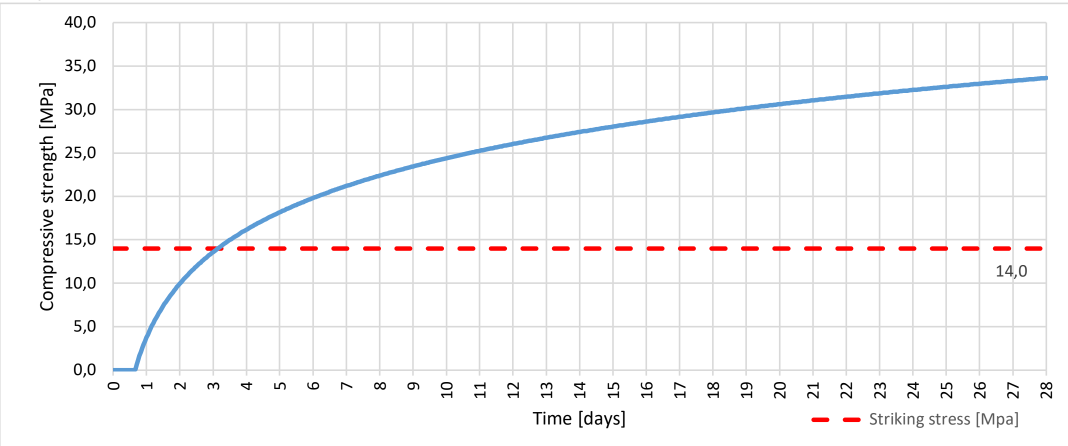
Precamber:	Yes		Extra precamber height:	10 mm

6.2 Output

6.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	84139	68994,27	€ 65.208,00	€ 5.100,78
	Blast furnace slag	322,6	336557	6394,59		€ 518,07
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	0,60	631	454,35	€ 946,57	€ 58,21
Additional admixtures	Accelerator HA60	8,1	8414	6058,03355	€ 21.034,84	€ 776,19
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				167423	€ 169.260,36	€ 15.805,18
					€ 185.065,53	

6.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	76,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	45,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	56,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	76,0	hours

6 Variation 6d

6.1 Input

6.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

6.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	p_g = 6,25 + 1,40 = 7,65 kN/m²	(dead weight + finishing floor)		**Execution phase:**	6,25 kN/m²
	p_q = 1,75 + 1,00 = 2,75 kN/m²	(variable load + partitions)			1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement						$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
50,5	531	Ø	10	-	150			524	1,01

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement						$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
37,4	390	Ø	10	-	150			524	0,74

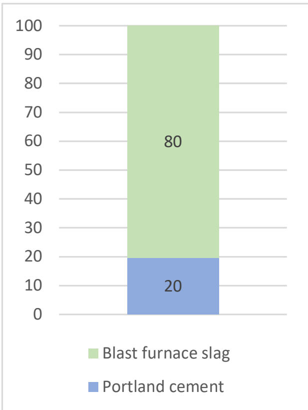
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

6.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Winter	-	-	
Curing temperature	10°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

6.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

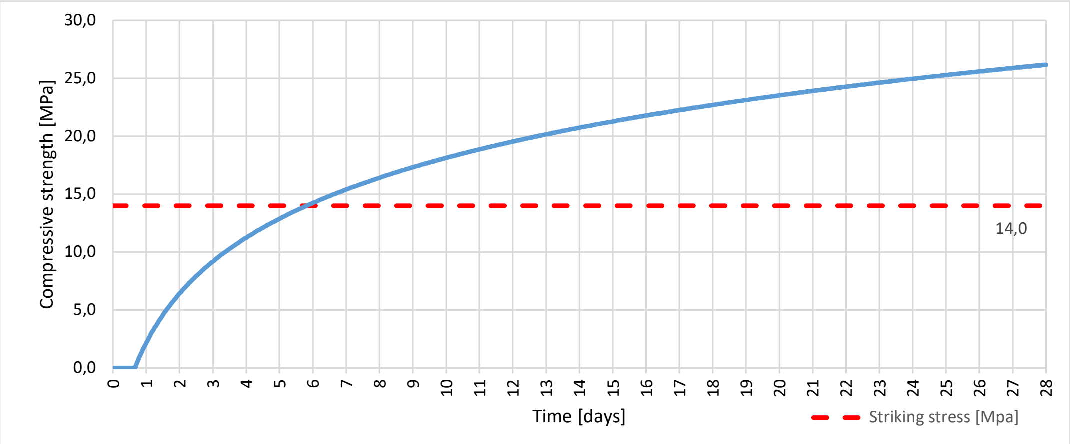
Precamber:	Yes		Extra precamber height:	10 mm

6.2 Output

6.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	84139	68994,27	€ 65.208,00	€ 5.100,78
	Blast furnace slag	322,6	336557	6394,59		€ 518,07
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	0,60	631	454,35	€ 946,57	€ 58,21
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				161365	€ 148.225,52	€ 15.028,99
					€ 163.254,50	

6.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	140,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	73,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	96,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	140,0	hours

6 Variation 6e

6.1 Input

6.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	Variable safety factor:	1,50

6.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:									
	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	
	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	Reinforcement:	B500	Exposure class:	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional		[mm²/m¹]	
50,5	531	Ø	10	-	150			524	1,01

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional		[mm²/m¹]	
37,4	390	Ø	10	-	150			524	0,74

Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

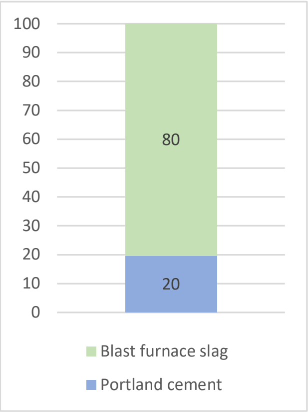
Amount of floor reinforcement applied	=	45456	kg
Amount of wall reinforcement applied	=	9132	kg
Total Amount of reinforcement applied	=	54588	kg

(without auxiliary reinforcement, hairpins and cuttings losses)

6.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	50°C	-	-	***

* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.



6.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Internal heating	Internal heating used, the internal curing temperature will increase to 50°C.	50°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

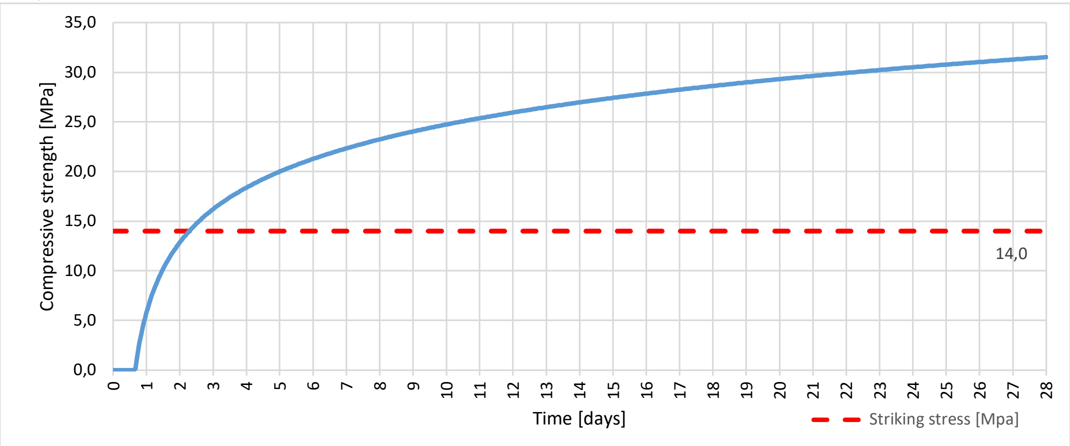
Precamber:	Yes	Extra precamber height:	10 mm

6.2 Output

6.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	84139	68994,27	€ 65.208,00	€ 5.100,78
	Blast furnace slag	322,6	336557	6394,59		€ 518,07
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	0,60	631	454,35	€ 946,57	€ 58,21
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1495	898,545087	€ 4.111,93	€ 192,33
Extra grinding costs		-	-			
				162263	€ 152.337,45	€ 15.221,31
					€ 167.558,76	

6.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	55,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	33,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	40,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	55,0	hours

6 Variation 6f

6.1 Input

6.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

6.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	p_g =	6,25 +	1,40 =	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25	kN/m²
	p_q =	1,75 +	1,00 =	2,75	kN/m²	(variable load + partitions)		1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement							$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*			*[mm²/m¹]*	
50,5	531	Ø	10	-	150				524	1,01

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement							$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*			*[mm²/m¹]*	
37,4	390	Ø	10	-	150				524	0,74

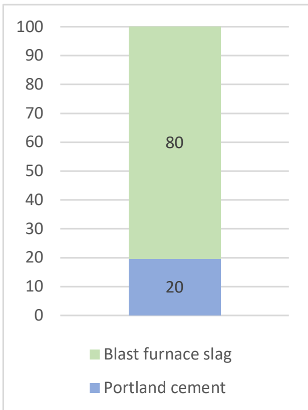
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

6.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	60°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

6.1.4 Additional execution methods

Additional execution method:	Explanation	New value
External heating	External heating used, the curing temperature will increase with 60°C.	60°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

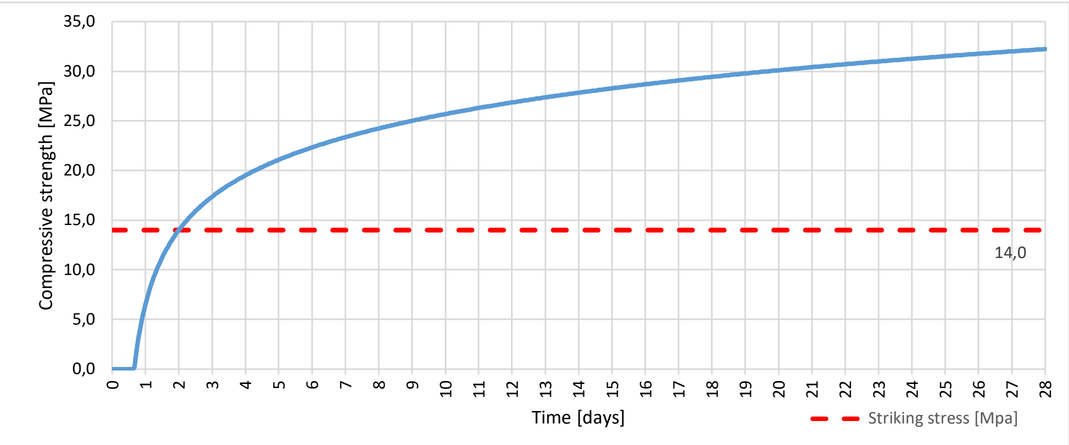
Precamber:	Yes		Extra precamber height:	10 mm

6.2 Output

6.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	84139	68994,27	€ 65.208,00	€ 5.100,78
	Blast furnace slag	322,6	336557	6394,59		€ 518,07
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	0,60	631	454,35	€ 946,57	€ 58,21
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1343	807,13298	€ 3.693,61	€ 172,76
Extra grinding costs		-	-			
				162172	€ 151.919,13	€ 15.201,75
					€ 167.120,87	

6.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	49,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	31,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	36,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	49,0	hours

6 Variation 6g

6.1 Input

6.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

6.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	p_g =	6,25 +	1,40 =	7,65 kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	p_q =	1,75 +	1,00 =	2,75 kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement		$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*	*additional*	*[mm²/m¹]*	
50,5	531	Ø 10 - 150		524	1,01

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement		$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*	*additional*	*[mm²/m¹]*	
37,4	390	Ø 10 - 150		524	0,74

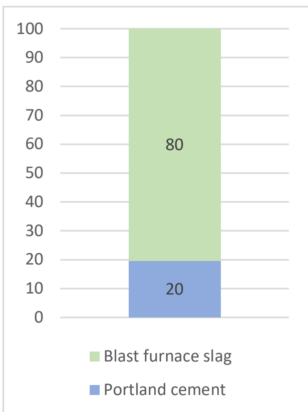
Wall Reinforcement v/a: Ø 6 - 150 = 188 mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

6.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

6.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Maturity process	The maturity method is used. New stresses will develop, the minimum compressive strength is:	12,8 MPa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	Yes

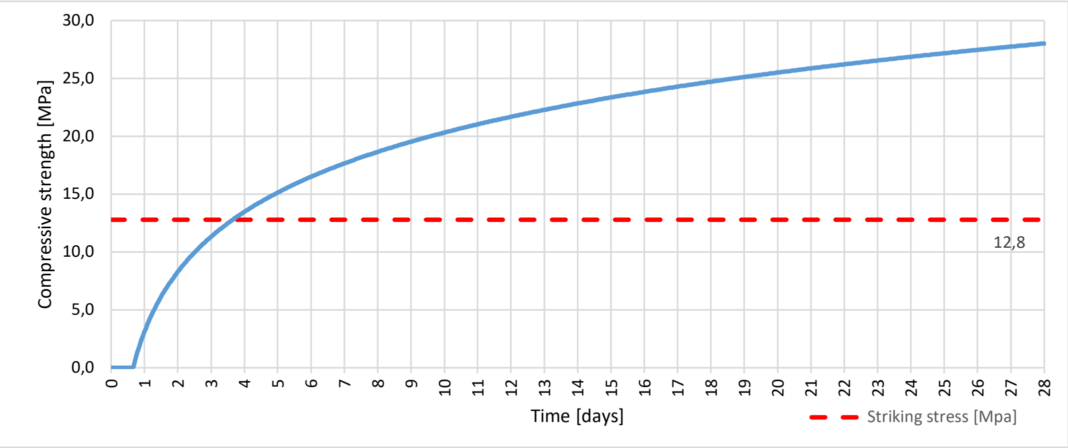
Extra precamber height:	10 mm

6.2 Output

6.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	84139	68994,27	€ 65.208,00	€ 5.100,78
	Blast furnace slag	322,6	336557	6394,59		€ 518,07
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	0,60	631	454,35	€ 946,57	€ 58,21
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				161365	€ 148.225,52	€ 15.028,99
					€ 163.254,50	

6.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	12,8	Mpa. Which is reached after	88,0	hours
The formwork can be removed when a tensile strength of	0,35	Mpa. Which is reached after	55,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	71,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	88,0	hours

6 Variation 6h

6.1 Input

6.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

6.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25	kN/m²
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional		[mm²/m¹]	
50,5	531	Ø	10	-	150			524	1,01

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional		[mm²/m¹]	
37,4	390	Ø	10	-	150			524	0,74

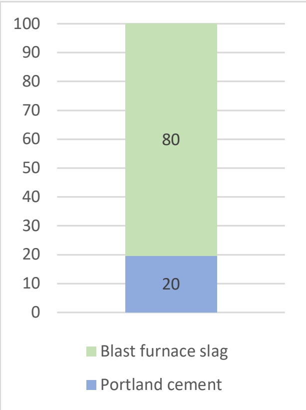
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

6.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

6.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Formwork	An extra support is applied, in the middle of each grid. New stresses will develop, the minimum compressive strength is:	9,2 Mpa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

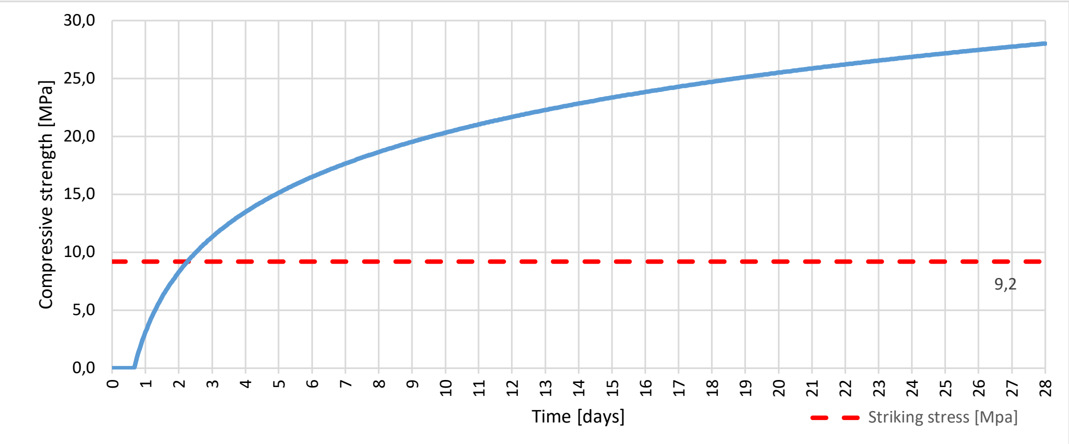
Extra precamber height:	0 mm

6.2 Output

6.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	84139	68994,27	€ 65.208,00	€ 5.100,78
	Blast furnace slag	322,6	336557	6394,59		€ 518,07
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	222	231383	78,67	€ 122,07	€ 7,38
Basic admixtures	Superplasticizer (PCE)	0,60	631	454,35	€ 946,57	€ 58,21
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				161365	€ 148.225,52	€ 15.028,99
					€ 163.254,50	

6.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	9,2	Mpa. Which is reached after	55,0	hours
The formwork can be removed when a tensile strength of	0,02	Mpa. Which is reached after	47,0	hours
The formwork can be removed is the deflection is less than	3	mm. Which is reached after	16,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	55,0	hours

6 Variation 6s

6.1 Input

6.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

6.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25	kN/m²
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional		[mm²/m¹]	
50,5	531	Ø	10	-	150			524	1,01

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional		[mm²/m¹]	
37,4	390	Ø	10	-	150			524	0,74

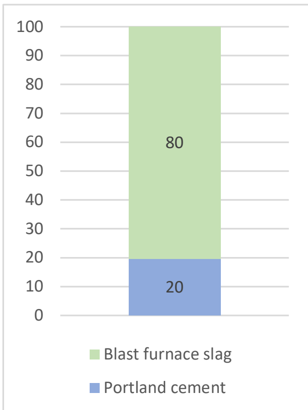
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

6.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,65	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	60°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

6.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Maturity process	The maturity method is used. New stresses will develop, the minimum compressive strength is:	12,8 MPa
External heating	External heating used, the curing temperature will increase with 60°C.	60°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-

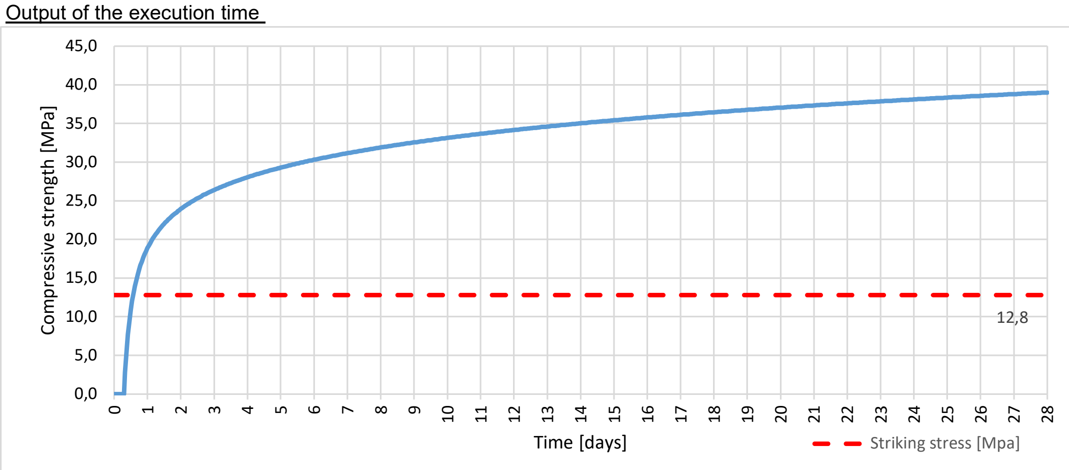
Precamber:	Yes		Extra precamber height:	10 mm

6.2 Output

6.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	86,2	89942	73752,50	€ 69.705,10	€ 5.452,55
	Blast furnace slag	344,8	359768	6835,60		€ 553,80
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	194	202370	68,81	€ 122,07	€ 6,46
Basic admixtures	Superplasticizer (PCE)	0,65	675	485,69	€ 1.011,85	€ 62,23
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1343	807,13298	€ 3.693,61	€ 172,76
Extra grinding costs		-	-			
				167392	€ 156.481,51	€ 15.592,34
					€ 172.073,85	

6.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	12,8	Mpa. Which is reached after	14,0	hours
The formwork can be removed when a tensile strength of	0,36	Mpa. Which is reached after	11,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	13,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	14,0	hours

6 Variation 6w

6.1 Input

6.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

6.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
6,00	8	2,55	36,00	9,60	22,96	6	250	250	1043,33

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25	kN/m²
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
50,5	531	Ø	10	-	150			524	1,01

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement						As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*		*[mm²/m¹]*	
37,4	390	Ø	10	-	150			524	0,74

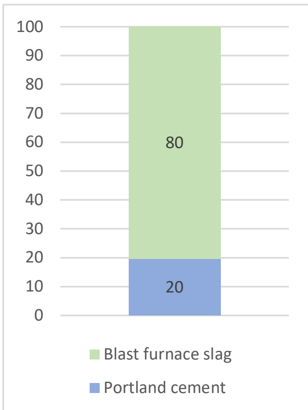
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**45456**	**kg**
Amount of wall reinforcement applied	=	**9132**	**kg**
Total Amount of reinforcement applied	=	**54588**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

6.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,65	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Winter	-	-	
Curing temperature	60°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

6.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Maturity process	The maturity method is used. New stresses will develop, the minimum compressive strength is:	12,8 MPa
External heating	External heating used, the curing temperature will increase with 60°C.	60°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-

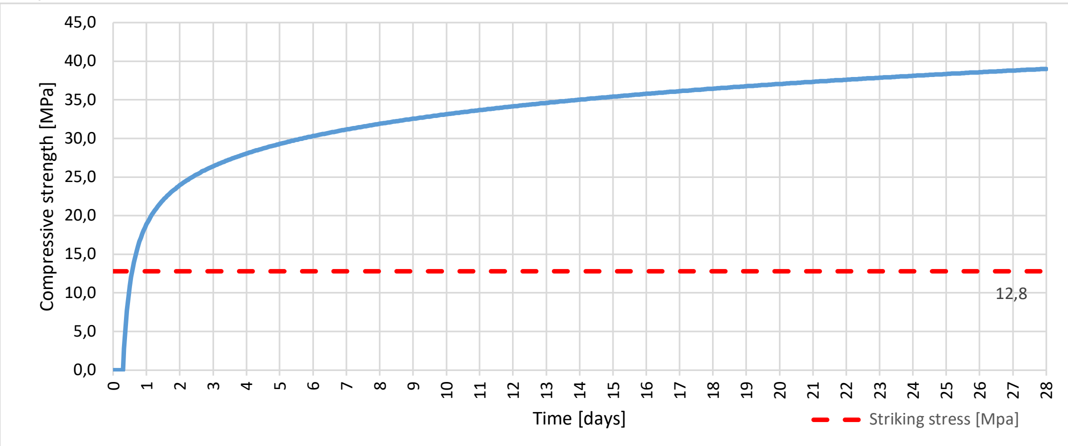
Precamber:	Yes	Extra precamber height:	10 mm

6.2 Output

6.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	86,2	89942	73752,50	€ 69.705,10	€ 5.452,55
	Blast furnace slag	344,8	359768	6835,60		€ 553,80
Reinforcement		7850 kg/m³	54588	81882,31	€ 68.255,20	€ 8.889,25
Aggregate	FA= Sand, river 0-4mm	750	782496	2269,24	€ 3.129,98	€ 356,19
	CA= Gravel, river >4mm	1125	1173744	1291,12	€ 10.563,70	€ 99,09
Water	Tap water	194	202370	68,81	€ 122,07	€ 6,46
Basic admixtures	Superplasticizer (PCE)	0,65	675	485,69	€ 1.011,85	€ 62,23
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1679	1008,91622	€ 4.617,01	€ 215,95
Extra grinding costs		-	-			
				167594	€ 157.404,91	€ 15.635,53
					€ 173.040,45	

6.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	12,8	Mpa. Which is reached after	14,0	hours
The formwork can be removed when a tensile strength of	0,36	Mpa. Which is reached after	11,0	hours
The formwork can be removed is the deflection is less than	16	mm. Which is reached after	13,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	14,0	hours

7 Variation 7

7.1 Input

7.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

7.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement		As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*	*additional*	*[mm²/m¹]*	
72,8	778	Ø 12 - 150		754	1,03

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement		As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*	*additional*	*[mm²/m¹]*	
53,8	567	Ø 12 - 150	+ Ø 10 - 150	1.278	0,44

L = 5,00 m

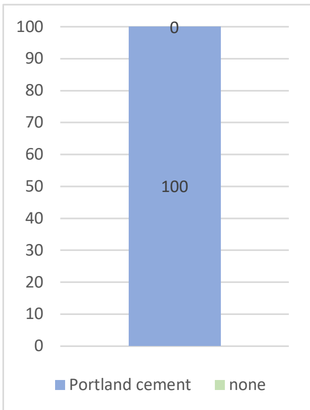
Wall Reinforcement v/a:	Ø 6 - 150 = 188	mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

7.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM I 52.5R	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,3	1,21	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

7.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

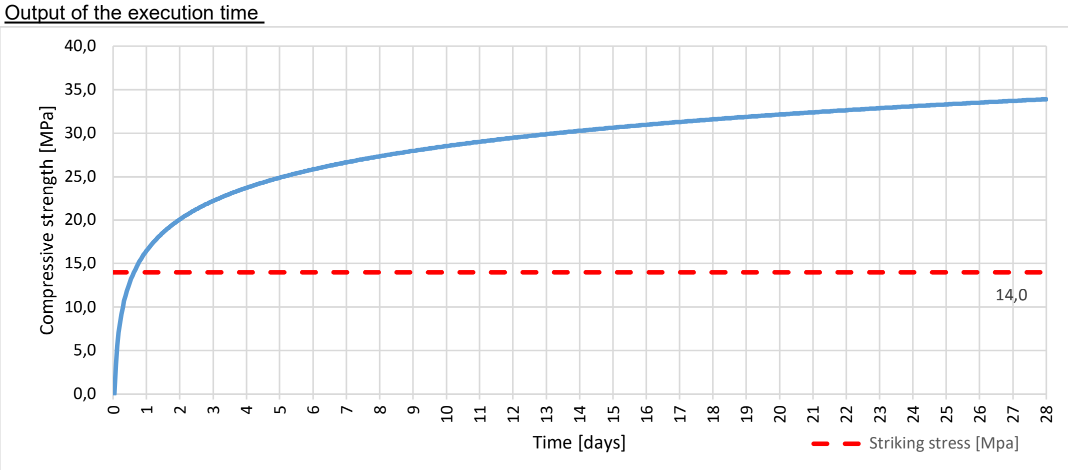
Precamber:	Yes	Extra precamber height:	10 mm

7.2 Output

7.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	403,2	400413	328338,58	€ 68.070,19	€ 24.274,22
	none					
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	1,21	1201	864,89	€ 1.801,86	€ 110,81
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				453011	€ 175.806,48	€ 37.890,04
					€ 213.696,51	

7.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after		16,0	hours
The formwork can be removed when a tensile strength of	0,30	Mpa. Which is reached after		6,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after		9,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after		16,0	hours

8 Variation 8

8.1 Input

8.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

8.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
$[m^1]$	*(incl. GF)*	*$[m^1]$*	*$[m^1]$*	*$[m^1]$*	*$[m^1]$*		*$[mm^1]$*	*$[mm^1]$*	*$[m^3]$*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	p_g = 6,25 + 1,40 = 7,65 kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	p_q = 1,75 + 1,00 = 2,75 kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement *base*	Applied Reinforcement *additional*	$A_{s;prov}$	U.C.
$[kNm^1/m^1]$	*$[mm^2/m^1]$*			*$[mm^2/m^1]$*	
72,8	778	Ø 12 - 150		754	1,03

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement *base*	Applied Reinforcement *additional*	$A_{s;prov}$	U.C.
$[kNm^1/m^1]$	*$[mm^2/m^1]$*			*$[mm^2/m^1]$*	
53,8	567	Ø 12 - 150	+ Ø 10 - 150	1.278	0,44

L = 5,00 m

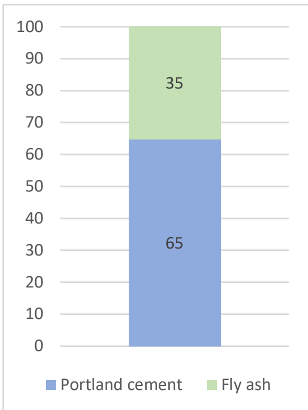
Wall Reinforcement v/a:	Ø 6 - 150 =	188 mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

8.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

8.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

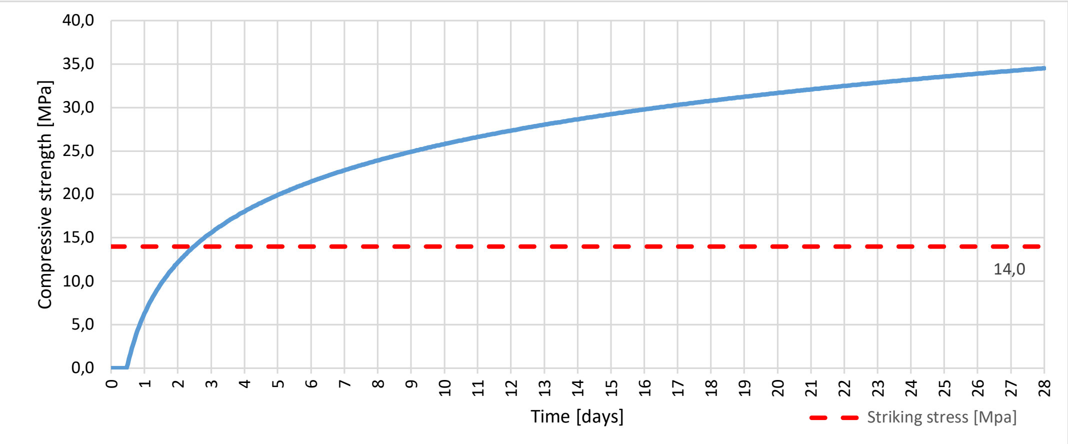
Precamber:	Yes		Extra precamber height:	10 mm

8.2 Output

8.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	260268	213420,08	€ 64.066,06	€ 15.778,24
	Fly ash	141,1	140145	462,48		€ 48,34
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	1,01	1001	720,74	€ 1.501,55	€ 92,35
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				338410	€ 171.502,04	€ 29.423,94
					€ 200.925,97	

8.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	60,0	hours
The formwork can be removed when a tensile strength of	0,30	Mpa. Which is reached after	34,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after	42,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	60,0	hours

8 Variation 8a

8.1 Input

8.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

8.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg =	6,25 +	1,40 =	7,65 kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25	kN/m²
	pq =	1,75 +	1,00 =	2,75 kN/m²	(variable load + partitions)		1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement								As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*				*[mm²/m¹]*	
72,8	778	Ø	12	-	150					754	1,03

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*					*additional*				*[mm²/m¹]*	
53,8	567	Ø	12	-	150	+	Ø	10	-	150	1.278	0,44

L = 5,00 m

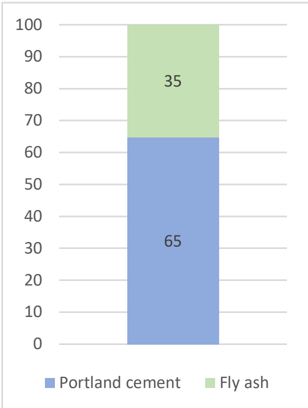
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

8.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,08	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

8.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

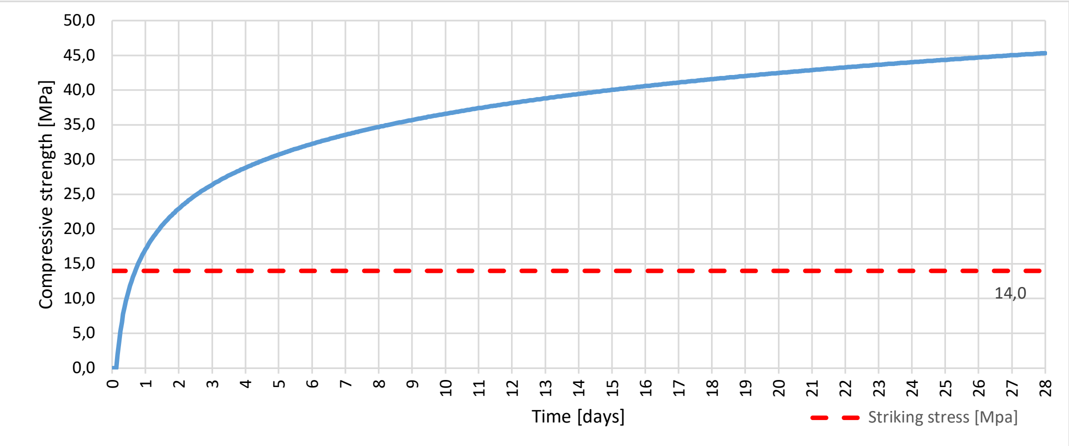
Precamber:	Yes	Extra precamber height:	10 mm

8.2 Output

8.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	280,2	278218	228138,70	€ 68.484,41	€ 16.866,40
	Fly ash	150,9	149810	494,37		€ 51,68
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	194	192612	65,49	€ 116,18	€ 6,15
Basic admixtures	Superplasticizer (PCE)	1,08	1070	770,45	€ 1.605,10	€ 98,71
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				353201	€ 176.023,94	€ 30.520,91
					€ 206.544,85	

8.2.2 Output of the execution time



The formwork can be removed when a compressive strength of		14,0	Mpa. Which is reached after	17,0	hours
The formwork can be removed when a tensile strength of		0,30	Mpa. Which is reached after	10,0	hours
The formwork can be removed is the deflection is less than		17,2	mm. Which is reached after	12,0	hours
The determining valiation is the	Compressive strength		. So the formwork can be removed after	17,0	hours

8 Variation 8b

8.1 Input

8.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

8.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25 +	1,40 =	7,65 kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	pq	=	1,75 +	1,00 =	2,75 kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*					*[mm²/m¹]*	
72,8	778	Ø	12	-	150						754	1,03

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*					*[mm²/m¹]*	
53,8	567	Ø	12	-	150	+	Ø	10	-	150	1.278	0,44

L = 5,00 m

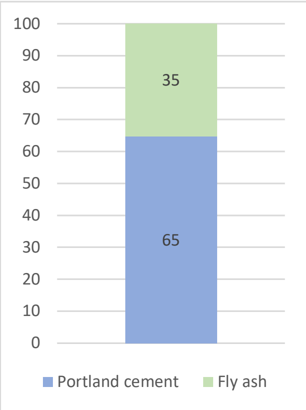
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

8.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	400m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

8.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

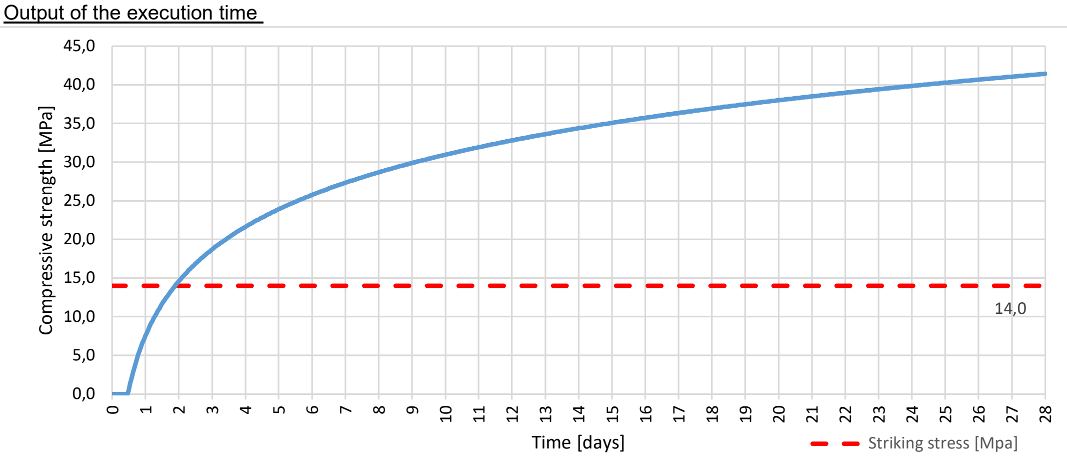
Precamber:	Yes	Extra precamber height:	10 mm

8.2 Output

8.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	260268	213420,08	€ 64.066,06	€ 15.778,24
	Fly ash	141,1	140145	462,48		€ 48,34
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	1,01	1001	720,74	€ 1.501,55	€ 92,35
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-	65667,72	€ 12.012,39	€ 4.854,84
				404078	€ 183.514,42	€ 34.278,78
					€ 217.793,20	

8.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	46,0	hours
The formwork can be removed when a tensile strength of	0,30	Mpa. Which is reached after	28,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after	34,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	46,0	hours

8 Variation 8c

8.1 Input

8.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

8.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement		As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*	*additional*	*[mm²/m¹]*	
72,8	778	Ø 12 - 150		754	1,03

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement		As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*	*additional*	*[mm²/m¹]*	
53,8	567	Ø 12 - 150	+ Ø 10 - 150	1.278	0,44

L = 5,00 m

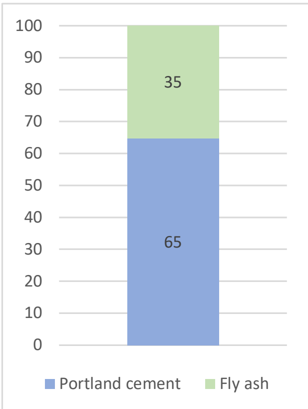
Wall Reinforcement v/a:	Ø 6 - 150	= 188	mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

8.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	Accelerator HA60	2	8,06	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

8.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

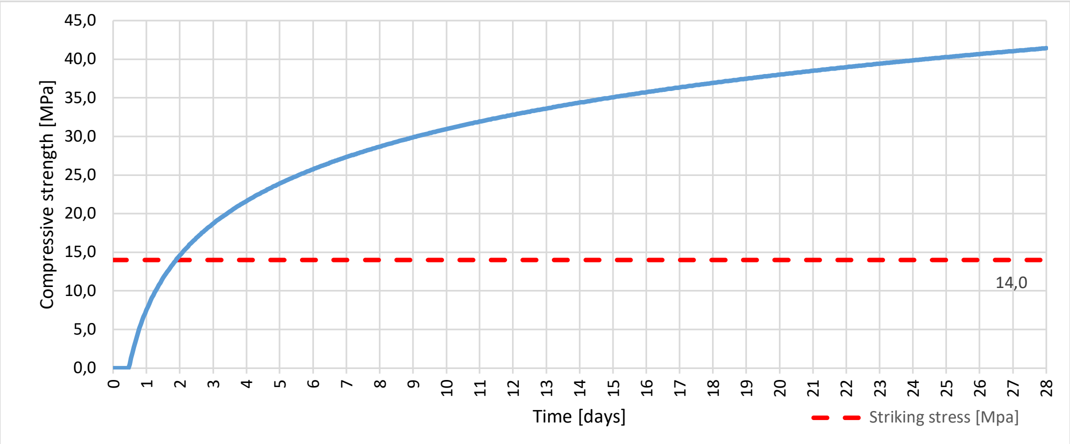
Precamber:	Yes	Extra precamber height:	10	mm

8.2 Output

8.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	260268	213420,08	€ 64.066,06	€ 15.778,24
	Fly ash	141,1	140145	462,48		€ 48,34
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	1,01	1001	720,74	€ 1.501,55	€ 92,35
Additional admixtures	Accelerator HA60	8,1	8008	5765,94581	€ 20.020,65	€ 738,77
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				344176	€ 191.522,68	€ 30.162,70
					€ 221.685,38	

8.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	46,0	hours
The formwork can be removed when a tensile strength of	0,30	Mpa. Which is reached after	28,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after	34,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	46,0	hours

8 Variation 8d

8.1 Input

8.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

8.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*					*[mm²/m¹]*	
72,8	778	Ø	12	-	150						754	1,03

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*					*[mm²/m¹]*	
53,8	567	Ø	12	-	150	+	Ø	10	-	150	1.278	0,44

L = 5,00 m

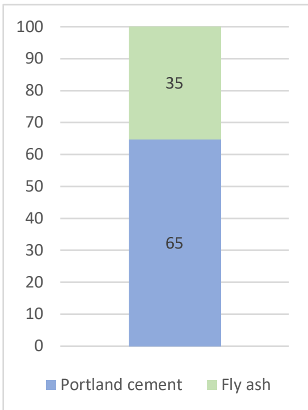
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

8.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Winter	-	-	
Curing temperature	10°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

8.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

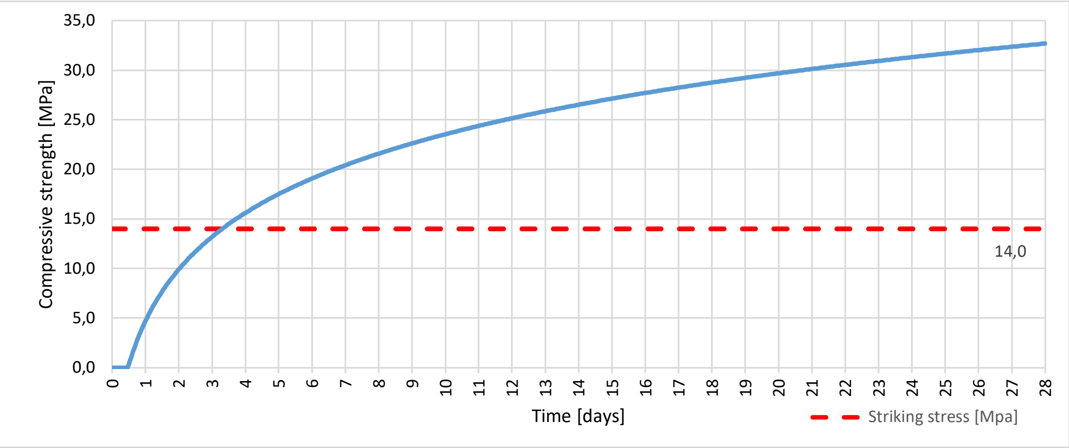
Precamber:	Yes	Extra precamber height:	10 mm

8.2 Output

8.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	260268	213420,08	€ 64.066,06	€ 15.778,24
	Fly ash	141,1	140145	462,48		€ 48,34
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	1,01	1001	720,74	€ 1.501,55	€ 92,35
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				338410	€ 171.502,04	€ 29.423,94
					€ 200.925,97	

8.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	80,0	hours
The formwork can be removed when a tensile strength of	0,29	Mpa. Which is reached after	43,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after	54,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	80,0	hours

8 Variation 8e

8.1 Input

8.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

8.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*					*[mm²/m¹]*	
72,8	778	Ø	12	-	150						754	1,03

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*					*[mm²/m¹]*	
53,8	567	Ø	12	-	150	+	Ø	10	-	150	1.278	0,44

L = 5,00 m

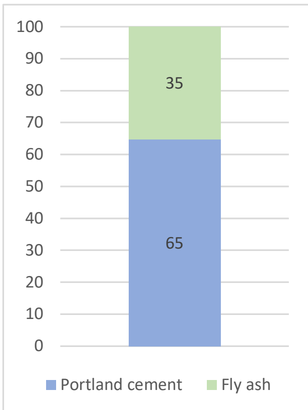
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹	

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

8.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	50°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

8.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Internal heating	Internal heating used, the internal curing temperature will increase to 50°C.	50°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

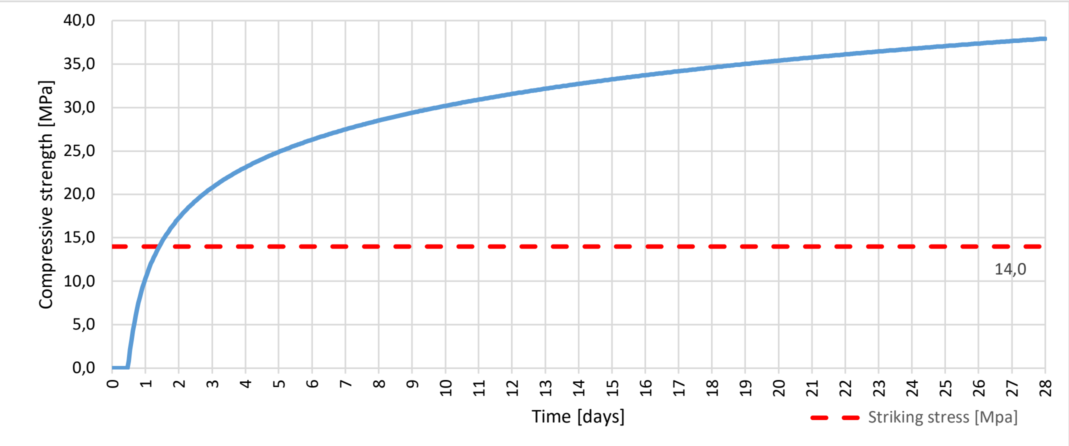
Precamber:	Yes	Extra precamber height:	10 mm

8.2 Output

8.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	260268	213420,08	€ 64.066,06	€ 15.778,24
	Fly ash	141,1	140145	462,48		€ 48,34
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	1,01	1001	720,74	€ 1.501,55	€ 92,35
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1423	855,221787	€ 3.913,67	€ 183,05
Extra grinding costs		-	-			
				339266	€ 175.415,71	€ 29.606,99
					€ 205.022,70	

8.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	34,0	hours
The formwork can be removed when a tensile strength of	0,30	Mpa. Which is reached after	22,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after	26,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	34,0	hours

8 Variation 8f

8.1 Input

8.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

8.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25 +	1,40 =	7,65 kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	pq	=	1,75 +	1,00 =	2,75 kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional					[mm²/m¹]	
72,8	778	Ø	12	-	150						754	1,03

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional					[mm²/m¹]	
53,8	567	Ø	12	-	150	+	Ø	10	-	150	1.278	0,44

L = 5,00 m

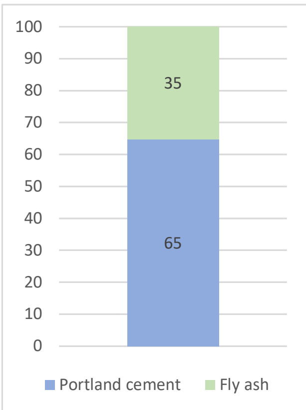
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

8.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	60°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

8.1.4 Additional execution methods

Additional execution method:	Explanation	New value
External heating	External heating used, the curing temperature will increase with 60°C.	60°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

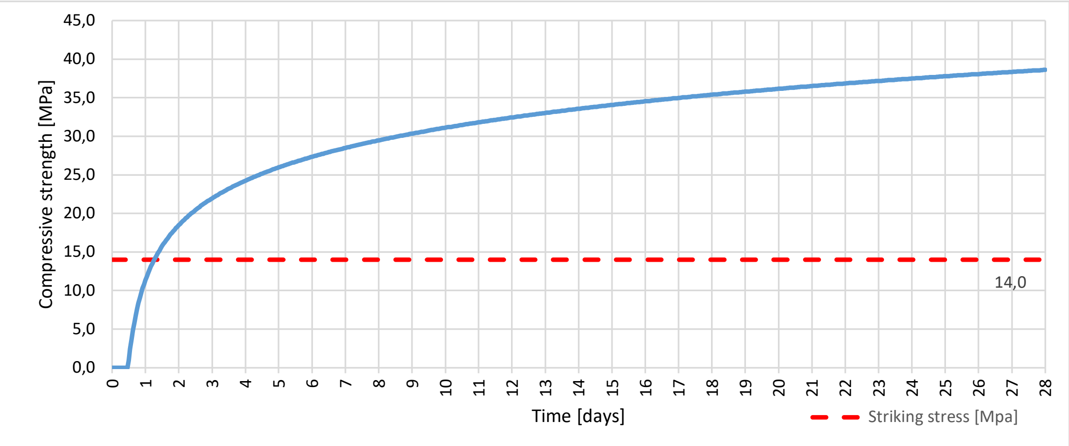
Precamber:	Yes	Extra precamber height:	10 mm

8.2 Output

8.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	260268	213420,08	€ 64.066,06	€ 15.778,24
	Fly ash	141,1	140145	462,48		€ 48,34
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	1,01	1001	720,74	€ 1.501,55	€ 92,35
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1311	787,776198	€ 3.605,03	€ 168,62
Extra grinding costs		-	-			
				339198	€ 175.107,07	€ 29.592,55
					€ 204.699,62	

8.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after		31,0	hours
The formwork can be removed when a tensile strength of	0,29	Mpa. Which is reached after		20,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after		23,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after		31,0	hours

8 Variation 8g

8.1 Input

8.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

8.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)	

Execution phase:	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement								As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*				*[mm²/m¹]*	
72,8	778	Ø	12	-	150					754	1,03

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*					*additional*				*[mm²/m¹]*	
53,8	567	Ø	12	-	150	+	Ø	10	-	150	1.278	0,44

L = 5,00 m

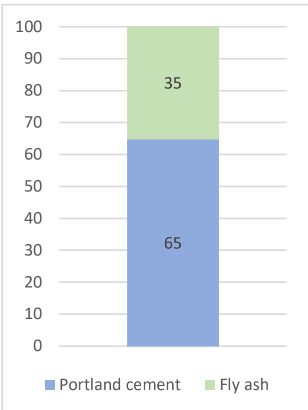
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

8.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

8.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Maturity process	The maturity method is used. New stresses will develop, the minimum compressive strength is:	14,98 MPa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	Yes

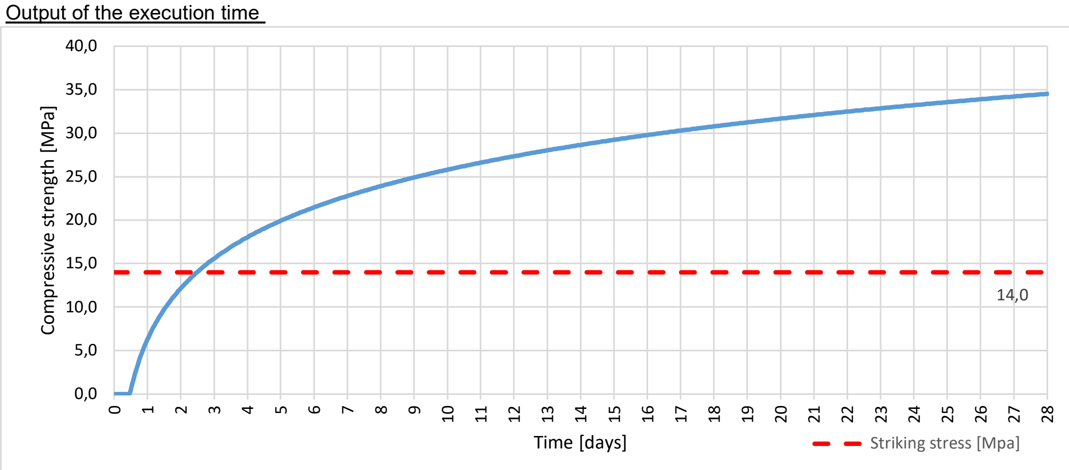
Extra precamber height:	10 mm

8.2 Output

8.2.1 Output of the building costs and shadow costs

Material			kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement		262,1	260268	213420,08	€ 64.066,06	€ 15.778,24
	Fly ash		141,1	140145	462,48		€ 48,34
Reinforcement			7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA=	Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA=	Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water		222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)		1,01	1001	720,74	€ 1.501,55	€ 92,35
Additional admixtures	None						
Heating	Propaan gas - fossil		-				
Extra grinding costs			-	-			
					338410	**€ 171.502,04**	**€ 29.423,94**
						€ 200.925,97	

8.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after		60,0	hours
The formwork can be removed when a tensile strength of	0,30	Mpa. Which is reached after		34,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after		42,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after		60,0	hours

8 Variation 8h

8.1 Input

8.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

8.1.2 Design of the structure

Grid size [m¹]	Amount of levels (incl. GF)	Level height [m¹]	Total length [m¹]	Total depth [m¹]	Total height [m¹]	Amount of grids	Floor thickness [mm¹]	Wall thickness [mm¹]	Total volume [m³]
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd [kNm¹/m¹]	As;req [mm²/m¹]	Applied Reinforcement base				Applied Reinforcement additional	As;prov [mm²/m¹]	U.C.
72,8	778	Ø	12	-	150		754	1,03

Floor Reinforcement: BOTTOM

MEd [kNm¹/m¹]	As;req [mm²/m¹]	Applied Reinforcement base				Applied Reinforcement additional	As;prov [mm²/m¹]	U.C.
53,8	569	Ø	12	-	150		754	0,75

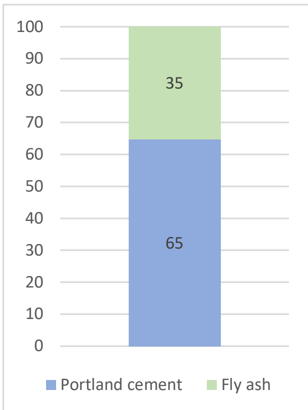
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**65457**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**73284**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

8.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,01	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

8.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Formwork	An extra support is applied, in the middle of each grid. New stresses will develop, the minimum compressive strength is:	9,74 Mpa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

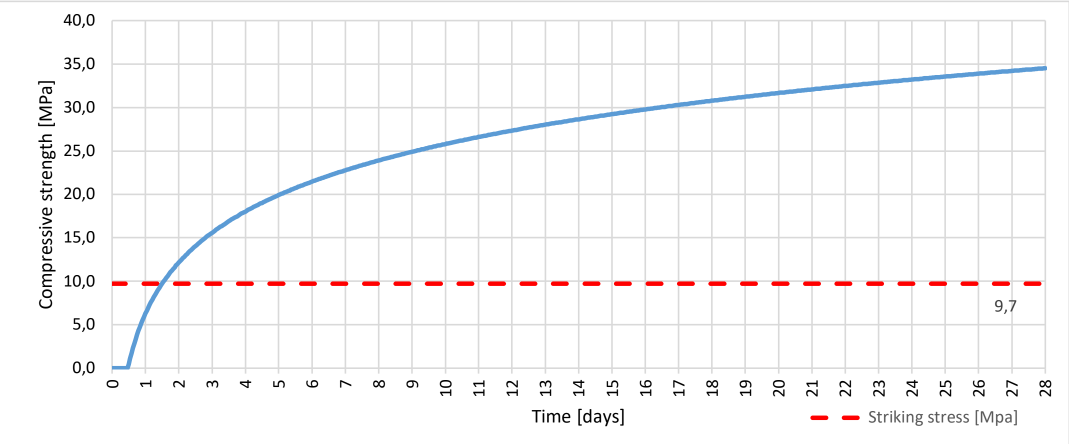
Extra precamber height:	0 mm

8.2 Output

8.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	262,1	260268	213420,08	€ 64.066,06	€ 15.778,24
	Fly ash	141,1	140145	462,48		€ 48,34
Reinforcement		7850 kg/m³	73284	109926,44	€ 92.304,80	€ 11.933,76
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	1,01	1001	720,74	€ 1.501,55	€ 92,35
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				327993	€ 171.022,04	€ 28.293,05
					€ 199.315,09	

8.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	9,7	Mpa. Which is reached after	36,0	hours
The formwork can be removed when a tensile strength of	0,06	Mpa. Which is reached after	30,0	hours
The formwork can be removed is the deflection is less than	3,6	mm. Which is reached after	12,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	36,0	hours

8 Variation 8s

8.1 Input

8.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

8.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement					$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
72,8	778	Ø	12	-	150		754	1,03

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement					$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
53,8	569	Ø	12	-	150		754	0,75

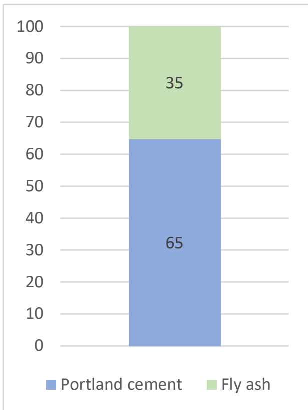
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**65457**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**73284**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

8.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM II/B-S 52.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,08	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

8.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Formwork	An extra support is applied, in the middle of each grid. New stresses will develop, the minimum compressive strength is:	9,74 Mpa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

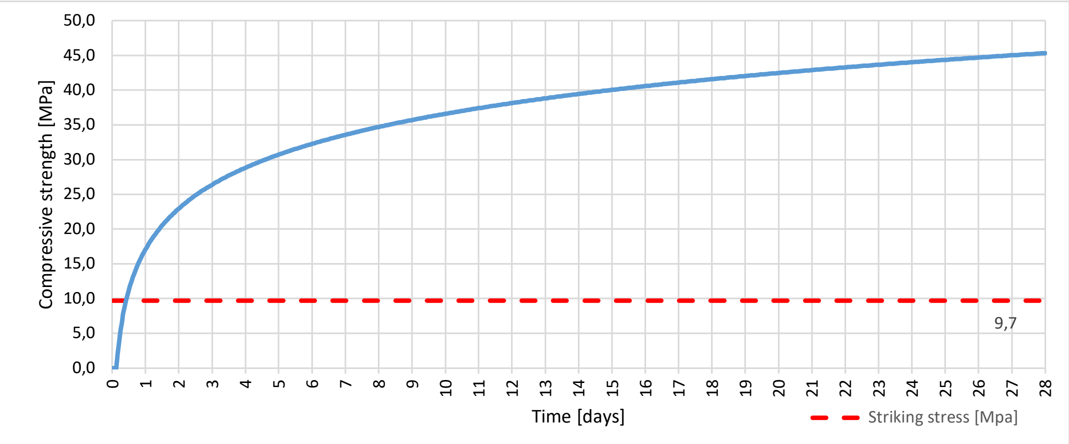
Extra precamber height:	0 mm

8.2 Output

8.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	280,2	278218	228138,70	€ 68.484,41	€ 16.866,40
	Fly ash	150,9	149810	494,37		€ 51,68
Reinforcement		7850 kg/m³	73284	109926,44	€ 92.304,80	€ 11.933,76
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	194	192612	65,49	€ 116,18	€ 6,15
Basic admixtures	Superplasticizer (PCE)	1,08	1070	770,45	€ 1.605,10	€ 98,71
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				342784	€ 175.543,94	€ 29.390,03
					€ 204.933,97	

8.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	9,7	Mpa. Which is reached after	11,0	hours
The formwork can be removed when a tensile strength of	0,09	Mpa. Which is reached after	9,0	hours
The formwork can be removed is the deflection is less than	3,6	mm. Which is reached after	4,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	11,0	hours

8 Variation 8w

8.1 Input

8.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

8.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25 + 1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	pq	=	1,75 + 1,00	=	2,75	kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement		As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*	*additional*	*[mm²/m¹]*	
72,8	778	Ø 12 - 150		754	1,03

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement		As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*	*additional*	*[mm²/m¹]*	
53,8	569	Ø 12 - 150		754	0,75

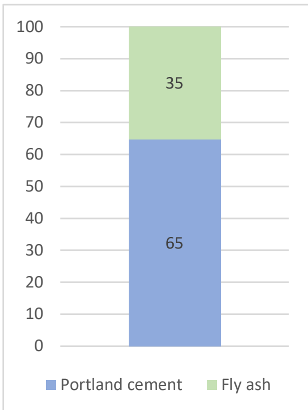
Wall Reinforcement v/a:	Ø 6 - 150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**65457**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**73284**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

8.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM II/B-S 52.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,25	1,08	**
Additional admixtures	Accelerator HA60	2	8,62	**
Blaine value	300m²/kg	-	-	
Sesaon	Winter	-	-	
Curing temperature	10°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

8.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Formwork	An extra support is applied, in the middle of each grid. New stresses will develop, the minimum compressive strength is:	9,74 Mpa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

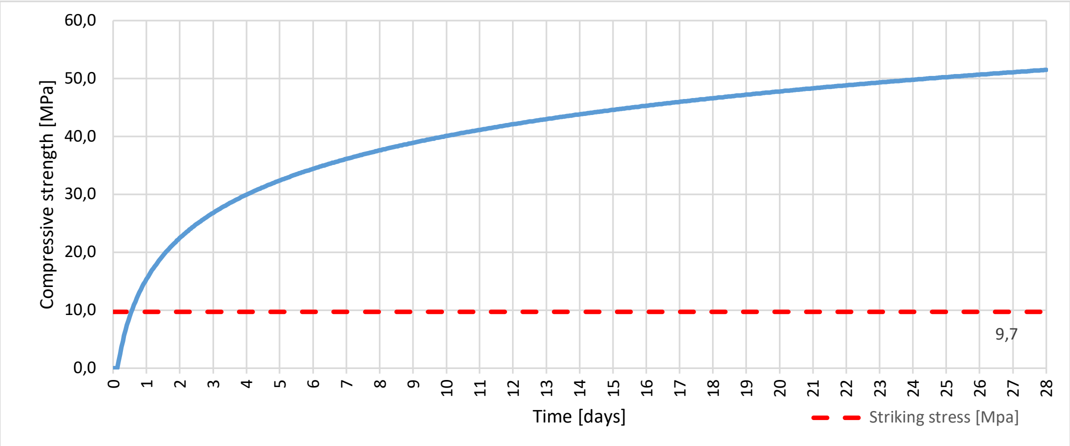
Extra precamber height:	0 mm

8.2 Output

8.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	280,2	278218	228138,70	€ 68.484,41	€ 16.866,40
	Fly ash	150,9	149810	494,37		€ 51,68
Reinforcement		7850 kg/m³	73284	109926,44	€ 92.304,80	€ 11.933,76
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	194	192612	65,49	€ 116,18	€ 6,15
Basic admixtures	Superplasticizer (PCE)	1,08	1070	770,45	€ 1.605,10	€ 98,71
Additional admixtures	Accelerator HA60	8,6	8561	6163,59724	€ 21.401,38	€ 789,72
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				348948	€ 196.945,32	€ 30.179,74
					€ 227.125,06	

8.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	9,7	Mpa. Which is reached after	14,0	hours
The formwork can be removed when a tensile strength of	0,08	Mpa. Which is reached after	11,0	hours
The formwork can be removed is the deflection is less than	3,6	mm. Which is reached after	4,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	14,0	hours

9 Variation 9

9.1 Input

9.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

9.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*					*[mm²/m¹]*	
72,8	778	Ø	12	-	150						754	1,03

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*					*[mm²/m¹]*	
53,8	567	Ø	12	-	150	+	Ø	10	-	150	1.278	0,44

L = 5,00 m

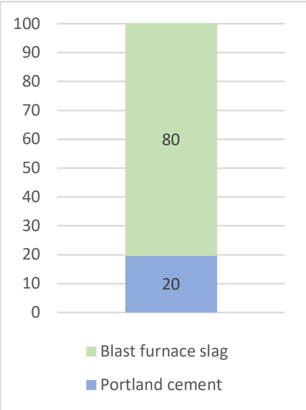
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

9.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

9.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

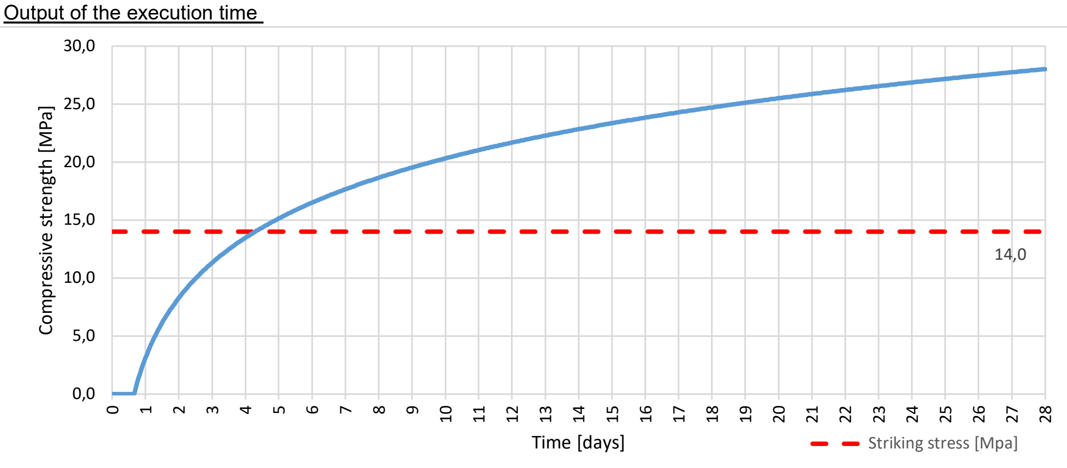
Precamber:	Yes	Extra precamber height:	10 mm

9.2 Output

9.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	80083	65667,72	€ 62.064,00	€ 4.854,84
	Blast furnace slag	322,6	320330	6086,28		€ 493,10
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	0,60	601	432,45	€ 900,93	€ 55,41
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				195993	€ 168.899,35	€ 18.908,35
					€ 187.807,70	

9.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	104,0	hours
The formwork can be removed when a tensile strength of	0,29	Mpa. Which is reached after	53,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after	68,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	104,0	hours

9 Variation 9a

9.1 Input

9.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

9.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement									$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*					*[mm²/m¹]*	
72,8	778	Ø	12	-	150						754	1,03

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement									$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*					*[mm²/m¹]*	
53,8	567	Ø	12	-	150	+	Ø	10	-	150	1.278	0,44

L = 5,00 m

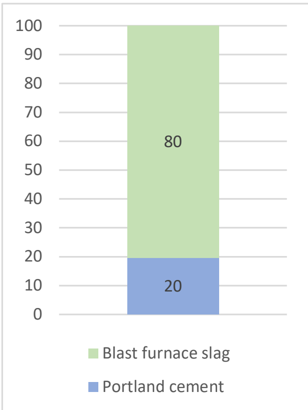
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

9.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,65	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

9.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

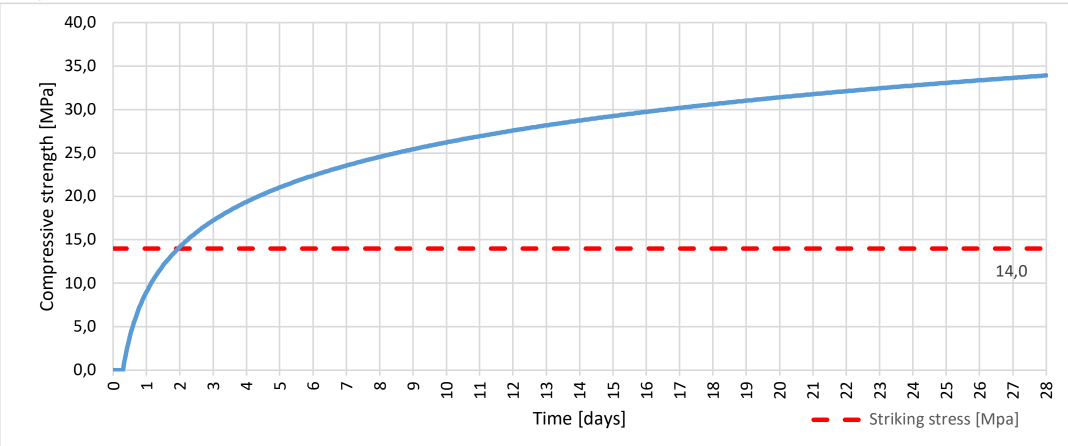
Precamber:	Yes	Extra precamber height:	10 mm

9.2 Output

9.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	86,2	85606	70196,52	€ 66.344,28	€ 5.189,66
	Blast furnace slag	344,8	342422	6506,02		€ 527,10
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	194	192612	65,49	€ 116,18	€ 6,15
Basic admixtures	Superplasticizer (PCE)	0,65	642	462,27	€ 963,06	€ 59,23
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				200962	€ 173.241,76	€ 19.280,12
					€ 192.521,88	

9.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	47,0	hours
The formwork can be removed when a tensile strength of	0,29	Mpa. Which is reached after	24,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after	31,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	47,0	hours

9 Variation 9b

9.1 Input

9.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

9.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd [kNm¹/m¹]	As;req [mm²/m¹]	Applied Reinforcement base	Applied Reinforcement additional	As;prov [mm²/m¹]	U.C.
72,8	778	Ø 12 - 150		754	1,03

Floor Reinforcement: BOTTOM

MEd [kNm¹/m¹]	As;req [mm²/m¹]	Applied Reinforcement base	Applied Reinforcement additional	As;prov [mm²/m¹]	U.C.
53,8	567	Ø 12 - 150	+ Ø 10 - 150	1.278	0,44

L = 5,00 m

Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

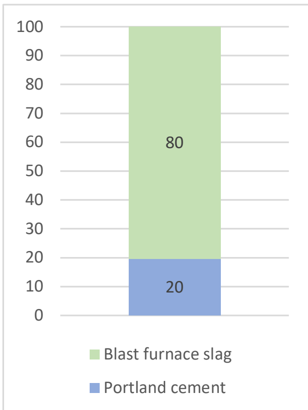
Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

9.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	400m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***

* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.



9.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

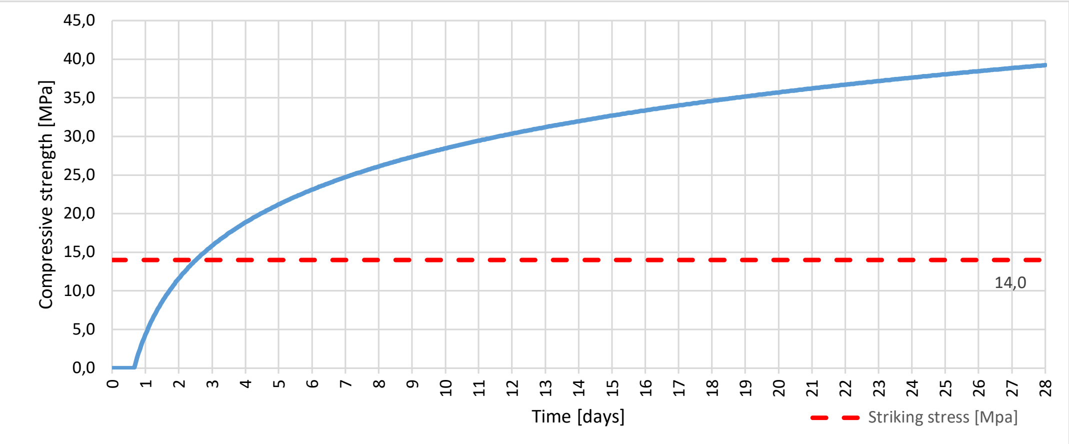
Precamber:	Yes	Extra precamber height:	10 mm

9.2 Output

9.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	80083	65667,72	€ 62.064,00	€ 4.854,84
	Blast furnace slag	322,6	320330	6086,28		€ 493,10
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	0,60	601	432,45	€ 900,93	€ 55,41
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-	65667,72	€ 12.012,39	€ 4.854,84
				261661	€ 180.911,74	€ 23.763,20
					€ 204.674,94	

9.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	61,0	hours
The formwork can be removed when a tensile strength of	0,29	Mpa. Which is reached after	38,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after	45,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	61,0	hours

9 Variation 9c

9.1 Input

9.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

9.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25 +	1,40 =	7,65 kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	pq	=	1,75 +	1,00 =	2,75 kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement									$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*					*[mm²/m¹]*	
72,8	778	Ø	12	-	150						754	1,03

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement									$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*					*[mm²/m¹]*	
53,8	567	Ø	12	-	150	+	Ø	10	-	150	1.278	0,44

L = 5,00 m

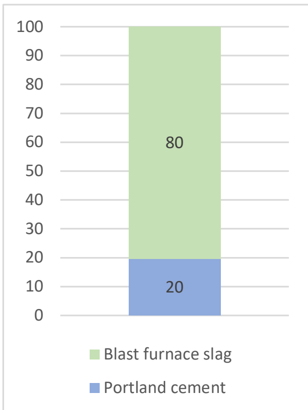
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

9.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	Accelerator HA60	2	8,06	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

9.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

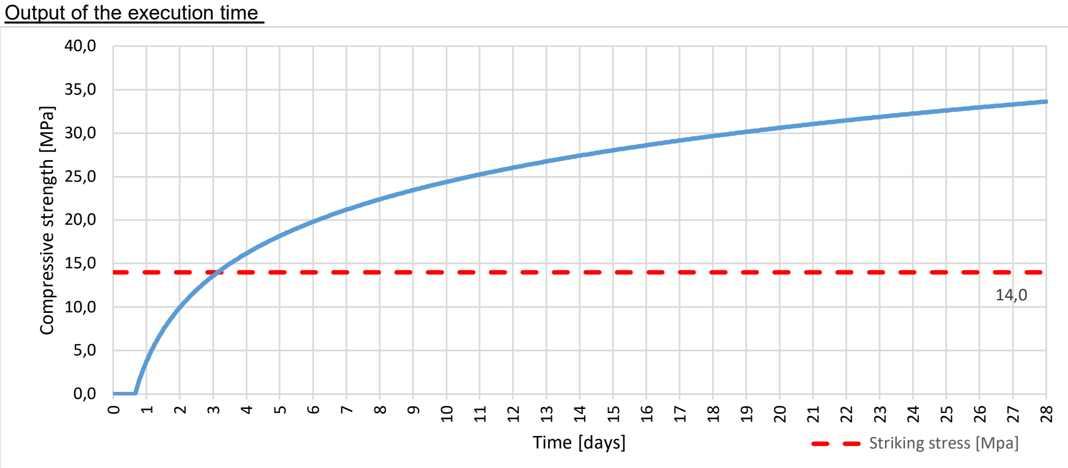
Precamber:	Yes		Extra precamber height:	10 mm

9.2 Output

9.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	80083	65667,72	€ 62.064,00	€ 4.854,84
	Blast furnace slag	322,6	320330	6086,28		€ 493,10
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	0,60	601	432,45	€ 900,93	€ 55,41
Additional admixtures	Accelerator HA60	8,1	8008	5765,94581	€ 20.020,65	€ 738,77
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				201759	€ 188.920,00	€ 19.647,12
					€ 208.567,12	

9.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	76,0	hours
The formwork can be removed when a tensile strength of	0,29	Mpa. Which is reached after	43,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after	53,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	76,0	hours

9 Variation 9d

9.1 Input

9.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

9.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional					[mm²/m¹]	
72,8	778	Ø	12	-	150						754	1,03

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional					[mm²/m¹]	
53,8	567	Ø	12	-	150	+	Ø	10	-	150	1.278	0,44

L = 5,00 m

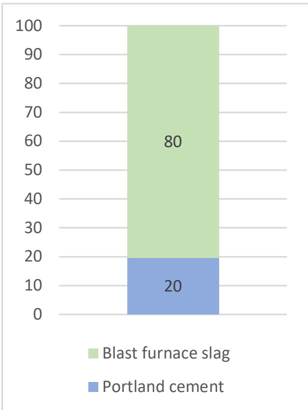
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

9.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Winter	-	-	
Curing temperature	10°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

9.1.4 Additional execution methods

Additional execution method:	Explanation	New value
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

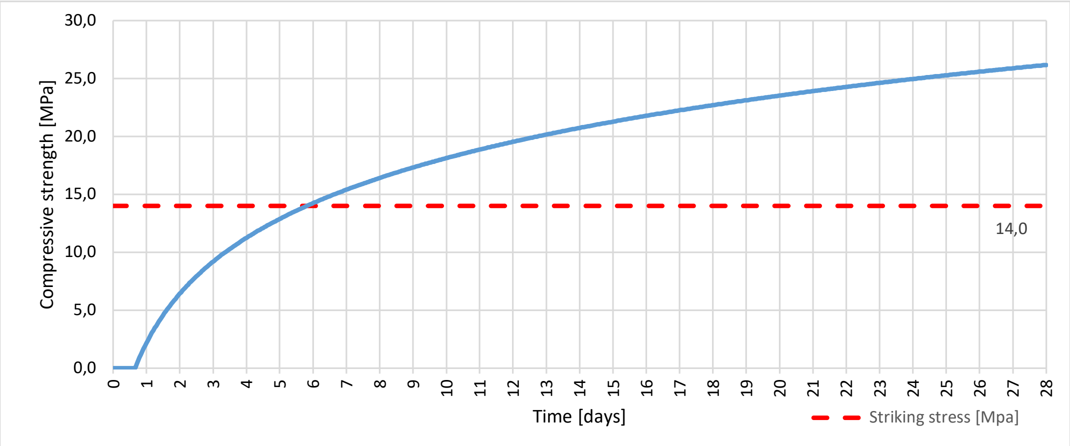
Precamber:	**Yes**	**Extra precamber height:**	**10 mm**

9.2 Output

9.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	80083	65667,72	€ 62.064,00	€ 4.854,84
	Blast furnace slag	322,6	320330	6086,28		€ 493,10
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	0,60	601	432,45	€ 900,93	€ 55,41
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				195993	**€ 168.899,35**	**€ 18.908,35**
					€ 187.807,70	

9.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	140,0	hours
The formwork can be removed when a tensile strength of	0,29	Mpa. Which is reached after	70,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after	91,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	140,0	hours

9 Variation 9e

9.1 Input

9.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

9.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25 +	1,40	=	7,65 kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	pq	=	1,75 +	1,00	=	2,75 kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement								As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*				*[mm²/m¹]*	
72,8	778	Ø	12	-	150					754	1,03

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*					*additional*				*[mm²/m¹]*	
53,8	567	Ø	12	-	150	+	Ø	10	-	150	1.278	0,44

L = 5,00 m

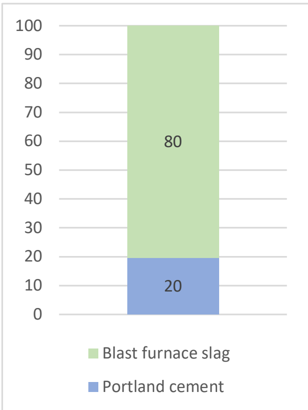
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

9.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	50°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

9.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Internal heating	Internal heating used, the internal curing temperature will increase to 50°C.	50°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	Yes

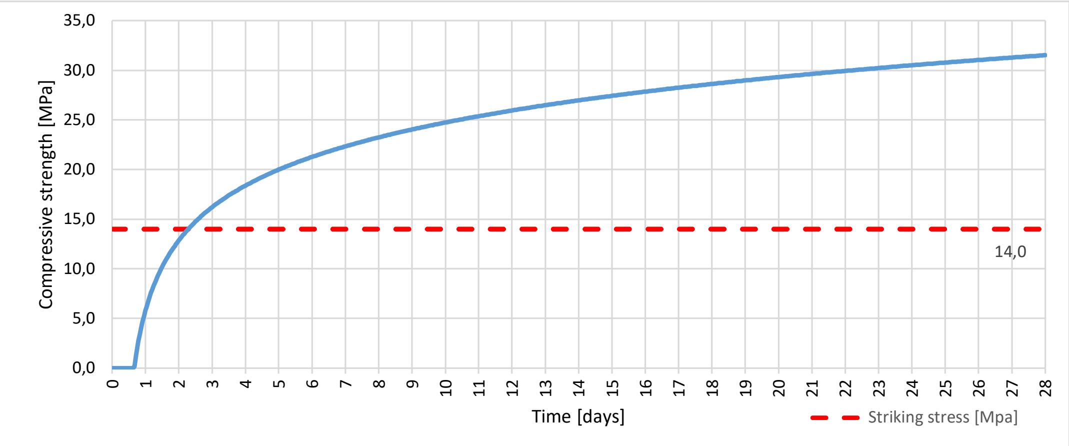
Extra precamber height:	10 mm

9.2 Output

9.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	80083	65667,72	€ 62.064,00	€ 4.854,84
	Blast furnace slag	322,6	320330	6086,28		€ 493,10
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	0,60	601	432,45	€ 900,93	€ 55,41
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1423	855,221787	€ 3.913,67	€ 183,05
Extra grinding costs		-	-			
				196849	€ 172.813,03	€ 19.091,40
					€ 191.904,43	

9.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	55,0	hours
The formwork can be removed when a tensile strength of	0,30	Mpa. Which is reached after	33,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after	39,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	55,0	hours

9 Variation 9f

9.1 Input

9.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

9.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement									$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*					*[mm²/m¹]*	
72,8	778	Ø	12	-	150						754	1,03

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement									$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*					*[mm²/m¹]*	
53,8	567	Ø	12	-	150	+	Ø	10	-	150	1.278	0,44

L = 5,00 m

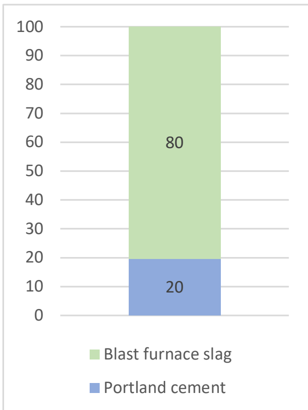
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

9.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	60°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

9.1.4 Additional execution methods

Additional execution method:	Explanation	New value
External heating	External heating used, the curing temperature will increase with 60°C.	60°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

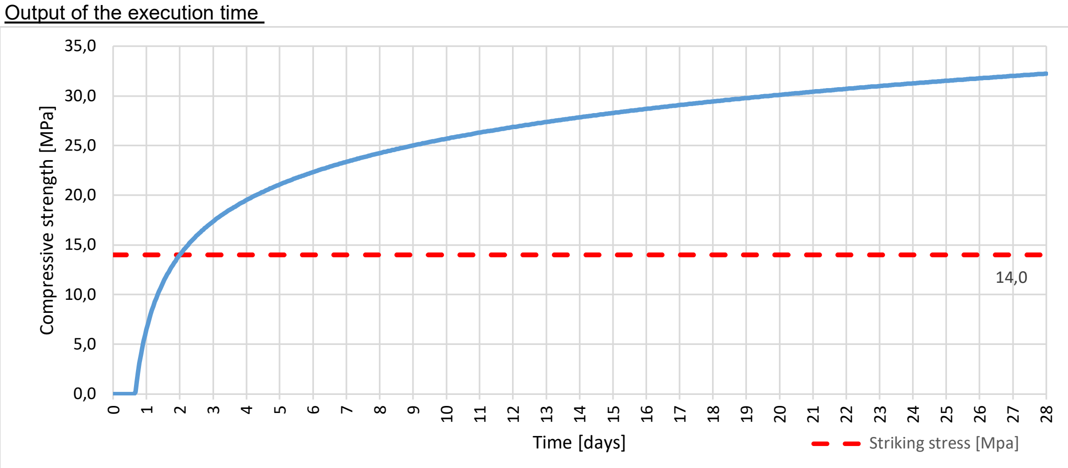
Precamber:	Yes	Extra precamber height:	10 mm

9.2 Output

9.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	80083	65667,72	€ 62.064,00	€ 4.854,84
	Blast furnace slag	322,6	320330	6086,28		€ 493,10
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	0,60	601	432,45	€ 900,93	€ 55,41
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1311	787,776198	€ 3.605,03	€ 168,62
Extra grinding costs		-	-			
				196781	€ 172.504,38	€ 19.076,97
					€ 191.581,35	

9.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	49,0	hours
The formwork can be removed when a tensile strength of	0,29	Mpa. Which is reached after	30,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after	35,0	hours
The determining valiation is the Compressive strength		. So the formwork can be removed after	49,0	hours

9 Variation 9g

9.1 Input

9.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

9.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)	
	pq	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)	

Execution phase:	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement								As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base				additional				[mm²/m¹]	
72,8	778	Ø	12	-	150					754	1,03

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement									As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base					additional				[mm²/m¹]	
53,8	567	Ø	12	-	150	+	Ø	10	-	150	1.278	0,44

L = 5,00 m

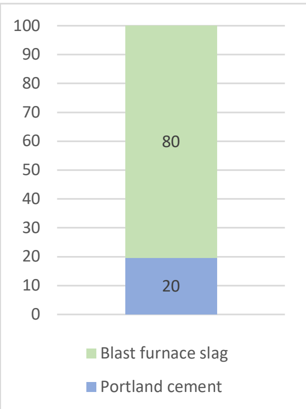
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**72401**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**80229**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

9.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

9.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Maturity process	The maturity method is used. New stresses will develop, the minimum compressive strength is:	14,98 MPa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	Yes

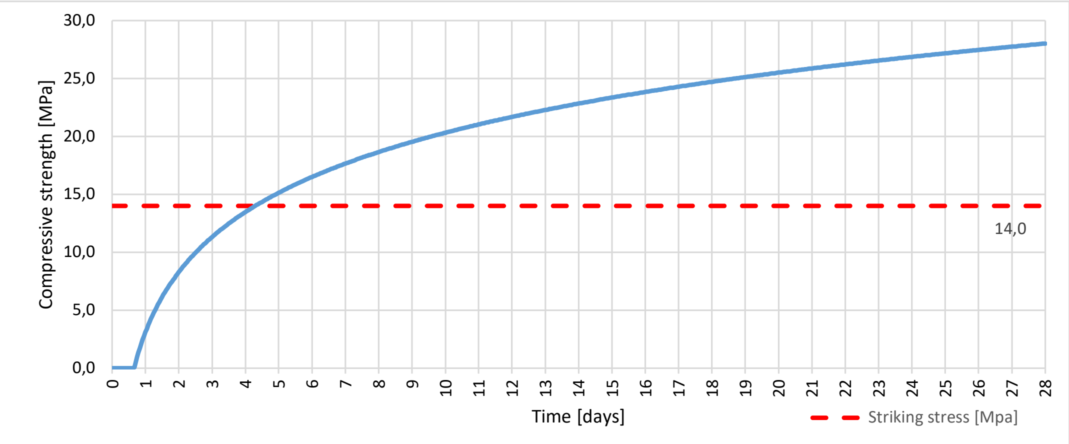
Extra precamber height:	10 mm

9.2 Output

9.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	80083	65667,72	€ 62.064,00	€ 4.854,84
	Blast furnace slag	322,6	320330	6086,28		€ 493,10
Reinforcement		7850 kg/m³	80229	120343,46	€ 92.784,80	€ 13.064,64
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	0,60	601	432,45	€ 900,93	€ 55,41
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				195993	€ 168.899,35	€ 18.908,35
					€ 187.807,70	

9.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	14,0	Mpa. Which is reached after	104,0	hours
The formwork can be removed when a tensile strength of	0,29	Mpa. Which is reached after	53,0	hours
The formwork can be removed is the deflection is less than	17,2	mm. Which is reached after	68,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	104,0	hours

9 Variation 9h

9.1 Input

9.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

9.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	(incl. GF)	[m¹]	[m¹]	[m¹]	[m¹]		[mm¹]	[mm¹]	[m³]
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	pg	=	6,25 +	1,40 =	7,65	kN/m²	(dead weight + finishing floor)	**Execution phase:**	6,25 kN/m²
	pq	=	1,75 +	1,00 =	2,75	kN/m²	(variable load + partitions)		1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

MEd	As;req	Applied Reinforcement				As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base			additional	[mm²/m¹]	
72,8	778	Ø	12	-	150	754	1,03

Floor Reinforcement: BOTTOM

MEd	As;req	Applied Reinforcement				As;prov	U.C.
[kNm¹/m¹]	[mm²/m¹]	base			additional	[mm²/m¹]	
53,8	569	Ø	12	-	150	754	0,75

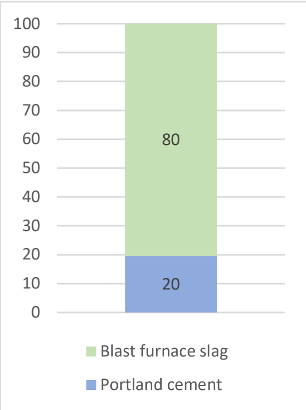
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**65457**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**73284**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

9.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM III/B 42.5N	16,1	403	
w/c ratio	0,55	-	-	
Water	Tap water	8,9	222	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,60	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	20°C	-	-	***



* = Percentage of total amount of aggregate.
** = Percentage of the weigth of the cement
*** = Depents also on the additional execution methods.

9.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Formwork	An extra support is applied, in the middle of each grid. New stresses will develop, the minimum compressive strength is:	9,74 Mpa
None	No additional execution methods used.	-
None	No additional execution methods used.	-
None	No additional execution methods used.	-

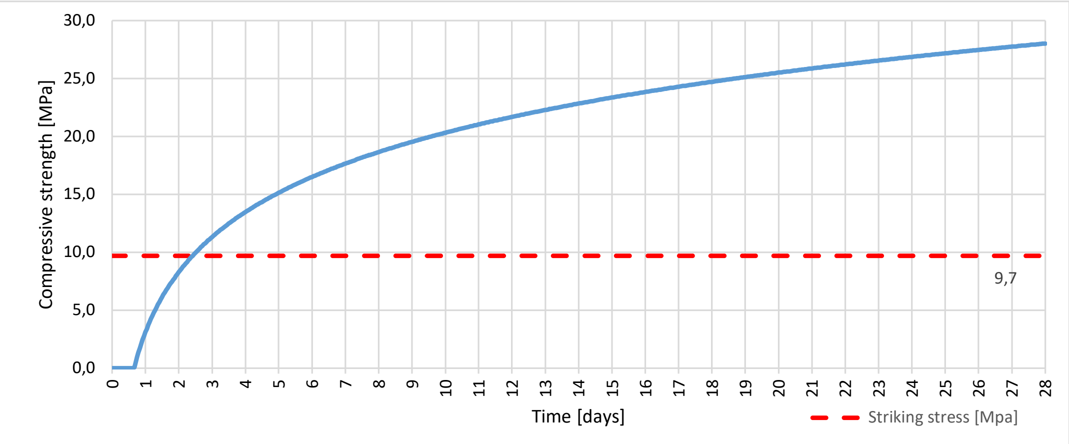
Precamber:	No	Extra precamber height:	0 mm

9.2 Output

9.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	80,6	80083	65667,72	€ 62.064,00	€ 4.854,84
	Blast furnace slag	322,6	320330	6086,28		€ 493,10
Reinforcement		7850 kg/m³	73284	109926,44	€ 92.304,80	€ 11.933,76
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	222	220227	74,88	€ 116,18	€ 7,03
Basic admixtures	Superplasticizer (PCE)	0,60	601	432,45	€ 900,93	€ 55,41
Additional admixtures	None					
Heating	Propaan gas - fossil	-				
Extra grinding costs		-	-			
				185576	**€ 168.419,35**	**€ 17.777,47**
					€ 186.196,82	

9.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	9,7	Mpa. Which is reached after	59,0	hours
The formwork can be removed when a tensile strength of	0,03	Mpa. Which is reached after	47,0	hours
The formwork can be removed is the deflection is less than	3,6	mm. Which is reached after	16,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	59,0	hours

9 Variation 9s

9.1 Input

9.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

9.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:									
	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	
	6,25 kN/m²
	1,00 kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement					$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
72,8	778	Ø	12	-	150		754	1,03

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement					$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
53,8	569	Ø	12	-	150		754	0,75

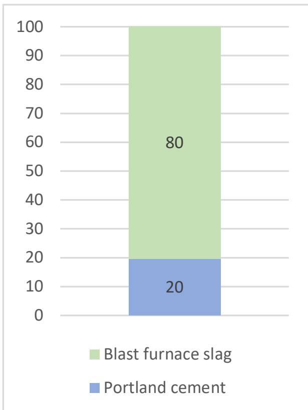
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**65457**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**73284**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

9.1.3 Design of the concrete mixture

Parameter	Type/value	Amount		
		%	kg/m³	
Cement mixture	CEM III/B 42.5N	17,2	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,65	**
Additional admixtures	None	-	-	**
Blaine value	300m²/kg	-	-	
Sesaon	Summer	-	-	
Curing temperature	60°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

9.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Formwork	An extra support is applied, in the middle of each grid. New stresses will develop, the minimum compressive strength is:	9,74 Mpa
External heating	External heating used, the curing temperature will increase with 60°C.	60°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-

Precamber:	No

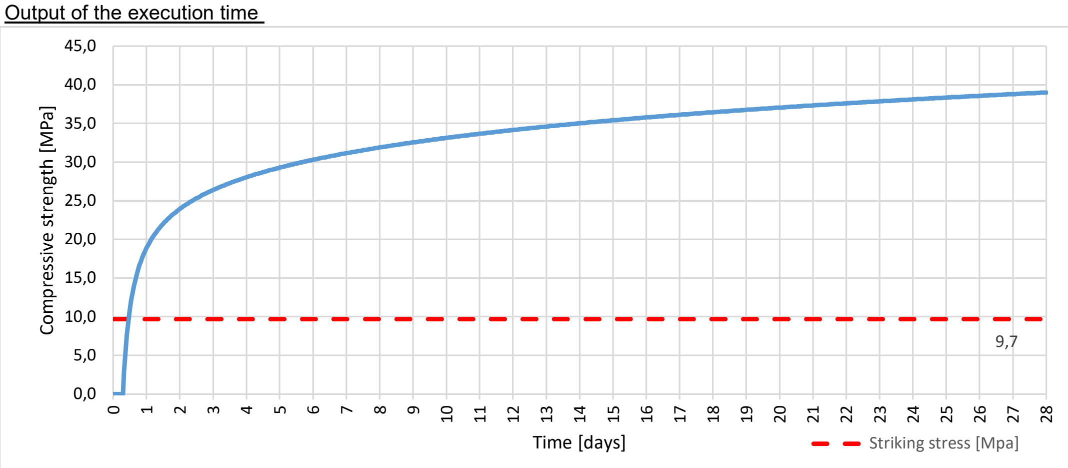
Extra precamber height:	0 mm

9.2 Output

9.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	86,2	85606	70196,52	€ 66.344,28	€ 5.189,66
	Blast furnace slag	344,8	342422	6506,02		€ 527,10
Reinforcement		7850 kg/m³	73284	109926,44	€ 92.304,80	€ 11.933,76
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	194	192612	65,49	€ 116,18	€ 6,15
Basic admixtures	Superplasticizer (PCE)	0,65	642	462,27	€ 963,06	€ 59,23
Additional admixtures	None					
Heating	Propaan gas - fossil	-	1311	787,776198	€ 3.605,03	€ 168,62
Extra grinding costs		-	-			
				191333	**€ 176.366,79**	**€ 18.317,85**
					€ 194.684,64	

9.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	9,7	Mpa. Which is reached after	12,0	hours
The formwork can be removed when a tensile strength of	0,10	Mpa. Which is reached after	11,0	hours
The formwork can be removed is the deflection is less than	3,6	mm. Which is reached after	8,0	hours
The determining valiation is the	Compressive strength	. So the formwork can be removed after	12,0	hours

9 Variation 9w

9.1 Input

9.1.1 Properties of the structure

Service class:	Category A	Domestic, residential areas
Consequence class:	EC: Class CC2 / RC2	Residential buildings, hotels, and office buildings
Service life:	Class 3 - 50 years	Buildings and other ordinary structures

Permanent safety factor:	1,20	**Variable safety factor:**	1,50

9.1.2 Design of the structure

Grid size	Amount of levels	Level height	Total length	Total depth	Total height	Amount of grids	Floor thickness	Wall thickness	Total volume
[m¹]	*(incl. GF)*	*[m¹]*	*[m¹]*	*[m¹]*	*[m¹]*		*[mm¹]*	*[mm¹]*	*[m³]*
7,20	8	2,55	36,00	9,60	22,96	5	250	250	993,02

Floor load:	p_g	=	6,25	+	1,40	=	7,65	kN/m²	(dead weight + finishing floor)
	p_q	=	1,75	+	1,00	=	2,75	kN/m²	(variable load + partitions)

Execution phase:	6,25	kN/m²
	1,00	kN/m²

Strength class concrete:	C30/37	**Reinforcement:**	B500	**Exposure class:**	XC1

Floor Reinforcement: TOP

M_{Ed}	$A_{s;req}$	Applied Reinforcement					$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
72,8	778	Ø	12	-	150		754	1,03

Floor Reinforcement: BOTTOM

M_{Ed}	$A_{s;req}$	Applied Reinforcement					$A_{s;prov}$	U.C.
[kNm¹/m¹]	*[mm²/m¹]*	*base*				*additional*	*[mm²/m¹]*	
53,8	569	Ø	12	-	150		754	0,75

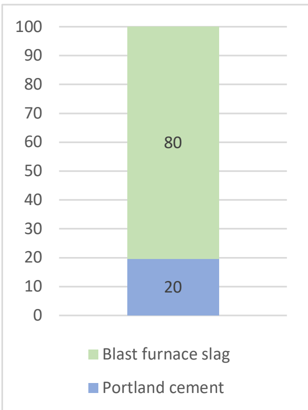
Wall Reinforcement v/a:	Ø	6	-	150	=	188	mm²/m¹

Amount of floor reinforcement applied	=	**65457**	**kg**
Amount of wall reinforcement applied	=	**7828**	**kg**
Total Amount of reinforcement applied	=	**73284**	**kg**

(without auxiliary reinforcement, hairpins and cuttings losses)

9.1.3 Design of the concrete mixture

Parameter	Type/value	Amount %	Amount kg/m³	
Cement mixture	CEM III/B 42.5N	17,241	431	
w/c ratio	0,45	-	-	
Water	Tap water	7,8	194	
Aggregate		75	1875	
Fine aggregate	Sand, river 0-4mm	40	750	*
Course aggregate	Gravel, river >4mm	60	1125	*
Basic admixtures	Superplasticizer (PCE)	0,15	0,65	**
Additional admixtures	Accelerator HA60	2	8,62	**
Blaine value	300m²/kg	-	-	
Sesaon	Winter	-	-	
Curing temperature	60°C	-	-	***



* = Percentage of total amount of aggregate.

** = Percentage of the weigth of the cement

*** = Depents also on the additional execution methods.

9.1.4 Additional execution methods

Additional execution method:	Explanation	New value
Formwork	An extra support is applied, in the middle of each grid. New stresses will develop, the minimum compressive strength is:	9,74 Mpa
External heating	External heating used, the curing temperature will increase with 60°C.	60°C
None	No additional execution methods used.	-
None	No additional execution methods used.	-

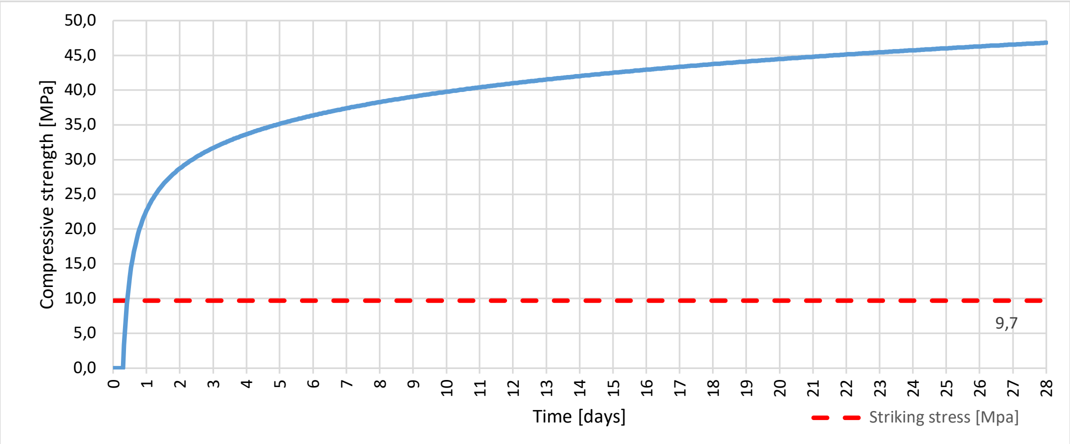
Precamber: **No** **Extra precamber height:** **0 mm**

9.2 Output

9.2.1 Output of the building costs and shadow costs

Material		kg per m³ concrete	Weight kg	GWP kg*CO2	Material cost	Shadow cost
Cement	Portland cement	86,2	85606	70196,52	€ 66.344,28	€ 5.189,66
	Blast furnace slag	344,8	342422	6506,02		€ 527,10
Reinforcement		7850 kg/m³	73284	109926,44	€ 92.304,80	€ 11.933,76
Aggregate	FA= Sand, river 0-4mm	750	744768	2159,83	€ 2.979,07	€ 339,02
	CA= Gravel, river >4mm	1125	1117152	1228,87	€ 10.054,37	€ 94,32
Water	Tap water	194,0	192612	65,49	€ 116,18	€ 6,15
Basic admixtures	Superplasticizer (PCE)	0,6	642	462,27	€ 963,06	€ 59,23
Additional admixtures	Accelerator HA60	8,6	8561	6163,59724	€ 21.401,38	€ 789,72
Heating	Propaan gas - fossil	-	1638,650	984,720247	€ 4.506,29	€ 210,77
Extra grinding costs		-	-			
				197694	**€ 198.669,43**	**€ 19.149,72**
					€ 217.819,14	

9.2.2 Output of the execution time



The formwork can be removed when a compressive strength of	9,7	Mpa. Which is reached after	11,0	hours
The formwork can be removed when a tensile strength of	0,10	Mpa. Which is reached after	10,0	hours
The formwork can be removed is the deflection is less than	3,6	mm. Which is reached after	8,0	hours
The determining validation is the	Compressive strength	. So the formwork can be removed after	11,0	hours