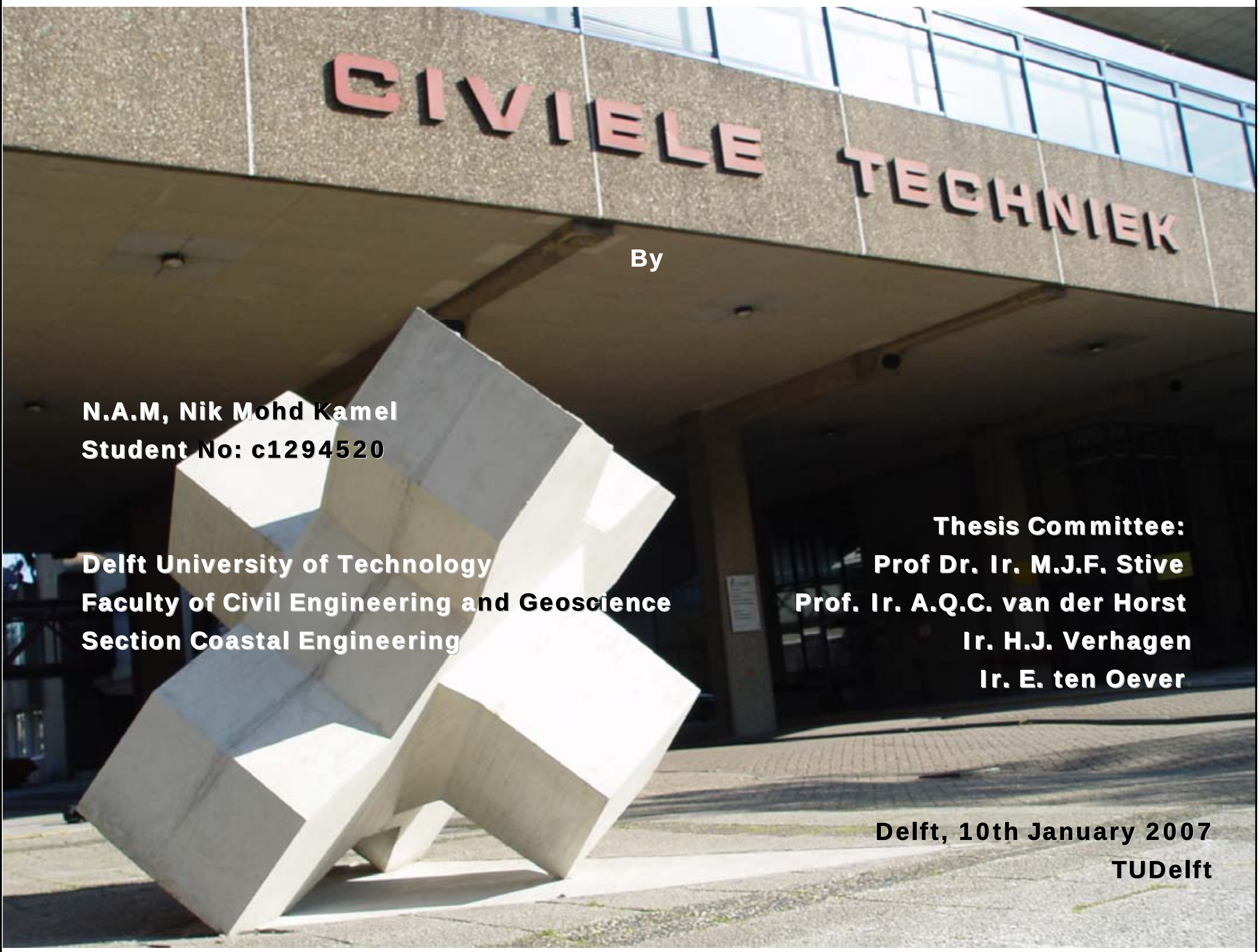
EXPERIMENTAL STUDY ON XBLOC® PLACEMENTS FOR BREAKWATER CURVATURE SECTIONS

Master of Science Thesis



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Cover Photo: $3m^3$ *of Xbloc unit courtesy of DMC in front of TUDelft Civil Engineering and Geoscience Faculty, Stevinweg 1, Delft (Http://gallery.citg.tudelft.nl/xbloc)*

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Submitted in partial fulfilment of the
requirements for the award of the degree of

Master of Science Thesis

In

Civil Engineering Specialisation in Hydraulic Section

From

Delft University of Technology
Faculty of Civil Engineering and Geoscience
Section Hydraulic Engineering, Coastal Engineering

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ACKNOWLEDGEMENT

With the delivery of this master thesis, marks the completion of my MSc study at the Delft University of Technology, Faculty of Civil Engineering and Geoscience, Section of Coastal Engineering. The study was performed in association with Delta Marine Consultants (DMC) in Gouda, The Netherlands.

This study aims to improve the quality of the placement of the Xbloc on a breakwater slope and hence in relation to the overall development of the Xbloc as concrete armour unit. In the completion of this study, I have personally gained countless information and experiences especially in leading the path for me to broaden my knowledge further in the field of Coastal Engineering.

Therefore, I would like to express my gratitude and appreciation to my supervising thesis committee, Prof. Ir. Dr. M.J.F. Stive (TUDelft), Prof. Ir. A.Q.C. van der Horst (TUDelft), Ir. H.J. Verhagen (TUDelft) and Ir. E. ten Oever (DMC) for their utmost guidance, support and knowledge in the realisation of this thesis.

My profound thanks to Delta Marine Consultants and the staff for the opportunities and assistance in obtaining the facilities, knowledge and time spent for this research. To my colleagues of MSc students in TUDelft, and to all my Malaysian friends who have supported and assisted me in one way or another contributing in the completion of this thesis. Thank you for creating the good atmosphere and making my life in the Netherlands feels so much at home.

Last but not least, a very big thank you to my parents, my wife, my 1-year old son and all in my family for their continuous support and encouragement.

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ABSTRACT

The use of concrete armour layer units is becoming more common nowadays as a replacement for the rock armour in the breakwater rubble mound design. The development of concrete armour units in time led to various individual types and forms with specific individual characteristics. One of the latest developments of concrete armour layer units is the Xbloc® unit by Delta Marine Consultants (DMC). The primary objective of this thesis is to investigate and validate the study of the placement of the Xbloc unit specifically on a curved section of the breakwater using a large scale model test.

Xbloc unit are placed on a breakwater slope row by row starting from bottom. Then the placement will be continued to another new row above until the units are completely covering the whole slope of the breakwater. Placement of the Xbloc unit on a straight section is quite straight forward with a constant relation between the surrounding units. The relations are based on the horizontal distances to the other unit in the same row and the distance to the unit upslope on the next row above. With a correct placement distances a required packing density and the interlocking effect between the units can be achieved.

However, the relations of the distances are not applicable for a curved section of a breakwater. A curved section of a breakwater has a difference in radius length further upslope. The differences in radius lengths create improper placement distances between the units in the higher upslope. The horizontal distance between the two units becoming smaller and very close to each other. Eventually one unit has to be left out. The calculation of the packing density are also differs from the method used to calculate for the unit on a straight section. Hence, a new method was used to calculate the packing density for the breakwater curved section.

The relations of the unit placement distances on a breakwater curve have been studied by ten Oever in his MSc thesis in 2006. A theoretically study are made and was validated by a placement tests on a model of a breakwater straight section. From the study, a computer model was developed to generate an optimal design grid position to place the Xbloc unit on a breakwater slope. ten Oever suggested a new unit are place off centre with an angle when the horizontal distances on the row below are becoming closer and closer. The off centre distance will be based on the horizontal distances between the two units. The maximum off centre distance are 0.4D and the unit will be left out. The angle is called the unit adjust angle and to be 45^0 from the horizontal line.

Hence, this thesis focuses on validating the design placement grid generated by the computer model. Two placement tests have been performed using a model of a quarter of a breakwater head. The first test was performed following the generated design grid from the computer model. The output result of the final Xbloc position from the first placement tests was generally can be achieved according to the design grid with some distortion. The distortions of the units are mostly on the upper part of the breakwater slope especially in the row above where there is a left out unit. Furthermore, the packing density was 3% lower than the required theoretical packing density.

In accordance to the first placement test, the second placement test was made to further improve the placement of the Xbloc unit. The second test is performed by correcting the design grid by using a coherent judgement before placing a new unit. Judgments are made by visually looking to the overview of the units in surrounding to ensure the new unit are placed in a suitable position for better fit between the two base units. The packing density resulted in higher values. Most of the units after the row where there is a left out unit are placed with a lower upslope distances than the design grid. The gap resulted from the left out unit are also being reduced when the unit a placed with a lower upslope distances.

In conclusion, the placement quality can be improved by lowering the upslope distances in the computer algorithm for generating the optimal design grid. This could possibly be done by changing the parameters of maximal off centre distance to 0.3D and unit adjust angle in the order of 30^0 to 40^0.

A comparison of the placement made in the laboratory and the placement of the prototype unit from the breakwater project in Port Oriel are made. Although a direct comparison could not be made in accordance to the relations between the placement grids, nevertheless there are several conclusions that can be drawn from the placement made in Port Oriel. The placement of the units in the Port Oriel was denser than the placement of the model units in the laboratory. This is mainly due to the larger forces on the edges of the units and due to the use of the excavator which actively pushed the units into a tight placement pattern. This is not done in the laboratory as the placements made are based on the use of a crane. Denser placement is acceptable for the stability of the armour layer but it leads to higher concrete use on the breakwater head.

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Chapter 1

Introduction

The work presented in this thesis is a continuation of the study made previously in January 2006 on the topic of "*Theoretical and Experimental Study on the Placement of Xbloc*" by ten Oever (2006). The latter study focused on the theoretical placement of the Xbloc unit for the straight and curved section of the breakwater which includes the grid design, placement accuracy and the quality control. Experiments were also has been done to verify the outcome from the theoretical study.

The present study is also dealing with the placement of the Xbloc unit but this time by experimentally. This study was focusing at the placements of the Xbloc unit on the curved section or on the breakwater head. In the study done by ten Oever, (2006), the experiment on the placements of the Xbloc unit on a curved section have actually been done. However, it was done on a straight (trunk) section and not on a real curved breakwater with placing the units as if they were on a curved section. The results from the previous study have lead to a development of a computer model which generates a grid for placing the Xbloc units. The grids that generated from the computer model are used in this experimental study to verify whether it is possible to construct it and recommendation will be made to enhance the quality of the placements if necessary.

1.1 Background

As a general introduction, Xbloc is a single layer interlocking concrete armour unit. It was invented by Delta Marine Consultant (DMC) in The Netherlands in 2001 and was introduced in September 2003. The use of the Xbloc is as a single armour layer unit for a breakwater which serves as a first layer of impact protection from the waves. The development of the unit is based on several concepts of existing armour unit with many physical model and prototype tests. Looking at the development, breakwaters traditionally are made by use of a composition of several layers of rocks and commonly known as a rubble mound breakwater. The top layer or armour layer were consisted of bigger and heavier stones than the one below to withstand a specific load from the wave attacks. Rock is a natural material and in some cases, it is hardly available in some countries and very expensive to obtain. Some may have to be imported and transported a long way from other countries before it can reach the destination in order to get a larger size with a certain type of quality. This is very impractical in terms of planning, logistics and especially the cost of a certain projects. Hence, a concrete armour unit were introduced to replace the natural material having the same quality or better improved quality.

Typical characteristics of the armour unit are mostly related to its structural integrity and hydraulic stability where the unit need to be able to withstand load especially from impact of the waves. Usually, the armour units are almost placed randomly and some armour units consist of double layers on the slope. The Xbloc however, are used as a single layer armour unit on a breakwater similar like the Accropode which was first introduced in the breakwater design in 1980's as a single layered armour unit breakwater. The advantage of using the single layer armour units are translated in terms of economical benefits as less concrete material are use.

The Xbloc has a high interlocking criterion which has been tested and can be achieve even with a random orientation. This random orientation however, needs a suitable placement which positioning of the Xbloc units are done in a predefined staggered position with a placement grid. The placement grid was based on the horizontal distance and the upslope distance of the units and resulted to a diamond shape pattern of placement. The predefined grid for the placement of the units is essential in order to ensure a good interlocking between the units for the stability of the breakwater armour layer. Many experiments have been done on Xbloc performances namely the hydraulic stability, interlocking and structural integrity. Thus to comprehend the full development of the Xbloc unit, study on the placement are also vital giving a better performance and reliability of the unit.

1.2 Problem Definitions

At the moment, research on the Xbloc placement is only verified using the model of a straight section of a breakwater. The placement tests on a straight section were done either for placement of the Xbloc for a straight (trunk) section or placement of the Xbloc for a curve section. The placement of the Xbloc for the curve section was made on a straight section breakwater with the assumptions that the Xbloc unit acting and behaves as on a curve section.

A clear overview from the previous studies by ten Oever (2006) shows that the placements of the Xbloc unit are in relation with all the other surrounding units. This relation will affect the interlocking of the units and hence related to the overall stability of the armour layer. With the recommended placement according to the relations where the horizontal distances between two units should lies in the range of 95-120% of 1.33 of the unit size D, the recommended packing density will be constant throughout the position of the whole range of the unit. The placement pattern for the straight section of the breakwater will result in a diamond shaped placement pattern with a constant relation to the horizontal and upslope placement distances (ten Oever, 2006).

The placement of the Xbloc unit in relations with the other surrounding units on the straight section is quite constant and easy to construct. Nevertheless, this does not bring about contentment anymore for the curved section and for the breakwater head. The problem of the curve occurs due to the difference in radius length of the upslope rows of the breakwater which results in improper placement distances between the units at the higher upslope. The suggestion made by ten Oever was to shift the unit out to certain distance and angle or left the unit out whenever the unit was in a position where the two base units are too close (i.e., small horizontal distances). This left out unit will be creating a considerable amount of gap and will reduce the packing density significantly.

The assumptions made from the theoretical study were lead to a development of a computer model called the Xbloc Grid Generator to generate the placement grid. Hence, this study is to try to do the Xbloc placement according to the grids using a model of a real breakwater curve and verify whether the assumptions made in the computer model are correct.

1.3 Aims and Objectives

This thesis targets to enhance the quality of the Xbloc placement as a single armour layer on the curvature area of the breakwater. Since the different radius in the breakwater curvature resulting a complicated placement and inappropriate placement pattern of the unit, this study will be based on objectives as below:

- Primarily is to perform a placement test on the breakwater curvature section according to the placement grid that has been generated by the computer model.

- Secondly is to investigate and validate whether the placement of the Xbloc unit developed using the computer model is possible to be construct. This is also to see whether all the assumptions made was assumed correctly and the units are behaves as expected.

- Finally, the ultimate goal of this study is then to establish a good and optimal placement pattern for the Xbloc unit in the curvature section of the breakwater by improving the placement grid made previously. Any discrepancies will be analysed and corrected if necessary to enhance the placement quality of the Xbloc on a curve section.

1.4 Scope of Study

The scope of this study particularly concentrates on the Xbloc placement on a curvature section of the breakwater or the breakwater head. The study will be made based on the experimental work in a large 2.5x2.5 m^2 basin using a large physical model test of an Xbloc unit. The experiments are done with no influence on the waves since this experiment is only to investigate the placement of the Xbloc and not on the stability of the units. The placement tests will be made in dry conditions where the overview of the placement can be clearly seen.

1. At first, the study was made by creating the layout of the breakwater head model that need to be constructed in the basin. The model for the experimental test is based on the optimal designed of the curvature section as a representative part of the breakwater.
2. Secondly, the computer model called Xbloc Grid Generator are used with the selected optimal profile to see whether it is possible to place the Xbloc unit with a sufficient numbers on the breakwater layout in order to have a good overview resembling the placement of the prototype unit on a real breakwater head.
3. Then, after the breakwater head model has been constructed, the placement tests are made in two stages. These placement tests were made according to the grid resulted from the output of the computer design tool. First the placement test was made exactly according to the designed grid and secondly, the placement tests were also made according to the designed grid but this time the placement made with more towards coherent judgement. The judgement approach basically according to the overview of the unit visually in relations to other surrounding units whether the unit might has a better position to be placed.
4. The placement behaviour for each of the units are recorded and investigated for any difficulties encounters to see what are the best approach for placing the unit in difficult situation.
5. The placement tests results were then analysed and discrepancies were investigated. Packing Densities, horizontal and upslope distance are analysed to see the differences compared to the designed grid.
6. The encountered difference that has been analysed was used for recommendation in order to improve the placement quality of the Xbloc. Remarks especially the placement techniques and approach are made for any crucial information that lead can lead for a better placement.
7. Finally, placement results were compared with the prototype placement of the Xbloc unit from a project that has been executed in Port Oriel, Ireland.

In this study, the large scale of the Xbloc unit are used in order to get the result as close as the Xbloc in reality especially the way it is behave. The results would be then comparable to the latter study by ten Oever (2006) and most importantly, the test done would resemble the placement behaviour as in the prototype unit.

1.5. APPROACH AND RESEARCH METHODOLOGY

This study is divided into five parts. First, it was focused on the finding and designing the most optimal curvature section of the breakwater to be designed to fit in the 2.5 x 2.5 m^2 basins. The basin is located at the TUDelft Hydraulic laboratory with a dimension of 2.5(L) x 2.5(B) x 2.0(D) m^3. This breakwater curvature profile is needed in order to use as an input in the computer model for generating the optimal grid. The profile is designed based on the size of the Xbloc available. Several layouts were considered and compared to see which one are the optimum of all in resembling the real breakwater head with a sufficient amount of surface area to place and Xbloc unit. Designing the curvature section of the breakwater will be based on the recommended/typical design profile of the Xbloc armour unit which consist of dimensions of breakwater profile with a slope ratio of 3:4 [V:H].

The computer model that has been used basically is a software tool that generates an optimal placement grid which includes all the variables encountered in the analysis of a placement of an Xbloc unit on the breakwater which later will be discuss in Chapter 2. The computer model is available at the DMC office and was develop by ten Oever in his MSc study in 2006 on the theoretical placement of the Xbloc unit on the breakwater.

Secondly, to obtain an insight and to get the feel on how the Xbloc unit are really behaved. A smaller scale of the Xbloc unit that is available at the DMC office was used. At first, the behaviour of the small Xbloc unit will be investigated and a small breakwater round head model will be used which also available at the DMC. Placements are done on the smaller scale breakwater head to see what is the expected behaviour and results of the placement of the Xbloc unit. With this, a location of the left out unit can be estimated which normally lies after row 5. Thus, at this location the design water level was chosen and has been also taken into consideration when designing the optimal layout for the breakwater head.

Thirdly, to validate the experimental works done in the previous study of Xbloc placement on a breakwater curved section large experimental setups are made. The curvature section of the breakwater was made based on a profile which described in earlier paragraphs consist of a quarter section of a breakwater head. The tests are made in a static dry conditions with no influence on waves as this experiments only interested for the unit placement and not for the hydraulic stability. The model of the Xbloc unit is available in the size of 5kg which is approximately 1:10 in the scale for the dimension of the typical breakwater application.

Units will be placed using hoisting equipments acting as a crane and a visual measurement system will be used using a laser to see the positions each of the units after the placement test were conducted. The Xbloc unit are placed accordingly to the output result of the computer model. The result of packing density, horizontal and upslope distance and units interlocking within the units will be examined throughout the test results.

Placement distances will be made according to the values suggested by ten Oever as shown in the table below:

Table 2.1 – Placing Distances versus Unit Size

Unit Size, m^3	Dx (horizontal Distance)	Dy (Upslope Distance
$V \leq 5$	1.30D	0.64D
$5 < V \leq 12$	1.33D	0.655D
$12 < V$	1.36D	0.67D

**D – Xbloc Length* (ten Oever, 2006)

The required results from the experiments to achieve are based on the recommended design packing density for Xbloc unit which is $1.20/D^2$. Calculations of the packing density are made slightly different compared by method used by ten Oever (2006) in his study. Basically, the units in a row were schematized and the surface areas were computed by adding up parts several triangles covering up the surface area of the unit covering the breakwater.

Fourthly, the results from the placement tests were investigated. This was done mainly by investigating the unit's deviations from the designed grid, values of packing densities, and the relations as well the values of the unit's upslope and horizontal distances. These values were then compared between the designed grid, first and second placement test. The placement patterns were also looked at to see whether deviations or errors in placement will leads to cumulative errors.

Finally, the last part of the study are done by investigating and comparing the results of the experimental work to the placement data from the real case study of the breakwater construction using Xbloc unit from the Port Oriel in Ireland. The data from the project in Port Oriel was actually not available as the contractor did not actually perform the placement according to the designed grid. Nevertheless, photographs of the unit's placements were available to be analysed and to be compared to the placement made in the laboratory.

Chapter 2

Literature Review

In this section, preliminary results and discussions related to the placement of the Xbloc unit will be briefly discussed. It is important at first to know why this study is important and what constitutes the problem related to placement of the Xbloc unit on the breakwater head.

In an attempt to perform a placement test for the Xbloc unit on the breakwater head, an insight information are important in order to understand the concept of the Xbloc unit in term of its physical characteristics, behaviours, method to place and the related placement problems. Relevant aspects will be used as a guide in order to achieve the objectives of this study. The chapter will discuss the design of the breakwater using Xbloc and the current methods and practises used for placing the Xbloc unit on the slope. This includes the use of the computer model to generate the theoretical placement grid.

2.1 Breakwater in General

Breakwaters play a major contribution along the coasts of many parts of the world today. Its role in protecting a certain constituent of the coast from the wave actions and sometimes from the currents makes it as one of the very good solutions in coastal protection works. The primary protection using breakwaters mostly used to protect a harbour which is designed to accommodate safe navigational and berthing of the vessel in the port is by eliminating or reducing the wave actions. Siltation problems can also be eliminated or reduced in the access channel by introducing the breakwaters.

The existence of the breakwaters determines the functional requirements to design a particular port. The major constituent of the cost to build a port is normally contributed with a large percentage of expenditure just for a breakwater itself. The breakwaters are generally very expensive structures and the cost increases dramatically with the increasing of the water depth. A large port with a deep design vessel draught sometimes requires a long breakwater in a very deep water depth. This will result in very costly breakwater designs and constructions. This shows how important the impact of the breakwater and a proper design of a breakwater are needed in order to avoid hindrance of port operations due to the failure of the breakwaters.

Breakwaters can come in many forms and traditionally, the most well known breakwaters are the breakwaters composed of natural materials such as rocks which are known as rubble mound breakwaters. The type of breakwaters depends on their structural features. While the choice of the breakwater types often

depends on the availability of the material, site conditions and local experiences. The rubble mound type of breakwater is most simple and consists only of a mound of stones. The principle of the structure is that there is a core layer which consists of finer material and larger stones covering the core layer called an armour layer. The armour layers are built with large sized stones to resist displacements due to wave forces. Large stones however can be very expensive and difficult to obtain in certain parts of the world.
The introduction of the armour layer which consists of materials made from concrete for the breakwater replaced the big sized stones to a smaller size material. The concrete armour layer can be smaller in terms of the volume as compared to the large stones but it has the same or higher hydraulic stability towards the wave loads. The concrete armour unit can consists of two layers or one single layer like the Accropode and the Xbloc.

Some of the concrete armour units in use are:

- Cubes (-)
- Tetrapod, 1950
- Stabit, 1961
- Akmon, 1962
- Dolos, 1963
- Cob, 1969
- Antifer Blocks, 1973
- Seabee, 1978
- Shed, 1982
- Accropode, 1982
- Core-loc, 1996
- Xbloc, 2003

The concrete armour unit development began with concrete cube units. The concrete armour unit at first were merely has a stability due from its own weight. It is low in hydraulic stability but has a high structural stability. In 1950 there is the introduction of a concrete armour unit called Tetrapod which also has a stability with the units own weight with slight interlocking. The unit mostly were placed in a double layer armour system. The development moves further in second stage with an armour unit that has a characteristic in improving the interlocking. The development of the unit from this point was designed in such towards a slenderer type of body. This slender body is weak in terms of the unit structural stability and may leak to progressive failure if the units are breakage.

Thus, in 1980 the development of the concrete armour unit was in the new next stage with a single layer armour unit was introduced. The unit has a bulky shape type with a high interlocking criterion for better hydraulic stability and better structural integrity. Single placements of the units initiate an economical solution. The first type of this unit is Accropod which introduced in 1982.

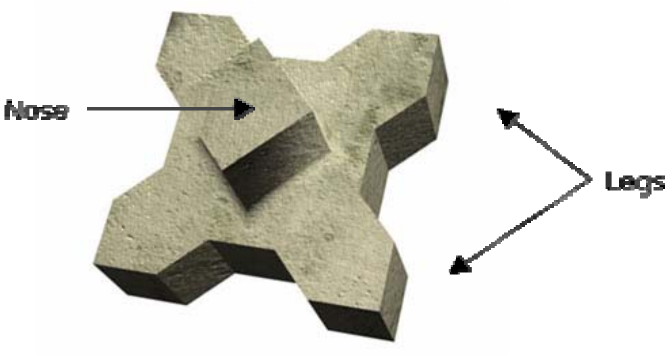
Furthermore, there is also a development of the concrete armour unit which has a friction criterion for its stability. The developments start in late 1060 and consist of a uniformly placed armour unit in a single layer system. The examples of this type of armour unit are Cob and Shed. The Xbloc was made with a basis to introduce a concrete armour unit with a high interlocking criterion which provide hydraulic stability with a structural stability. Xbloc unit is also easy to handle with an easy placement during the project execution.

2.2 Xbloc and Breakwater Design

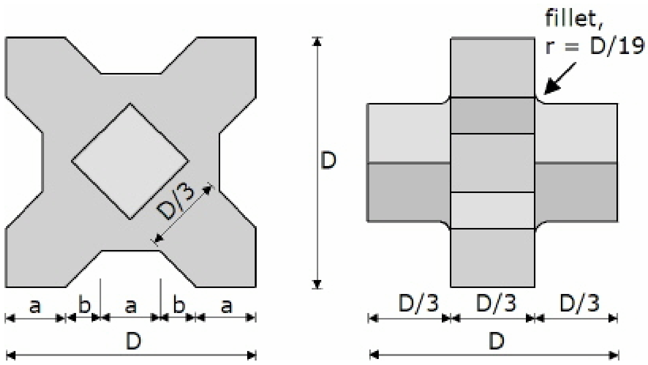
This section briefly discusses the insight into the Xbloc to see the units' characteristics and its performance in its relation to placement and the breakwater design. It is important to get into the insight of the Xbloc as the characteristics of the units determine the way the unit is to be handled during placement as well as the unit's performance in terms of interlocking with the other units. Xbloc standard breakwater design will also be discussed as the design will determine the dimension and the characteristics of the breakwater to be constructed in the basin at the TUDelft laboratory.

2.2.1 Xbloc Unit

The Xbloc armour layer has a specific concept of design when used as a breakwater armour layer unit. The information used for the concept design is shown in the figure below:



Xbloc Layout



Source: Xbloc Design Manual

Figure 2.1 Xbloc Dimensions Indicator

Figure 2.1 shows the basic dimension used to determine the size of the Xbloc. The significant features of the Xbloc unit are the 4 rectangular pointed legs with 2 cubes attached in the centre. The unit weight of the unit to be used for the design can be described in terms of the unit size D.

The characteristics shape of the Xbloc has an influence in terms of the units' ability to interlock with each other. Due to the fact that the Xbloc has only two faces, the Xbloc has more sides for interlocking. The Xbloc has the ability to easily interlock with adjacent blocks on the slope and provide automatic interlocking. ten Oever described the shape of the Xbloc as a characteristic with no anvils and has even distributed notches which can ensure more ease of placement and proper interlocking. (ten Oever, 2006). With the interlocking feature it will bring advantage to the overall stability of the armour unit. The ease of placement was benefited from the shape of the Xbloc due to the fact that the blocks can be placed in any orientation for each of the individual unit.

Xbloc Hydraulic characteristics and Xbloc breakwater design

The Xbloc performance in terms of stability was done based on several hydraulic tests which are presented in a technical paper by Bakker et al in 2006. The stability numbers for the Xbloc used for the design are presented below:

$$\frac{H_s}{\Delta D_n} = 2.8 \quad \text{(Trunks)} \qquad \text{and} \qquad \frac{H_s}{\Delta D_n} = 2.57 \quad \text{(Breakwater head)}$$

Where,
Hs – Significant wave height
D_n – nominal diameter of armour unit [$V^{1/3}$]
Δ - Relative Density, $\Delta = \left[\frac{\rho_{concrete}}{\rho_{concrete}} - 1 \right]$

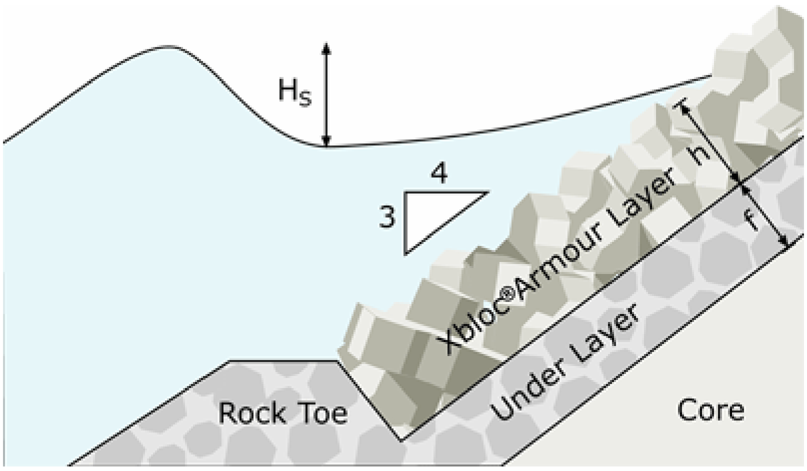
For additional information regarding the stability of the Xbloc unit, Xbloc has a K_D value of 16 and 13 for trunks and head sections consecutively which need to be applied in the design. The recommended armour units to be used for the breakwater head are 25% heavier than the trunk sections. K_D is the value of coefficients which signifies the degree of damage related to the definition of design wave. However, Xbloc was designed to have no degree of damage at all. The coefficient K_D actually used in the Hudson formula represents the function of damage which is related to the weight of the armour unit which is based on several sets of experiments. The formula consists of several parameters which includes the significant wave height H and slope angle α which is expressed in terms of unit weight. (d' Angremond et al, 2001).

Hudson formula, $W \geq \frac{\rho_r g H^3}{\Delta^3 K_D \cot\alpha}$ Surf similarity parameter,

$$\zeta_z = \frac{\tan\alpha}{H_s / L}$$

The Hudson's formula was not actually applicable for the single layer armour unit due to the slope effect. However the K_D values were used only to show the relations for comparison with the degree of damage with other type of armour unit (Bakker et al, 2006). The stability number used for the Xbloc was derived from the tests and with a relation to the surf similarity parameter which includes the wave period in terms of wave length L.

For the design layout of a breakwater with an Xbloc as an armour unit, the figure below shows the recommended layout of cross section of the Xbloc armoured layer breakwater:



Source: Xbloc Design Manual

Figure 2.2 Xbloc Armoured Layer Breakwater Cross Section Layout

The standard design for slope of the breakwater with the Xbloc armour layer has to be in the order of 3:4 (Vertical:Horizontal) placing on top of a layer of rocks or the underlayer. The armour layer or the first layer has the dimension of thickness in the order of the size of the Xbloc unit size D. The thickness of the underlayer depends on the unit size of the Xbloc and the recommended values can be obtained in the design table from Xbloc manual.

The unit weight for the underlayer or the filter layer needed is equal to:

$$W_{filter} = \frac{W_{Xbloc}}{15} to \frac{W_{Xbloc}}{7}$$

The filter layer formula is used in order to determine the dimension of stones to be constructed in the laboratory for the test in order to represent an actual situation when representing the smaller scale of the Xbloc unit.

2.2.2 Breakwater Head

Focusing the performance of the Xbloc on the curvature section in relation to its placement for the breakwater head is rather important. There are special physical processes represented by the breakwater heads which lead to a higher load compared to the trunk section. With improper placement, the Xbloc on the breakwater head could not perform to its best capability.

In the CUR report 169, Manual on the use of Rock pp.5-84, 1995 there is a quote which was taken from Jensen in 1984 stated that a large velocities and wave forces are lead when waves are forces to break around the breakwater heads. Only a limited area of the head is highly exposed with a specific wave direction. The area is typically around the still water level where the wave orthogonal is tangent to the surface and on the lee side of the area. It was concluded that, for any breakwater heads design procedures, the weight of the armour layer are to be increased to achieve the same stability as the stability of the trunk sections. It was also suggested that the slope of the breakwater can be made gentler than the trunk alternatively or combinations of those two. Additionally, Jensen also mentioned that the in the breakwater head, the damage curve are usually steeper compared to the trunk leading to a progressive damage.

Moreover, Burcharth also mentioned in an edited book by Abbot et al is that the hydraulic stability of armour unit in the breakwater head is reduced as in the trunk sections. He added that in case of shallow water situations, the toe in the area is also vulnerable to damage which also can prompt the failure and instability of the armour layer. Bigger armour units and flatter slope were suggested for a stable armour unit in breakwater heads. (Abbott et al, 1994). Providing the 25% heavier weight of the Xbloc unit for the breakwater head might be insufficient if the Xbloc was not properly in place. Hence, attention to details in obtaining a good quality placement are essentials to ensure good interlocking between the units hence providing good stability on the breakwater head.

2.2.3 Xbloc Special Toe Unit

In accordance to the usage of the Xbloc special toe unit, the placement pattern of the Xbloc on a breakwater may be affected. Currently, there is no specific guideline or recommendation on how the unit are to be placed. The characteristic shape of the Xbloc special toe unit is exactly the same as the Xbloc unit but only without one of the nose.

The toe of a breakwater is one of the most important aspect for the overall stability of the breakwater namely for the armour unit. The armour layer shall be supports by a toe as an anchor on the sea bed. The toe is acts as a berm structure and supporting the armour layer. With the toe, the use of the armour layer can also be limited need not to be constructed until the water depth which then saves on the material cost. The standard material used for the toe is made from a natural rocks being 1/10 of the weight of the armour unit approximately the same size as the undrlayer. Recently in 2005, DMC has developed a special Xbloc toe unit to cater for the Xbloc armour layer unit. The development of the toe unit was discovered during one of the test by DMC where the Xbloc in the first row lying on the sea bed may roll to the incoming waves. The only difference of the special toe unit from the ordinary Xbloc unit is that the toe unit has only one nose at one side and a flat surface acting as a base at the other side.

Figure 2.3 Special Xbloc Toe Unit

The advantage of the Xbloc toe unit is that it does not sensitive to overturning during waves action. It can be part of the armour layer and has a higher stability compared to the conventional rock toe.

Nevertheless, further investigation is needed for the use of the special Xbloc toe unit. The question to be answered here for the special Xbloc toe unit is that a guideline on the method to place the toe unit is needed. The units' positions, horizontal distance between the two units as well as the orientation need to be investigated in order to see the performance of the toe unit. So far in reality, several methods has been adopted depending on the individual contractors including placing the toe unit very close apart creating like a chain of toe unit in the first row. This may be over designed and is not cost efficient due to the use of extra unneeded amount of concrete.

2.3 Xbloc Placement

The importance of positioning each of the unit into its proper placement within a certain allowable distance is very essential to obtain good hydraulic stability of the armour layer and the structural integrity of the individual Xbloc unit.

The recommended placement of the Xbloc unit is in relation to its surrounding unit distances, that is, the upslope and the horizontal distances. These distances are in a constant relation with each other. The influence of the placement of the Xbloc in terms of packing densities, placement pattern and its interlocking will be presented in the paragraph below.

2.3.1 Placement pattern and Guidelines

To achieve good hydraulic stability for the Xbloc unit, a placement pattern is necessary to ensure a good interlocking unit. The pattern is according to a predefined staggered grid. This grid is related to the distances of the unit in relation to the other surrounding units which consist of distances for horizontal direction and in the upslope direction.

Placement Pattern

In terms of the placement pattern related to the orientation of the Xbloc unit, as reported by Bakker et al (2006), "*there is no significant indication that pattern leads to a higher hydraulic stability*" as in Figure 2.4(b) compared to the random placement in Figure 2.4(a). Random placement is done by randomly placing variable orientation of the units while pattern placement is done in such a way that the units have a fixed pattern where all the orientation of the units is prescribed. Both were place on a slope with a predefined staggered grid as in Figure 2.4(a) & 2.4(b).

a) Random Placement **b) Pattern Placement**

Figure 2.4 Placement Pattern

In the same paper presented in Dubai, Bakker et al (2006) quoted which referring to a series of hydraulic tests done previously on Xbloc with a packing density of $1.23/D^2$ with a different placement pattern:

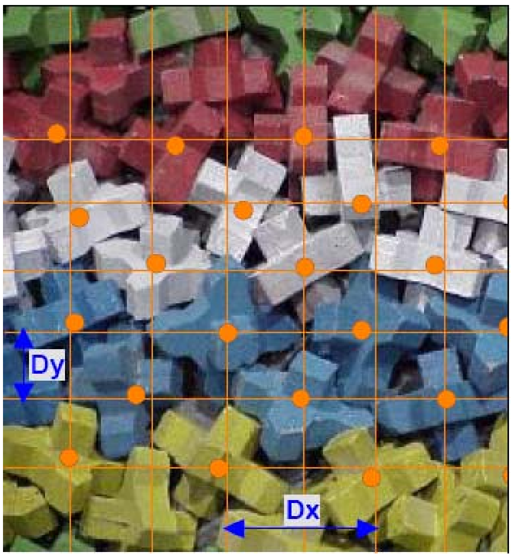
'During this test, no damage was observed but the maximum wave height was only $Hs/\Delta D_n$ = 3.74. During the test with random placement and with the same placement density ($1.23/D^2$), start of damage occurred at $Hs/\Delta D_n$ = 3.72 and no failure occurred whereas the maximum wave height was $Hs/\Delta D_n$ = 4.31'.

Bakker et al (2006)

Pattern placement was not adopted due to the practical difficulties for construction especially in a curved section and in the case of sloping bottoms. It has also not been investigated further. Hence, random placements with no degree of fixed orientation are adopted for the placement tests of the Xbloc on the breakwater head in this study. It was adopted since it was proven that the stability of the Xbloc in relation to the random placements is adequate from the results of the hydraulic tests .(Bakker et al, 2006).

Placement Guidelines

The only requirement for the Xbloc placement on the breakwater slope is the placement pattern which is based on a placement grid which is staggered and form a diamond shaped pattern. The pattern of such are based on the requirement of the placement of each Xbloc shall be secured by two other Xbloc in the row above and by contact with the under layer as mentioned in the Xbloc specifications. The units are separated by a horizontal distance (Dx) and upslope distance (Dy) as shown in Figure 2.5 below.



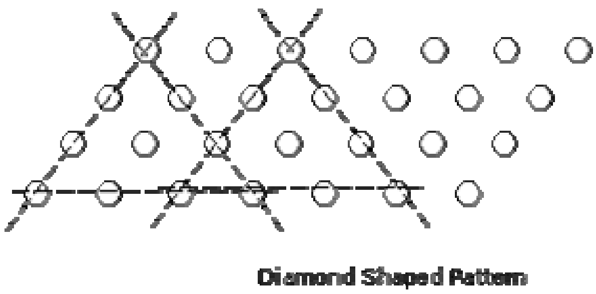


Figure 2.5 Staggered Placement Grid and Diamond Shaped Pattern

The grid shall have an approximate parallel line in the horizontal rows following the breakwater slope contour lines and within range of distance between the base units depending on the packing density.

The recommended placement for the Xbloc unit as in the Xbloc specifications is 1.33D and 0.64D for Horizontal and Upslope distances consecutively. This is done based on several tests which were performed at WL|Delft hydraulics in 2002. With the recommended placing distances, the resulted packing density would be in the order of $1.20/D^2$ which is the required recommended theoretical packing density. However, the recommended distances were used for an Xbloc unit size with less than $5m^3$. For the Xbloc size more than $5m^3$, the recommended distances are presented in the Table 2.1. This was simply due to more difficult placement for the larger size of the Xbloc unit during project execution. The corresponding packing densities related to the unit size are presented in Table 2.2. For a larger unit size, the packing density will drop as a result of the increment in the horizontal and upslope distances.

Table 2.1 Placing Distances versus Unit Size

Unit Size, m^3	**Dx (horizontal Distance)**	**Dy (Upslope Distance**
V ≤ 5	1.30D	0.64D
5 < V ≤ 12	1.33D	0.655D
12 < V	1.36D	0.67D

**D – Xbloc Length (ten Oever, 2006)*

Table 2.2 Packing Density with Respect to Unit volume size, V

Unit Size, m^3	**Packing Density**
V ≤ 5	$1.20/D^2$
5 < V ≤ 12	$1.15/D^2$
12 < V	$1.10/D^2$

The packing density of the Xbloc unit need to be checked in terms of curvature section of the breakwater as the values given are made from the tests of a trunk section of breakwater. The diamond shaped pattern does not fit perfectly in a curve section as well as with a variation by the toe level of the breakwater. With the variation of the breakwater radius in the curvature section of a breakwater or in the breakwater head, the horizontal and upslope placement could not be achieved with accordance to the recommended placing distances. The placement grid shall be modified in such good interlocking still maintained within the units which will be presented in section 2.4.

2.3.2 Packing Density

In order to access the quality of the placement of the breakwater, it is important to determine the number of the unit in a section of an armour layer of a breakwater. The number of units placed is essential for ensuring the right quantity needed for use in the breakwater which essentially determines the hydraulic stability. This quantity is expressed in terms of packing density or placement density as it is related to the number of unit that has been placed. The packing density is defined by the number of units per square meter. The method to measure the packing density is by measuring the distances between all the units. The following formula is used taken from ten Oever (2006) to measure the packing density of an Xbloc unit by measuring each of the units' numbers and distances individually.

$$PD = \frac{(N_x - 1)(N_y - 1)}{L_x L_y}$$ (ten Oever, 2006)

Where,

PD	= Packing Density	[1/m^2]
Nx	= horizontal number of units	
Ny	= number of horizontal rows	
Lx	= horizontal length of the section	[m]
Ly	= length up the slope along the slope	[m]

The test on placement density was done in 2002 based on a 2D test in Delft Hydraulics. The test results obtained are presented in the Figure 2.4 below which were obtained from a paper presented by Bakker et al in 2006. Tests have been done using variation of the Xbloc horizontal and upslope distance spacing of 1.11D – 1.29D and 0.63D – 0.73D consecutively. The results have been plotted using graphs of the stability number versus the placement density. Bakker et al (2006) described in the paper which referring to the graph in Figure 2.6, he quoted that:

'For placement densities above 1.18/D^2, higher placement densities lead to a better hydraulic stability. Furthermore, it can be concluded that for lower placement densities, the hydraulic stability is constant'.

Bakker et al (2006)

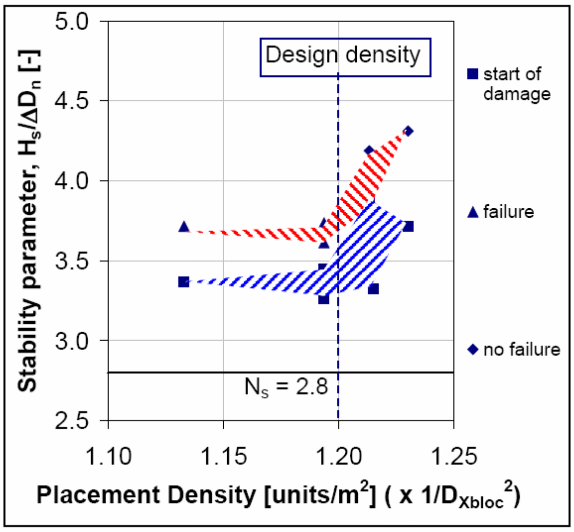


Figure 2.6 Placement Density Test Results by DMC

According to Bakker (2006), the design placement density is chosen to be 1.20/ D^2. It was found that for a lower placement densities, a settlement will occur and the units are settled leading to a placement density that are closed to the design placement density. This explains why packing densities below $1.18/D^2$ are considered to be constant and the low packing density affects the settlement of the units. The recommended range for packing density values are to be in the order of 98% to 105% of the required value.

However, no hydraulic test has been done to see the effect of the packing density on a breakwater curve or on a breakwater head. There is a hydraulic test performed on a breakwater head in 2004 in the multi-directional wave basin at WL|Delft Hydraulic which is available as a report in DMC. Although there is no progressive damage reported, the tests were done by only using one packing density value. The packing achieved was based on the numbers of the Xbloc unit placed on the breakwater head which is 104% higher than a theoretical value. DMC (2004). So it is not known what will be the effect of the hydraulic stability of the Xbloc on the breakwater head if the packing density is in the lower value of the recommended theoretical packing density.

ten Oever (2006) performed a placement test using 4.3 cm Xbloc units with varying horizontal placement distances between the units which was presented in his Msc study to see the effect on the horizontal distances on packing densities for an application on a breakwater head. With varying the horizontal distances, ten Oever suggested the packing densities shall be in the range of 95-120% from the theoretical values. ten Oever (2006) quoted:

'The 95% up to 120% the placement pattern and density were good. This range can be used to overcome curved sections of breakwater and toe level variations'.

Nevertheless, it has never been tested in the hydraulic test. Therefore, further hydraulic test on varying the packing densities on the breakwater head are highly recommended.

2.3.3 Interlocking

Apart from the placement pattern and packing densities, the placement method also needs to be investigated. It was recommended that to place the Xbloc unit, a special sling technique is advised with one of the Xbloc legs pointing downwards. It has been proven that by applying this method, it will provide a higher stability number. As a matter of fact, the sling techniques recommended above provide ease for the placement of the unit. The orientations of the units need to be in a manner that it has random orientation. This is to ensure interlocking with the neighbouring armour units. The interlocking is obtained by placing the armour unit in the middle between two base units. The interlocking strength of the unit is determined based on the pullout test where the unit will be tested experimentally to obtain the pull out forced. The pullout forced obtained for the Xbloc is in average approximately 7 times larger than the weight of the rock armour unit which varied between 5G and 10G according to Muttray at el in a technical paper (Muttray, 2005). Methods of placement, placement grid and diamond shaped pattern of the Xbloc unit enhanced the interlocking between the Xbloc units.

For the method to predict the interlocking between the units, the use of potential interlocking coefficients is recommended by then Oever (2006). The definition is that the potential is based only on the position of the surrounding units and each unit interacts with four other units both left and right above and below the units.

2.4 Current Methods and Practices of Placing the Xbloc Prototype unit

Placement tests to place the Xbloc units on the breakwater head were made as close as possible to resemble the placements made as for the placing of the Xbloc prototype units. Hence, this section is to elaborate the methods used to place the Xbloc prototype unit with the recommended procedures. Information is mostly taken from the Xbloc specification and recommendation from MSc study by ten Oever (2006).

In current practise, Xbloc concrete armour units were placed onto a breakwater are lifted using a sling lifted by a crane. The crane can be either positioned from the top of the breakwater crest or crane on the barge. The crane on the breakwater crest is far more stable and the placing accuracy is in the higher side as there are no influence form sea conditions.

Figure 2.7 Xbloc Prototype unit attached to a sling Lifted by a Crawler Crane

Source: www.xbloc.com: Port Oriel

Two methods of lifting the Xbloc unit using a sling are recommended. One is for the placement of the units in the first row where Xbloc were lifted with three points pointing downwards. See Figure 2.8(a). The units on the first row shal rest on 3 points for stability purposes. Furthermore, the second method is for placing the units on upslope where the Xbloc are lifted with one leg pointing downwards. See Figure 2.8(b). The ideal sling length as recommended by ten Oever (2006) is to be three times the characteristics size D.

a) Three Points Pointing Downwards

b) One Leg Pointing Downwards

Figure 2.8 Recommended lifting of the Xbloc Unit using a Sling

No requirements are made about the orientation of the Xbloc. Placing the units using the sling with one leg pointing downwards is a good technique to place the units easily on the required positions and leads to a good interlocking state. Nevertheless, units can be also placed using a clamp which introduce no stuck or jammed situation of the sling in between the units after placement is made.

Xbloc units were placed row by row horizontally from the first row starting from the toe. The units were then being placed further upslope and shall be secured by two other Xblocs in the row above and in contact with the underlayer. The placements of the unit row by row horizontally have a big advantage especially for the crane working on top of the breakwater. The lengths of the crane boom are not changed frequently which saves a lot of time.

In terms of placement quality, divers can check easily the placement made for each of the units and position can be adjusted easily when the units are placed row by row. Diver's assistance is needed for the placement quality when placing the units underwater by controlling the positions. The correct positions in relation to the placement grid are needed to ensure proper interlocking of the armour layer. When the units are placed above water, the positions were simply controlled by the use of land surveying equipments. The placement accuracy and quality for the first row of the units are important as it became as a base for the whole placement positions further upslope.

For the accuracy of the placement in relations to the placement grids, the positions of the Xbloc units were measured using land base surveying equipments such as theodolite and Differential Global Positioning System (DGPS).

2.5 Placement Issues in Breakwater Curvature Sections

These issues have been derived by ten Oever, 2006 in his thesis. At first, a hypothesis has been made for the relation between the horizontal placing distance and the upslope distance between the units. He suggested that the distance between two units which are in contact is constant and the minimum upslope distance is determined by the unit two rows before. Two units which have contact and support with the unit higher upslope have a constant distance. The upslope distances will decrease if the two units' horizontal distance below the upslope unit is increased. Upslope placement distance will be constant if approximately 120% of the horizontal placement is made. Due to the higher percentage of horizontal distance a decrease in packing density will also occur. From a test result done by DMC, a range of horizontal distance shall lie between 95% and 120% to achieve good packing density. This range can be used to overcome the curved section in the breakwater and toe level variations.

A problem that occurs in the breakwater curved section addressed by ten Oever is that a placement of Xbloc unit will get distorted due to the decreation of the radius length higher up slope. Placement of the units at one level of row higher upslope needs to be in between the two of the units in the row below. Fitting the unit in the middle of the two units below will be a problem with a small radius of breakwater curvature. The unit then need to be left out. ten Oever in 2006 suggested that the unit need to be shifted a little towards the side before the unit is left out. This shifting of the units is called off centre placement.

Tests has been done by ten Oever (2006) in his study to determine the range of the off centre unit placement by making a 0.1D, 0.2D and 0.3D off centre placement. The off centre placement are done to determine the off centre distance ΔX and the unit adjust angle α. The schematic diagram of the shifting unit distance and angle adopted from the ten Oever thesis are shown in Figure 2.9 below being u1, u2 and u3 as the neighbouring unit of the Xbloc and N is the shifted unit:

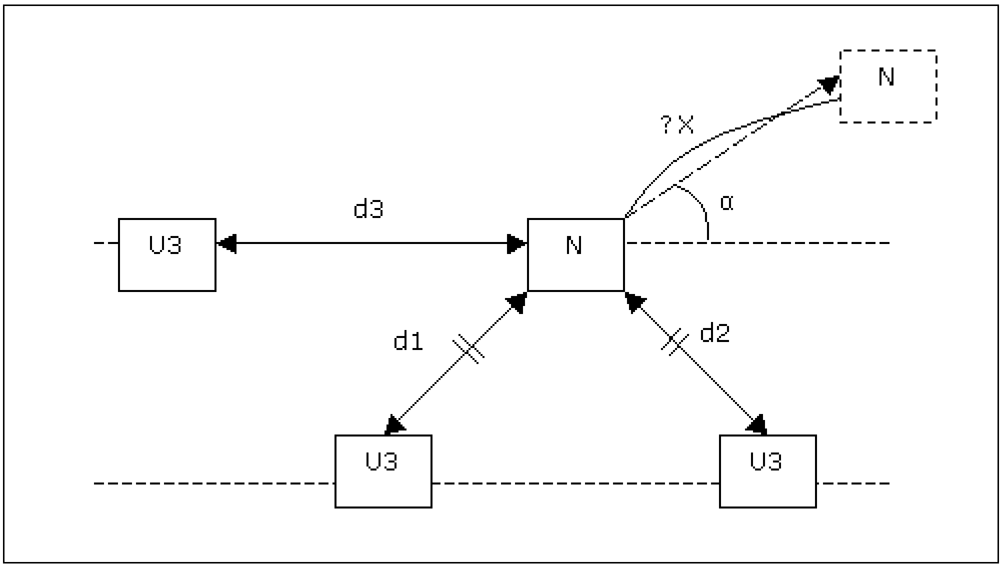


Figure 2.9 Schematic Diagram of Shifting the Unit by Δx

Source: ten Oever, 2006

Test revealed that the off centre distance shall be within the applicable range. All each of the unit has an ideal off centre distance due to its roll back to the centre position after placement. The range limited for the off centre placement is between 0.2D and 0.4D. This means that any unit with off centre distance smaller than 0.2D are left positioned in the centre position and a unit with an off centre distance larger than 0.4D are left out. The unit adjustment angle was found to be approximately constant being in 45 degrees angle. Therefore, a 45 degree angle will be used for the adjustment angle.

Having said this, the tests were done using the trunk section with units placing closely closed together as in the curvature sections. Thus, this thesis is to study and investigates clearly the adjustment distance and angle adopted.

2.6 Computer Model: Xbloc Grid Generator

The position of the Xbloc grid was generated by a computer model called Xbloc Grid Generator. This program is available in the DMC office and was made prior to the theoretical study of the Xbloc placement by ten Oever in 2006. The model is simple and easy to use provided that the user has the information on the breakwater profiles and the size of the Xbloc in terms of unit volume that needs to be used.

The breakwater cross section profile needed for the input are: (see Figure 2.10 and 2.10)

- Crest Level, CL
- Crest Width, CW
- Xbloc Crest, XC
- Toe Level, TL
- Slope (V:H)

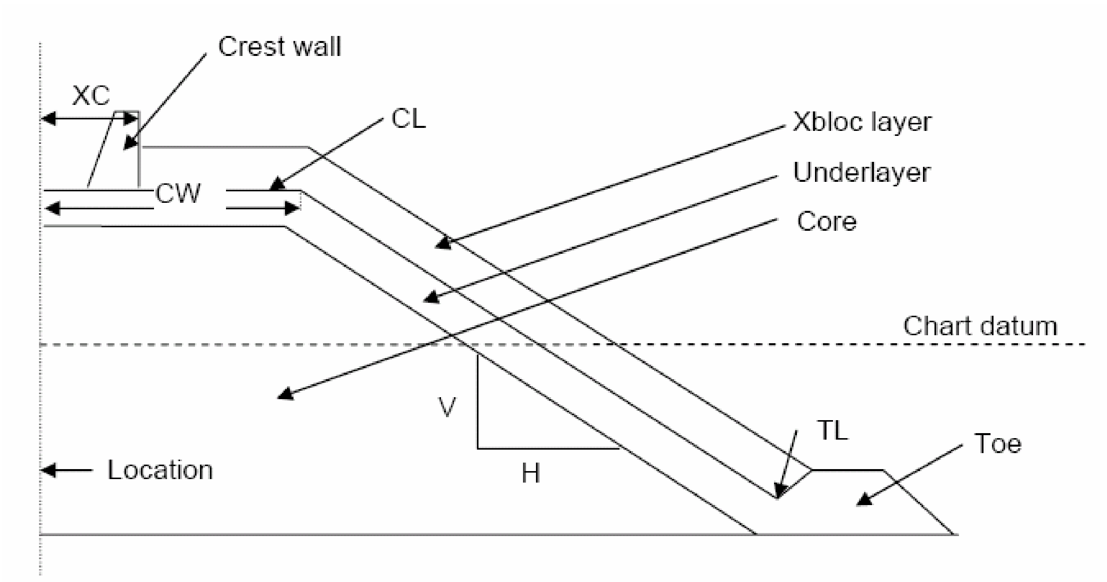


Figure 2.10 Definitions on Dimension of a Breakwater Cross Section

Source: ten Oever, 2006

The profile of the breakwater will be used and Xbloc grid will be generated part by part according to the cross section, which is separated by using coordinates and angles that shows the direction of the breakwater. The computer model will defined the optimum positions for the Xbloc grid by interpolating linearly between two given cross sections. The grids were computed from one row beginning from the very lowest level to further upslope up to the crest level where each is based on a favourable position which takes into account the distance to the surrounding units.

There are sections where some parameters need to be keyed in. At the moment, the parameters in the model are predefined with recommended values which are obtained from the previous study by ten Oever. The recommended parameters that need to be used are presented in Figure 2.11.

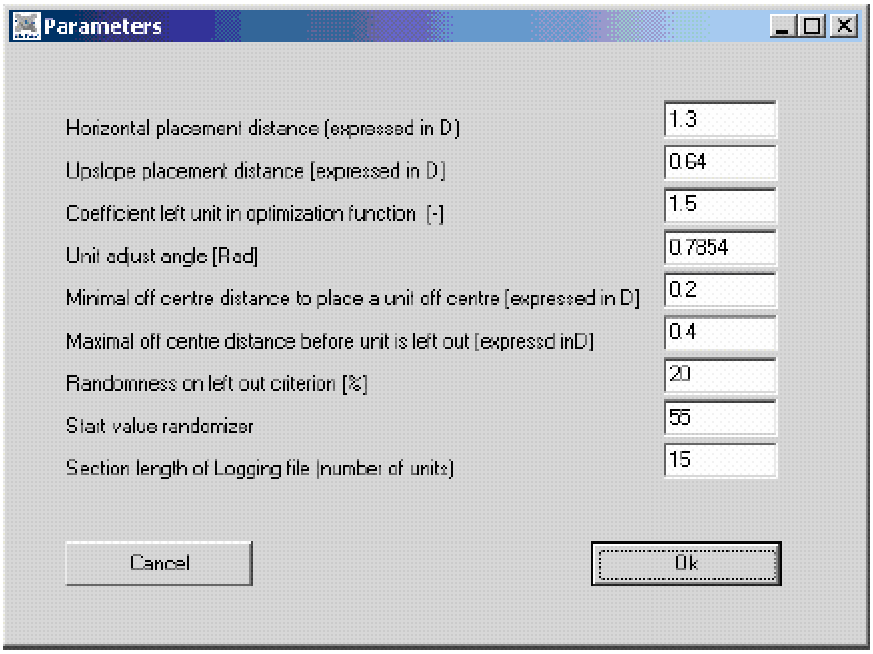


Figure 2.11 Recommended Values of Parameters

The important values for this study on placement of the Xbloc on a curve section is the values related to the minimal off centre distance to place a unit off centre, maximal off centre distance before unit is left out and the unit adjust angle. 0.2D, 0.4D and 45^0 are the recommended values to be used consecutively. The results from this study will lead to the determination on the validity of these values. This is due to, as mentioned previously, the determined factor of using the breakwater model from a straight section acting as a curved section. Hence, the recommended values found previously may need to be adjusted if it does not satisfy the actual Xbloc placement on the breakwater curved section.

In the user interface for the input in the program, there is an option for the type of toe to be used. Option 0 is used if Rock toe is to be used and option 1 is selected if the Special Xbloc is to be used. See Figure 2.12. The Xbloc toe unit will be computed on the basis of the bottom row and will be computed as the last part of the whole grid. The placements at the moment are based on some simplification where the units were placed in the middle with no adjustment and the level is copied from the level of the first row. Further studies in this area may lead to a new position for the Xbloc toe unit. This includes the orientation, spacing between two units and the distance from the first row of the Xbloc unit.

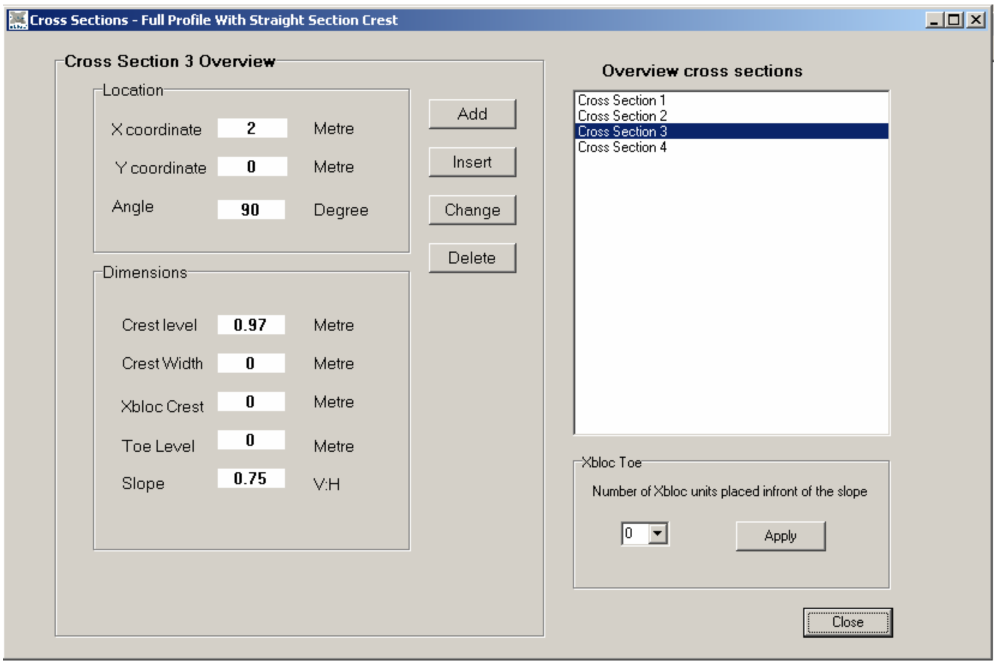


Figure 2.12 User Interface for Breakwater Cross Section

Finally, the result obtained from the computer model was a graphical overview of the Xbloc grid generated together with a window of a dynamical output form which can be used to adjust the design. With this, there is also a set of data that can be opened using an excel sheet. The data consist of the number of the Xbloc units together with the x,y,z coordinates of the individual units. This set of x,y,z data are used for the Xbloc placement test model.

The only limitation of this computer model to generate the Xbloc placement grid is the non-ability to compute the placement of the Xbloc with a very small radius especially on the crest. The computer model also could not compute the different slopes per cross section as well as computation for a very small cross section.

2.7 Conclusions

In conclusions, information on the issues of the placing the Xbloc unit on the breakwater head has been discussed and identified in order to perform and improve placement on the breakwater head. The information is obtained from various technical papers and Xbloc specification from DMC and previous MSc study by ten Oever in 2006. This includes the current practise to place the unit as well as the motivation for developing the computer model to generate the placement grid.

Xbloc is a bulky type concrete armour which its stability according to the units weight and its interlocking criteria. Placements are made with a sling attached with 3 point legs for the first row and 1 leg pointing downwards for unit higher upslope. This is due to the characteristics of the Xbloc shape the ease of placement and can be placed in random orientations. The pattern of the placement is in a diamond shaped pattern which placed starting from the first row to the row above in higher upslope.

Breakwater head consists of curvature sections that the radius will be smaller as it progress to higher upslope. Unit horizontal distance will be smaller and the unit will be placed off centre from 0.2D on the 45 degree line. The unit will be left out when the off centre distance reach 0.4D. This is verified using the placement tests on the straight section of the breakwater and was used in the computer model to generate the placement grid. Proper placement will affect the units interlocking which is vital as the overall stability of the breakwater armour to withstand wave forces. The quality of the placement can be assessed by checking the unit interlocking as well calculating the packing density of the unit on the slope.

Hence, further study on the placement of the Xbloc unit on the breakwater head are needed in order to verify the applicability of the generated computer model grid. Any unforeseen behaviour can be predicted and further improvement of the computer model to generate the optimal placement grid can be made.

Chapter 3

Experimental Setup

3.1. Introduction

In Chapter 2 it has been discussed that the placement of the Xbloc units on the breakwater curved section was only established by a theoretical description with an experiment analysis on a straight section. Therefore, tests were carried out in which the placements of the Xbloc units were done in a model of a real breakwater curve section.

Objectives

The main objective of the experiments is essentially to validate the theoretical Xbloc placement on the breakwater curve study presented in the thesis report by ten Oever, (2006). It is simply to see whether the grid generated by the computer grid is possible to be constructed.

Placement Tests Approaches

The placement tests are made according to the generated computer model design grid with 2 sets of placement tests series. By performing the placement tests of the Xbloc unit on a real breakwater curvature section, the actual behavior of the unit can be clearly seen. The assumptions made in the computer model can be well predicted and evaluated.

As for the first series of the test, the placement will be made according to the designed grid which used the recommended input of the parameter values derived from a previous study by ten Oever (2006) into the computer model as presented in Chapter 2. This will be the basis of the experiment to be performed. For the second placement test, placements are performed also according to the designed grid but this time the placements were made with coherent judgments. The word coherent judgment in this context means that the placements are made by visually looking at the overview of the whole placement especially in the surrounding unit where the new Xbloc unit is to be placed. The new Xbloc unit is placed not according to the designed grid only if it was believed that there is a better position for the unit. The position of the unit to be placed is preferably in a stable position and with possibilities to be in contact with the two other base units below.

Placements are done using the sling and with guidance as recommended for better placement accuracy and was made in a static dry conditions. The water was not used in this test as this test is only for the study to validate the placement theory of the Xbloc units on a curve section. Test done in water has already been done by ten Oever in 2006 and it is clear that there is no specific problem with the submerged placement. The only problem mentioned by ten Oever is that related to the packing density in which he quoted *'the unit should be guided with even more precision in between the base unit'* as resulted from the reduced gravity. (ten Oever, 2006). The assumptions made for the Xbloc influence by waves during placement has also been done by ten Oever in his MSc study. The response amplitude is in the order of the characteristics of the unit diameter D when the wave period is close to the period of the unit hanging on the crane (ten Oever, 2006).

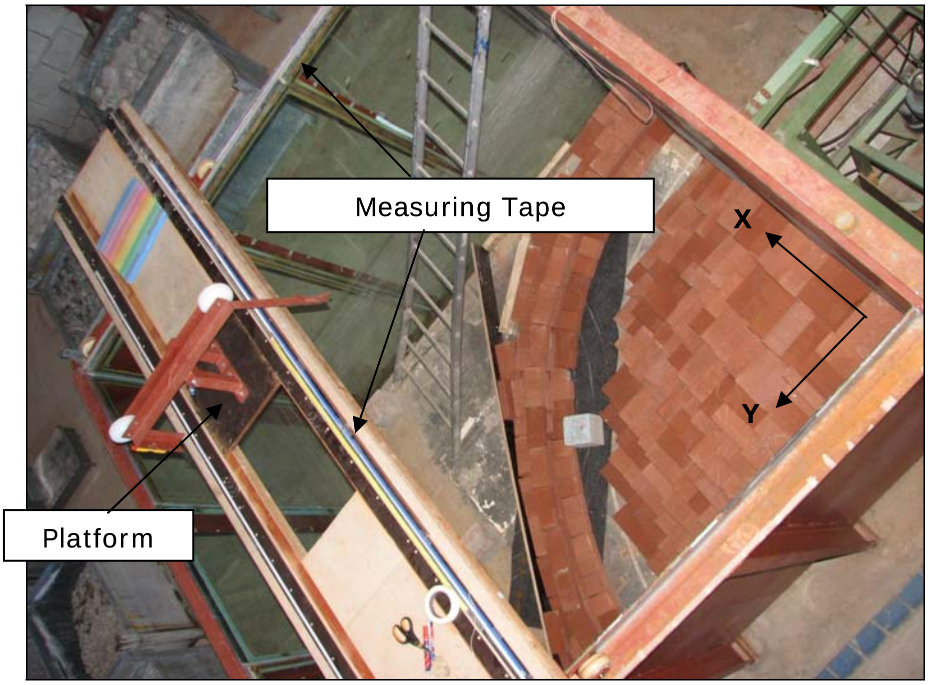
Each placement tests were done in 3 repetitive sequences to obtain reliable sets of measurements and also to enhance the common behavior of the Xbloc during the tests. Pictures are taken of each and every row after the placement perpendicular to the surfaced area in front of the breakwater.

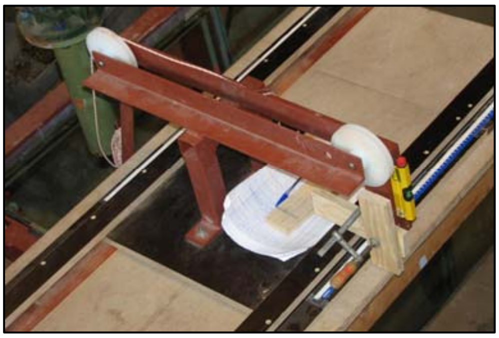
3.2. Model Setup (Test Facilities and Equipments)

Experiments were conducted in a 2.5x2.5m^2 basin with a 2.0m height in the laboratory at Delft University of technology. Figure 3.1 gives the overview of the test basin facilities.

Figure 3.1 Test Basin

On top of the basin, there is a beam acting as a platform attached with hoisting equipment that both could be moved across the basin. See Figure 3.2. This equipment is used to lower the Xbloc unit to the required positions acting as a crane when placing the prototype unit. Measurements were taken according to the attached measuring tape on the side of the basin as well as on top of the platform beam. The system used to position the Xbloc unit was based on x and y coordinates. These coordinates corresponded to the output from the computer model generated for each point of the Xbloc unit.





Top: Beam Platform on top of the basin.
Right: Hoisting equipment to hold and position the unit.

Figure 3.2 Platforms and Hoisting Equipment on Top of the Basin

The measurement device used for the tests is the laser beam pointing downwards directly on to the unit. This laser beam is attached to the hoisting equipment near the cable where it is used for lowering down the Xbloc unit. A water leveler is used to check in order to make sure the laser beam is in the vertical direction pointing downwards.

Figure 3.3 Laser Used for Measuring the Position of the Xbloc Unit

Xbloc Unit Model

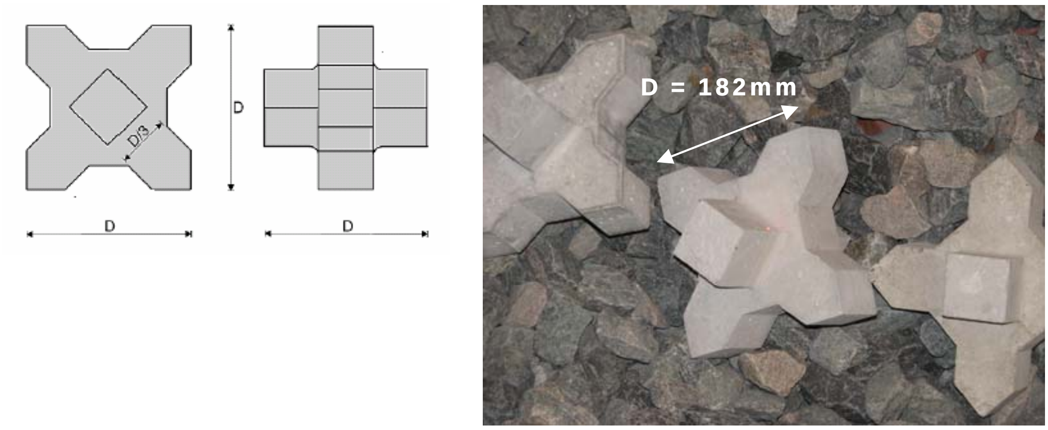


Figure 3.4 Xbloc Unit used for the Placement Test

The Xbloc unit used in the placement test has a dimension of D = 182mm with a volume of 2.0x10^{-3} m^3. The average weight of the unit is approximately 4.75kg with a concrete density of 2.375kg/m^3. The Xbloc unit model represents 1:10 scale of the size of the prototype unit with the dimension of D = 1.82m and volume of 2.0m^3. The units were fabricated in TUDelft laboratory and were used in the previous study by ten Oever (2006).

Breakwater Head Model

The breakwater head is made according to the designed layout is presented in Figure 3.10. The breakwater consists of a core made by piles of clay bricks stacked together forming the structure of the breakwater with the required slope. The bricks were placed according to the required dimensions and covered by a stones acting as an underlayer. The underlayer covering the core layer has a thickness of 0.13m. The recommended weight of the underlayer according to the Xbloc design manual should lie in the range between 1/15 to 1/7 of the Xbloc unit weight.

$$W_{filter} = \frac{W_{Xbloc}}{15} to \frac{W_{Xbloc}}{7}$$

This resulted weight of the stones for the underlayer from 4.75kg Xbloc unit lies in the range of 0.32kg to 0.68kg. The only available size of stones in the lab close to this range is W_{50} of 0.2kg with the D_{50} 20% smaller than the required stones. This stone size was selected and used for the placement tests. The stone size used is believed to have a minimal effect on the placement tests and since the tests were performed without any influence on hydraulic conditions it is acceptable. This is also true for the construction of the breakwater toe which uses the same order of the stone size.

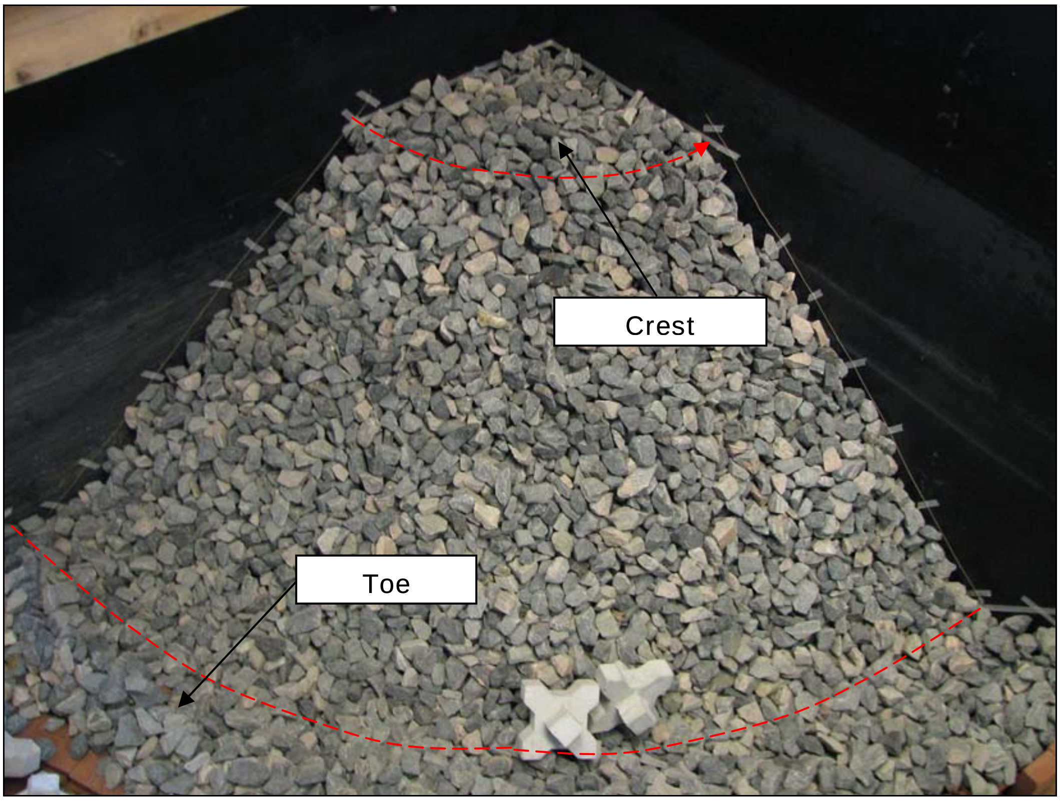


Figure 3.5 Overview of the Breakwater Head Model

3.3. Design Layout

The design layout for the breakwater head model was based on certain elements and boundary conditions. At first, the layout was based on the predetermined boundary conditions according to the size of the Xbloc unit model that is available. The size of the model that is available are representing a prototype unit of D = 1.82m for a design wave height of H_s 4.65m or a model of 1: 10.

The first dimension of the breakwater that can be determined using the design wave height are the location of the design water level. The design water level in practice are recommended to be situated at the radius of the breakwater which equivalent to 3 times design wave height Hs or $R_{DWL} = 3H_S$ regardless the water depth. The design water level in this placement test however are just imaginary and it is only used to determine the dimension of the breakwater head model.

With the curvature of the breakwater at DWL of R = 3Hs, it will represent the most extreme condition in case of impact from the wave actions onto the breakwater. With the selected radius, the curvature will be also the most critical area for the placement of the Xbloc as it represents the start of the sharpest and critical curvature in the placement pattern.

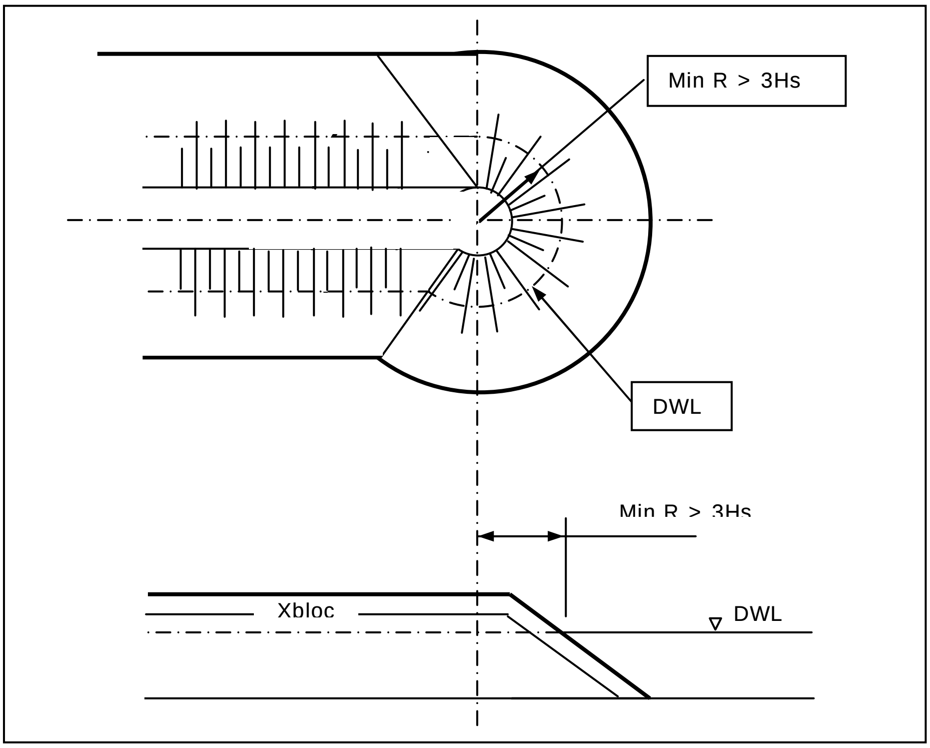


Figure 3.6 Designed Breakwater Radius

The layout then can be determined according to how the curvature of the breakwater is to be fitted in the $2.5x2.5m^2$ basin. The optimum and the best solutions will be adopted for designing the layout of the breakwater.

From the trial of placement test for breakwater curvature section done in the DMC office using the Xbloc size of 5.5cm, it was discovered that the left out unit were found generally beginning from row 5. This is the critical area where the unit starts to loose its packing density and hence loose its interlocking. Thus, with the information on the starting point where the left out unit begins, the breakwater model imaginary DWL height was determined which is based on the height of 5 rows of Xbloc placed together on the slope.

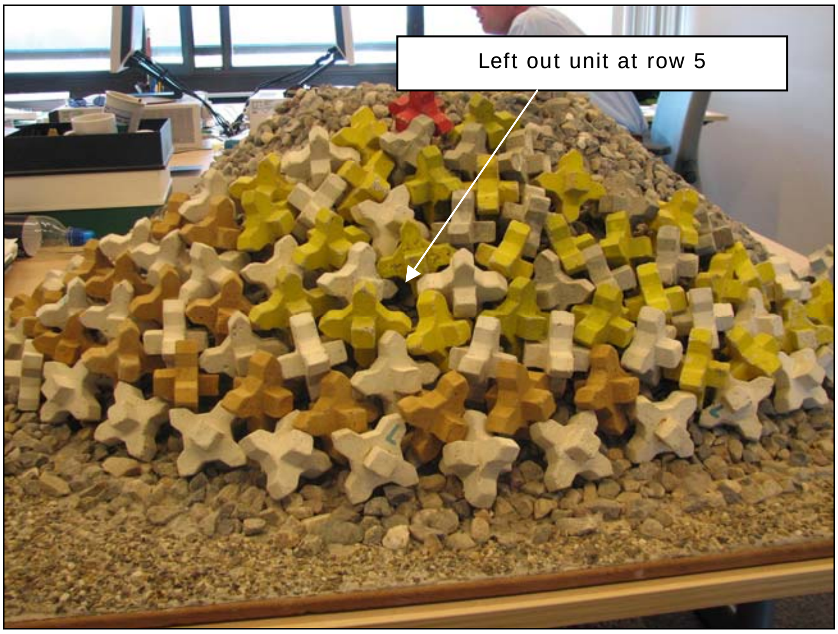


Figure 3.7 Starting point of the Left out Unit in Xbloc Trial Placement

The left out unit row chosen to be the level for the imaginary DWL is due to the fact that the impact from the waves is at the highest and most critical where the design water level is. Off course in reality, the critical location will be effected by other sources such as tidal variations. The selected location as the DWL are just to have an arbitary depth of the breakwater head model to represent the extreme case scenario.

3.3.1. Breakwater Profile

With the curvature of the breakwater obtained which was described in the previous sections, the layout of the breakwater to be fitted in the basin hence can be determined. The layout chosen for the breakwater head model is to be a section of a quarter of the breakwater head. This is found to be the optimum layout that can be used to enhance the effect of the placement test as much as possible.

The motivation in choosing the best layout depends on the most critical curvature section of the breakwater which is at the Design Water Level (DWL). The DWL is related to the radius of curvature which in turn is related to the 3 times H_s which represents the start of the sharpest curvature. It is the most critical part of the breakwater which experiences the highest impact load from the waves. The profile of the breakwater are then created for the placement to resemble the critical placement at the DWL. The sharp curvature will affect the placement pattern of the units and by analysing the placement for the critical area will ensure the quality of the total placement of the Xbloc unit on the breakwater.

The profiles then were chosen according to how large is the surface area that can be achieved in representing the section of the curvature section of the DWL which at the same time is possible to be fitted in the test basin. This is to achieve as much as possible the numbers of the Xbloc unit that can be placed on top of the breakwater. With the higher surface area needed to be covered by the units, there will be many sections representing the left out unit. With this, the general observation can be seen resulting from the left out unit especially related to the cumulative errors that may be produced. Figure 3.8 shows various alternatives of the breakwater profile considered with different profiles to be fitted in to the basin.

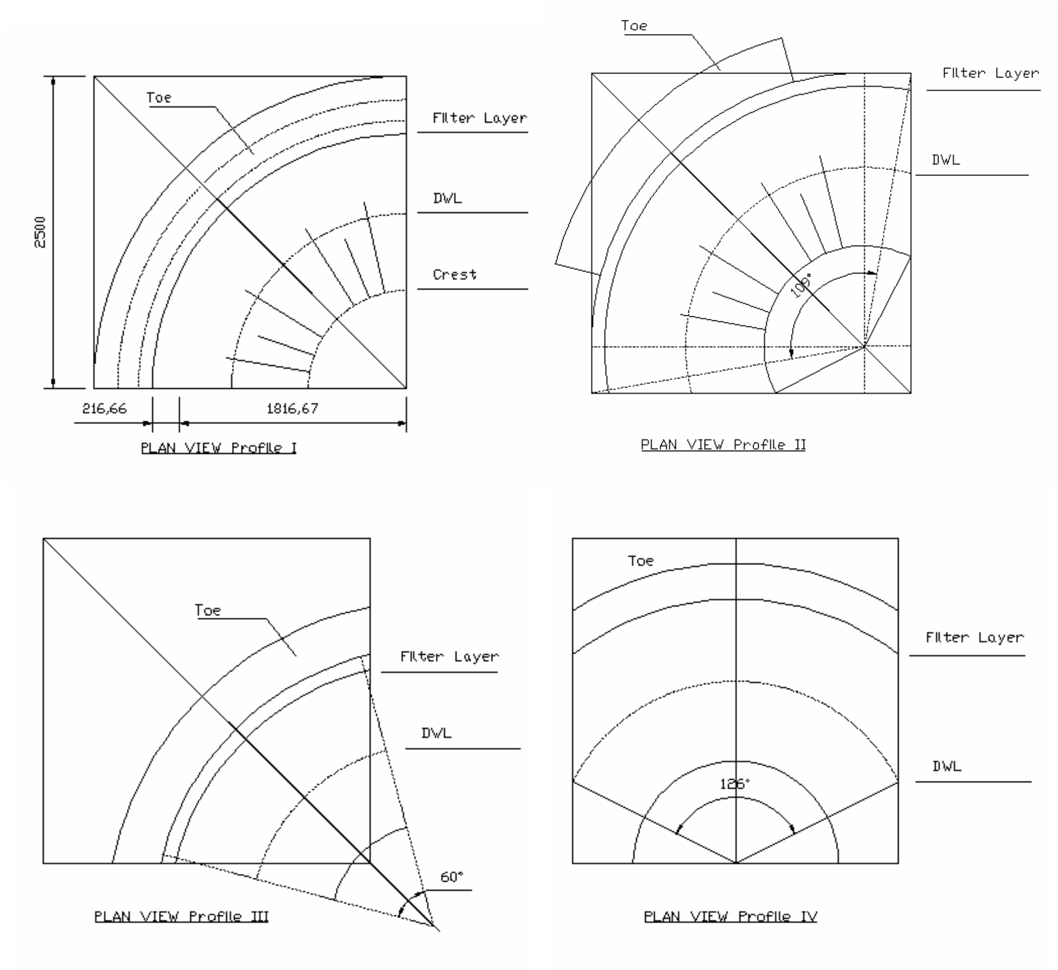


Figure 3.8 Alternatives for Breakwater Head Layout Selection

The breakwater Profile-I is chosen for the test model. It consists of a quarter section of the breakwater head. The Profile-I gave the most optimum surface area for the Xbloc unit to be placed in relation to the most critical curvature of the breakwater.

Although Profile-II gave a larger surface area which can accommodate a longer section of the most critical curvature of the breakwater, there is no room left in the basin for logistic purposes. With Profile-III, the centre point of the breakwater lies outside the basin and gave only 1/3 of the breakwater head. With this profile, the depth of the imaginary DWL does not counterpart with the height of 5 rows of the Xbloc units. Thus the left out unit area does not lie in the highest load from the wave impact that represents in reality. Profile-IV would have the same situation with Profile-II with a less surface area. Although the area above the DWL is larger in Profile IV, most of the unit will hang over on to the wall of the basin and thus did not really provide a real placement situation in the prototype. Thus, the selected optimum profile to investigate the placement of the Xbloc unit on the curvature of the breakwater with a 2.5x2.5m basin is Profile I.

3.3.2 Breakwater Cross Sections

When the final layout of the breakwater profile which consists of a quarter sections has been adopted, the design on the breakwater cross-section can be performed. Figure 3.9 and 3.10 below shows the cross section and the plan view of the breakwater model constructed in the 2.5x2.5m test basin.

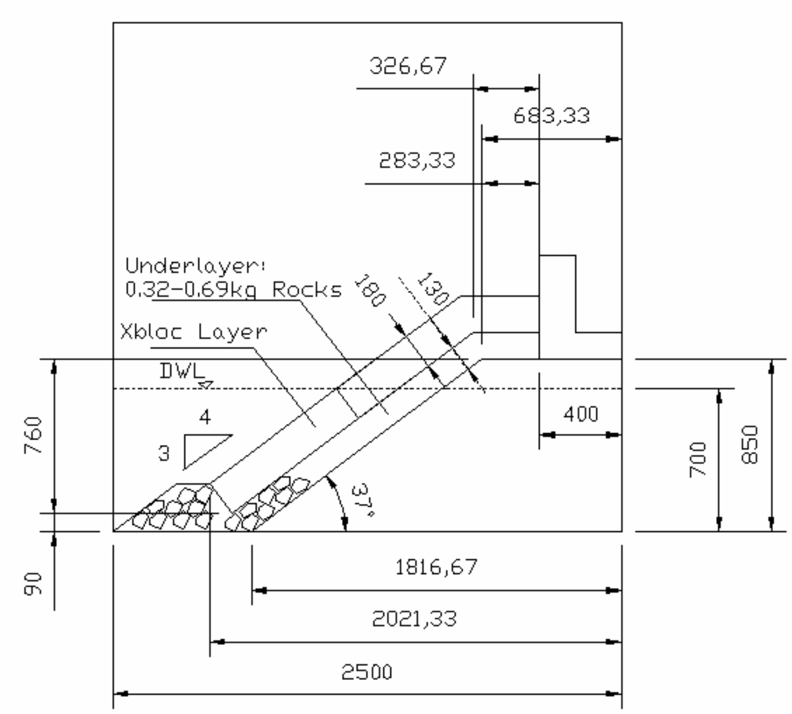


Figure 3.9 Breakwater Cross Section

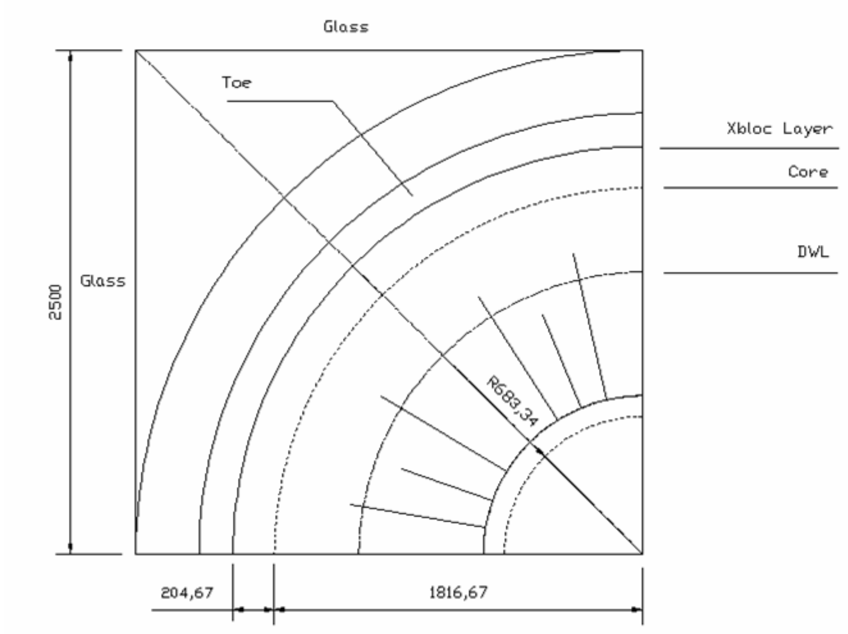


Figure 3.10 Plan View of the Breakwater Model

The thickness of the Xbloc armour layer is simply from the size of the Xbloc D = 182mm since the application of the Xbloc is only applied as a single armour layer breakwater. From the Xbloc manual, the underlayer required for the Xbloc unit is with the Xbloc size of 1.82m is 1.3m. Hence, the underlayer used for the model are 130mm.

3.4. Xbloc Grid Generator

3.4.1 Computer Model Overview

The position for the Xbloc unit was based on the grid generated by the computer model called Xbloc Grid Generator by ten Oever (2006). This computer model generates the optimum placement by means of grid in x and y coordinates according to the relation of the parameters that have to be input by the users.

The parameters used are according to the recommended values for the test which is presented in Figure 3.11 below:

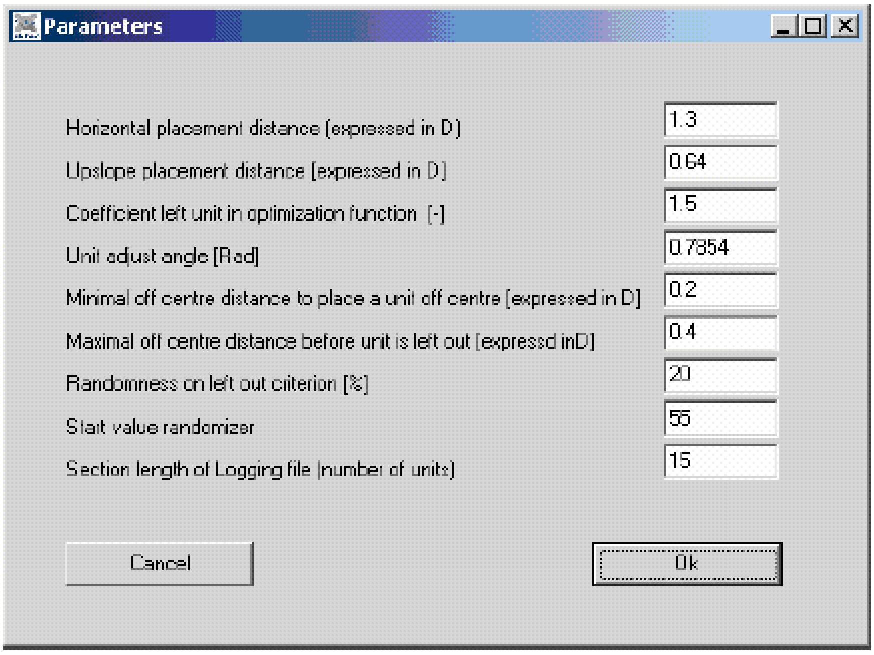


Figure 3.11 Input Parameters used in for the Design Grid

Descriptions of each of the parameters are presented in Chapter 2.

From the cross section in Figure 3.9, the dimensions of the model of the breakwater will be used for input to the computer model to generate each of the individual grids according to the given profile. The toe of the breakwater model was selected to 0 as only toe rocks will be used.

Figure 3.12 below shows the input values for generating the breakwater profile in the test basin.

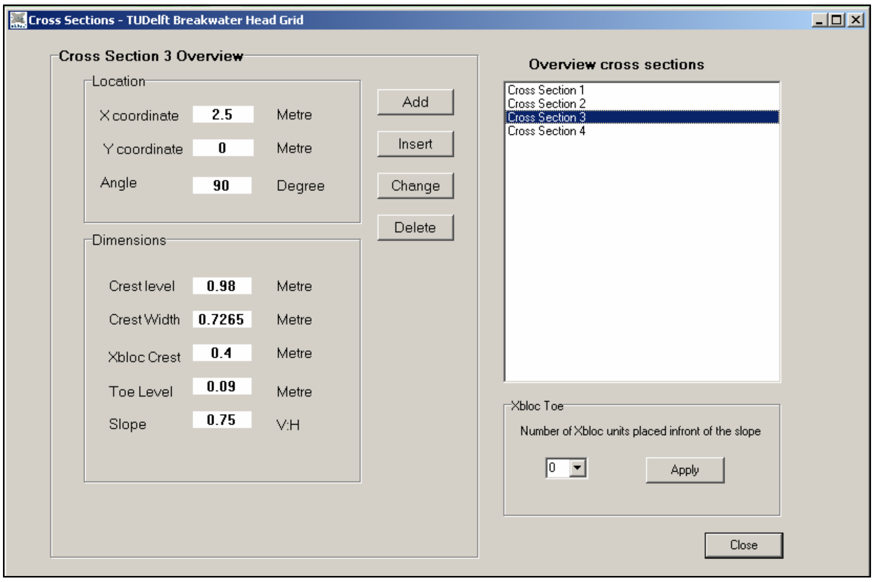


Figure 3.12 Input values for Generating Breakwater Profile in the Computer Model

The profile of the quarter of the breakwater was not simply adopted by putting the values of the quarter of the breakwater into the computer model. This will only result in a partial Xbloc grid which does not cover the entire surface of the breakwater as shown in the Figure 3.13 below. Only two left out unit areas can be revealed with this profile. Hence general overview of the effect and cumulative placement errors could not be seen with only two left out units.

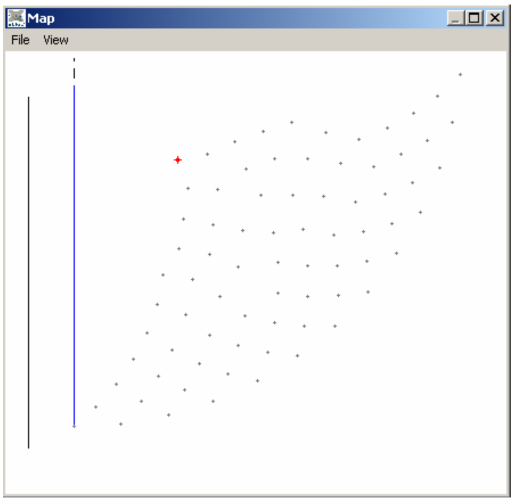


Figure 3.13 Xbloc Grid for Quarter Section of the Breakwater

The profile chosen to represent the quarter of the breakwater was the profile of a quarter breakwaters with a two straight section at both sides. See figure 3.14.

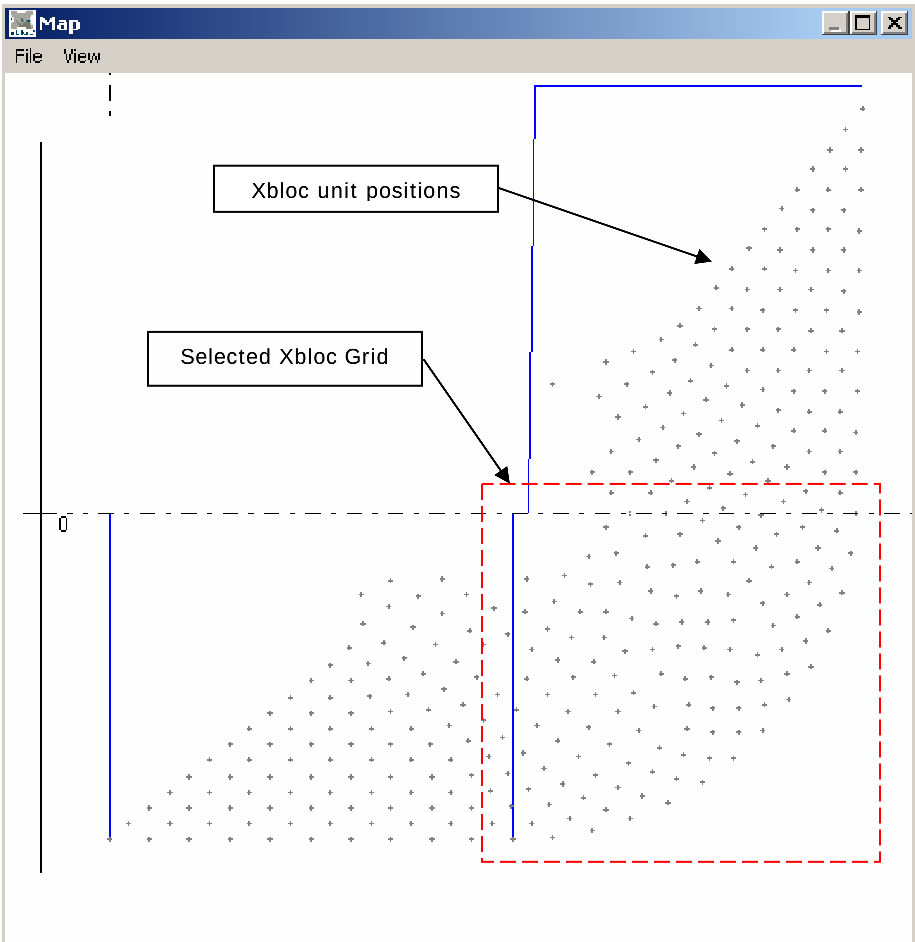


Figure 3.14 Selected Breakwater Profiles Representing the Xbloc Grid for the Placement Test

With this profile in Figure 3.14, the grid was well distributed over the surface of the breakwater. An incomplete breakwater profile would also produce a distorted result of the grid. See Figure 3.15.

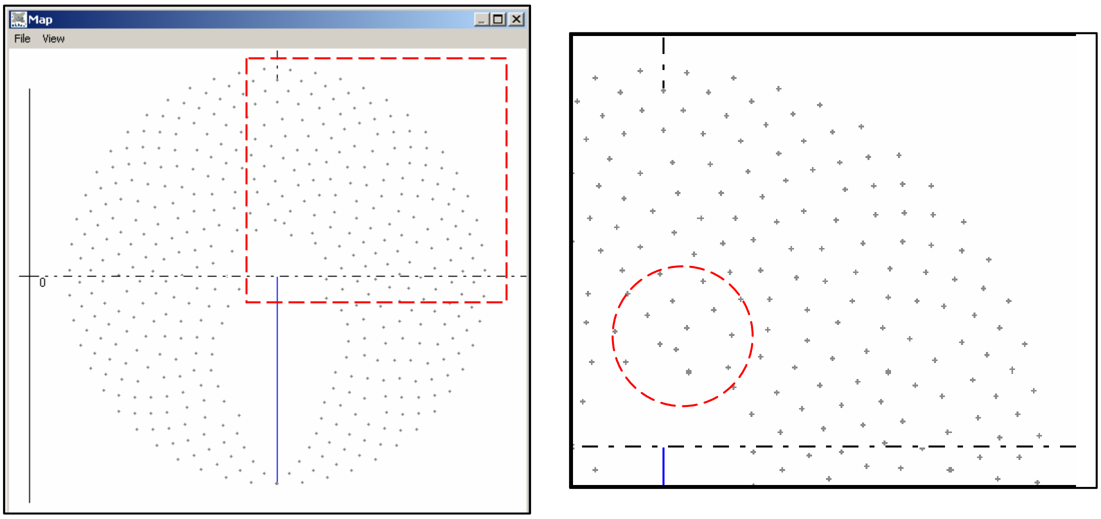


Figure 3.15 Distorted Grid

These distorted grids were found especially at the crest area as the grid was calculated according to the unit distance relative to each other over a small radius. The calculations of the grid over the small radius are the limit of the computer model capabilities. The distorted grid with incomplete breakwater profiles does not truly represent the ideal breakwater situation in reality that need to be performed in the test.

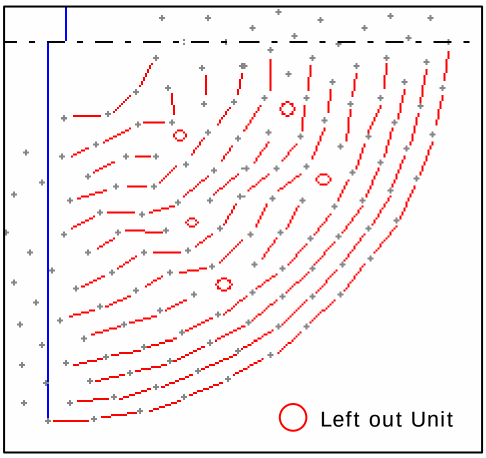


Figure 3.16 Xbloc Grid with Left out Units

The maximum numbers of the left out units for the dimension of the breakwater in the test basin can be achieved are 5 units. This will be sufficient enough to see the general overview of the placement of the Xbloc unit on the breakwater curve section. The overview of the problem caused by the left out unit could also possibly be seen. Choosing the grid with any section of the curve (e.g. $0\text{-}90^0$ or $45\text{-}135^0$) does not really matter as the number of the Xbloc unit which can be fitted in the basin for the first row is only 12 units.

3.4.2. Design Grid for Optimal Xbloc Positions in Test Basin

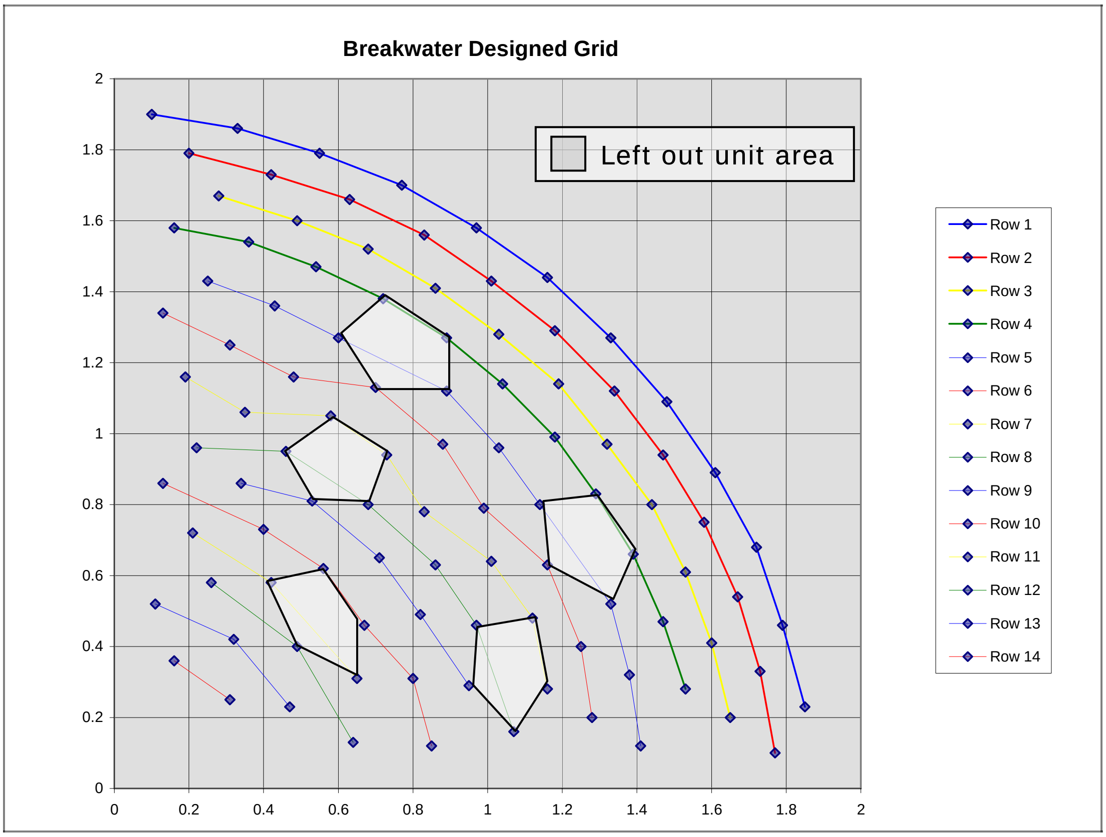


Figure 3.17 Overview of the Designed Grid for Xbloc Placement Test

Figure 3.17 above shows the final designed grid for the Xbloc position to be placed on the breakwater model in the test basin which has been rotated. The grid is shows from the top view of the basin representing with 5 left out unit. Row 11 till row 14 is to be positioned on the crest. As predicted before the grid was generated, the left out unit would be situated somewhere in row five. This is exactly where the design water level is. In reality, this would be the critical point where the breakwater experienced the highest load from the wave impact.

The packing density for the design grid is 35.39 unit/m^2 which 97.7% from the recommended theoretical packing density value of 36.23unit/m^2. The packing density value obtained is just in the lower range of the theoretical packing density values which should be in the order of 98%-105%.

3.4.3 Parameters Effects

In this section, changing the parameters of the input into the computer model will be made. The parameters were changed to see the effect of the values to the placement grids. The parameters that have been changed are shown in the table below. It was made by changing the parameters individually and leaving the other parameters as it is with the recommended values. The variations made are one by one by changing each of the parameters while maintaining other parameters as the recommended values. The packing density is also being compared when the changes made to the value of the parameters. The values of the packing density are obtained from the computed values from the computer model.

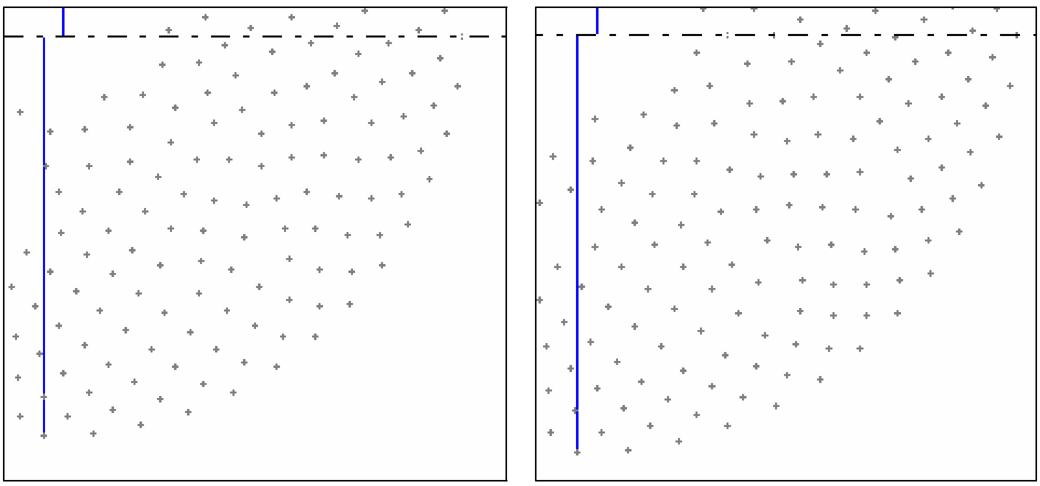
Table 3.1 Variable Input Parameters in the Computer Model

No.	Parameters	Recommended Values	Values Changed
1	Minimal off centre distance to place a unit off centre	0.2D	0.1D, 0.3D, 0.4D
2	Maximal off centre distance before the unit is left out	0.4D	0.2D, 0.3D, 0.5D, 0.6D, 0.7D
3	Unit adjust angle	45^0	0, 20, 30, 40, 50, 60, 70, 90

**The Graphical results of the generated grids were presented in Appendix A*

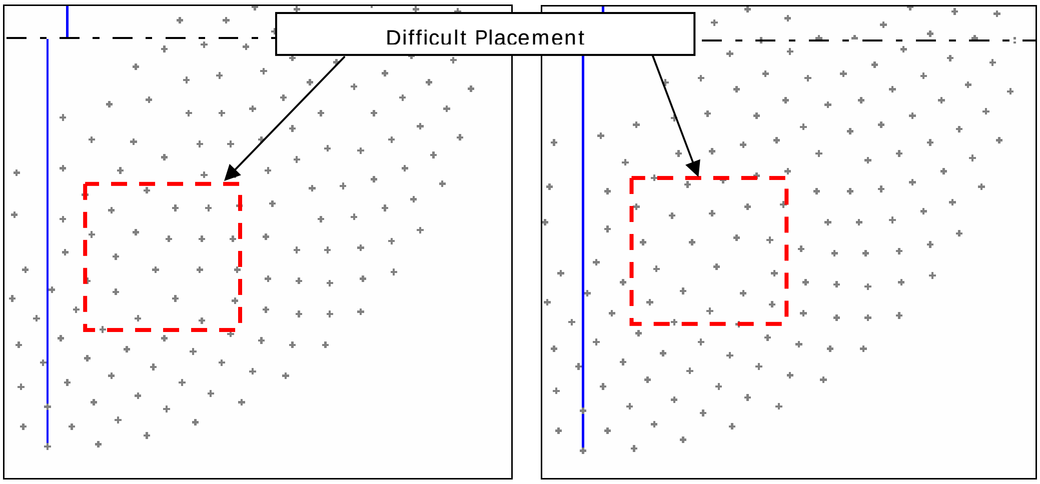
1) Breakwater Grid with variation of Minimal off centre Distances

From the results obtained, by changing the minimal off centre distance to 0.1, 0.3 and 0.4D, the placement grids packing density increased from 94.18%, 100.93% and 101.43% consecutively. This can be explained due to the fact that the units were placed in the middle between the two units even though the horizontal distance were quite close and thus creating a very dense placement. The packing density for the minimal off centre value of 0.1D is far below the other packing densities from other minimal off centre distance value. It is also lower than the recommended theoretical packing density range.



a) Minimal off centre 0.1D
Packing Density = 94.18%

b) Minimal off centre 0.2
Packing Density = 97.77%



c) Minimal off centre 0.3D
Packing Density = 100.93%

d) Minimal off centre 0.4D
Packing Density = 101.43%

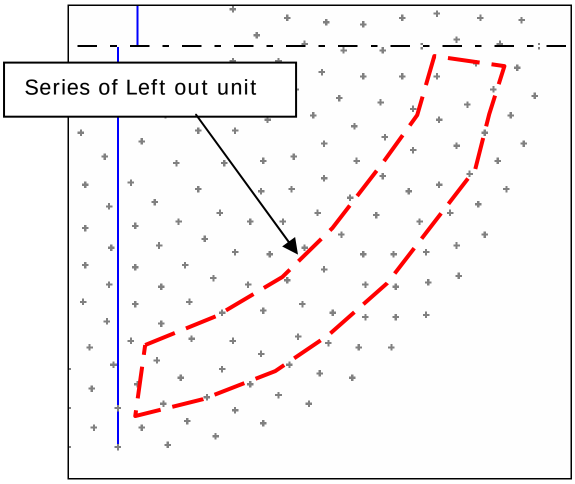
Figure 3.18 Placement Grids for Variable Minimal off Centre

However, by looking at the last pictures for minimal off centre distance of 0.4D of Figure 3.18(d), the placement looks rather quite difficult (which is marked in red box) as some of the units are placed directly on top of the other units. This certainly will have no or less interlocking effect. The same goes for the placement with the minimal off centre distance before the unit left out of 0.3D. For the minimal off centre distance of 0.2D, the placement grid generates a bit better than 0.3D and 0.4D distances but there was still some units which were sitting almost just on top of only one unit or on two of the base unit which are not in the same level. Placement of the unit with this situation is rather difficult as the unit is not entirely stable and prone to roll to the side where the base unit was in the lower position level. This type of placement conditions are discussed in the Chapter 4 test results.

2) Breakwater Grid with variation of Maximal off centre Distance

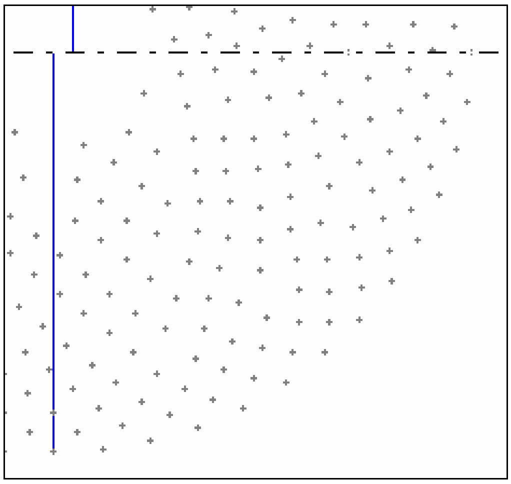
Parameters of the maximal off centre distance before the units were left out were varied from 0.2D to 0.7D and the girds were presented in Figure 3.19. The packing were values when the left out unit was at 0.2D and decreased at the distance of 0.5D. Then, the packing density was increased back close to 100% values of recommended packing density when the values were changed to 0.7D off centre distance before the units were left out.

For the value of maximal off centre of 0.2D, although the packing density is the highest among all the values, there were many left out units and most of them were situated on the same row. See Figure 3.19(a). This is undesirable as the individual packing density in the left out unit were quite low and the interlocking in the area are less because some of the unit were placed with only one base unit. The situation is more unfavourable when the row of the left out units were in the position where the DWL is situated as it is the most extreme part where the breakwater experience the wave impacts.



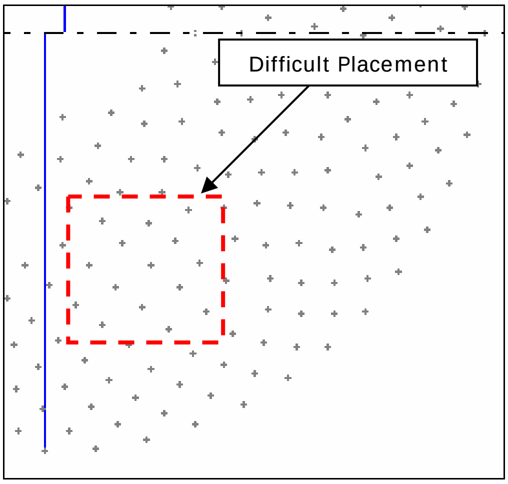
a) Maximal off centre 0.2D

PD = 100.87%



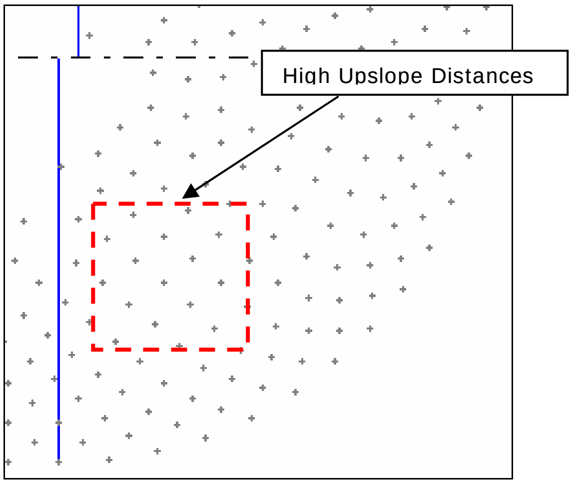
b) Maximal off centre 0.3D

PD = 99.50%



c) Maximal off centre 0.5D

Packing Density = 96.14%



d) Maximal off centre 0.7D

Packing Density = 99.13%

Figure 3.19 Placement Grids for Variable Maximal off Centre

Placement grids with the maximum off centre distance before the left out unit of 0.5D, 0.6D and 0.7D also generated an unfavorable grid as many grids were placed leaning on top of only one base unit. The most significant part is clearly seen in the upper part of the breakwater grids. The unit is almost impossible to be placed as the unit will be in unstable conditions. The grid of the placement also seems to have a very high upslope distances. See Figure 3.19 (d).

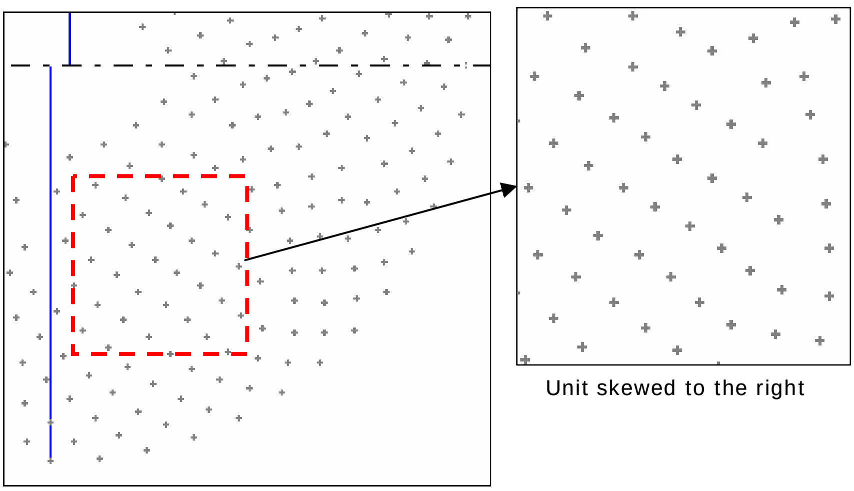
0.3D were quite suitable for units to be placed. However, the left out unit number were more than 0.4D maximal off center. There were 4 left out units in the same row which could lead to unwanted result as the packing density in those specific area are quite low with anticipated less interlocking effect.

3) Unit Adjust Angle

The unit adjust angle were varied from 0^0 to 90^0. The Packing density for the grids when the unit adjust angle were varied are quite good. Most of the packing densities were in the recommended range value except with the angle of 45^0 and 50^0 where the packing density consecutively are about 1% and 2% less than the recommended pacing density value range.

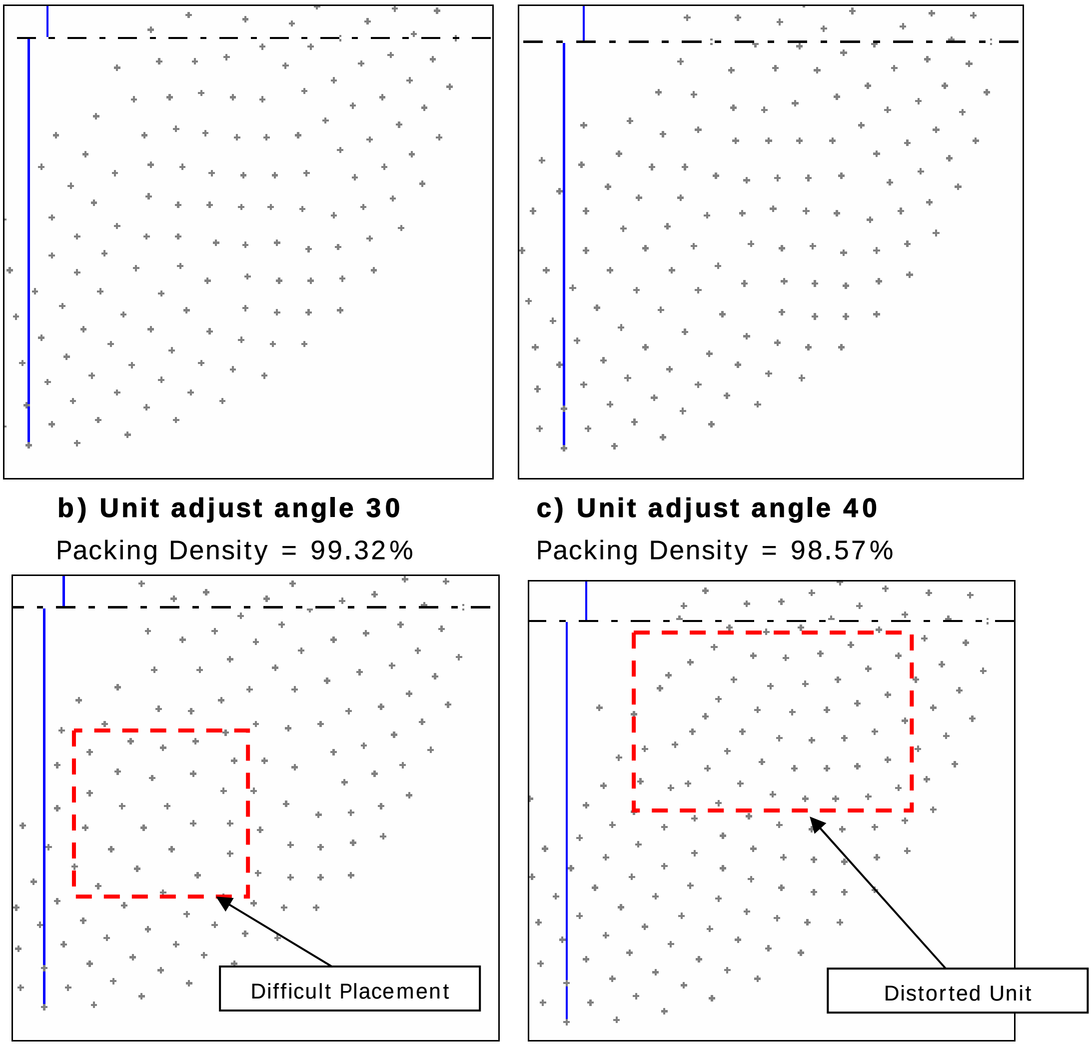
In terms of the placmeent grids, for a unit adjust angle of 0^0-30^0, most of the unit grids were placed skewed to one side of the base unit. By definition, this unit will not be in a favorable position if the unit is not in contact with the other base units (less interlocking effect). Thus, these values are not really recommended.

Furthermore, varying the unit adjust angle from 60^0-90^0 would give a rather funny looking grids. See Figure 3.20(e). The grids were quite distorted. For the unit adjust angle of 50^0, some of the unit in the upper part of the grids towards the crest of the breakwater were positioned in such a way that the two base units were not in the same level. There also unit lies towards only on one base unit. This creates difficulties especially when placing the units according to grids as described in Chapter 4 and units are not fully interlocked with one of the base unit as most of the units will be rolled to the unit that has a lower positioning level. As for the unit adjust angle of 90^0, the generated grids are mostly quite distributed. The only problem is that there are many distorted grids especially on the upper part of the breakwater. This is most probably due to the smaller size of the breakwater radius which with the 90^0 angle the units were not positioned away from the other units even though the units in the same row were quite close but the units were only being positioned to the higher upslope level.



a) Unit adjust angle 0

Packing Density = 101.4%



b) Unit adjust angle 30
Packing Density = 99.32%

c) Unit adjust angle 40
Packing Density = 98.57%

d) Unit adjust angle 50
Packing Density = 96.87%

e) Unit adjust angle 90
Packing Density = 105.01%

Figure 3.20 Placement Grids for Variable Unit Adjust Angle

From this, it is clearly seen that for the unit adjust angle values from 30 to 50 degrees produced a better grid position for the Xbloc units. Unit adjust angle less than 30^0 would give the grids skewed to one side and with unit adjust angle more than 50^0 will give grids positioned higher upslope sitting close to each other. Hence, the adopted value of 45^0 at the moment by ten Oever (2006) to be used is reasonable. Nevertheless, the unit adjust angle will also be further analyzed in Chapter 4 in relation to the placement of the units.

3.5. Limitations / errors (validity of experiments)

The limitations of this experiment obviously has an effect but with no influence from the wave attacks. Although there may be a perfect placement which means the placement results achieved were according to the theoretical recommended values, actual performance of the breakwater would not be known unless the hydraulic tests were to be made. This were emphasized especially with the Xbloc unit that has been left out creating a low packing density value for a certain individual unit. The stability of the underlayer may be investigated due to the possible exposure from the large area by the left out unit. Nevertheless for the other units, with the recommended placement of upslope and horizontal distances as well as the packing density would ensure the interlocking and the stability of the unit based on the previous tests.

This test represents a 1:10 scale to the prototype model and the assumptions made are to be close to the placement made in the reality. Since this is a non-dynamic test with no hydraulic conditions, no scale effects are are to be encountered during the tests which has been also decribed by ten Oever (2006) in his MSc thesis performing the placements test for the Xbloc unit.

Chapter 4

Xbloc Placement Test

4.1. Introduction

The Xbloc placement tests were done according to the theoretical designed grid, this grid was generated by the computer model as discusses in Chapter 3 (Xbloc Designed grid).

Two different tests were performed, each test was repeated three times to minimise the errors and to clarify the common behavior of the Xbloc placement.

The conducted tests are:

Test 1 - Placement According to the designed placement grid

Test 2 - Placement According to the designed placement grid with coherent judgment for better fit

Each test is repeated 3 times to obtain more reliable data sets. Besides the measured location of the units, pictures are taken each and every row after the placement perpendicular to the surfaced area in front of the breakwater. Each of the tests was labeled as T1a, b and c consecutively as which T1 representing Test 1 and a, b and c representing the repetition of the test. The overview of the conducted tests is shown in the Table 4.1 below:

Table 4.1 Overview of Tests Conducted

No	Test	Items	Test Code		
1	Test 1	Placement According to Recommended Placement Grid	T1a	T1b	T1c
2	Test 2	Placement According to the designed placement grid with coherent judgment for better fit	T2a	T2b	T2c

The placement was done row by row, covering the surface area of the breakwater until crest level was reached. All the units were placed with guidance as a recommended by ten Oever (2006); in which guidance means the unit is rotated around the axis of the hoist cable. In this way of placement the unit has a better fit with the already placed units and has a more stable position. The position for each of the unit is then recorded after each row has been completed. Besides the position of every units the way of placement and possible difficulties encountered are logged.

Special attention is paid to the behavior of the Xbloc during placement. The analysis will be mostly on the possibility to place the Xbloc unit according to required positions hence resulted to the required packing density and interlocking among the units.

The placement results are also compared with the theoretical relations used to design the placement grid. Validations have been done on the relations between the upslope and horizontal distances, minimal off centre distance, maximal off centre and the unit adjust angle.

From the data of placed units the packing density is then determined. As mentioned in the previous chapters, the achieved packing densities for the Xbloc unit shall be between 98%-105% of the required packing density. The packing densities will be computed locally for each of the unit and also for the total test slope.

Besides the packing density, the individual deviation of all the units in relation to the design grid is determined. Based on these deviations, it is possible to see whether the units can be placed on the slope according to the predetermined grid or not.

4.1.1. Measuring the Unit

The location of the unit is defined as the centre point of the unit, see Figure 4.1. In order to accurately obtain the centre point of the unit, points were taken at both ends of the adjacent leg. The centre point of the unit lies directly on the line between those leg points.

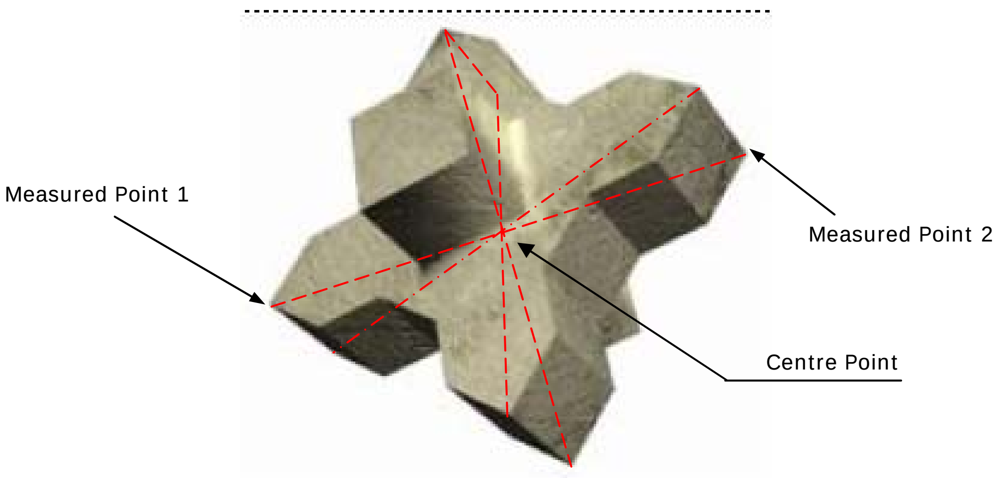


Figure 4.1 Centre Point of the Xbloc Unit

4.1.2. Calculating Packing Density

The natural shape of the breakwater head is cone shaped. For straight sections the packing densities is calculated with horizontal (D1) and upslope distances (D2), see Figure 4.2.

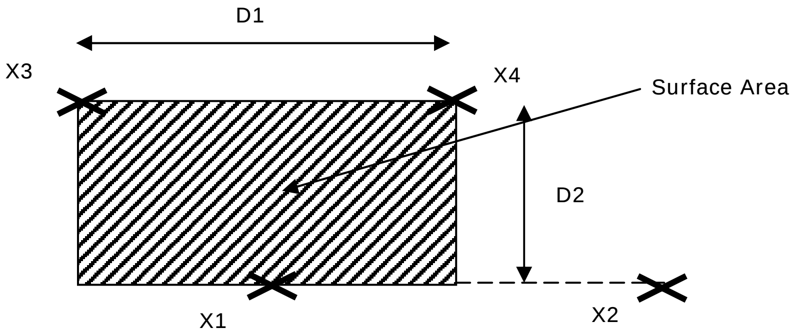


Figure 4.2 Computing Surface Area of One unit for Straight Section

This method of determining the packing density is not applicable anymore for cone shaped surfaces. Therefore a more sophisticated method to determine the packing density is presented below. Instead of using the only the upslope and horizontal distance 5 surrounding units are used to calculate the individual packing density. For example in Figure 4.3, the surface area of the unit X4 is computed based on total surface areas of Triangle T1, T2 and T3. All consist of distances between the units of X4, X5, the middle point of X1-X2 which is O1, and middle point X2-X3 which is O2.

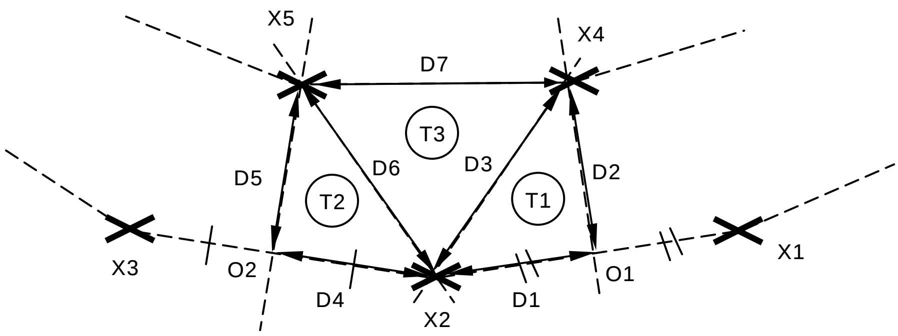
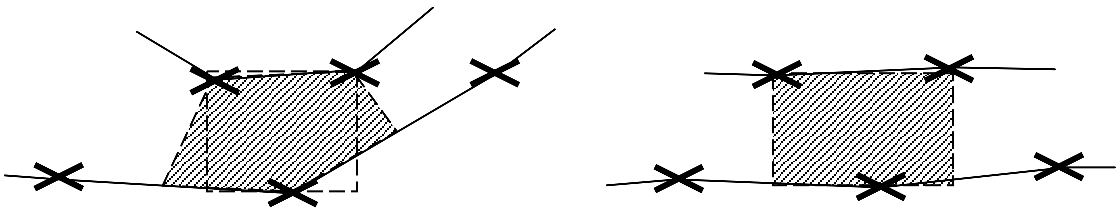


Figure 4.3 Composition of the Surface Area of One Unit

On a cone shape structure the units are sometimes scattered and not positioned on the same levels, this is accounted for in the new method. Therefore this method is chosen to determine the packing density for the curved section of breakwater. Nevertheless, the differences between both methods will be compared later in the report to see how significant is the differences in the packing density are.



(a) Curved Section (b) Straight Section

Figure 4.4 Surface Area of the Unit

Xbloc Placement Test 1

4.2. Test 1 - Placement Test According to Recommended Placement Grid

4.2.1. Introduction

Objective

This test is done to see whether it is possible to place the units according to the recommended placement from the computer model designed grid. The deviations will be investigated if any and will be observed if it has any effect to the unit higher upslope.

Test Description

Units are placed according to the designed theoretical grid. If the unit is not stable on the designed position, the units are guided to have better fit, maintaining the connection with two base units and the breakwater underlayer. Nevertheless, it is tried to keep the units as close as possible to the designed position. All placement tests have been performed with the idea that prototype units are quite big and are being placed using a crane which is somewhat difficult to handle. Hence, no placements were made which are impossible to be placed by a crane in prototype.

The placement grid for this test is generated by the Xbloc Grid Generator with the input of the following parameters:

Minimal off centre distance to place a unit off centre: 0.2D
Maximal off centre distance before the unit is left out: 0.4D
Unit Adjust Angle: 45^0

These three parameters are recommended placement of the Xbloc units on the curve section of the breakwater by ten Oever (2006).

4.2.2. Placement Results

Placement of the Xbloc units took approximately 1.5-2 hours for every 12 units. This includes lifting up the unit, positioning, detaching form the sling and measuring the unit position using the laser. With 101 numbers of units, to completely cover the breakwater surface slope in the basin took effectively about 2 days.

Figure 4.5 – Photograph of the Xbloc Recommended Placement Test T1b

Observations and Behavior of units

During the placements, there were certain behaviors of the Xbloc which could be a hindrance when placing the units according to the designed placement grid. The difficulties of the placement start in row 5 where the units in surroundings are very much close to each other. The usual difficulties encountered during placement of the units were:

1. Horizontal distance between two base units is too small: There are some areas where the unit is difficult to place as the tightness of the two base units are already close to each other. As a result the unit will be in contact only with one of the two base units.

2. Neighboring units are too close hence hard to touch both units below: This is normally in the area above where there is the left out unit. The critical row is the row 2 above the row where the left out unit is situated.

3. The unit is hard to place when the level of two base units are not leveled: The unit tends to roll to the unit with the lower level or gets stuck with the unit in the higher level and did not touch and interlocks with the other base unit.

4. Most of the units in the higher upslope of the breakwater need to be rolled or placed lower than the designed grid in order to have in contact with the two base units. The units are rolled if the unit can be positioned stable close to the designed grid without any significant repositioning. Repositioned of the unit only made if the unit are not entirely in contact with two base units. The unit's leg touched the breakwater underlayer first and did not touch the two units below.

5. One of the legs of the two units below can caused hindrance for placing the new unit. The new unit placed directly on the leg of the already placed unit will not be in a stable position. The unit will be rolled left or right or slightly shifted for a better fit and thus deviate from the designed position.

6. The region between the slope and crest is rather difficult to place. If placement made with one leg pointing downwards the units tend to roll off instead of finding a position between the two base units. Hence, it is recommended to place the units on the crest with three points pointing downward.

The overall impression of the placements apart from the left out unit area is rather good. The visual overviews of the gap in the left out unit area where there is an exposed area of the underlayer are quite significant. Nevertheless, the stability of the exposed underlayer can only be assured by hydraulic model testing.

Furthermore, the left out unit area are also where there were some of the loose units. This is probably due to the distortion of the units in the area where units in the same row are not in the same level and not sitting in a stable position. The other reasons for the loose units are when the unit upslope did not make contact to the base units properly. This is however only in certain case. Most of the time, there were also units that were not touched by the unit upslope but still interlock with the other units (e.g unit in the same row) and sits in a stable position.
Apart from that, all the units are quite interlocked from each other. The interlocking is assessed visual and pulling individual units by hand. The

interlocking seems to be quite strong but this should be confirmed by hydraulic model testing.

The overview of the measurement of the placement Test 1 is presented in Appendix B. The Appendix consists of figures of all the placement tests for Test 1 including the photographs taken and tables with the actual position of each unit.

Appendices B1, B2, B3 show the photographs of each placement done row by row with a little explanation on behaviour and how the units are being placed.

In Appendix B4, the placement grids were presented for each of the placement done with relation to the designed grid position.

Appendix B5 is the Figure for all the Unit Deviations with respect to the unit size D.

Appendix B6 is the Placement Results showing the computed values of all the deviations as well as the packing density for each of the individual units.

4.2.3. Unit Deviations

The results of placement test T1b are shown in Figure 4.6. The designed positions are marked in blue and the measured positions in red. The positions of the units on the crest were not analyzed as the unit on the crest behaves differently from the unit on the slope. Therefore the units can not be compared units located on the slope. Following from the test results, the observations are elucidated in the paragraph below:

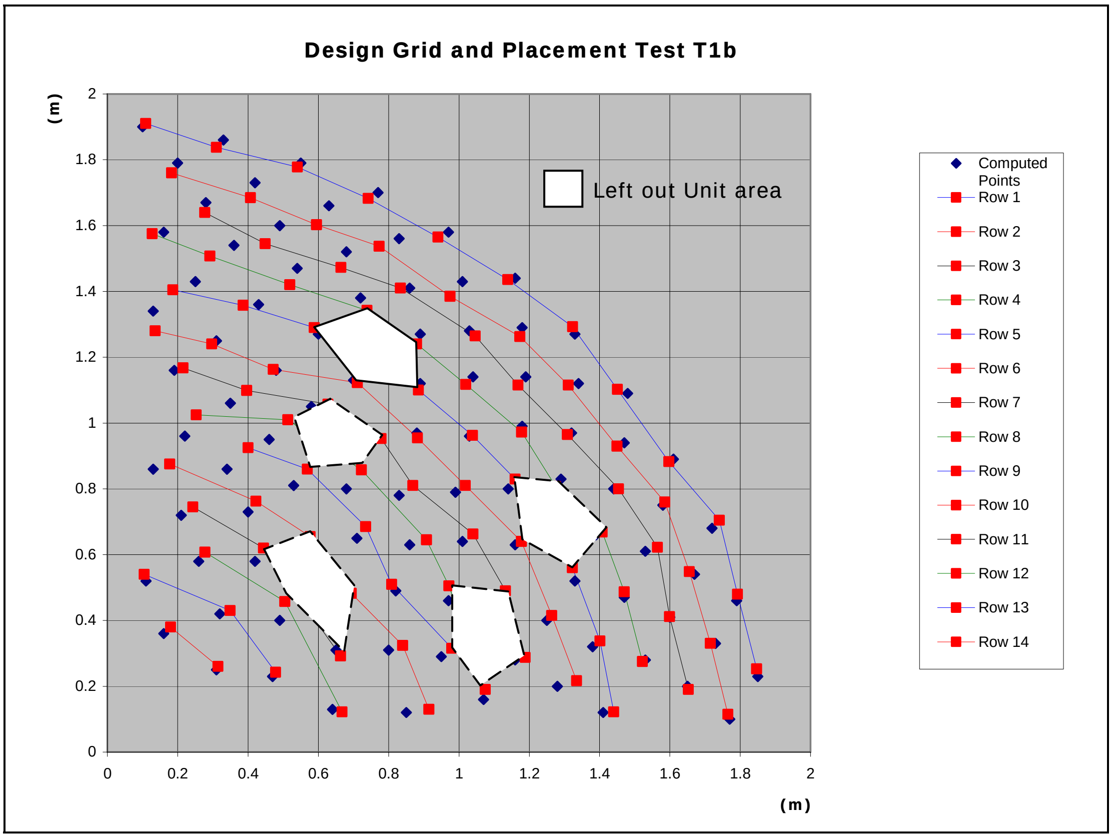


Figure 4.6 Computer Model Grid Position and Placement Test T1b

Figure 4.6 show that in row 6 and 7 (one row higher than where the first units are left out) the units do not behave as expected by the theoretical model. As a result the units above a left out unit are disturbed. Most of the units are positioned lower than the designed grid. The errors can be seen cumulative and seems to prolong when there is another section where there is a left out unit again.

The reason for such deviations was first contemplated to be due to the starting point of the placement for each of the row and at the end point of the unit near the wall of the basins. The unit in this location has no support on the unit either left or right one row below. But looking at the first 6 row, this is not a problem. The units at the wall can be positioned according to the designed grid. Thus the deviation of the units near the wall that has no proper support of the two base units does not contribute to the overall units' deviations.

The apt justification for the deviations of the units observed from the test can be explained mostly due to the different levels of the base units at the row below. This is where the row one above the left out unit area is. One of the base units is sitting in a lower level which positioned where there was a left out unit in another row below. This base unit sitting on the large gap, which needs to be stretched out, and the level differences with the neighboring unit is quite significant. Thus, when the two base units are not leveled, the new unit from the row above to be fitted in between can be unstable and the unit need to be positioned further downslope. Thus, this new unit is difficult to be placed and can be distorted. Figure 4.7 shows the exaggerated situation where the common problem persists.

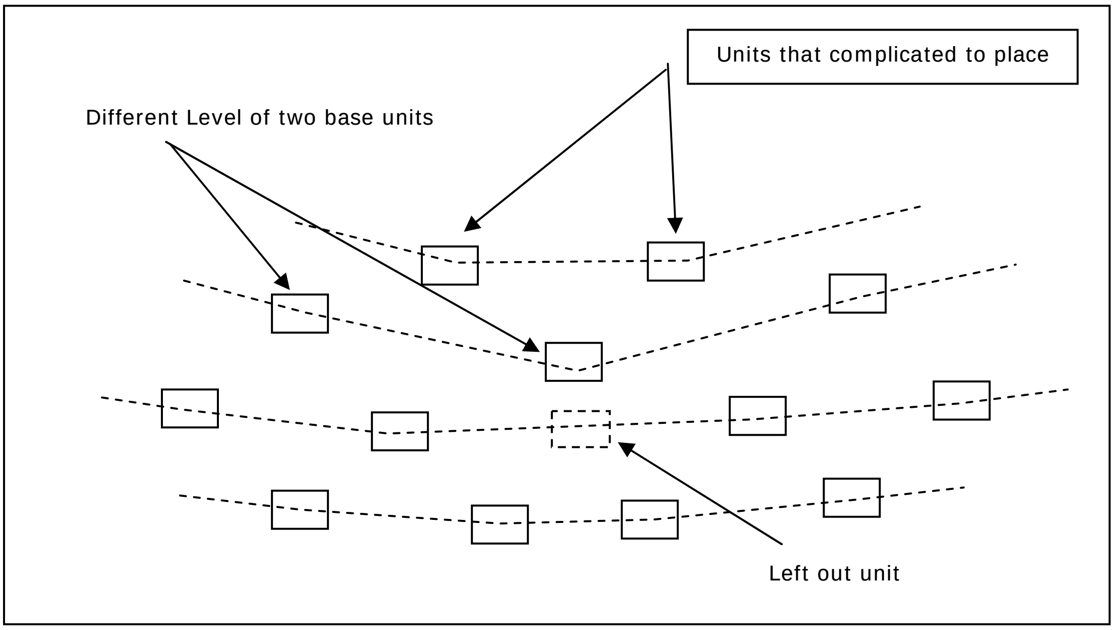


Figure 4.7 Problematic Area

The deviations of the units started in this area can be also seen in the other tests which presented in the same graphs as in Figure 4.6 which can be found in Appendix B.

The other reason for the new unit one row above the left out unit area can be distorted is due to the small horizontal distances of the two base units. To place the unit on top of those base units was not easy and complicated to ensure a proper placement. To position the unit exactly on the design grid was possible but the unit touched only one base unit and left a considerable gap. See Figure 4.8. It is difficult to make a stable placement without touching both of the two base units.

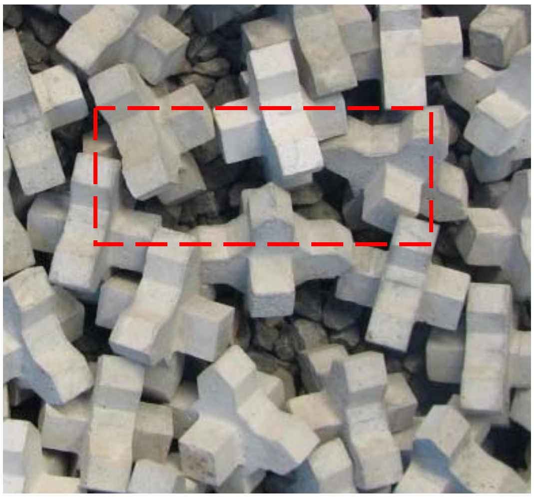


Figure 4.8 Gap Created by Two Small Horizontal and Unleveled base Units

Apart from the deviations of the units in the left out unit area, some units only touched one base unit and leave a gap to the other base units. This is assumed to be the off centre distance where the unit could not fit in best to the centre position. When the new unit one row above was placed on top of this unit, this new unit tends to rolled and disturb a few other units in the surroundings. Due to one unstable unit, the positions for the surrounding units could not match the designed positions from the computer model. The units that are not stable are then were placed again and guided directly in between of the two base units. The areas where the unit are left touches only one base unit will has an effect on the interlocking between the units and the units will be in a loose conditions in the area. Some of the units that are possible to be placed with only touching one base unit are not well interlocked. The units can be moved but considerably difficult to be pulled out from the placement by hand.

Below in Figure 4.9 showing the deviations of the units related to the designed position from the grid generated from the computer model.

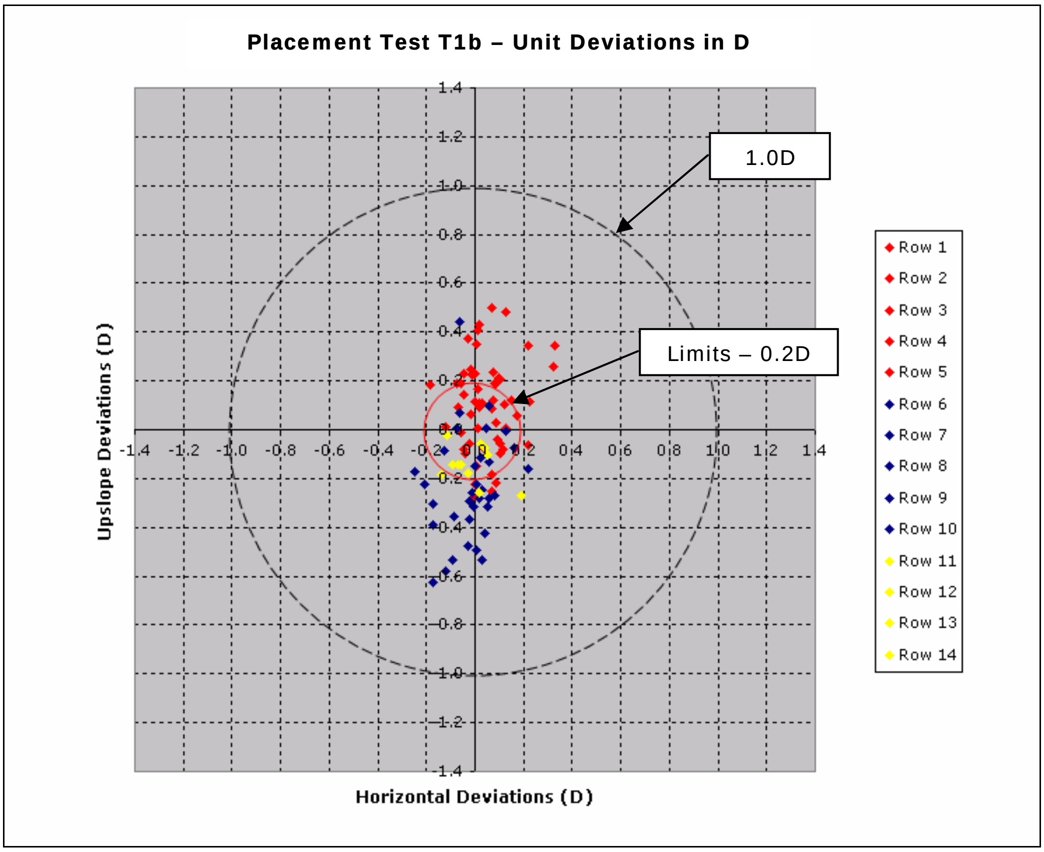
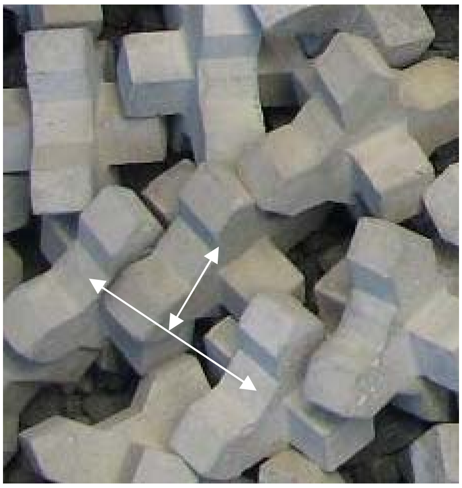


Figure 4.9 Deviations on Designed Positions (Test T1b)

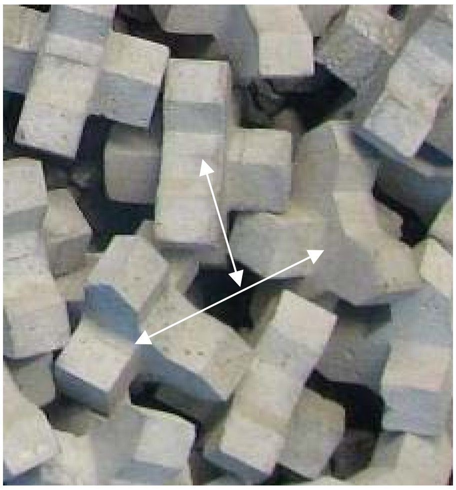
Observing from the Figure 4.9 above, the deviations of the units are mostly in the upslope direction. The blue points are the units above row 5 which is the beginning of the row where the left out unit is situated. The units in blue are in the lower position of the upslope deviations. As can be seen, the deviations of the units sitting in the lower range are mostly from the units above the left out unit area. The upslope deviations are larger for the unit upslope as the deviations error can be cumulative if starting from the row below.

The average upslope deviation of the placement tests in comparison to the designed grid are -0.018D with a standard deviation of 0.27D. While the average deviation for the horizontal distances are 0.018D with a standard deviation of 0.109D. If the upslope deviation were computed starting from row 6 and above, the value of the average upslope deviation will be -0.22D with a standard deviation of 0.24D. This indicates most of the units were place a little lower than the designed grid.

The red point is where the unit from row 1 to row 5 has no left out unit. The deviations towards upslope can be explained simply due to placement of the units not directly in the gap between two base units. When units were placed using both legs touching the base units, units will be hanging to the higher position upslope. This was discovered after all the placements were done and many placements were done in this manner. Hence, placement of the unit directly in the middle of the two base units is recommended in order to achieve accuracy for placement according to the designed grid and to limit the upslope distances close to the recommended value.



a) Units placed in the middle between two gaps of two base units. Perfect placement



b) Units placed between two base units using legs. Leaving a gap and creating upslope deviations

Figure 4.10 Placement Affecting Upslope Deviations

The other reason for the deviations higher upslope for the first 5 rows is due to the units placed on top of the two base units that are positioned with a small horizontal distances which many cases in Row 3 and Row 4. The unit could not be positioned and fitted directly in the gap that closed the two base units. The units are then positioned higher than the recommended upslope distance from the base unit below.

The yellow point is simply the unit on the crest, which basically is easy to be positioned according to the designed grid because the units are sitting on the horizontal surface. The only deviations that has on the crest unit is simply due to establishing a connection between the unit in the row below on the slope that has deviated or settled further down the slope especially at the edge of the crest.

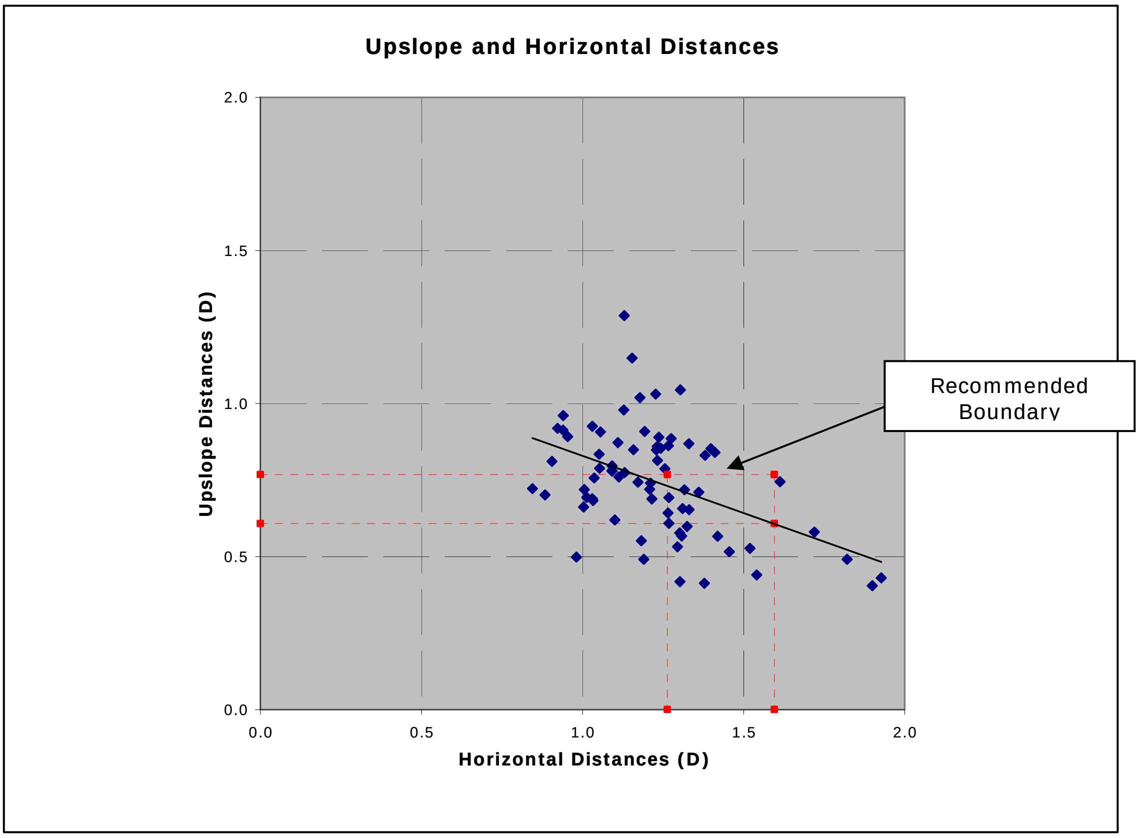


Figure4.11 Relations between upslope and Horizontal Distances Test T1b

Most of the units were positioned in the area where the horizontal distances are quite small. This can be seen in Figure 4.11 which shows the relation of the upslope and the horizontal distances. The average upslope distances from all the placement tests are 0.72 (113% from Upslope distance) and the average horizontal distances are 1.23 (92% from the horizontal distance) with the average standard deviation of 0.17D and 0.20D consecutively. This is due to the curvature of the breakwater which created the small horizontal distances between the units as the placement goes further upslope. The concentration of the unit positions are mostly at the lower values of the horizontal distances and in the higher values of the upslope distances. Placements of the unit between small horizontal distances (1.0-1.33D) are possible nevertheless the placements made are sometimes difficult.

Hence, the relations between upslope and horizontal distances could not be followed to the subsequent recommended distances suggested when placing the Xbloc on a curve section or on a breakwater head. The effect of the small curvature on the round head gives the results in horizontal distances smaller than expected.

Self Correcting Behavior

As discussed in the previous study (ten Oever, 2006), any small deviations will be automatically adjusted by the unit upslope and will be self corrected. However, for the curve section it is unlikely to produce a self corrected behavior. There is a limit for this correction as it is entirely based on the positions of the unit higher up slope. In order to have a self correcting behavior, the unit higher upslope need to have a correct average horizontal placing distance. As in the case of the curve section, the horizontal placing distances are likely based on the off centre distance of the unit and this does not give a correct averaging horizontal placing distance. Hence the deviation of the unit in the row below will have an effect to the placement of the unit higher upslope. Furthermore, most of the units affected are the unit in a higher upslope after the row where there is a left out unit. The errors will become more when there is another row with a left out unit higher upslope. Thus there is hardly any self corrected behavior and the errors will subsist as long as there is a left out unit.

4.2.4. Packing Density

Generally, the packing density of each of the unit will be calculated based on the methods described in section 4.1.2. With the left out unit surface area, further division of the triangle area will be made for calculation. On the crest, the rectangular surface area used.

Average packing density = 34.37 unit/m^2 (94.87%)
Average packing density for the left out unit = 17.62 unit/m^2 (48.64%)

The packing density values above are made by averaging the packing density value of all the three repetition tests. Figure 4.12 gives the average packing density for each of the individual test.

Average packing density calculating using simple rectangular section (ten Oever, 2006) gives an average of about 4% higher values than calculating it as described in section 4.1.2. This value gives the percentage of the packing density to 98% which is higher and within the recommended values. Although the difference is small, however it does not quite reveal the true values of the average packing densities especially if the value were in the edge of the lower boundary of the recommended theoretical values. Hence, calculation of the packing density using the methods suggested is recommended.

In addition, the packing density obtained from the designed grid is also not so much in difference. The packing density for the designed grid computed by the computer model is 35.39 unit/m^2 which is 97.7% in relation with the theoretical packing density value of 36.23 unit/m^2. This packing density was computed by the computer model using the rectangular area approach as suggested by ten Oever (2006). In comparison with the Xbloc placement test, the difference is quite small with only 4% less however, hydraulic tests may be appropriate to reveal the stability of the armour layer with a slight less in packing density value and especially towards the stability of the unit in the left out unit area. The tests may also be useful to see whether the left out unit would lead to a progressive failure.

There are hydraulic model tests of breakwater head which has been done in 2004 by DMC performed in WL | Delft Hydraulics multi-directional wave basin (Jo Vinje wave basin). The test model test was done to study the hydraulic stability of the Xbloc unit and to analyze the behaviour of the Xbloc armour layer after the start of damage on the breakwater head. Nevertheless, there was not mention any tests on variability of the packing density of the Xbloc armour layer on the breakwater head. The packing density used for the test was only with a 104% of the theoretical packing density value.

Visual Descriptions

From the photographic placement of the Xbloc, it can be seen that the area where there is a left out unit is substantially large. Underlayer can be seen through. The packing densities at the higher upslope after the left out unit area considerably have a lower packing density comparing to the row below. Some units in this area were rather loose with large gaps. Figure 4.12 below shows a series of photographic view of the placement made for the tests.

a) Test T1a
Average Packing Density:
33.99 unit/m^2 (93.84%)
Standard Deviations:
7.8 unit/m2

b) Test T1b
Average Packing Density:
34.48 unit/m^2 (95.18%)
Standard Deviation:
9.0 unit/m^2

c) Test T1c
Average Packing Density:
34.64 unit/m^2 (95.62%)
Standard Deviation:
10.2 unit/m^2

Figure 4.12 Packing Density Visual Inspection for recommended Design Grid Placement Tests

The average packing density is just under the recommended theoretical packing density (<98%) and only 4% less than the designed packing density from the computer model. As mentioned before in the previous paragraph the gap however is still considerably large. These large gaps were found especially at the area where the left unit is situated. Some of the gaps were quite big and looks like there is a possibility to fit in another Xbloc unit.

The average size of the gap is covered by the two circles which are shown in Figure 4.13 below. Each of the circles is approximately 7cm in diameter. In comparison with the size of the underlayer, the sizes of the gaps were considerably larger and with the underlayer consisting of D_{50} of approximately 4 cm. Nevertheless, the underlayer stone size used in this test was 20% smaller than the required underlayer stoe size as the lack of material availability. The required stone size for the size of the Xbloc should be in the order 5-6.5 cm of D_{50}. Hence, in order to clarify the effect of the exposed underlayer with the left out unit, using correct required stone size and further hydraulic tests are recommended.

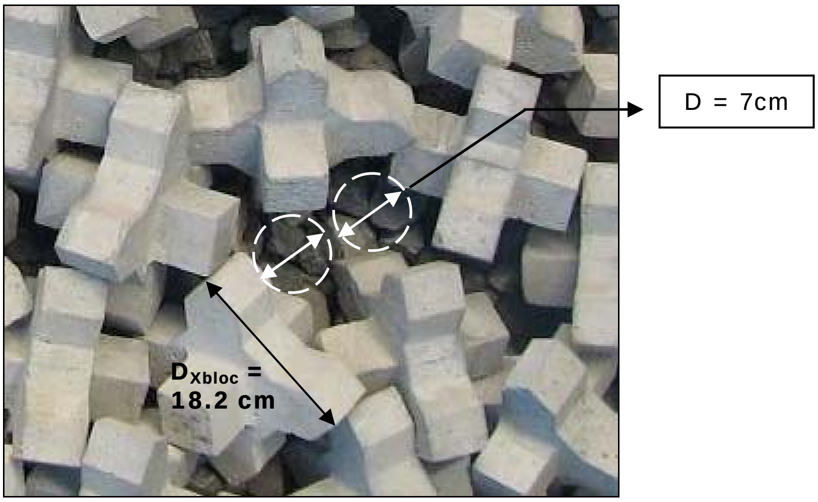


Figure 4.13 Gap resulted from the Left Out unit

4.2.5. Remarks and Conclusions for Placement Test 1

Placements of the Xbloc units according to the designed grid were satisfactory especially in the first 5 rows where there is no left out unit with acceptable deviations. Some were deviated towards the higher upslope due to the method of placing the units. The deviations however get larger as the placement goes upslope beginning when there are left out units (after row 5). The deviations are mostly in the lower side from the designed positions. This is due to the unit were rolled and position in the lower levels which has a smaller upslope distances.

Below are the remarks and conclusions made on the placement of the Xbloc following the recommended designed grid:

Remarks

1. The left out unit area is the critical area and it is normally difficult to place the unit upslope after the unit has been left out.

2. Some units which only touched one base unit. This is normally when one of the base units lies at a lower level than the other base units or in the case of off centre distance. The unit in this position is not entirely stable.

3. The gap in the left out unit is considerably large where it is bigger than the D_{50} of the underlayer material. The stone size however is 20% less than the required size. Further investigations maybe be needed to verify this (e.g. by performing hydraulic tests with the required stone size).

4. Units on the crest are in poor contact with the units on the slopes. Many units in this area are not in an interlocking state. Hence 3 point legs method for placement on the crest are recommended.

Conclusions

The conclusions can be derived from the placement tests are:

1. Measuring the unit positions as described in Section 4.1.1 gave the positions for each of the individual units accurately which is within 10mm accuracy.

2. The units could not achieve the self correcting behavior and the errors prolonged in the placement higher upslope when there is another left out units.

3. There are small number if units in loose conditions nevertheless, the overall units interlocking are also quite satisfactory. This is done by checking the individual unit by rocking and pulling out the unit by hand.

4. Some of the off centre distance unit are not entirely stable. Furthermore the unit might contribute to the lower packing density. Further placement tests may be carried out to see the possibilities to reduce the number of the off centre distance unit.

5. Further placement test with the higher maximal off center distance from 0.4D to e.g 0.5D before the unit is left out may also be wise to check as the gap in the left out unit with the current design grid is quite large. With the horizontal distances, sometimes it seems that the Xbloc unit is still possible to be fitted in between.

6. Optimization is needed in choosing between the packing densities (ie. The gap) and the interlocking between the units (Small horizontal distances). Leaving the unit out will create a gap and position the unit in the very small horizontal distance will decrease the interlocking between the units.

7. The averaged packing density for the placement are 94.87% less than the recommended theoretical packing density values which should lies in the range of 98% to 105%. Hydraulic testing may be needed in order to clarify few items especially the range of the packing densities for the Xbloc unit with left out unit area. Further testing is also needed for determining the behavior of the exposed underlayers due to the left out unit.

8. Calculating the packing density by schematizing the individual unit covering the surface area as described in section 4.1.2 calculate the value accurately of the individual packing density of the units.

Xbloc Placement Test 2

4.3. Test 2 - Placement Test According to Grid with Coherent Judgments for Better Fit

4.3.1. Introduction

Placements of the Xbloc unit in this test were based on the designed grid presented in Chapter 3 which used the same grid as in the first test in section 4.2. Results from the first test show the unit deviates mainly in the upslope distances. The average packing density obtained was a little lower than the recommended theoretical packing density values and the gap in the left out unit area is quite large. For this reason, the test of the placement of the unit is made again to see if the unit perhaps has a better position for the placement compared to the designed grid. It was performed at first according to the designed grid. Placements are then made with coherent judgments when units are deemed to have a better position simply by visually analyzing the placements and looking at the other surrounding units. A relation between units' horizontal and upslope distance and the unit performances comprise of the interlocking and packing density will be examined.

Objective

The placements test for the units using the coherent judgement are made to find out whether there are possibilities to have a better placement and position for the units. In addition with the better position of the units will possibly to increase the packing density for the overall placement. The test was also done to perceive whether there is a possibility to decrease the size of the gap in the area where the left out unit is.

Test Description

Placements were made following the guidance from the recommended designed placement grid same as in the first test in section 4.2. The interaction between all the units and the possibilities to decrease the size of the gap in the left out unit area were the main motivation for repositioning the units. The units are placed in a favorable stable position which in contact with the two base units and with the breakwater underlayers.

Nevertheless, this placement tests relatively in the optimistic approach in comparison to placement made in reality with the submerged units. The placement was made with a clear overview of the whole breakwater whereas in reality it is not. Furthermore, in comparison to the first placement tests, the first placement tests was done more less only following the design grid as close as possible.

4.3.2. Placement Results

Figure 4.14 Photograph of the Xbloc Recommended Placement with Coherent Judgement Test T2b

Observations and Behaviors of Units

As expected, the difficulties encountered during the placement starting from and after row 5 was where the row of the left out units are situated. The segregation of the unit can be clearly seen after the row 5 towards the upslope to the crest. Units were placed either roll to the front to have better connection with the base unit or simply repositioned to a new grid to have a better fit. The upslope distances were much lower as many units were placed as close as possible to the two base units to have units in contact. The observations during the placement of the unit with the coherent judgment are:

1. The upslope distances in the designed grid were larger than the unit which can actually fit in. Many units needed to be rolled in or shifted to the lower position in order to have a proper contact with the two base units with a stable position. Therefore it minimizes the gap that can clearly expose the underlayer.

2. Unit is rolled only whenever it is possible to have the unit to be fitted in the gap and in contact with two of the base units. It was done when the design grid is very close to the unit in surroundings but could not be placed properly or the unit is in unstable situation.

3. In order to roll the unit in, the unit is rolled forward. If the unit is rolled backwards, the underlayer sometimes will be exposed. The underlayer will be exposed when the unit that has been rolled backwards is situated on top row of the left out unit area.

4. The unit covering the left out unit is placed at a lower level than the recommended positions resulting to a smaller upslope distance. These are done mainly to cover the large amount of space of the left out unit. However, drop in the level of these units creating problems for the upslope unit in the row above to fit in and placement is rather difficult.

5. The units on the higher upslope are totally being positioned lower than the design grid. The unit in this area has larger upslope deviations. This is due to the cumulative error of the unit further downslope.

6. As the most of the units are placed further downwards, the connections with the unit on the crest (Row 11- 14) were complex and sometimes almost impossible. Hence the unit on the crest would be also repositioned to further downslope.

7. Since the placement was made based on judgment, hence there is no off centre placement made. If the placement made with the off centre distance, most of the units are not in a stable position and not interlocking with the other surrounding units.

8. Visually the overall gaps which exposing the underlayer were less than in the first test, with lowering the upslope distances of the unit. In a later section, the packing density of the placement will be examined to see whether it is possible to achieve higher than the required theoretical packing density.

9. With this placement test, there were very few loose units found which came to approximately 2-3 units for each test. Nevertheless, unit a difficult to be pulled out by hand.

As in Test 1, The overview of the results of the placement Test 2 can be seen further in Appendix C. Figures of all the placement tests for Test 2 including the photographs taken are presented as well as the tables consisting of each of the individual placement results.

4.3.3. Unit Deviations

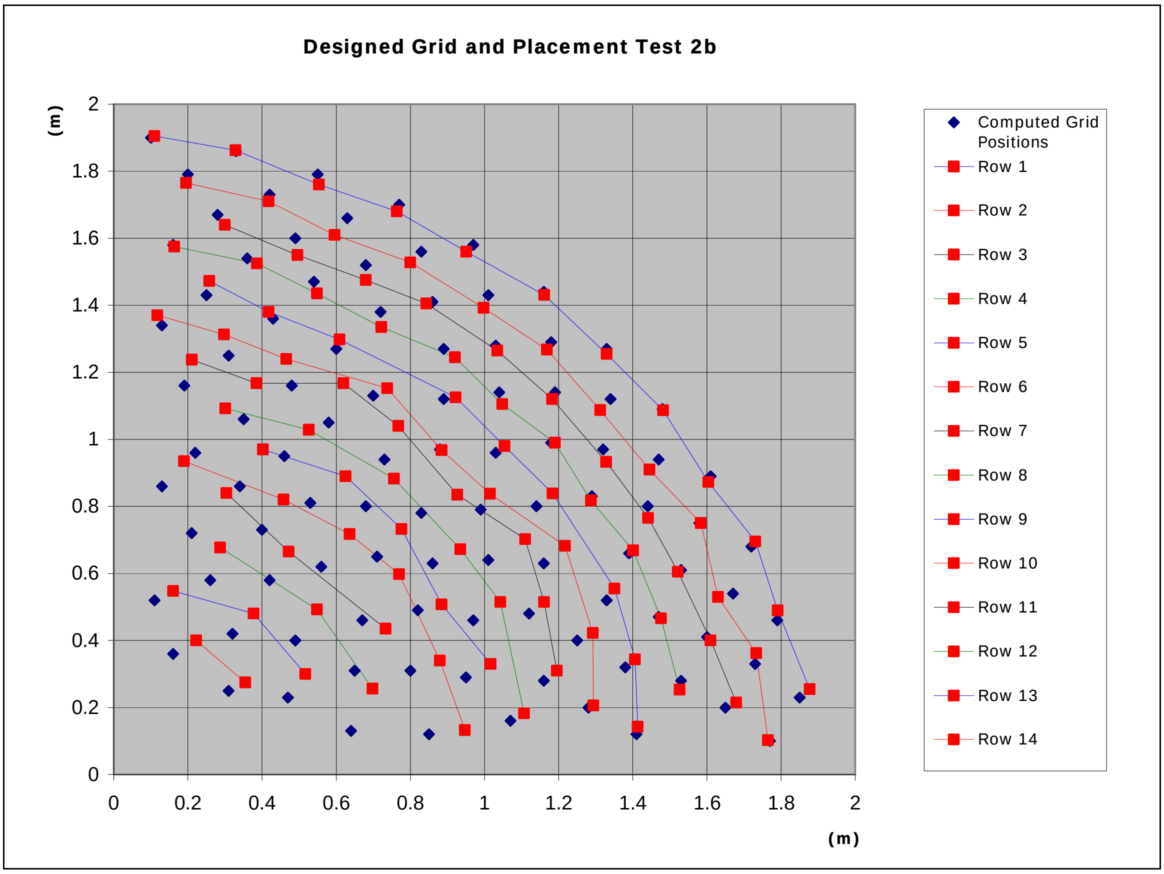


Figure 4.15 Computer Model Grid Position and Placement for Test T2b

From the figure above, it clearly shows where the unit deviations are situated and where it starts to differ with the designed positions greatly. This is the same as in the first tests. The first five rows are more or less can be placed according to the designed grid. Starting from row five, most of the units were placed with lower upslope distance although the horizontal distances were small. For the placement with the coherent judgments, the units' positions have smaller upslope distances than expected. The repositioning of the upslope units were done as the units seems possible to be placed in between the two tight base units with the motivation to make contact between all those 3 units. With the repositioning of the units lower upslope distance, the deviations would be continued further as positioning the unit further upslope.

On the crest area the connections of the units with the units on the slope are rather uncertain as the weight of the unit on crest did not lie directly on the unit one row below. The deviation of the crest units as in other units on the slope follows to be deviated further downslope.

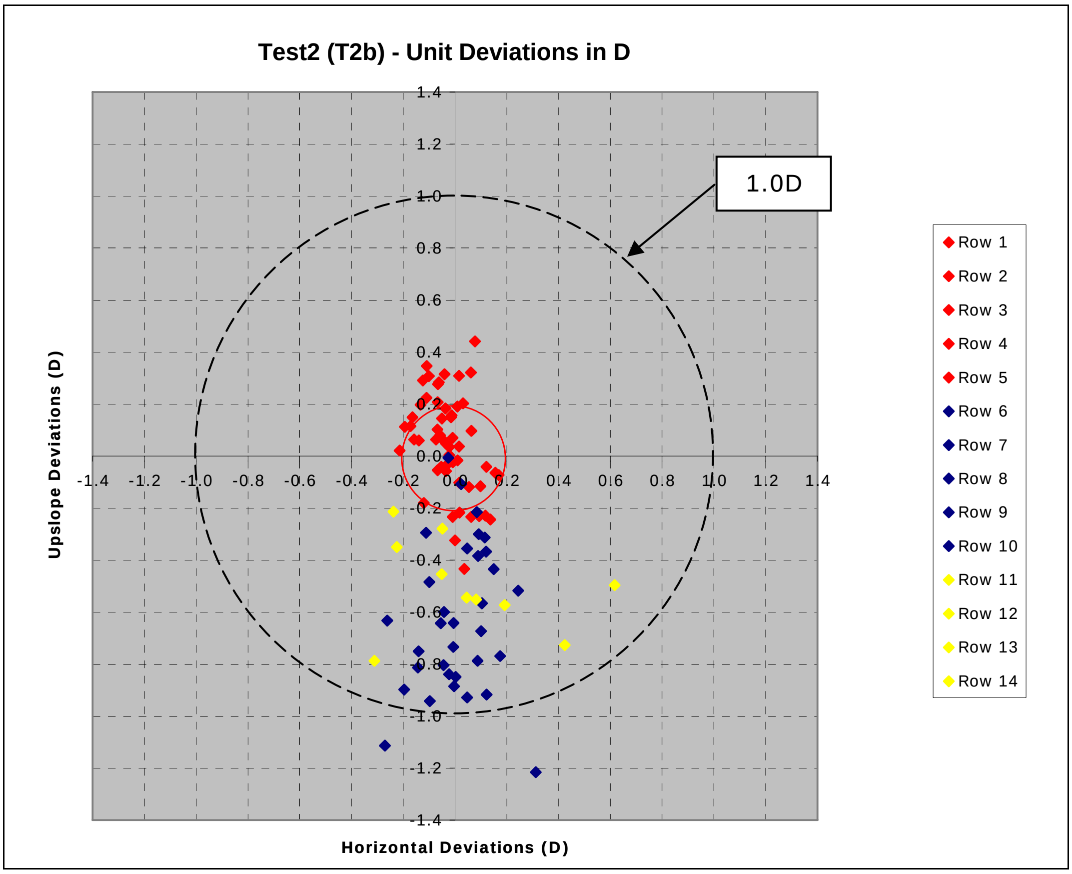


Figure 4.16 Deviations on Designed Positions for Test T2b

Here, in Figure 4.16 are the units' deviations again in terms of unit size D. The deviations of the upslope show the units after row 5 were placed well below the designed grid. As mentioned in the previous paragraph, the unit seems to have a possibility to position lower and close in contact to the 2 base units below. These units were positioned low to have a connection with the base unit for better interlocking.

The average unit upslope deviations compared to the designed grid are -0.586D with a standard deviation of 0.28D. While the average horizontal deviations are 0.016D with a standard deviation of 0.12D. The average deviations were taken only from row 6 to the upslope above as the interested area of study is starting from row 6 where the unit started to differ from the designed grid.

When the lower units deviate to the lower position, the entire units on the row upslope deviated further downwards as described in the first test. Thus the downslope deviation continues when placing the unit further upslope. Some units will get larger downslope deviations. The significant reposition of the unit with the smaller upslope distance is done almost for all of the units that cover the left out unit. This is done as it is seems the unit is possible to be placed lower and by looking at the size of the gap which could simply be smaller with small upslope distance.

Unit Deviations in comparison to the First Test

Since the upslope deviations are cumulative for the unit on the higher upslope, comparing the unit deviations in relations to the designed grid gave the higher upslope deviations results. Hence, comparisons of the placement grid of Test 2 are made in relation to the first placement test. Figure 4.17 below shows the comparison of the unit deviation of placement Test 2 (T2b) in relation to the unit in the placement Test 1 (T1b).

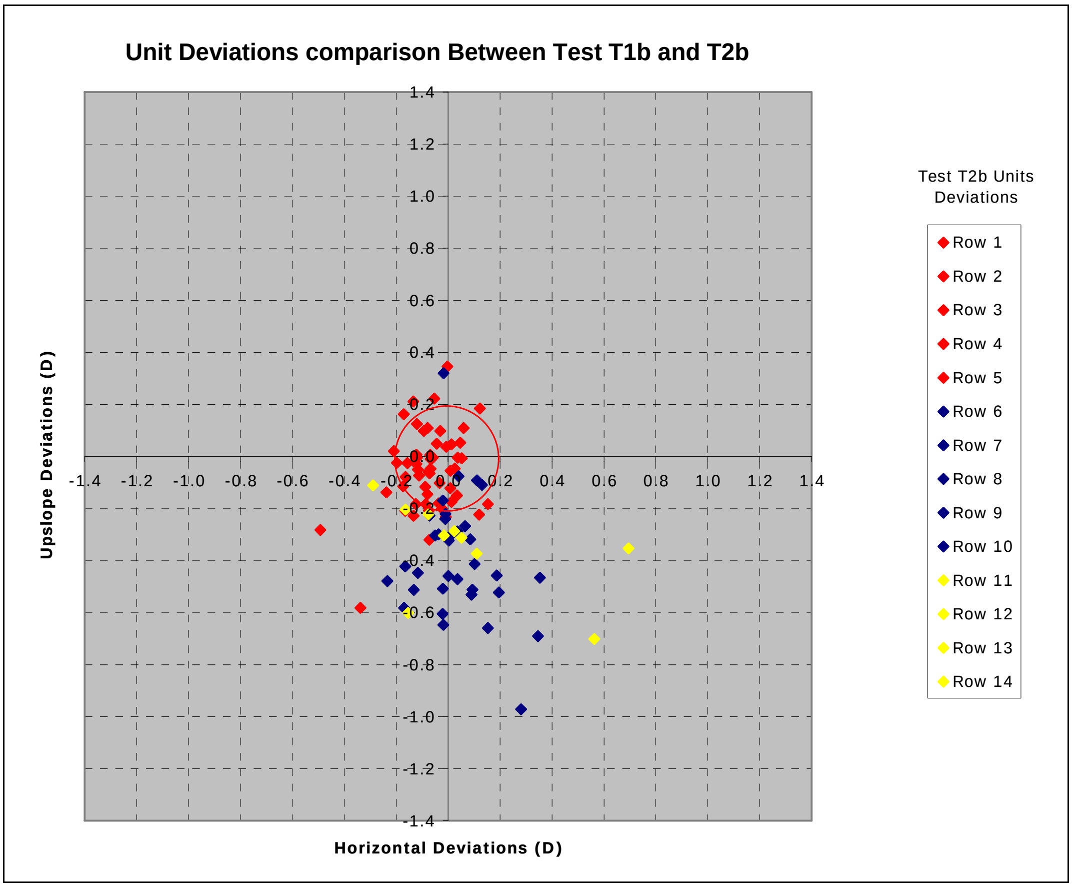


Figure 4.17 Unit Deviations of Test T2b versus Unit location in Test T1b

The average upslope deviations of the units in the placement Test 2 (T2b) in comparison to the unit position in Test 1 (T1b) are -0.362D with a standard deviation of 0.22D. While the average horizontal deviations are -0.036D with a standard deviation of 0.14D. This indicates that with the placement made in Test 2, the units are placed lower than the placement made in the first placement test.

In order to see the possibilities of the unit to be placed with less upslope distance than the design grid, please refer to the Figure 4.18 below.

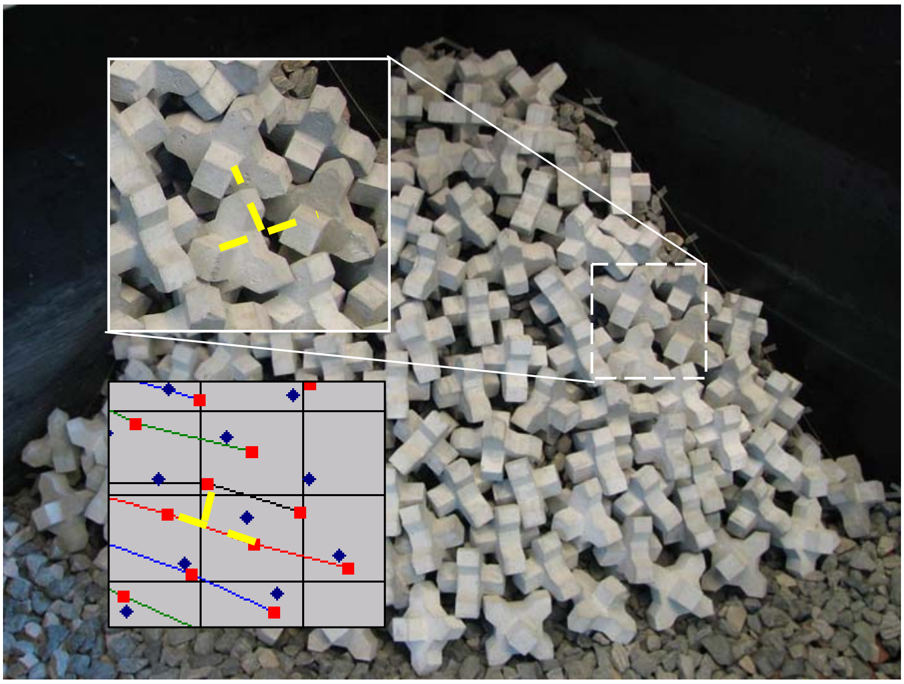


Figure 4.18 Unit with Smaller Upslope Distance (Test T2b)

Figure above shows the visual example of the placement done with lowering the upslope distance than the upslope distance recommended from the designed grid position. When placing the Xbloc unit, if the placements are done with the designed upslope distance it will be impossible to touch both the two units below. Thus one of the units below will be in loose conditions. What has been done in this test was the units are placed further downward to have in connection with two base units. From the example of the units shown in Figure 4.18, the designed upslope distance was 1.14D. From this test as there is possibility to reduce the upslope distances for better connection with two base units, the achieved upslope distance is 0.97D. This reduction in upslope distance resulted in approximately 15% lower than recommended in the designed grid.

Relations between upslope and Horizontal Distances

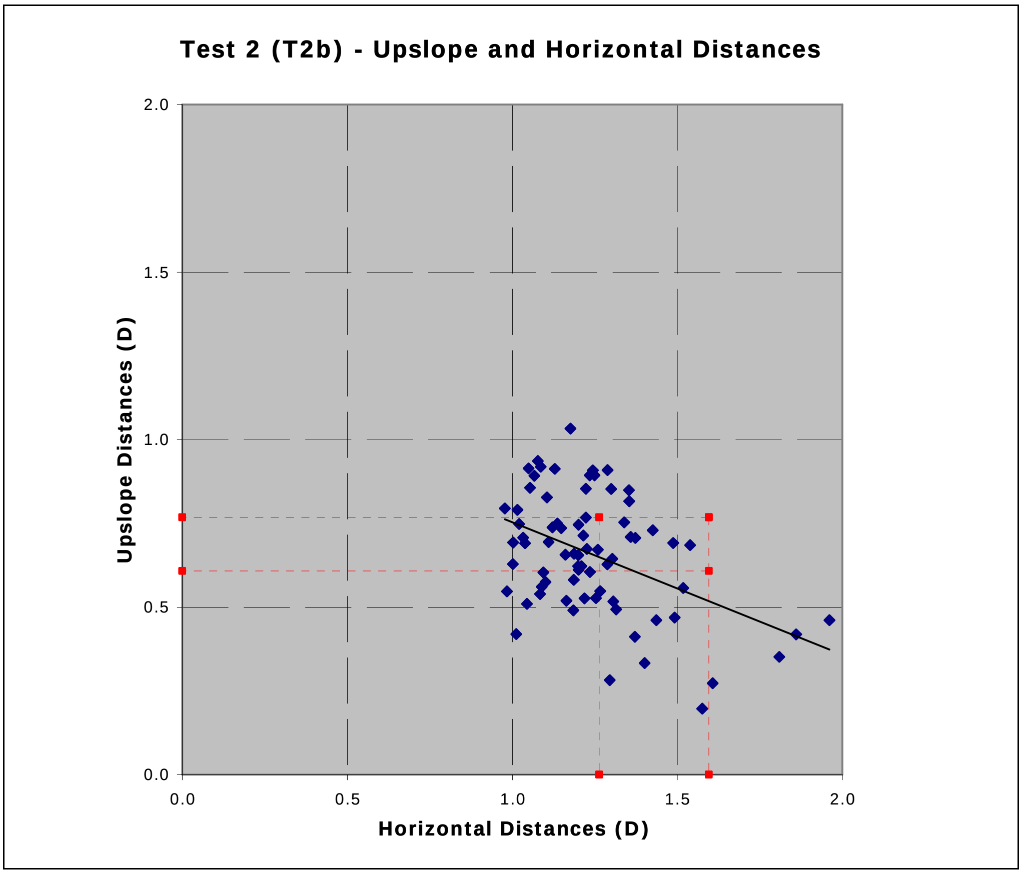


Figure 4.19 Relations between upslope and Horizontal Distances Test T2b

With the round head, units have smaller horizontal distances and the relations with the upslope distances are in such approximately 90% of the upslope distances which lies in the range from 0.5D to 1.0D.

The average Horizontal distance is 1.25D which is 94% from the theoretical distances with a standard deviation of 0.21D. While the average upslope distances is 0.65D, 100.1% from the theoretical distances with the average standard deviations of 0.18D. The upslope distances are still possible to remain in the recommended theoretical distances of 0.64D although with the smaller horizontal distance.

Looking at the relation between the upslope and the horizontal distances of the placement in Figure 4.19, although the regression line (black colour) showing that the upslope distance is relative to the horizontal distances, however most of the units upslope distances are situated in the area of 1.0D to 1.3D of the horizontal distances. This shows practically somehow the upslope distances are varied from 0.5D to 0.9D when the horizontal distances are in the range of 1.0D to 1.3D. Meaning unit can still be placed with a same upslope distances when the horizontal distances are in the range of 1.0D to 1.3D.

Moreover although placing the units with a smaller upslope distances with a small horizontal distance between two base units, the units interlocks with the surroundings units quite well and did not produce any loose units. The only problem encountered with this placement is that it is not so easy. In some cases however, it does not touch one of the base unit at all and touched the unit next to it in the same row instead. The gap is much worst if the unit will be placed off centre with higher upslope and it will start to touch with the unit on the right where it was placed earlier.

4.3.4. Packing Density

As anticipated, the packing density for this test is better than the previous test. This is due to the optimistic placement done which have a better fit for the placement of unit. The packing densities achieved for this test are resulted in the higher range of the recommended theoretical packing density. The average packing density achieved is 38.43 unit/m^2, which is 106.1% from the recommended packing density. Nevertheless the left out unit packing density were still in the range of 50% lower than the recommended packing density, which mainly was already predicted. The average values however, improved a little bit from the previous test, which increased from 17.62 unit/m^2 (48.64%) to 19.78 unit/m^2 (54.6%). Hence, lowering the unit upslope distance in the left out unit area gives a smaller gap in the left out unit area relative to the first test.

Visual Descriptions

From the visual photograph of the placement of the unit with the coherent judgment approach, the units are positioned well closer and denser than the first placement test. The gap in the left out unit area shows slight improvements.

The average packing densities achieved with this placement is:

Average Packing Density = 38.43 unit/m^2 (106.1%)
Average Packing Density of the left out unit = 19.78 unit/m^2 (54.6%)

This is again the average of the individual packing density of the three repetition tests. Below in Figure 4.20 are the pictures for each of the placement Test 2 together with their individual average packing density:

a) Test T2a
Average Packing Density:
38.39 unit/m^2 (105.97%)
Average left out unit packing density: 18.93 unit/m^2 (52.25%)
Std. dev = 12.2 unit/m^2

b) Test T2b
Average Packing Density:
38.58 unit/m^2 (106.49%)
Average left out unit packing density: 20.15 unit/m^2 (55.63%)
Std. dev = 12 unit/m^2

c) Test T2c
Average Packing Density:
38.32 unit/m^2 (105.79%)
Average left out unit packing density: 20.26 unit/m^2 (55.92%)
Std. dev = 9.9 unit/m^2

Figure 4.20 Packing Density Visual Inspection for Placement Test with Coherent Judgement

The gaps in the left out unit area are the most important part and with positioning the units lower than the designed grid, the hole is smaller if not a little bit less than the previous test. Figure 4.21 below shows the size of the gap determined by measuring the hole using schematized circles resulted from the placement with a smaller upslope distance. Same measure was taken from the first test to estimate the size of the gap and the circles representing the exposed area of the underlayer. Visually, it appears to have better results than in the first test with less visibility of the exposed underlayer.

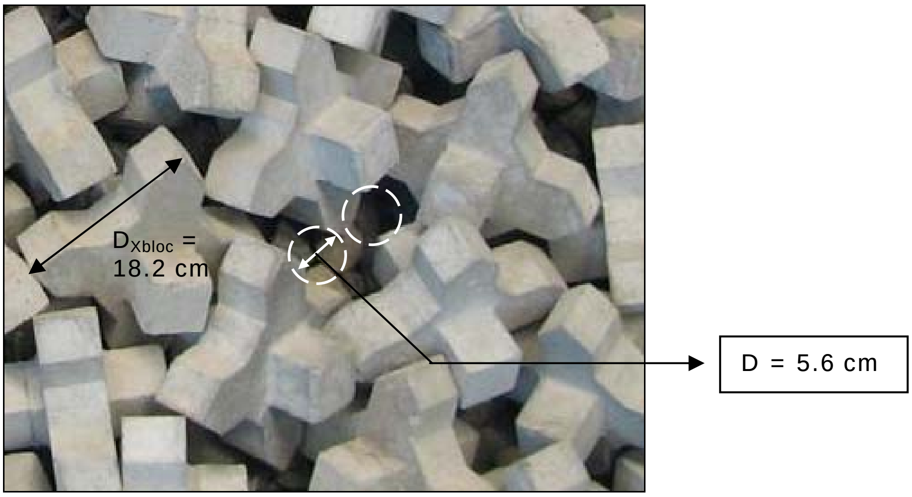


Figure 4.21 Gap in the Left Out unit Area

The opening gap can be fitted with the circles of average size of 5.6 cm. This is about the size of the D_{50} of the required underlayer of 5-6.5 cm. From the first test, the average size of the opening diameter is approximately 7 cm. Thus in comparison with the first test, placing the unit with decreasing the upslope distance of the unit in the row above left out unit will reduce the exposed underlayer area by 20%.

4.3.5. Remarks and Conclusions for Placement Test 2

Remarks

1. In positioning the unit that is not really stable or to make a good contact with the two base units, unit was rolled to the front instead of backwards. If the unit is rolled backwards, the underlayer of the breakwater will be exposed.

2. Although the placement made with a higher packing density values, however this is in the optimistic approach. In order to achieve this in placing the prototype unit, the use of high labour intensive may needed especially using the diver for placement made underwater.

Conclusions

1. The units were perfectly in contact and interlocks with each other by performing the test with the coherent judgement. Only 2-3 units were in loose state conditions.

2. Upslope distances in this test are lower than from the designed grid. Many units have a better connection with the two base units below when placed with smaller upslope distance than the designed grid. This is also resulted to a smaller gap which exposed the underlayer of the breakwater especially in the left out unit area.

3. In comparison to the first placement tests, units are placed in average 0.362D lower than the first placement test.

4. The average upslope distances are in the recommended theoretical value even when the horizontal distances are smaller up to 1.0D which is 75% from the theoretical value of 1.33D. Upslope distance can be varied between the range of 0.5D to 0.9D when placing the unit with the horizontal distance of 1.0D to 1.3D.

5. Lowering the units' upslope distances in the left out unit area reduced the gap and increased the packing density value. The average packing density achieved from this test is is in the upper limit of the theoretical recommended value. The packing density achieved from this test was increased from 94.9% to 106.1% in comparison from the first placement tests.

6. The opening gap of the left out unit area is also reduced by 20% which resulted from decreasing the unit upslope distance with a slight increased in average packing density approximately 6% from test 1.

4.4 Placement Parameters

In conjunction with the placement tests, this section described the relation of the placements made to the parameters that used as an input in the computer model that generating the placement grids. The parameters namely:

- The minimal off centre distance to place a unit off centre
- The maximal off centre distance before the unit is left out
- The Unit adjust angle

With the second test, placement made with coherent judgement, decreasing the upslope distance would increase the packing density of the whole Xbloc unit on the breakwater head. Nonetheless, in the second placement test there were no off centre placement made if the unit were repositioned. The off centre distance are made only if it was possible to be placed according to the design grid. Thus, the only possibility to see the relation between all the parameters are made based on the observations of the results obtained in terms of the unit relation in horizontal and upslope distances and the unit deviations.

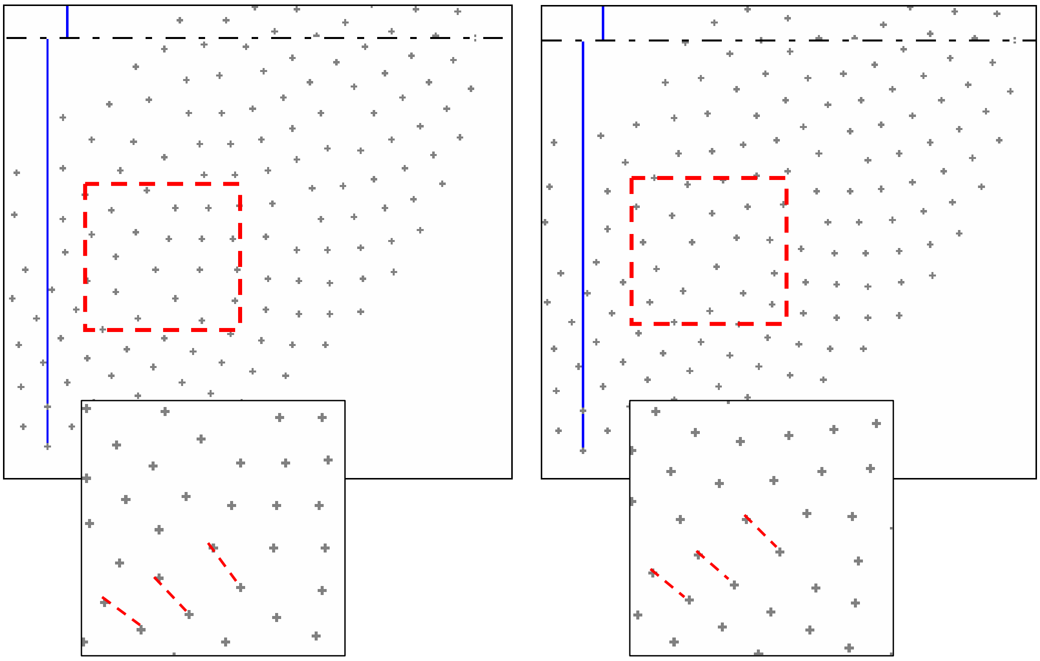
The parameters were varied in the computer model and the graphical output which presented in Section 3.4.2 was compared to the designed grid used in the placement tests. The grids are compared in terms of the difficulties and behaviors of the units encounters during the placement tests.

4.4.1 Minimal off Centre Distance to Place a Unit off Centre

The minimal off centre distance to place a unit off centre suggested by ten Oever (2006) are in the order of 0.2D. As described in his MSc thesis, the off centre unit less than 0.2D would lead to the unit to roll back. Hence, the unit was place directly in the middle of the two base units. ten Oever (2006).

While for the minimal off centre distance of more than 0.2D before the unit are place off centre (e.g 0.3D and above), this would lead to a distorted placement grid. There many units sitting on top of only one base unit as described in section 3.4.2. See also Figure 4.22 (a) and (b).

In the highlighted small square box in Figure 4.22 shows the distorted unit when applying the minimal off centre distance of 0.3D and 0.4D. The grids of the units in the box are positioned almost directly on top of the unit below. With the experience form the placement tests in the laboratory, unit that placed directly on top of only one unit were not merely stable and easily in loose state conditions. Thus, 0.2D of minimal off centre distance to place a unit off centre is an optimal value.



a) Minimal off centre 0.3D b) Minimal off centre 0.4D

Figure 4.22 Placement Grids for Variable Minimal off Centre

4.4.2 Maximal off Centre Distance before the Unit is Left Out

The analysis of the maximal off centre distance before the unit is left out unit was also analyzed by changing the parameters in the computer model. First, the patterns of the grid were analyses. It was discovered that when the parameters of the maximal off centre distance were reduced to 0.2D, there were many left out unit in one section and hence reduced the packing density of the individual units in the section significantly. More underlayer will be in exposed conditions. See Figure 4.23.

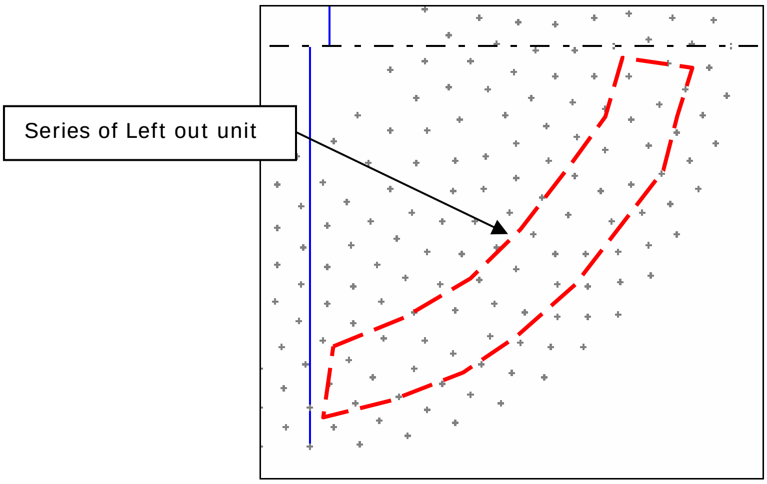


Figure 4.23 Placement Grids for 0.2D Maximal off Centre

On the other hand, placement with the maximal off centre distance of 0.4D (design value) would already encounters difficulties in terms of when the units were placed only at one side of the base unit. The unit is not entirely stable and prone to roll back in the centre when the new unit higher upslope made a slight contact with the unit. The units were also in loose conditions and can be easily shake by hand. Hence, according to the experienced made in the placement tests, maximal off centre of more than 0.4D would not be recommended.

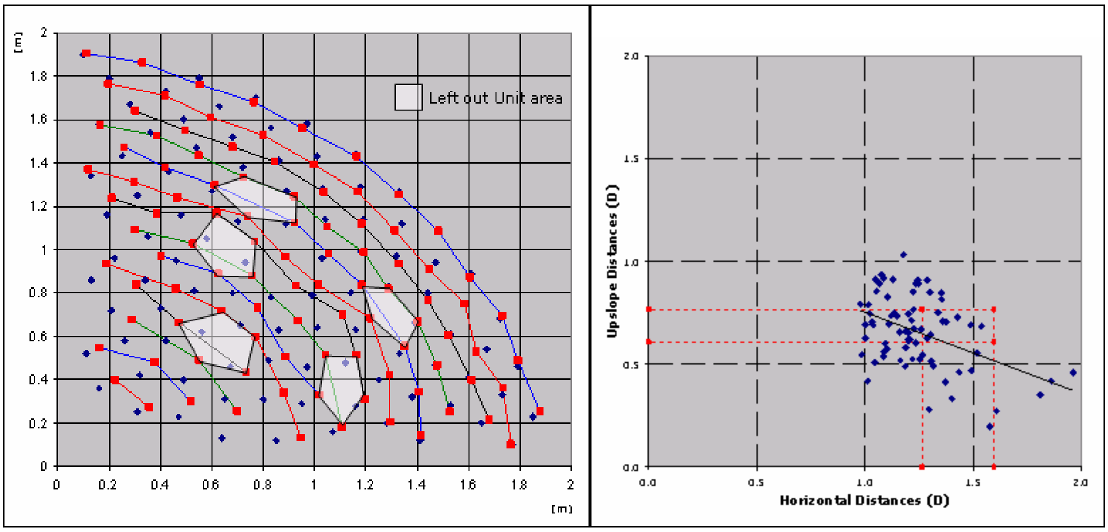
From the computer model, placement grid with a maximal off centre 0.3D would produced a denser placements and the packing density are higher than the value of maximal off centre of 0.4D. The average packing density is increased from 97.7% to 99.5%. Hence, maximal off centre of 0.3D could result the optimum placement of the Xbloc unit before the unit is left out.

Because of time constraints, placement tests with the maximal off centre distance before the unit is left out of 0.3D has not been made. However, it is recommended that this test is to be performed in order to see the actual behaviors of the units during the placement. Nonetheless, keeping in mind that by changing the value from 0.4D to 0.3D, the number of left out units are more and this would lead to a reduce in the interlocking effect of the placement and more exposed of the underlayer.

4.4.3 Unit Adjust Angle

As described in Section 3.4.2, the unit with the unit adjust angle of less than 30^0 and more than 60^0 produced a grid that is unfeasible to be placed. This is verified by the experienced gained when performing the placement tests made previously described in Chapter 4. 0 degrees of unit adjust angle means that the unit purely to be off centered by horizontally towards one base unit. While unit adjust angle of 90 degrees means that the units are placed further upslope.

As the placements made in Test 2 suggested that the upslope distances were resulted in a lower value than expected as shows in Figure 4.24, adjusting the unit adjust angle to lower than 45^0 might also be the solution for the optimal grid position for the Xbloc unit.



a) Placement Grids b) Upslope and Horizontal Distances

Figure 4.24 Placement Results of Placement Test 2

Hence, further placement test would be recommended for placing the Xbloc unit with the unit adjust angle in the order of 30^0 to 45^0. From the analysis of the graphical output of the computer model with the unit adjust angle of 30^0 to 45^0, the generated grid seems to be feasible to be placed. Figure 4.25 below shows the generated grid of the unit adjust angle of 30. The grid of the 30 degrees unit adjust angle seems evenly distributed with no grid being positioned directly only on one of the base unit.

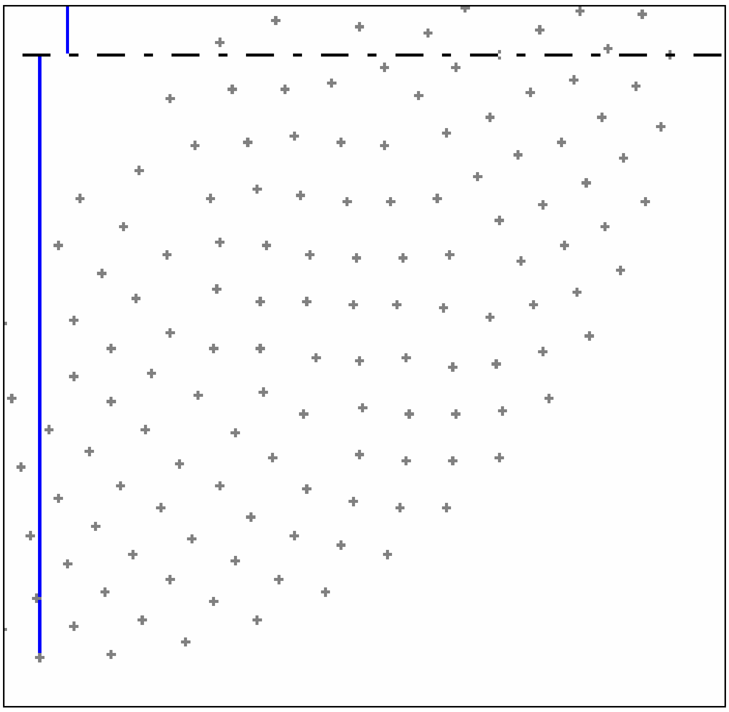


Figure 4.25 Evenly Distributed Placement Grids with the Unit Adjust angle of 30^0

Chapter 5

Placement of the Xbloc Prototype Unit

5.1 Introduction

In this chapter, a comparison is made between the theoretical Xbloc placement and the Xbloc placement at Port Oriel, Ireland. It was the intention to compare the as built Xbloc locations with the theoretical unit locations based on the computer generated grid. However as the alignment of the breakwater was changed slightly before the construction of the breakwater, the theoretical locations can not be compared to the as built locations. Furthermore it was observed that in Port Oriel the accuracy of the location measurement is limited as the location is measured with a prism attached to the sling far above the water. As the unit rolls into position, the prism attached to the sling does not completely follow this movement. This causes a difference between the actual location of the units and the measured locations. Therefore, only a photographic analysis will be made to compare between the placements made in the laboratory and the placement made in Port Oriel.

Project Background

Figure 5.1 Overview of Xbloc in Port Oriel, Ireland

Source: www.dmc.nl

The project location chosen for comparison is a project of a modernization and extension of Port Oriel in Ireland. One of the requirements for the extension of the port is by constructing 105m pier and an armoured breakwater on the sea side. The project in Port Oriel was the first project to use Xbloc as an armour unit for the breakwater in Europe and was chosen in this study as it was the first project initially to use the Xbloc placement grid on a breakwater curved section and on a breakwater head. The breakwater is approximately 190m long and contains a curved section and a breakwater head.

The area of interests for this study is the placement of the Xbloc at the curved sections. See Figure 5.2

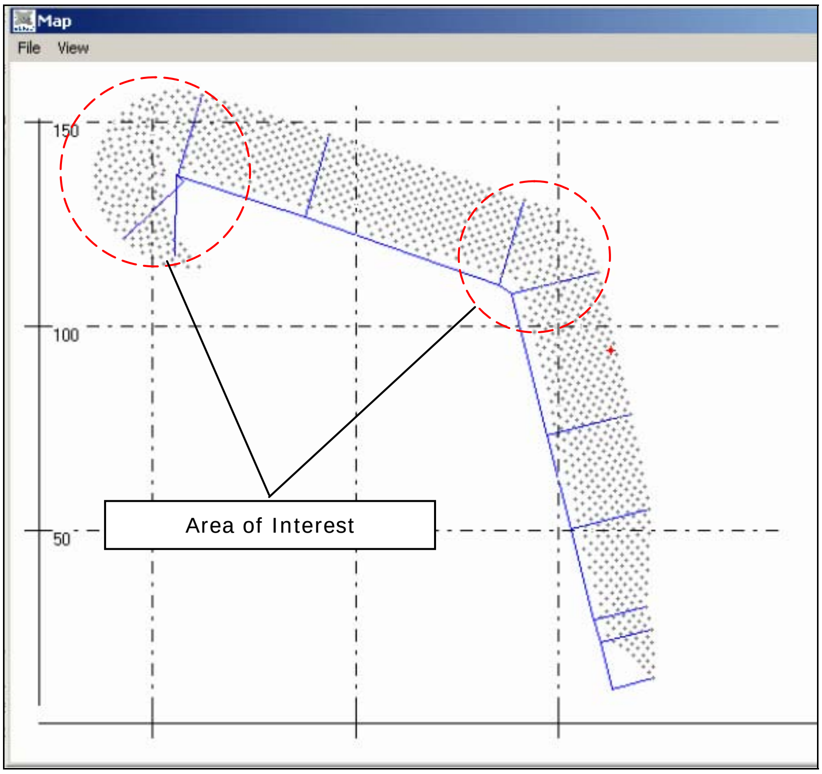


Figure 5.2 Placement Grids for Breakwater at Port Oriel

**Source: ten Oever, 2006*

Xbloc Details:

Xbloc unit weight: $4m^3$
Weight: 9.7 ton
Significant Wave height, H_s: 5.6m
Maximum water depth to MSL: 7.5m

Figure 5.3 Xbloc Unit in Port Oriel

5.2 Placement of the Xbloc Prototype Unit

The Xbloc used in this project weigh 9.7 ton and has a unit volume size of $4m^3$. The placement of units below the water line is done using a sling attached to the crawler crane as described in Chapter 2 with one leg pointing downwards. This method is the common practice and was also used for the placement tests as in the laboratory. The units in the first row are placed with a different sling position, resulting in units placed on three points.

Figure 5.4 Placement method

A hydraulic excavator was used for the placing the Xbloc units above the water line. The use of the hydraulic excavator was possible as the weight of the units is within the lifting capacity of the hydraulic excavator and within the reach of the excavator arm. The advantage of using the hydraulic excavator over the use of crawler crane is that it has a higher operating speed and lower operating cost. It is very suitable for a job which has a lower lifting capacity. It is also suitable placing the units with a small horizontal distance from the crest which in this case on the upper upslope of the breakwater.

Figure 5.5 Xbloc Placements on Upper Breakwater Head

The units were placed in the first row first. For placement under water, the units were placed with assistance from divers. The units in the first row were placed at the correct horizontal distances and checked by divers before the hook was released. The divers were checking the horizontal distances between the units and the orientation of the Xbloc resting on 3 points. For the other rows of Xblocs, the interlocking position between the two units in the row below was also checked by the divers. The placement above the water was simply done on sight and controlled by the land survey equipment.

The positions of the units after the placement however are not known exactly. The units were placed initially by measuring only the position of the hoisting cable attaching the units on the crane before it was released. Hence, the final exact positions of the units are not known as some of the unit might have moved from the measured position.

5.3 Photographic Analysis

The only comparison can be made between the placement of the Xbloc prototype unit and the placement made in the tests on the breakwater head is by analyzing the photographical overview of the placement. Nevertheless, photographs between the prototype and scale model of the Xbloc are taken were from the different angle. Hence, direct interpretation could not be made easily. Figure 5.6 and 5.7 below shows the pictures of the Xbloc unit on the trunk and in the head section of the breakwater in Port Oriel, Ireland.

The quality of the placement is made by assessing the achieved packing density of the placements. Since there is no information on the exact position of the units, the packing density for each of individual units are not known. Thus, in for the Port Oriel, the packing densities are taken as a whole by determining the numbers of the units placed in each section. In the case of the breakwater head as in Figure 5.7, the packing density achieved is higher and placements were much denser than the packing density achieved in the placements made in the laboratory in Figure 5.8. The packing density achieved was in the order of 107% of the recommended theoretical packing density. This is approximately 12% denser than the placement made in the laboratory.

Figure 5.6 Xbloc Unit on the Trunk Section of the Port Oriel Breakwater

Figure 5.7 Xbloc Units on the Head Section of the Port Oriel Breakwater

The reasons that the placement made in Port Oriel is much denser than the placement made in the laboratory is that the way of the unit were placed and the size of the prototype unit compared to the model unit.

Placements made in the laboratory were made by means of sling, comparable to the use of a crawler crane. Hence, it was made with a direct placement in to the gap between the two base units. No force was carried out on the units as it is impossible do so with a crawler crane. Nevertheless, in Port Oriel, placement in the upper part was done by the hydraulic excavator. With this equipment, the orientation of the units can be controlled better. The units were placed by sliding and pushing them into the gap thus creating denser placement.

Besides the placement by hydraulic excavator, the size of the Xbloc unit plays another role in the possibilities to create denser placements. As the Xbloc units were larger, the forces on the edges of the units are larger which leads to crushing of the edges of the units. Due to this the units can sink deeper into the gap between the units in the row below. During the placement in the laboratory no damage to the edges of the Xblocs was observed. It can therefore be assumed that the larger weight of the units in Port Oriel has led to larger tensions at the edges of the Xblocs and hence to denser placement.

Figure 5.8 Xbloc Units Placements in TUDelft Laboratory: Test T2c

5.4 Conclusions

Although a direct comparison between the placements made in the laboratory and the placements of the prototype unit Port Oriel could not be made in accordance to the relations between the placement grids, nevertheless there are several conclusions that can be drawn from the placement made in Port Oriel. Conclusions that can be made are:

- In Port Oriel, the units were placed denser on a breakwater head than during the placement of model units in the laboratory. This is mainly due to the larger forces on the edges of the units and due to the use of the excavator which actively pushed the units into a tight placement pattern.
- Denser placement is acceptable for the stability of the armour layer but it leads to higher concrete use on the breakwater head.

Chapter 6

Conclusions from the Placement Tests

6.1 Outcomes from the tests

1. The placement test according to the recommended designed grid produced by the computer model is reasonable with slight upslope distances deviations especially on the higher upslope after the left out unit area. This is mainly due to the unstable unit especially if the unit were in the off centre distance conditions and touches only one base unit. The deviations of the units especially in the upslope deviation does not produced a self correcting behavior and thus influence the placement further upslope. These upslope deviations accumulated the upslope deviations and hence preventing proper connection with the unit on the crest which then need to be placed towards downslope.

2. Calculation of the packing density made by a schematized curved section for a breakwater head gave a lower packing density values. This is more accurate than calculating the packing density by means of only rectangular section as in the trunk section.

3. In the first test the placement of the unit according to the designed grid, the results for the packing density was only slightly lower than the packing density produced by the design grid. Nevertheless, this packing density was in the lower range of the theoretical packing density. Furthermore, looking at the individual packing density especially in the left out unit area, the packing density from the first test gave average results of 50% below than the theoretical packing density with a large exposure of the underlayer. Placement was resulted in few loose units and the rest of the units are well interlocked.

3. Placement of the unit with lower upslope distances as made in the second test produced more satisfying results in terms of interlocking and packing density. The value for the average packing density increased significantly with the range in the higher part of the recommended theoretical packing density. The exposed area resulted from the left out unit were also improved with the area of 20% lower than the first test when reducing the upslope distance. The number of loose units was quite minimal and mostly the units are well interlocked.

For comparison, table 5.1 below gives overviews of the packing densities from the two tests in comparison to the designed packing density and theoretical packing density:

Table 5.1 Overviews if Packing Densities from the Tests

No	Item	Packing density (Unit/m^2)	%
1	Theoretical Packing density	36.23	100
2	Designed Grid Left out unit area	35.39	97.7
3	Test#1 Recommended Placement Left out unit area	34.37 17.62	94.9 48.6
4	Test#2 Placement with judgment Left out unit area	38.43 19.78	106.1 54.6

**Range of Recommended theoretical packing densities: 98-105%*

6.2 Conclusions

In conclusions, placements made according to the designed grid position generated by the computer model are rather possible to be constructed in the prototype. The results were in the acceptable conditions only with the slightly lower average packing density. The only concern is the large area produced by the left out unit which exposing the underlayer. Hence, in order to improved the overall packing density of the unit, decreasing the upslope distance would increased the value of the packing density significantly to the higher limit of the range recommended theoretical packing density. The amount of the exposed underlayer in the left out unit area would be also reduced. Further hydraulic testing is also highly recommended in order to test the breakwater with left out unit area that would not lead to the progressive failure.

The upslope distances in the computer model algorithm that generates the Xbloc grid position for the breakwater curve section maybe change to the lower values. The lower values of the upslope distance possibly to be maintained in the range of the recommended upslope distance of 0.64D regardless the reduction of horizontal distances in the in order to achieve higher results in packing density for the breakwater curve section. This however, attention is needed as the upslope distances for the unit covering the left out unit area has a lower upslope distance. Some of the placement will be quite difficult due the tightness of the two base unit but it is achievable as the placement made in the test are representing as much as possible as placing the unit using a crane. The change in the parameters of the computer model such as the unit adjust angle might also improve the upslope distances. For example, lowering the unit adjust angle would mean decreasing the upslope distances.

This test were made in dry conditions where a clearly visible towards the overview of the overall placement and position of the units. In reality however, some of the units were situated under the water. Hence, the results obtain in Test 2 may very well too optimistic and does not restrict the high precision placement. The results achieved in the prototype unit maybe slightly difference and towards the lower side of the achieved packing density values from the Test 2.

The very high packing density values achieved in Test 2 may not be achievable in reality. Nevertheless, by lowering the upslope distance it will still improve the overall average packing density value compared to the current design grid.

Furthermore, in addition to the lowering of the placement of the unit towards downslope, the placement for the prototype unit may required a highly labor intensive especially for the diver when placing the unit underwater to achieve the results as in Test 2.

Although a direct comparison between the placements made in the laboratory and the placements of the prototype unit Port Oriel could not be made in accordance to the relations between the placement grids, nevertheless there are several conclusions that can be drawn from the placement made in Port Oriel. Conclusions that can be made are:

- In Port Oriel, the units were placed denser on a breakwater head than during the placement of model units in the laboratory. This is mainly due to the larger forces on the edges of the units and due to the use of the excavator which actively pushed the units into a tight placement pattern.
- Denser placement is acceptable for the stability of the armour layer but it leads to higher concrete use on the breakwater head.

6.3 Recommendations

1. Change of the parameter value in the computer model

From the results of the placements tests it was concluded that the changing of the parameter used in the computer model might provide a better quality and easiness of the placement of the Xbloc units. Due to time constraints, further placement test with the change in parameters of the computer model could not be made. Hence, placement tests with the parameters described below would be recommended:

a) Maximal off Centre Distance before the unit is left out: 0.3D
b) Unit adjust angle: 30^0-45^0
c) Combination of (a) and (b)

2. Further Hydraulic Test

As the placement made only satisfying the Xbloc in terms of interlocking and the packing densities, it is somehow not known how is the unit behaves under the hydraulic load as the waves impact. The left out unit will be reducing the packing density of certain individual unit as well as leaving a gap with an expose under layer. The stability of the units and the underlayer are not known unless proven to be stable if it is tested with the hydraulic testing. The hydraulic test may includes series of test on a placement according to the generated computer grid with many left out unit as well as with a different packing density values.

3. Comparison with the Placement of the Prototype Unit

Since the data on the position of the placement of the Xbloc prototype unit are not yet available, it is recommended to compare the placement tests made in this study to the placement made with the Xbloc prototype unit whenever it is available. This is to see how well the placement made in the laboratory resembles the placement made in the actual conditions.

4. Further study on the Placement of the Xbloc unit on the Crest

It was discovered from the placement tests that connection between the Xbloc on the crest and the Xbloc on the slope were in poor connections in terms of interlocking. During the tests, placing the Xbloc with 3 points leg downwards provide better connections with the surrounding units. This is due to the units are not in a stable conditions when it was placed by pointing one leg down. Nevertheless, the actual grid for placing the Xbloc near the crest for the breakwater head should be investigated further. This is important in the case of designing the breakwater with the Xbloc as an armour unit with an overtopping criterion.

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APPENDIX A

Xbloc Designed Grid

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APPENDIX A – Xbloc Design Grid

A.1. Results Obtained From Computer Model

project name	TUDelft Breakwater Head Grid
project number	280606
dx	1.3
dy	0.64
minimum placing distance dx to place in the middle	0.2
error weight coefficient left unit	1.5
adjustment angle for error minimization	0.785398
Maximal error before unit is left out	0.4
percentage of randomness in left out criterium	20
start value randomizer	55
density in percentage of ideal	98.71502
section length of the logging is	15
total number xbloc units is:	342

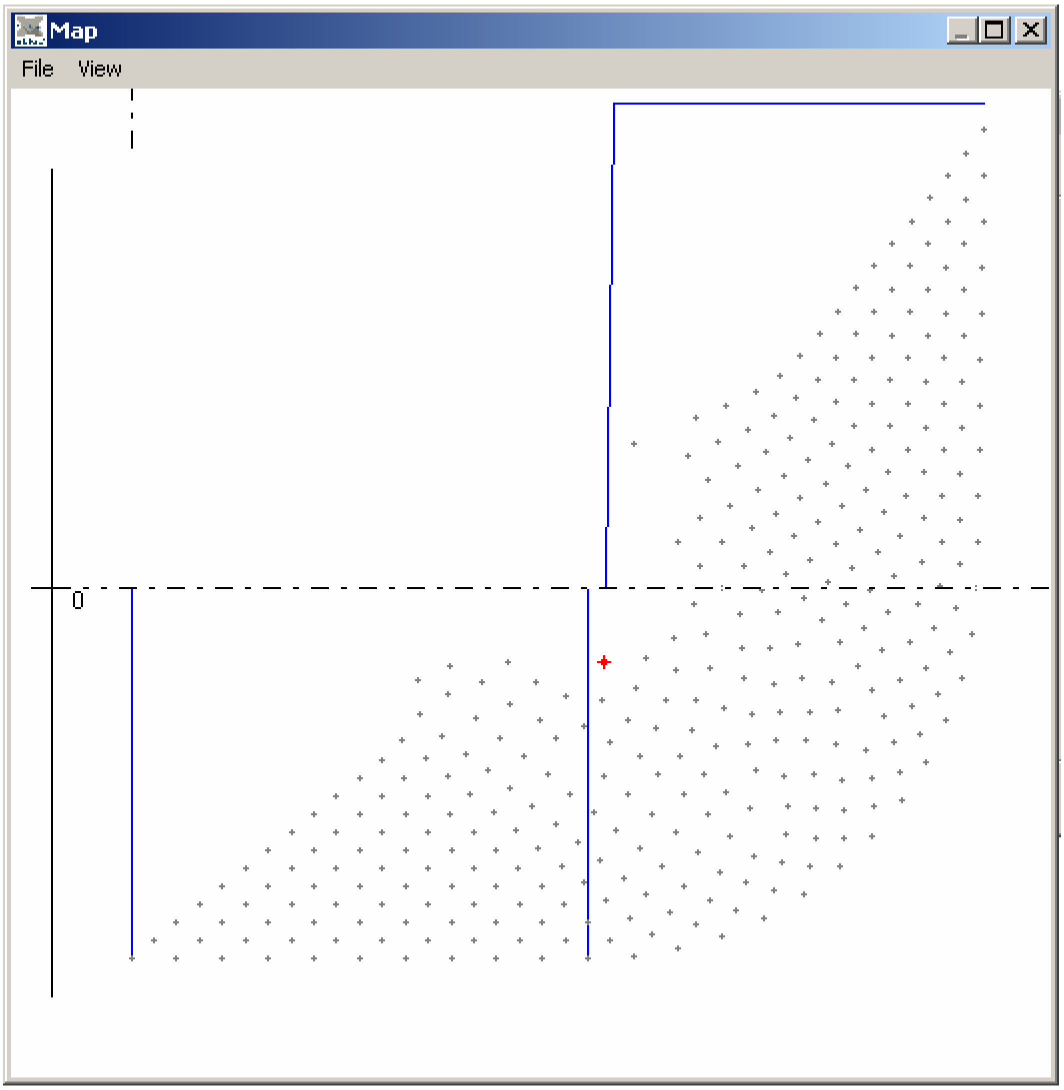
number	**No.**	x-pos	**x-pos 2**	y-pos	**y-pos 2**	z-pos	section	logging section	row	D	interlocking	volume	crestdistance	density
12	1	2.6	0.1	-1.9	1.9	0.18	2	1.95E+09	1	1.80E-01	5	0.002	1.913	0
13	2	2.83	0.33	-1.86	1.86	0.18	2	1.7E+09	1	1.80E-01	5	0.002	1.913	0
14	3	3.05	0.55	-1.79	1.79	0.18	2	41182821	1	1.80E-01	5	0.002	1.913	0
15	4	3.27	0.77	-1.7	1.7	0.18	2	1.36E+08	1	1.80E-01	5	0.002	1.913	0
16	5	3.47	0.97	-1.58	1.58	0.18	2	1.51E+08	1	1.80E-01	5	0.002	1.913	0
17	6	3.66	1.16	-1.44	1.44	0.18	2	1.7E+09	1	1.80E-01	5	0.002	1.913	0
18	7	3.83	1.33	-1.27	1.27	0.18	2	1.87E+09	1	1.80E-01	5	0.002	1.913	0
19	8	3.98	1.48	-1.09	1.09	0.18	2	1.73E+09	1	1.80E-01	5	0.002	1.913	0
20	9	4.11	1.61	-0.89	0.89	0.18	2	1.7E+09	1	1.80E-01	5	0.002	1.913	0
21	10	4.22	1.72	-0.68	0.68	0.18	2	40399972	1	1.80E-01	5	0.002	1.913	0
22	11	4.29	1.79	-0.46	0.46	0.18	2	1.41E+09	1	1.80E-01	5	0.002	1.913	0
23	12	4.35	1.85	-0.23	0.23	0.18	2	1.08E+08	1	1.80E-01	5	0.002	1.913	0
24	13	4.37	1.87	0	0	0.18	2	41182821	1	1.80E-01	5	0.002	1.913	0
46	14	2.7	0.2	-1.79	1.79	0.25	2	-2.1E+09	2	1.80E-01	9.981	0.002	1.817	38.241
47	15	2.92	0.42	-1.73	1.73	0.25	2	-2.1E+09	2	1.80E-01	9.981	0.002	1.818	38.241
48	16	3.13	0.63	-1.66	1.66	0.25	2	-2.1E+09	2	1.80E-01	9.981	0.002	1.819	38.241

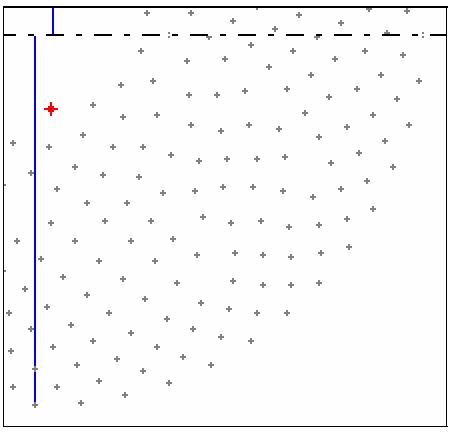
49	17	3.33	0.83	-1.56	1.56	0.25	2	0	2	1.80E-01	9.981	0.002	1.821	38.241
50	18	3.51	1.01	-1.43	1.43	0.25	2	-2.1E+09	2	1.80E-01	9.981	0.002	1.823	38.241
51	19	3.68	1.18	-1.29	1.29	0.25	2	-2.1E+09	2	1.80E-01	9.981	0.002	1.825	38.241
52	20	3.84	1.34	-1.12	1.12	0.25	2	-2.1E+09	2	1.80E-01	9.981	0.002	1.827	38.241
53	21	3.97	1.47	-0.94	0.94	0.25	2	-2.1E+09	2	1.80E-01	9.981	0.002	1.83	38.241
54	22	4.08	1.58	-0.75	0.75	0.25	2	-2.1E+09	2	1.80E-01	9.981	0.002	1.833	38.241
55	23	4.17	1.67	-0.54	0.54	0.25	2	-2.1E+09	2	1.80E-01	9.981	0.002	1.837	38.241
56	24	4.23	1.73	-0.33	0.33	0.25	2	-2.1E+09	2	1.80E-01	9.981	0.002	1.84	38.241
57	25	4.27	1.77	-0.1	0.1	0.25	2	-2.1E+09	2	1.80E-01	9.987	0.002	1.844	38.241
78	26	2.57	0.07	-1.7	1.7	0.32	2	-1	3	1.80E-01	9.923	0.002	1.715	37.321
79	27	2.78	0.28	-1.67	1.67	0.32	2	-1	3	1.80E-01	9.885	0.002	1.716	38.435
80	28	2.99	0.49	-1.6	1.6	0.32	2	-1	3	1.80E-01	9.885	0.002	1.717	38.435
81	29	3.18	0.68	-1.52	1.52	0.32	2	-1	3	1.80E-01	9.885	0.002	1.718	38.435
82	30	3.36	0.86	-1.41	1.41	0.32	2	-1	3	1.80E-01	9.885	0.002	1.72	38.435
83	31	3.53	1.03	-1.28	1.28	0.32	2	-1	3	1.80E-01	9.885	0.002	1.722	38.435
84	32	3.69	1.19	-1.14	1.14	0.32	2	-1	3	1.80E-01	9.885	0.002	1.725	38.435
85	33	3.82	1.32	-0.97	0.97	0.32	2	-1	3	1.80E-01	9.885	0.002	1.728	38.435
86	34	3.94	1.44	-0.8	0.8	0.32	2	-1	3	1.80E-01	9.885	0.002	1.731	38.435
87	35	4.03	1.53	-0.61	0.61	0.32	2	-1	3	1.80E-01	9.885	0.002	1.734	38.435
88	36	4.1	1.6	-0.41	0.41	0.32	2	-1	3	1.80E-01	9.885	0.002	1.737	38.435
89	37	4.15	1.65	-0.2	0.2	0.32	2	-1	3	1.80E-01	9.906	0.002	1.74	38.435
110	38	2.66	0.16	-1.58	1.58	0.4	2	-1	4	1.80E-01	8.956	0.002	1.609	37.507
111	39	2.86	0.36	-1.54	1.54	0.4	2	-1	4	1.80E-01	8.242	0.002	1.61	38.676
112	40	3.04	0.54	-1.47	1.47	0.4	2	-1	4	1.80E-01	7.895	0.002	1.611	38.676
113	41	3.22	0.72	-1.38	1.38	0.4	2	-1	4	1.80E-01	6.676	0.002	1.613	38.676
114	42	3.39	0.89	-1.27	1.27	0.4	2	-1	4	1.80E-01	7.281	0.002	1.615	38.676
115	43	3.54	1.04	-1.14	1.14	0.4	2	-1	4	1.80E-01	8.801	0.002	1.617	38.676
116	44	3.68	1.18	-0.99	0.99	0.4	2	-1	4	1.80E-01	8.147	0.002	1.62	38.676
117	45	3.79	1.29	-0.83	0.83	0.4	2	-1	4	1.80E-01	6.74	0.002	1.622	38.676
118	46	3.89	1.39	-0.66	0.66	0.4	2	-1	4	1.80E-01	7.281	0.002	1.625	38.676
119	47	3.97	1.47	-0.47	0.47	0.4	2	-1	4	1.80E-01	8.801	0.002	1.629	38.676
120	48	4.03	1.53	-0.28	0.28	0.4	2	-1	4	1.80E-01	8.213	0.002	1.632	38.676
121	49	4.06	1.56	-0.08	0.08	0.4	2	-1	4	1.80E-01	8.195	0.002	1.639	38.648
140	50	2.54	0.04	-1.49	1.49	0.48	2	-1	5	1.80E-01	8.747	0.002	1.502	36.476
141	51	2.75	0.25	-1.43	1.43	0.5	2	-1	5	1.80E-01	7.337	0.002	1.496	28.8

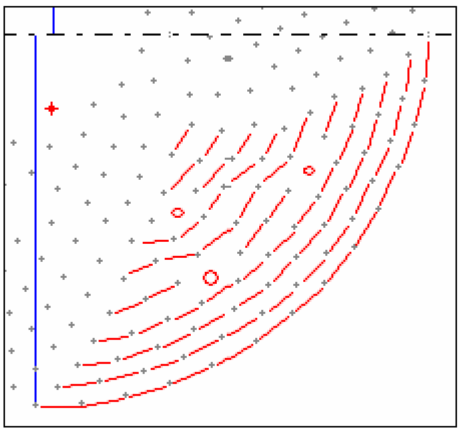
142	52	2.93	0.43	-1.36	1.36	0.51	2	-1	5	1.80E-01	6.143	0.002	1.497	28.781
143	53	3.1	0.6	-1.27	1.27	0.51	2	-1	5	1.80E-01	6.685	0.002	1.499	29.006
144	54	3.39	0.89	-1.12	1.12	0.48	2	-1	5	1.80E-01	8.562	0.002	1.501	21.749
145	55	3.53	1.03	-0.96	0.96	0.5	2	-1	5	1.80E-01	7.596	0.002	1.505	28.737
146	56	3.64	1.14	-0.8	0.8	0.51	2	-1	5	1.80E-01	7.286	0.002	1.508	28.657
147	57	3.83	1.33	-0.52	0.52	0.48	2	-1	5	1.80E-01	8.38	0.002	1.511	21.538
148	58	3.88	1.38	-0.32	0.32	0.5	2	-1	5	1.80E-01	8.319	0.002	1.518	28.737
149	59	3.91	1.41	-0.12	0.12	0.51	2	-1	5	1.80E-01	7.918	0.002	1.524	29.097
168	60	2.63	0.13	-1.34	1.34	0.58	2	-2.1E+09	6	1.80E-01	6.894	0.002	1.383	30.456
169	61	2.81	0.31	-1.25	1.25	0.61	2	-2.1E+09	6	1.80E-01	6.24	0.002	1.357	28.053
170	62	2.98	0.48	-1.16	1.16	0.63	2	-2.1E+09	6	1.80E-01	6.502	0.002	1.345	27.417
171	63	3.2	0.7	-1.13	1.13	0.56	2	-2.1E+09	6	1.80E-01	6.107	0.002	1.409	44.365
172	64	3.38	0.88	-0.97	0.97	0.57	2	-2.1E+09	6	1.80E-01	7.569	0.002	1.385	31.28
173	65	3.49	0.99	-0.79	0.79	0.6	2	-2.1E+09	6	1.80E-01	7.817	0.002	1.363	28.381
174	66	3.66	1.16	-0.63	0.63	0.56	2	0	6	1.80E-01	7.192	0.002	1.421	40.552
175	67	3.75	1.25	-0.4	0.4	0.57	2	0	6	1.80E-01	8.788	0.002	1.397	30.344
176	68	3.78	1.28	-0.2	0.2	0.59	2	0	6	1.80E-01	9.359	0.002	1.38	36.043
177	69	3.82	1.32	-0.01	0.01	0.58	2	0	6	1.80E-01	9.091	0.002	1.392	36.452
194	70	2.51	0.01	-1.24	1.24	0.66	2	0	7	1.80E-01	6.595	0.002	1.275	30.336
195	71	2.69	0.19	-1.16	1.16	0.7	2	0	7	1.80E-01	5.797	0.002	1.234	28.986
196	72	2.85	0.35	-1.06	1.06	0.73	2	0	7	1.80E-01	6.338	0.002	1.199	27.149
197	73	3.08	0.58	-1.05	1.05	0.67	2	0	7	1.80E-01	4.402	0.002	1.257	34.816
198	74	3.23	0.73	-0.94	0.94	0.66	2	0	7	1.80E-01	5.267	0.002	1.295	34.808
199	75	3.33	0.83	-0.78	0.78	0.69	2	0	7	1.80E-01	6.902	0.002	1.26	29.897
200	76	3.51	1.01	-0.64	0.64	0.65	2	0	7	1.80E-01	6.68	0.002	1.277	37.171
201	77	3.62	1.12	-0.48	0.48	0.63	2	0	7	1.80E-01	6.34	0.002	1.306	45.867
202	78	3.66	1.16	-0.28	0.28	0.66	2	0	7	1.80E-01	6.566	0.002	1.274	35.238
203	79	3.69	1.19	-0.08	0.08	0.67	2	0	7	1.80E-01	9.42	0.002	1.271	36.046
220	80	2.57	0.07	-1.06	1.06	0.78	2	0	8	1.80E-01	4.681	0.002	1.117	28.541
221	81	2.72	0.22	-0.96	0.96	0.83	2	0	8	1.80E-01	4.311	0.002	1.066	27.4
222	82	2.96	0.46	-0.95	0.95	0.77	2	0	8	1.80E-01	6.402	0.002	1.117	33.246
223	83	3.18	0.68	-0.8	0.8	0.76	2	0	8	1.80E-01	7.859	0.002	1.14	25.509
224	84	3.36	0.86	-0.63	0.63	0.75	2	0	8	1.80E-01	7.819	0.002	1.149	33.829
225	85	3.47	0.97	-0.46	0.46	0.74	2	0	8	1.80E-01	7.184	0.002	1.178	28.496
226	86	3.57	1.07	-0.16	0.16	0.75	2	0	8	1.80E-01	9.009	0.002	1.179	23.238

243	87	2.84	0.34	-0.86	0.86	0.87	2	0	9	1.80E-01	6.202	0.002	0.938	21.079
244	88	3.03	0.53	-0.81	0.81	0.83	2	0	9	1.80E-01	7.795	0.002	1.033	50.057
245	89	3.21	0.71	-0.65	0.65	0.82	2	0	9	1.80E-01	7.729	0.002	1.041	36.079
246	90	3.32	0.82	-0.49	0.49	0.82	2	0	9	1.80E-01	8.396	0.002	1.043	37.773
247	91	3.45	0.95	-0.29	0.29	0.8	2	0	9	1.80E-01	7.418	0.002	1.078	47.667
248	92	3.48	0.98	-0.05	0.05	0.83	2	0	9	1.80E-01	9.546	0.002	1.051	29.482
263	93	2.63	0.13	-0.86	0.86	0.91	2	0	10	1.80E-01	6.731	0.002	0.901	47.637
264	94	2.9	0.4	-0.73	0.73	0.93	2	0	10	1.80E-01	6.98	0.002	0.893	23.055
265	95	3.06	0.56	-0.62	0.62	0.91	2	0	10	1.80E-01	5.636	0.002	0.94	34.964
266	96	3.17	0.67	-0.46	0.46	0.93	2	0	10	1.80E-01	5.409	0.002	0.927	28.514
267	97	3.3	0.8	-0.31	0.31	0.9	2	0	10	1.80E-01	5.386	0.002	0.962	34.074
268	98	3.35	0.85	-0.12	0.12	0.91	2	0	10	1.80E-01	5.188	0.002	0.969	34.647
283	99	2.71	0.21	-0.72	0.72	0.99	2	0	11	1.80E-01	7.721	0.002	0.813	36.128
284	100	2.92	0.42	-0.58	0.58	1.01	2	0	11	1.80E-01	8.029	0.002	0.784	27.569
285	101	3.15	0.65	-0.31	0.31	1	2	0	11	1.80E-01	7.214	0.002	0.787	20.467
286	102	3.26	0.76	0	0	0.99	2	0	11	1.80E-01	9.099	0.002	0.819	22.421
298	103	2.57	0.07	-0.67	0.67	1.05	2	0	12	1.80E-01	9.618	0.002	0.702	39.406
299	104	2.76	0.26	-0.58	0.58	1.06	2	0	12	1.80E-01	8.701	0.002	0.693	41.742
300	105	2.99	0.49	-0.4	0.4	1.05	2	0	12	1.80E-01	7.658	0.002	0.717	45.555
301	106	3.14	0.64	-0.13	0.13	1.04	2	0	12	1.80E-01	7.919	0.002	0.739	38.316
313	107	2.61	0.11	-0.52	0.52	1.07	2	0	13	1.80E-01	8.329	0.002	0.589	43.254
314	108	2.82	0.32	-0.42	0.42	1.07	2	0	13	1.80E-01	9.068	0.002	0.615	45.24
315	109	2.97	0.47	-0.23	0.23	1.07	2	0	13	1.80E-01	8.688	0.002	0.642	47.162
316	110	3.05	0.55	0	0	1.07	2	0	13	1.80E-01	8.776	0.002	0.643	36.903
327	111	2.66	0.16	-0.36	0.36	1.07	2	0	14	1.80E-01	4.997	0.002	0.48	38.101
328	112	2.81	0.31	-0.25	0.25	1.07	2	0	14	1.80E-01	4.995	0.002	0.504	49.316
329	113	2.91	0.41	-0.08	0.08	1.07	2	0	14	1.80E-01	4.964	0.002	0.52	45.012

A.2. Graphical Output







APPENDIX B

Placement Test 1 Results - Placement according to Design Grid

Contents: **Page**

B.1. Photographs of Placement for TEST T1a AB2
B.2. Photographs of Placement for TEST T1b AB6
B.3. Photographs of Placement for TEST T1c AB6
B.4. Computer Model Grid Position and Placement Test Grid AB7
B.5. Unit Deviations AB9
B.6. Placement Results AB12

APPENDIX B – Recommended Placement Test 1 Results

B.1. Photographs of Placement for TEST T1a

Row 1

The placements of units for the first row are made using 3 points legs with completely random orientations.

Row 2

-X4 Touch right below only a little bit.
-X9 touch right below using leg

Placement was fairly easy with some based unit are touched only using the leg.

Row 3

-X8 touch left below using leg
-X9 did not touch right below, only touch right unit

This row has already started to feel the tightness of the unit. Some units in the same row were in contact.

Row 4

-X4 not touching right below (Loose)
-X9 Unit rolled, touch right below use leg.
-X11 Unit rolled, touch right below using leg

This row is a bit tricky as some of the unit were not positioned to be exactly in the centre and it is quite unstable. When the unit touch the right unit, it is hard to touch the base unit.

Row 5

-X1 not touching right below
-X2 touch right unit
-X4 touch left below using leg
-X5 not touching b/w
-X7 roll backwards

Unit leaving gaps between base unit as the unit is tight between two base unit.

Row 6

-X2 not touching right below
-X3 not touching right below

The unit covering the left out unit is not quite stable. The units need to be stretched out to optimize the position between two base units.

Row 7

-X2 Touch right unit (loose)
-X4 Touch right unit, not touching right below (difficult placement)
-X5 touching right unit
-X8 roll to left as left below has dropped

Unit on top of the left out unit area is quite difficult to place

Row 8

-X2 touch right below a bit only
-X6 using 3 points leg as hard to placed it (near wall)

It has hard to place the unit according to the designed grid.

Row 9

-X3 touching right unit (Loose)
-X4 (Loose)

The unit that did not touch the base unit normally touch the right unit in the same row. This unit is quite loose.

Row 10

-X1 3 points leg
-X2 (Loose)
-X4 not touching right below and Touch right unit
-X5 not touching right below and Touch right unit
-X6 3 point legs

Row 11

Transitions between crest and slope are difficult to place.

Row 12, 13 & 14

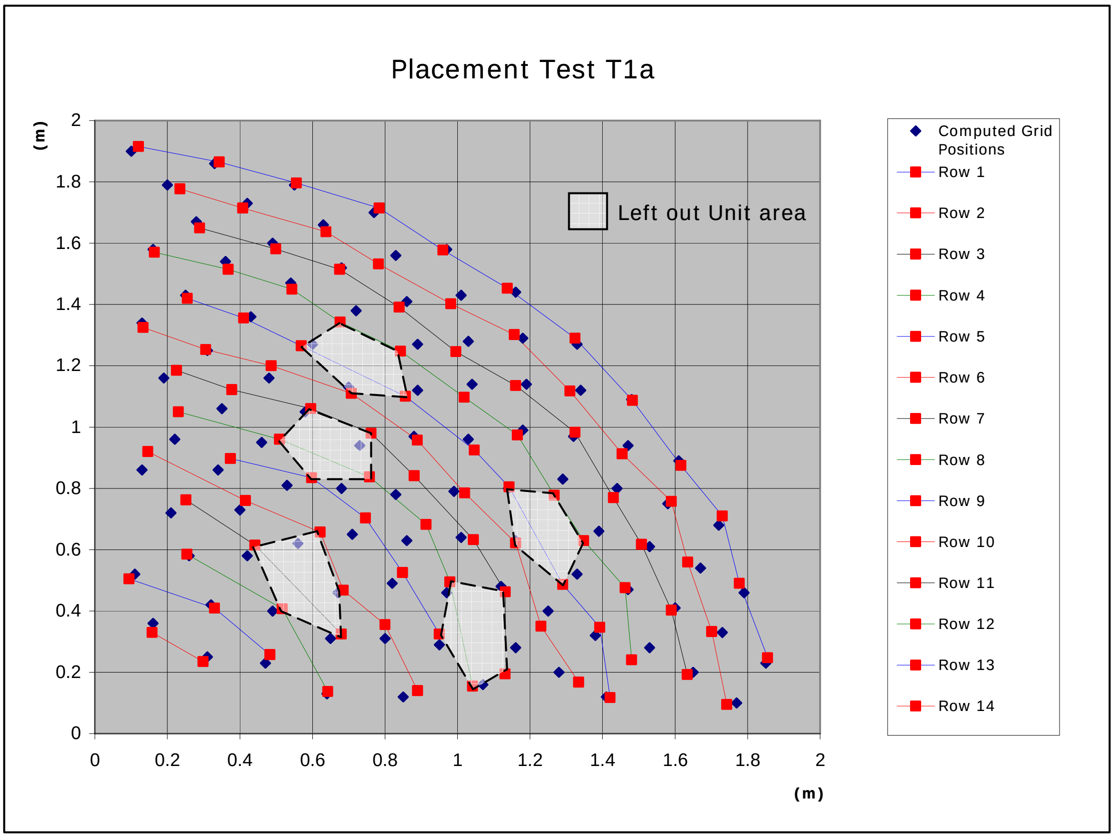
Xbloc unit on crest were placed using 3 point legs

The conditions for the Xbloc placement in test T1b and Test T1c were quite similar to the Test T1a. It is quite difficult to place the unit after the row where there is the left out unit. The difficulties can be either due to the tightness of the two base units or the different levels of the two base units.

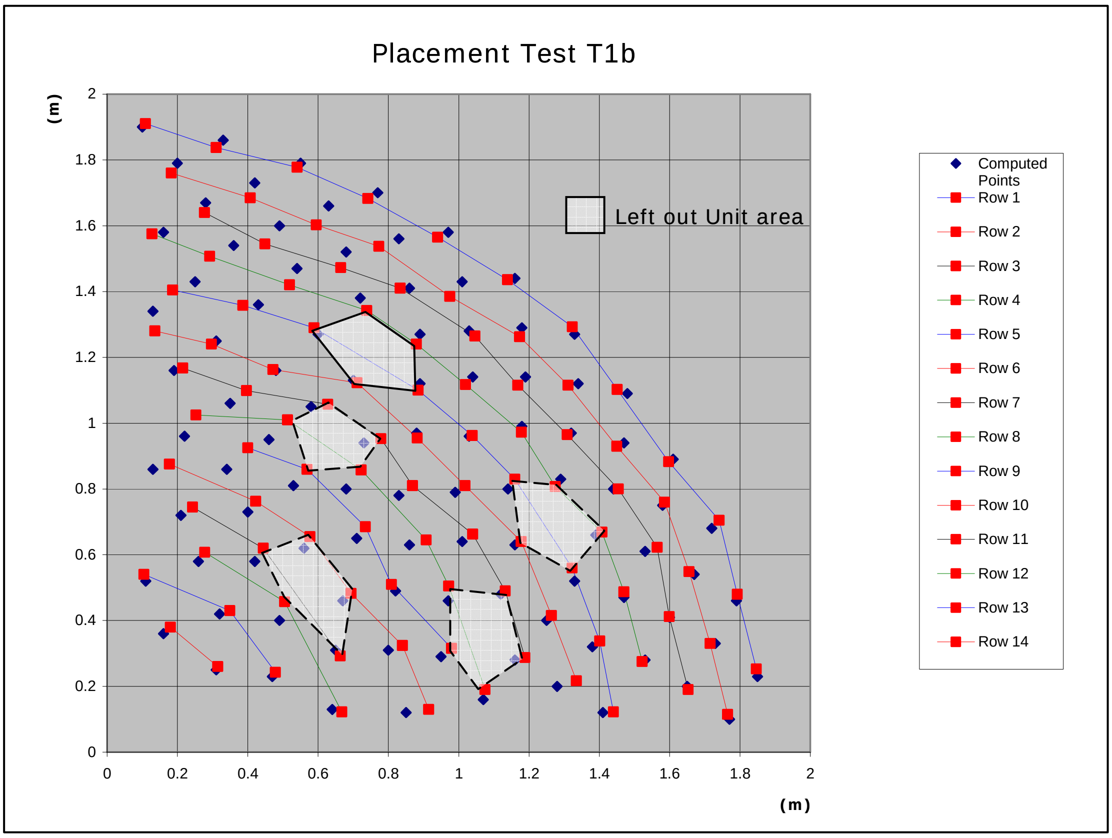
B.2. Photographs of Placement for TEST T1b

B.3. Photographs of Placement for TEST T1c

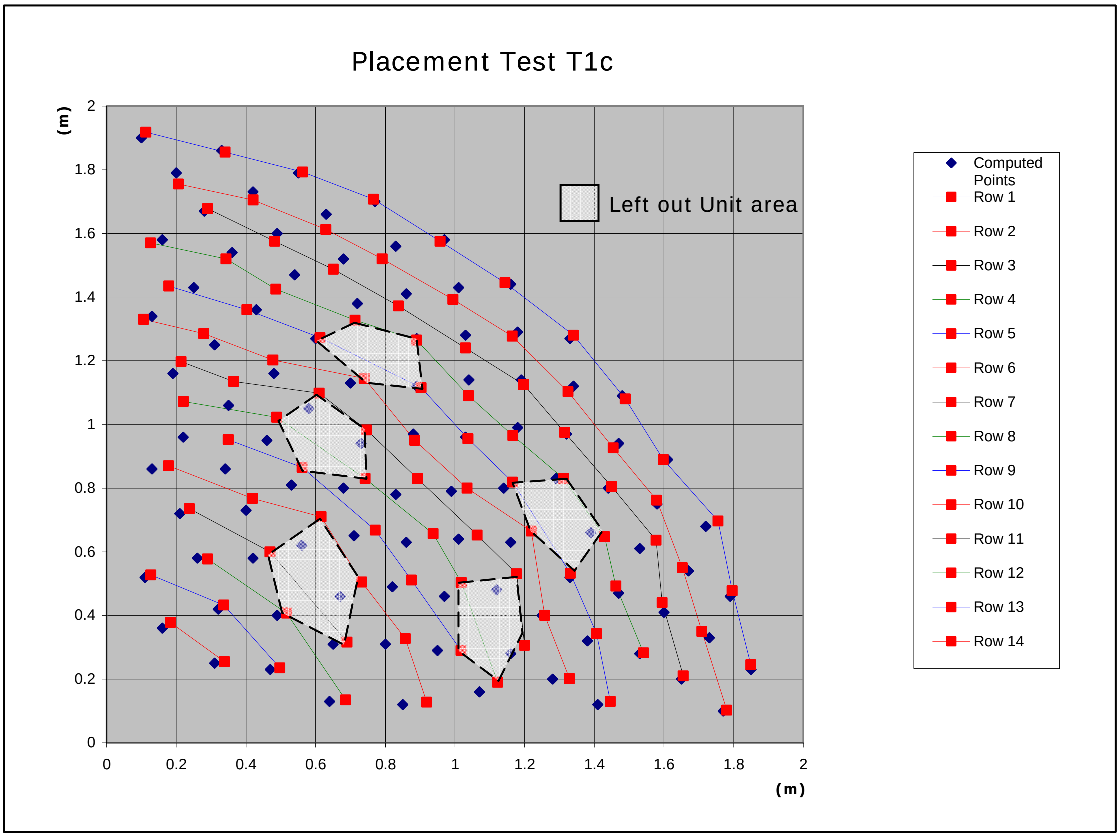
B.4. Computer Model Grid Position and Placement Test Grid



a) Measured Positions Test T1a



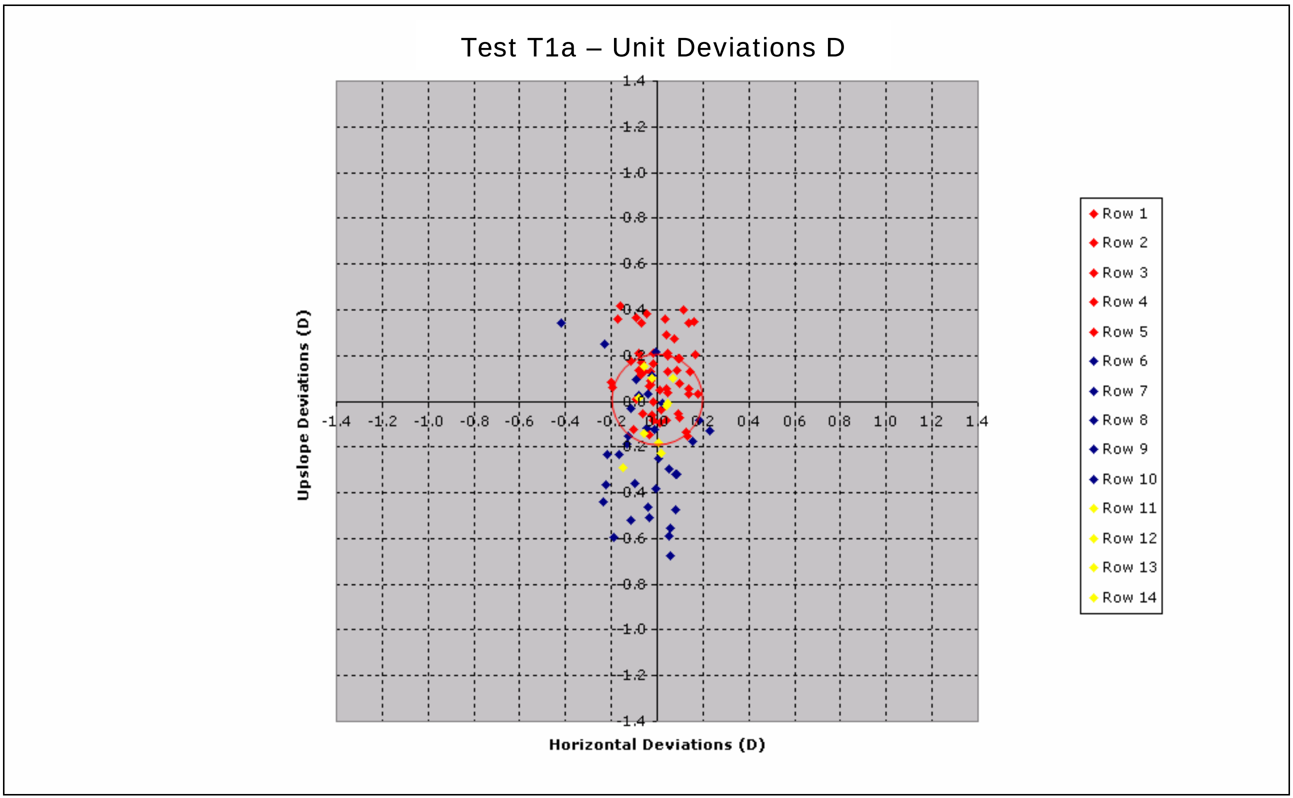
b) Measured Positions Test T1b

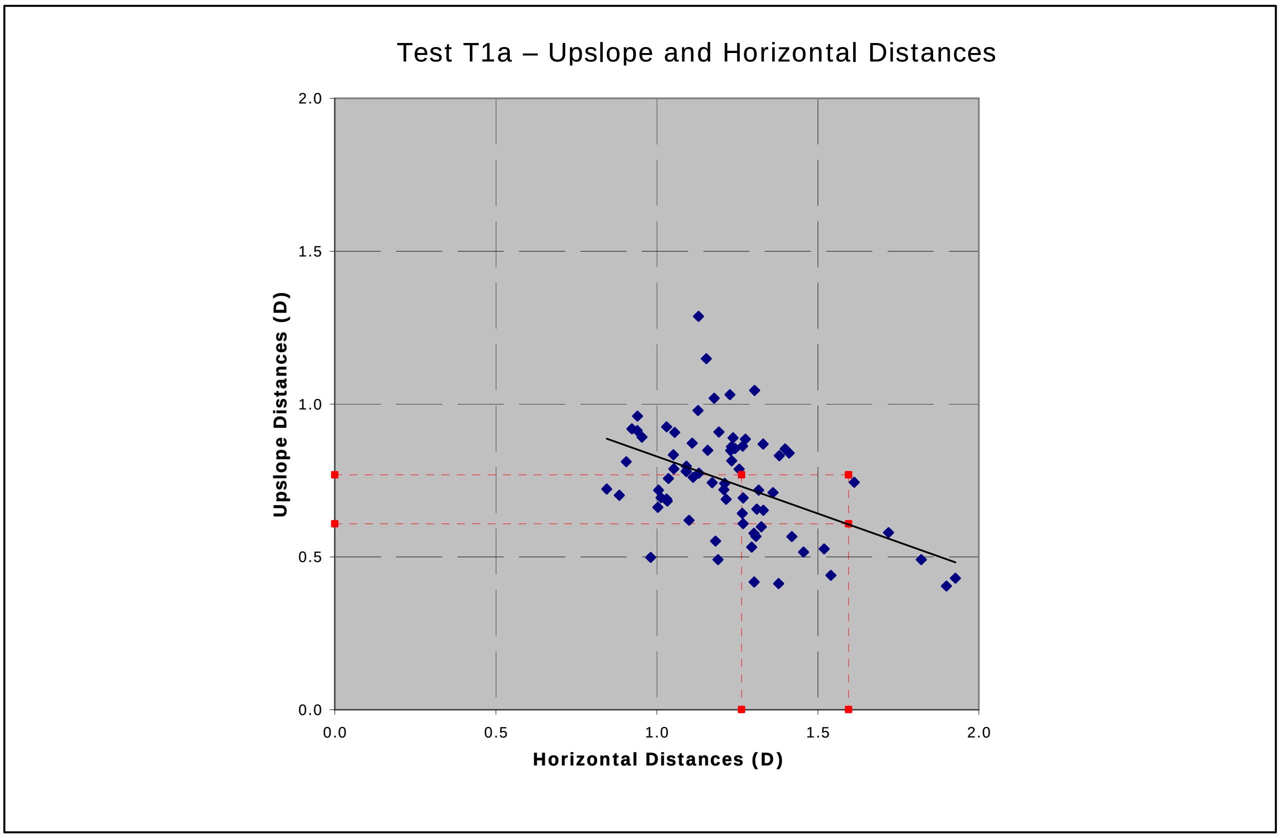


c) Measured Positions Test T1c

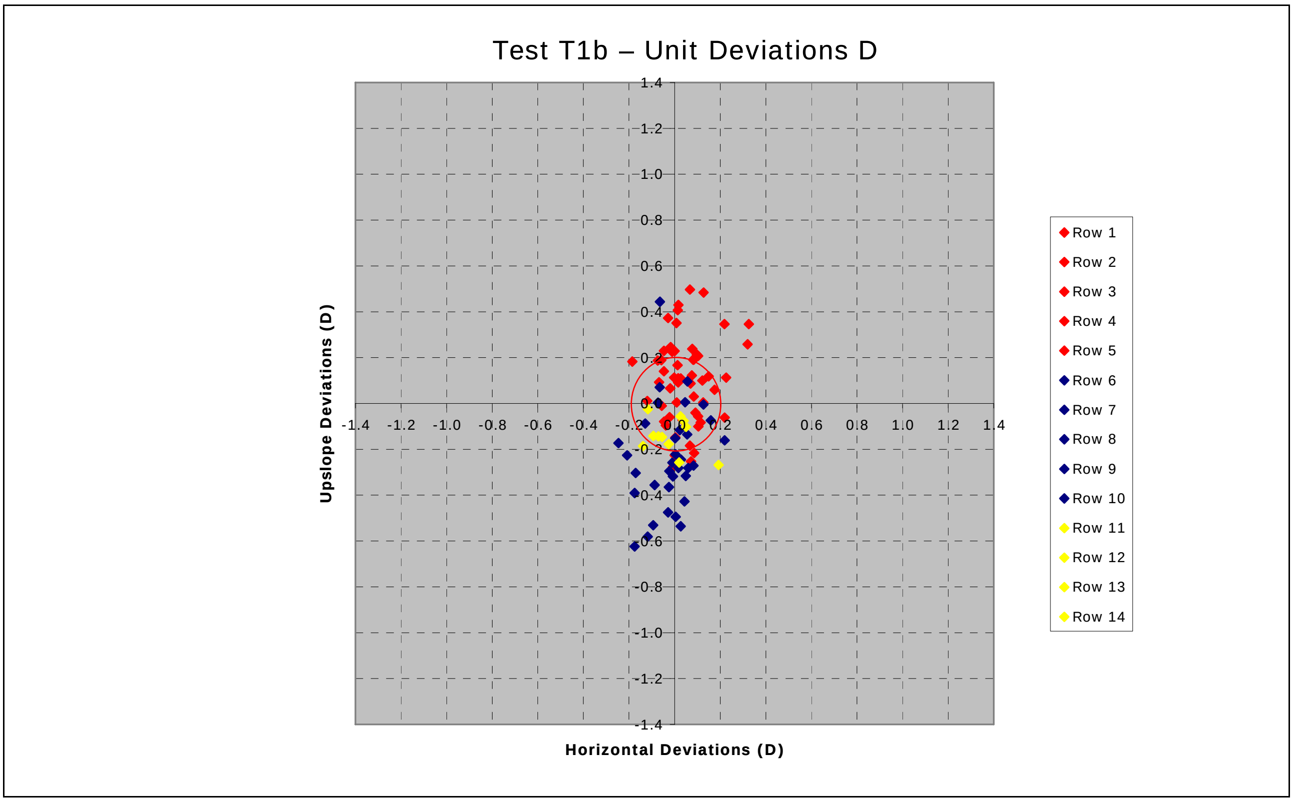
B.5. Unit Deviations

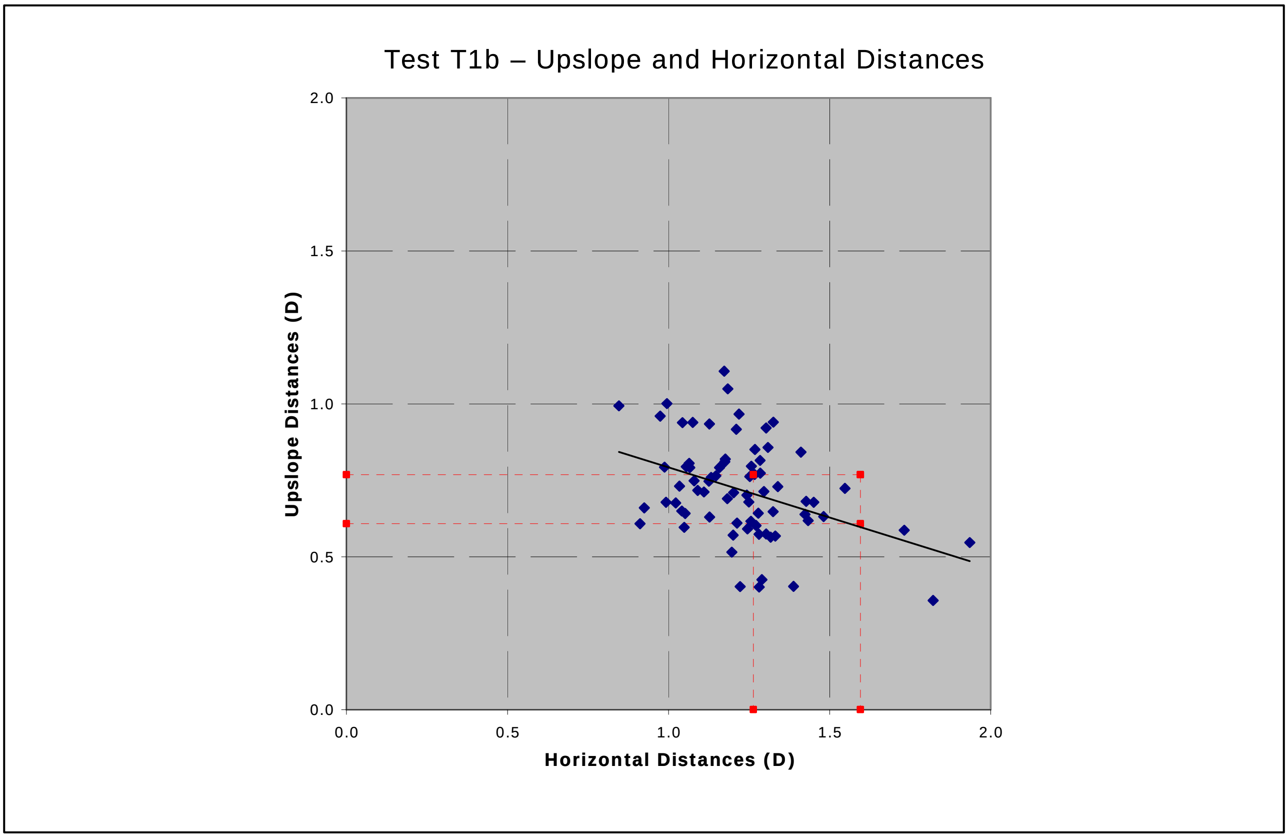
Deviations on Design Position – Test T1a



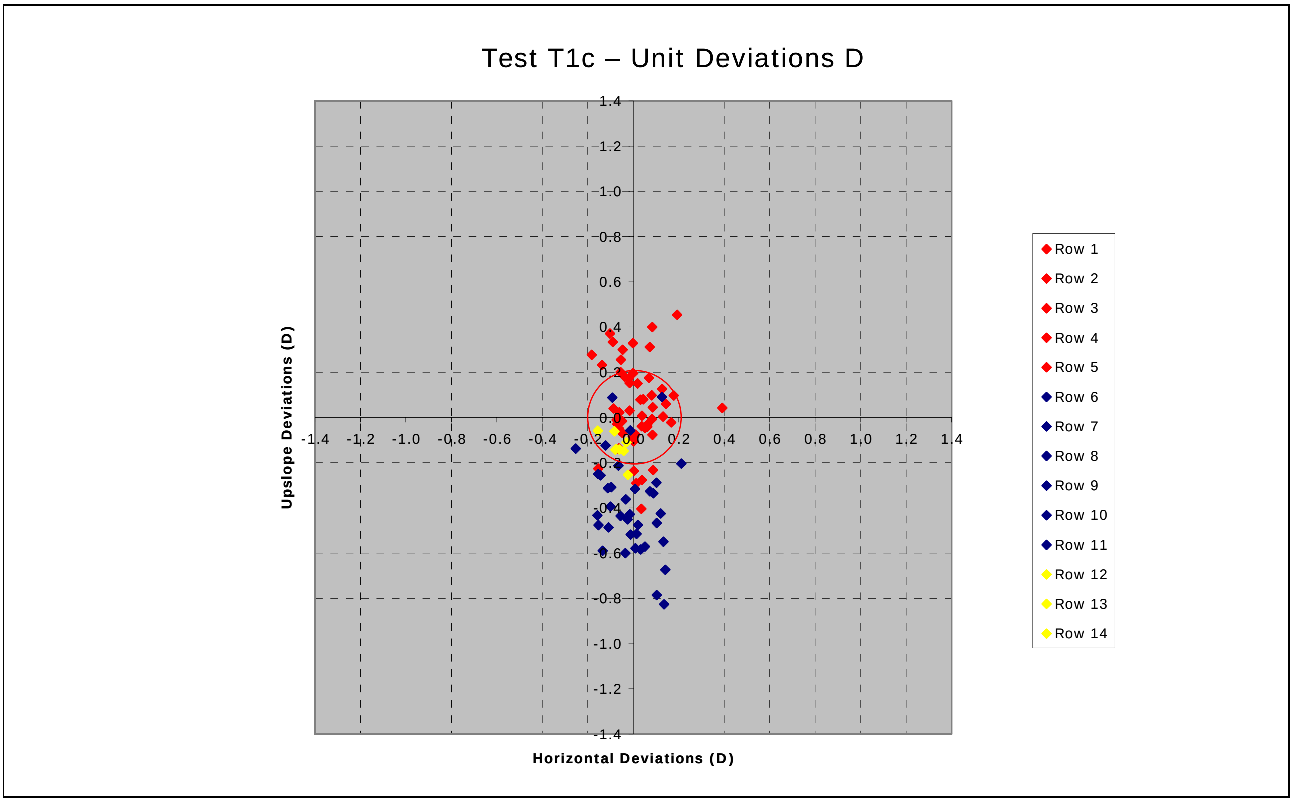


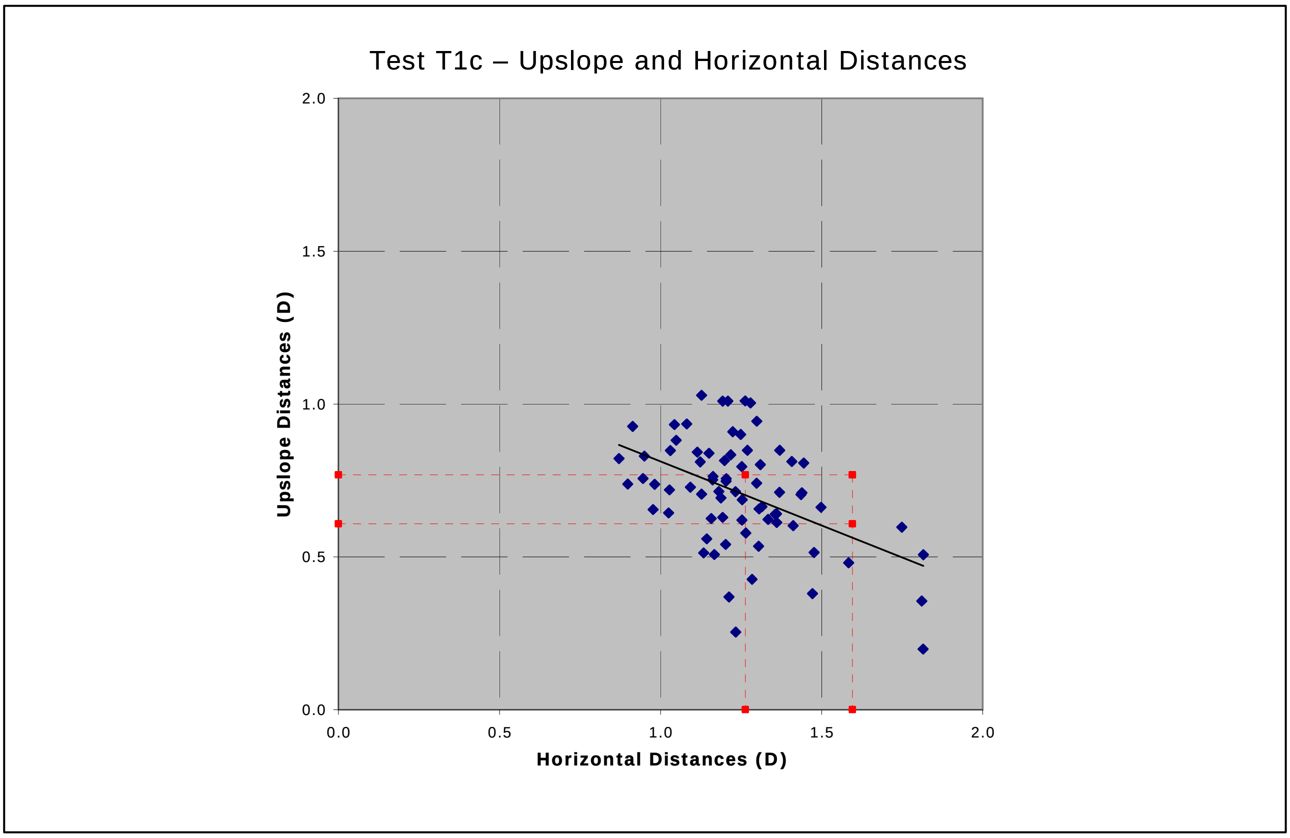
Deviations on Design Position – Test T1b





Deviations on Design Position – Test T1c





B.6. Placement Results

Summarized Xbloc Placement Grid - Placement Acoording to Designed Grid

				Test T1a		Test T1b		Test T1c	
Xbloc Designed Grid				Placement Test		Placement Test		Placement Test	
No.	x-pos 2	y-pos 2	Row	x-mid	y-mid	x-mid	y-mid	x-mid	y-mid
1	0.1	1.9	1	0.120	1.915	0.109	1.910	0.113	1.918
2	0.33	1.86	1	0.343	1.865	0.311	1.838	0.341	1.855
3	0.55	1.79	1	0.556	1.797	0.541	1.778	0.563	1.793
4	0.77	1.7	1	0.784	1.715	0.742	1.683	0.766	1.708
5	0.97	1.58	1	0.960	1.578	0.940	1.565	0.958	1.575
6	1.16	1.44	1	1.138	1.453	1.139	1.436	1.144	1.445
7	1.33	1.27	1	1.325	1.290	1.324	1.293	1.340	1.280
8	1.48	1.09	1	1.483	1.088	1.451	1.103	1.489	1.080
9	1.61	0.89	1	1.617	0.875	1.597	0.883	1.598	0.890
10	1.72	0.68	1	1.730	0.710	1.741	0.705	1.755	0.697
11	1.79	0.46	1	1.778	0.490	1.793	0.480	1.796	0.478
12	1.85	0.23	1	1.855	0.248	1.847	0.253	1.849	0.245
13			1						
14	0.2	1.79	2	0.235	1.778	0.183	1.760	0.206	1.755
15	0.42	1.73	2	0.408	1.715	0.408	1.685	0.421	1.705
16	0.63	1.66	2	0.638	1.638	0.595	1.603	0.630	1.613
17	0.83	1.56	2	0.782	1.533	0.773	1.538	0.792	1.520
18	1.01	1.43	2	0.982	1.403	0.975	1.385	0.994	1.393
19	1.18	1.29	2	1.157	1.302	1.173	1.263	1.164	1.278
20	1.34	1.12	2	1.310	1.118	1.311	1.115	1.325	1.103
21	1.47	0.94	2	1.455	0.913	1.450	0.930	1.455	0.927
22	1.58	0.75	2	1.590	0.758	1.586	0.760	1.579	0.762
23	1.67	0.54	2	1.635	0.560	1.655	0.549	1.653	0.550
24	1.73	0.33	2	1.701	0.333	1.715	0.330	1.709	0.350
25	1.77	0.1	2	1.743	0.095	1.765	0.115	1.780	0.103
26			3						
27	0.28	1.67	3	0.289	1.650	0.277	1.640	0.290	1.678
28	0.49	1.6	3	0.499	1.582	0.449	1.545	0.483	1.575
29	0.68	1.52	3	0.675	1.515	0.665	1.473	0.651	1.488
30	0.86	1.41	3	0.839	1.392	0.834	1.410	0.838	1.373
31	1.03	1.28	3	0.996	1.247	1.046	1.265	1.030	1.240
32	1.19	1.14	3	1.160	1.135	1.169	1.115	1.197	1.125
33	1.32	0.97	3	1.325	0.983	1.309	0.965	1.315	0.975
34	1.44	0.8	3	1.430	0.770	1.455	0.800	1.450	0.805
35	1.53	0.61	3	1.508	0.618	1.565	0.623	1.578	0.636
36	1.6	0.41	3	1.590	0.403	1.599	0.412	1.595	0.440
37	1.65	0.2	3	1.634	0.193	1.653	0.190	1.655	0.210
38	0.16	1.58	4	0.164	1.570	0.128	1.575	0.127	1.570
39	0.36	1.54	4	0.368	1.515	0.292	1.508	0.343	1.520
40	0.54	1.47	4	0.544	1.450	0.519	1.420	0.486	1.425
41	0.72	1.38	4	0.677	1.343	0.739	1.343	0.714	1.328
42	0.89	1.27	4	0.843	1.248	0.880	1.240	0.890	1.265
43	1.04	1.14	4	1.019	1.098	1.020	1.118	1.040	1.090
44	1.18	0.99	4	1.165	0.974	1.179	0.973	1.166	0.965
45	1.29	0.83	4	1.267	0.778	1.275	0.808	1.312	0.830
46	1.39	0.66	4	1.348	0.630	1.408	0.669	1.429	0.648
47	1.47	0.47	4	1.463	0.476	1.470	0.488	1.462	0.493
48	1.53	0.28	4	1.481	0.241	1.522	0.275	1.541	0.283
49			4						
50			5						
51	0.25	1.43	5	0.255	1.420	0.187	1.405	0.179	1.435
52	0.43	1.36	5	0.410	1.356	0.386	1.358	0.403	1.360
53	0.6	1.27	5	0.569	1.265	0.589	1.290	0.613	1.273
54	0.89	1.12	5	0.857	1.100	0.885	1.100	0.903	1.115
55	1.03	0.96	5	1.047	0.925	1.039	0.963	1.038	0.955

56	1.14	0.8	5	1.143	0.805	1.160	0.830	1.166	0.819
57	1.33	0.52	5	1.291	0.487	1.323	0.560	1.331	0.533
58	1.38	0.32	5	1.393	0.347	1.401	0.338	1.407	0.343
59	1.41	0.12	5	1.421	0.118	1.440	0.123	1.446	0.130
60	0.13	1.34	6	0.133	1.325	0.136	1.280	0.106	1.330
61	0.31	1.25	6	0.306	1.253	0.297	1.240	0.279	1.285
62	0.48	1.16	6	0.487	1.200	0.472	1.163	0.478	1.203
63	0.7	1.13	6	0.708	1.110	0.711	1.123	0.740	1.145
64	0.88	0.97	6	0.889	0.958	0.883	0.955	0.885	0.950
65	0.99	0.79	6	1.020	0.785	1.018	0.810	1.035	0.800
66	1.16	0.63	6	1.160	0.622	1.178	0.640	1.219	0.665
67	1.25	0.4	6	1.230	0.350	1.264	0.415	1.258	0.400
68	1.28	0.2	6	1.334	0.168	1.335	0.217	1.329	0.202
69			6						
70			7						
71	0.19	1.16	7	0.225	1.185	0.215	1.168	0.214	1.198
72	0.35	1.06	7	0.378	1.123	0.397	1.099	0.365	1.135
73	0.58	1.05	7	0.595	1.060	0.628	1.058	0.610	1.099
74	0.73	0.94	7	0.762	0.980	0.779	0.953	0.746	0.983
75	0.83	0.78	7	0.881	0.841	0.869	0.810	0.893	0.830
76	1.01	0.64	7	1.044	0.633	1.040	0.663	1.064	0.653
77	1.12	0.48	7	1.132	0.463	1.133	0.490	1.178	0.531
78	1.16	0.28	7	1.131	0.195	1.189	0.288	1.200	0.306
79			7						
80			8						
81	0.22	0.96	8	0.230	1.050	0.253	1.025	0.221	1.073
82	0.46	0.95	8	0.510	0.960	0.513	1.010	0.489	1.023
83	0.68	0.8	8	0.758	0.838	0.723	0.858	0.742	0.830
84	0.86	0.63	8	0.914	0.683	0.908	0.645	0.938	0.657
85	0.97	0.46	8	0.979	0.495	0.972	0.505	1.018	0.504
86	1.07	0.16	8	1.042	0.155	1.075	0.190	1.123	0.190
87	0.34	0.86	9	0.374	0.898	0.400	0.925	0.349	0.953
88	0.53	0.81	9	0.598	0.835	0.569	0.860	0.562	0.865
89	0.71	0.65	9	0.747	0.704	0.735	0.685	0.772	0.668
90	0.82	0.49	9	0.849	0.525	0.809	0.510	0.875	0.511
91	0.95	0.29	9	0.950	0.325	0.980	0.315	1.018	0.290
92			9						
93	0.13	0.86	10	0.146	0.920	0.178	0.875	0.178	0.870
94	0.4	0.73	10	0.415	0.760	0.423	0.763	0.419	0.768
95	0.56	0.62	10	0.622	0.658	0.577	0.655	0.616	0.710
96	0.67	0.46	10	0.685	0.468	0.694	0.483	0.733	0.505
97	0.8	0.31	10	0.800	0.355	0.840	0.324	0.858	0.328
98	0.85	0.12	10	0.890	0.140	0.915	0.130	0.919	0.128
99	0.21	0.72	11	0.251	0.763	0.244	0.745	0.238	0.735
100	0.42	0.58	11	0.442	0.615	0.445	0.620	0.469	0.600
101	0.65	0.31	11	0.680	0.325	0.663	0.293	0.690	0.316
102			11						
103			12						
104	0.26	0.58	12	0.254	0.585	0.278	0.608	0.290	0.578
105	0.49	0.4	12	0.517	0.408	0.505	0.458	0.517	0.408
106	0.64	0.13	12	0.643	0.138	0.668	0.123	0.686	0.135
107	0.11	0.52	13	0.094	0.505	0.105	0.540	0.127	0.528
108	0.32	0.42	13	0.330	0.409	0.349	0.430	0.337	0.433
109	0.47	0.23	13	0.483	0.258	0.479	0.243	0.498	0.235
110			13						
111	0.16	0.36	14	0.158	0.330	0.180	0.380	0.184	0.378
112	0.31	0.25	14	0.299	0.235	0.315	0.260	0.338	0.255
113			14						

Summarized Upslop and Horizontal Distances - Placement According to Designed Grid

				Test T1a				Test T1b				Test T1c			
Xbloc Designed grid				Upslope	%	Horizontal	%	Upslope	%	Horizontal	%	Upslope	%	Horizontal	%
No.	x-pos 2	y-pos 2	Row	x.xxD	0.12	x.xxD	0.24	x.xxD	0.12	x.xxD	0.24	x.xxD	0.11648	x.xxD	0.24
1	0.1	1.9	1												
2	0.33	1.86	1												
3	0.55	1.79	1												
4	0.77	1.7	1												
5	0.97	1.58	1												
6	1.16	1.44	1												
7	1.33	1.27	1												
8	1.48	1.09	1												
9	1.61	0.89	1												
10	1.72	0.68	1												
11	1.79	0.46	1												
12	1.85	0.23	1												
13			1												
14	0.2	1.79	2	0.79	122.94	1.26	94.41	0.82	128.04	1.18	88.47	0.94	147.41	1.30	97.67
15	0.42	1.73	2	0.85	132.51	1.23	92.43	0.86	133.91	1.31	98.40	0.85	132.62	1.27	95.48
16	0.63	1.66	2	0.87	135.76	1.33	100.03	0.97	150.99	1.22	91.66	1.01	157.77	1.21	90.92
17	0.83	1.56	2	1.03	161.08	1.23	92.27	0.77	120.15	1.27	95.29	1.00	156.77	1.28	96.20
18	1.01	1.43	2	0.91	141.98	1.19	89.69	0.92	143.86	1.30	97.97	0.90	140.75	1.25	93.92
19	1.18	1.29	2	0.71	110.99	1.36	102.35	0.81	127.31	1.28	96.56	0.81	126.90	1.41	105.84
20	1.34	1.12	2	0.84	131.24	1.41	106.11	0.80	124.35	1.26	94.53	0.85	132.61	1.37	103.03
21	1.47	0.94	2	0.83	129.81	1.38	103.78	0.68	105.91	1.45	109.08	0.75	116.82	1.20	90.49
22	1.58	0.75	2	0.62	96.76	1.10	82.73	0.62	96.24	1.26	94.43	0.71	111.08	1.37	102.94
23	1.67	0.54	2	0.89	139.02	1.24	92.98	0.85	132.92	1.27	95.36	0.91	142.05	1.22	92.05
24	1.73	0.33	2	0.85	133.23	1.40	105.17	0.77	120.79	1.28	96.60	0.80	125.23	1.31	98.51
25	1.77	0.1	2												
26			3												
27	0.28	1.67	3	0.69	108.36	1.01	76.19	0.57	89.69	1.30	97.98	0.37	57.57	1.21	91.19
28	0.49	1.6	3	0.65	102.01	1.33	100.07	0.75	116.72	1.13	84.63	0.62	96.88	1.25	94.23
29	0.68	1.52	3	0.50	77.82	0.98	73.79	0.65	101.50	1.04	78.29	0.64	100.55	1.02	77.07
30	0.86	1.41	3	0.57	88.54	1.31	98.37	0.40	62.99	1.39	104.40	0.66	103.74	1.31	98.86
31	1.03	1.28	3	0.87	136.23	1.11	83.47	0.40	62.61	1.28	96.36	0.70	110.15	1.13	84.79

32	1.19	1.14	3	0.72	112.21	1.32	98.99	0.71	111.24	1.11	83.45	0.53	83.50	1.30	98.10
33	1.32	0.97	3	0.41	64.47	1.38	103.61	0.60	94.03	1.27	95.60	0.54	84.49	1.20	90.39
34	1.44	0.8	3	0.77	120.95	1.13	85.05	0.52	80.53	1.20	89.94	0.51	80.13	1.13	85.23
35	1.53	0.61	3	0.76	118.73	1.11	83.68	0.40	62.89	1.22	91.91	0.25	39.65	1.23	92.76
36	1.6	0.41	3	0.58	90.22	1.30	97.86	0.59	92.32	1.24	93.61	0.56	87.31	1.14	86.00
37	1.65	0.2	3	0.60	93.48	1.32	99.60	0.61	95.27	1.21	91.19	0.60	94.05	1.41	106.17
38	0.16	1.58	4												
39	0.36	1.54	4	0.74	115.67	1.21	91.06	0.75	116.98	1.08	81.17	0.82	127.38	1.20	90.10
40	0.54	1.47	4	0.76	118.20	1.04	77.92	0.68	106.12	1.25	93.93	0.93	145.70	1.04	78.44
41	0.72	1.38	4	0.98	152.99	1.13	84.81	0.68	105.97	0.99	74.63	0.76	118.07	1.20	90.52
42	0.89	1.27	4	0.74	116.04	1.17	88.14	0.84	131.54	1.41	106.11	0.43	66.60	1.28	96.54
43	1.04	1.14	4	0.78	121.70	1.09	82.10	0.81	125.85	1.06	80.01	0.84	131.72	1.11	83.77
44	1.18	0.99	4	0.81	127.17	1.23	92.67	0.63	98.37	1.13	84.77	0.88	137.71	1.05	78.84
45	1.29	0.83	4	1.04	163.25	1.30	98.01	0.92	143.20	1.21	91.02	0.63	98.33	1.19	89.68
46	1.39	0.66	4	0.96	150.04	0.94	70.67	0.76	119.45	1.15	86.27	0.76	119.16	1.16	87.46
47	1.47	0.47	4	0.64	100.33	1.27	95.14	0.81	126.69	1.17	88.33	0.93	146.05	1.08	81.29
48	1.53	0.28	4	1.02	159.21	1.18	88.60	0.76	119.14	1.25	94.14	0.66	102.66	1.31	98.20
49			4												
50			5												
51	0.25	1.43	5	0.85	132.57	1.16	87.09	0.96	149.96	0.97	73.27	0.83	130.29	1.22	91.59
52	0.43	1.36	5	0.93	144.59	1.03	77.51	0.73	114.01	1.34	100.70	0.76	118.17	0.95	71.10
53	0.6	1.27	5	0.91	142.69	0.94	70.65	0.64	100.39	1.28	96.17	0.64	100.09	1.36	102.25
54	0.89	1.12	5	0.69	108.21	1.27	95.38	0.68	105.60	1.02	76.85	0.58	90.28	1.26	95.09
55	1.03	0.96	5	0.79	123.10	1.05	79.16	0.69	107.74	1.18	88.90	0.65	102.27	0.98	73.47
56	1.14	0.8	5	0.69	107.57	1.22	91.37	0.60	93.11	1.05	78.86	0.73	113.72	1.09	82.15
57	1.33	0.52	5	0.91	141.79	1.06	79.40	0.79	124.18	1.05	79.30	0.82	128.40	0.87	65.47
58	1.38	0.32	5	0.53	83.10	1.29	97.37	0.71	110.82	1.20	90.38	0.71	111.42	1.23	92.69
59	1.41	0.12	5												
60	0.13	1.34	6												
61	0.31	1.25	6	0.92	143.56	0.92	69.36	0.93	145.91	1.13	84.72	0.74	115.75	1.30	97.59
62	0.48	1.16	6	0.72	112.29	1.01	75.58	1.11	172.99	1.17	88.18	0.79	124.19	1.25	94.18
63	0.7	1.13	6	0.49	76.69	1.82	136.94	0.55	85.34	1.93	145.48	0.36	55.59	1.81	136.15
64	0.88	0.97	6	0.57	88.44	1.42	106.71	0.76	118.65	1.13	85.14	0.84	131.08	1.15	86.48
65	0.99	0.79	6	0.72	112.81	0.84	63.49	0.79	123.89	0.99	74.27	0.72	112.34	1.03	77.31
66	1.16	0.63	6	0.43	67.23	1.93	144.90	0.59	91.69	1.73	130.19	0.20	31.00	1.82	136.51

67	1.25	0.4	6	0.89	139.31	0.95	71.73	0.71	111.45	1.30	97.47	0.81	126.63	1.12	84.46
68	1.28	0.2	6	0.61	95.05	1.27	95.33	0.57	89.17	1.20	90.27	0.69	108.25	1.19	89.29
69			6												
70			7												
71	0.19	1.16	7	0.69	107.68	1.03	77.49	0.61	94.97	0.91	68.53	0.74	115.20	0.98	73.85
72	0.35	1.06	7	0.68	106.67	1.03	77.66	0.64	100.30	1.05	79.07	0.71	111.50	1.18	88.81
73	0.58	1.05	7	0.66	102.57	1.31	98.58	0.57	88.68	1.33	100.11	0.51	80.39	1.48	111.02
74	0.73	0.94	7	0.42	65.31	1.30	97.94	0.56	88.16	1.32	99.04	0.62	97.25	1.33	100.27
75	0.83	0.78	7	0.49	76.70	1.19	89.48	0.72	112.04	1.09	81.99	0.51	79.31	1.17	87.78
76	1.01	0.64	7	0.55	86.22	1.18	88.92	0.57	89.67	1.28	96.30	0.69	107.29	1.25	94.28
77	1.12	0.48	7	0.44	68.67	1.54	115.83	0.65	101.10	1.32	99.58	0.38	59.28	1.47	110.66
78	1.16	0.28	7	1.15	179.41	1.15	86.78	0.79	123.70	1.16	87.09	0.63	97.77	1.16	87.02
79			7												
80			8												
81	0.22	0.96	8	0.81	126.73	0.91	68.09	0.79	123.69	1.07	80.14	0.74	115.29	0.90	67.51
82	0.46	0.95	8	0.85	133.45	1.24	93.49	0.42	66.35	1.29	96.96	0.61	95.71	1.36	102.33
83	0.68	0.8	8	0.66	103.45	1.00	75.46	0.66	103.06	0.92	69.52	0.75	117.51	1.16	87.36
84	0.86	0.63	8	0.52	80.58	1.46	109.46	0.70	109.57	1.24	93.45	0.64	99.89	1.36	101.97
85	0.97	0.46	8	0.83	130.36	1.05	79.08	0.94	146.72	1.08	80.86	0.93	144.85	0.91	68.69
86	1.07	0.16	8												
87	0.34	0.86	9	0.74	116.25	1.61	121.31	0.62	96.57	1.43	107.80	0.66	103.45	1.50	112.63
88	0.53	0.81	9	0.53	82.24	1.52	114.27	0.64	99.73	1.42	107.05	0.60	93.21	1.75	131.50
89	0.71	0.65	9	0.72	112.42	1.21	90.85	0.72	113.10	1.55	116.40	0.70	109.90	1.44	107.98
90	0.82	0.49	9	0.78	121.90	1.09	82.05	0.99	155.25	0.85	63.59	0.83	129.60	0.95	71.42
91	0.95	0.29	9	0.40	63.26	1.90	142.81	0.36	55.73	1.82	136.98	0.51	79.16	1.82	136.52
92			9												
93	0.13	0.86	10												
94	0.4	0.73	10	0.89	138.31	1.28	95.87	1.00	156.36	0.99	74.80	1.01	157.91	1.26	94.94
95	0.56	0.62	10	0.80	124.43	1.09	82.10	0.94	146.88	1.33	99.65	0.48	75.06	1.58	119.10
96	0.67	0.46	10	1.29	201.08	1.13	84.93	0.94	146.69	1.04	78.41	0.85	132.50	1.03	77.51
97	0.8	0.31	10	0.86	134.38	1.23	92.66	0.68	106.38	1.43	107.28	0.81	126.03	1.44	108.63
98	0.85	0.12	10												
99	0.21	0.72	11	0.58	90.58	1.72	129.30	0.63	98.63	1.48	111.38	0.71	110.92	1.44	108.19
100	0.42	0.58	11	0.86	134.72	1.27	95.24	0.73	114.16	1.03	77.76	1.03	160.70	1.13	84.78
101	0.65	0.31	11	0.70	109.62	0.88	66.46	1.05	163.94	1.18	89.03	1.01	157.76	1.19	89.69

Summarized Unit Deviations - Placement Test According to Grid									
Xbloc Designed Grid				Test T1a		Test T1b		Test T1c	
No.	x-pos 2	y-pos 2	Row	Upslope,D	Horiz,D	Upslope,D	Horiz,D	Upslope,D	Horiz,D
1	0.1	1.9	1	-0.12	-0.11	-0.08	-0.05	-0.14	-0.06
2	0.33	1.86	1	-0.05	-0.07	0.19	0.08	0.02	-0.06
3	0.55	1.79	1	-0.06	-0.02	0.11	0.03	-0.05	-0.06
4	0.77	1.7	1	-0.15	-0.04	0.21	0.10	-0.04	0.04
5	0.97	1.58	1	0.06	0.04	0.21	0.10	0.08	0.04
6	1.16	1.44	1	0.03	0.14	0.12	0.08	0.05	0.09
7	1.33	1.27	1	-0.07	0.10	-0.08	0.11	-0.11	0.00
8	1.48	1.09	1	0.00	-0.02	0.12	0.15	-0.01	-0.07
9	1.61	0.89	1	0.01	-0.09	0.11	0.00	0.08	0.03
10	1.72	0.68	1	-0.15	0.13	-0.22	0.09	-0.29	0.01
11	1.79	0.46	1	0.03	0.18	-0.06	0.10	-0.08	0.08
12	1.85	0.23	1	-0.05	0.09	0.00	0.13	-0.01	0.08
13			1						
14	0.2	1.79	2	0.06	-0.20	0.24	0.08	0.26	-0.05
15	0.42	1.73	2	0.13	0.04	0.35	0.01	0.18	-0.04
16	0.63	1.66	2	0.14	-0.08	0.50	0.07	0.33	-0.09
17	0.83	1.56	2	0.35	0.16	0.35	0.22	0.40	0.08
18	1.01	1.43	2	0.29	0.04	0.43	0.02	0.30	-0.05
19	1.18	1.29	2	0.05	0.14	0.19	-0.07	0.15	0.02
20	1.34	1.12	2	0.18	0.10	0.19	0.08	0.17	-0.02
21	1.47	0.94	2	0.21	-0.08	0.17	0.01	0.15	-0.02
22	1.58	0.75	2	-0.09	0.01	-0.07	0.04	-0.03	0.06
23	1.67	0.54	2	0.20	0.16	0.09	0.07	0.10	0.08
24	1.73	0.33	2	0.21	0.04	0.11	0.02	0.13	0.13
25	1.77	0.1	2	0.21	-0.02	0.03	0.08	-0.08	0.01
26			3						
27	0.28	1.67	3	0.14	-0.07	0.23	-0.01	-0.07	-0.05
28	0.49	1.6	3	0.11	-0.07	0.48	0.13	0.20	0.00
29	0.68	1.52	3	0.05	0.01	0.37	-0.03	0.31	0.07
30	0.86	1.41	3	0.20	0.05	0.10	0.12	0.33	0.00
31	1.03	1.28	3	0.36	0.03	0.01	-0.12	0.23	-0.14
32	1.19	1.14	3	0.19	0.09	0.25	-0.02	0.04	-0.09
33	1.32	0.97	3	-0.08	0.04	0.09	0.02	0.01	0.04
34	1.44	0.8	3	0.17	-0.12	-0.10	-0.04	-0.08	0.00
35	1.53	0.61	3	0.14	0.08	-0.28	-0.01	-0.40	0.04
36	1.6	0.41	3	0.09	-0.03	0.00	0.01	-0.02	0.17
37	1.65	0.2	3	0.13	-0.03	-0.01	-0.06	-0.05	0.05
38	0.16	1.58	4	0.07	-0.03	0.06	0.17	0.10	0.18
39	0.36	1.54	4	0.17	-0.07	0.35	0.33	0.18	0.07
40	0.54	1.47	4	0.13	-0.06	0.41	0.01	0.45	0.19
41	0.72	1.38	4	0.40	0.12	0.18	-0.19	0.37	-0.10
42	0.89	1.27	4	0.34	0.14	0.23	-0.05	0.03	-0.02
43	1.04	1.14	4	0.34	-0.07	0.23	0.00	0.28	-0.18
44	1.18	0.99	4	0.16	-0.01	0.09	-0.07	0.20	-0.06
45	1.29	0.83	4	0.36	-0.17	0.19	-0.06	-0.14	-0.07
46	1.39	0.66	4	0.38	-0.05	-0.15	0.00	-0.23	-0.15
47	1.47	0.47	4	0.04	0.04	-0.04	0.09	0.00	0.13
48	1.53	0.28	4	0.42	-0.16	0.07	-0.02	-0.08	0.00
49			4						
50			5						
51	0.25	1.43	5	0.07	-0.04	0.26	0.32	0.04	0.39
52	0.43	1.36	5	0.08	0.10	0.11	0.23	0.06	0.14

53	0.6	1.27	5	0.13	0.14	-0.10	0.10	-0.06	-0.06
54	0.89	1.12	5	0.27	0.08	0.14	-0.05	-0.03	-0.07
55	1.03	0.96	5	0.08	-0.20	-0.06	-0.02	-0.02	-0.05
56	1.14	0.8	5	-0.04	0.01	-0.25	0.07	-0.24	0.00
57	1.33	0.52	5	0.37	-0.09	-0.06	0.22	-0.04	0.06
58	1.38	0.32	5	-0.14	0.13	-0.18	0.07	-0.23	0.09
59	1.41	0.12	5	-0.08	-0.02	-0.23	0.00	-0.28	0.04
60	0.13	1.34	6	0.11	-0.02	0.44	-0.06	0.09	0.13
61	0.31	1.25	6	-0.01	0.02	0.10	0.06	-0.20	0.21
62	0.48	1.16	6	-0.30	0.05	0.01	0.05	-0.29	0.10
63	0.7	1.13	6	0.10	-0.09	0.00	-0.07	-0.26	-0.14
64	0.88	0.97	6	0.02	-0.08	0.07	-0.07	0.09	-0.09
65	0.99	0.79	6	-0.15	-0.12	-0.26	-0.01	-0.31	-0.11
66	1.16	0.63	6	0.03	-0.04	-0.15	0.00	-0.51	0.01
67	1.25	0.4	6	0.25	-0.23	-0.13	0.06	-0.06	-0.01
68	1.28	0.2	6	-0.37	-0.22	-0.43	0.04	-0.36	-0.03
69			6						
70			7						
71	0.19	1.16	7	-0.23	-0.17	-0.09	-0.13	-0.31	-0.10
72	0.35	1.06	7	-0.51	-0.04	-0.39	-0.18	-0.57	0.05
73	0.58	1.05	7	-0.12	-0.05	-0.23	-0.21	-0.43	-0.02
74	0.73	0.94	7	-0.38	0.00	-0.30	-0.17	-0.33	0.07
75	0.83	0.78	7	-0.59	0.05	-0.37	-0.02	-0.60	-0.03
76	1.01	0.64	7	-0.19	-0.13	-0.28	0.02	-0.39	-0.10
77	1.12	0.48	7	-0.03	-0.11	-0.12	0.02	-0.55	0.13
78	1.16	0.28	7	0.34	-0.42	-0.22	0.00	-0.33	0.09
81	0.22	0.96	8	-0.68	0.06	-0.53	-0.09	-0.83	0.14
82	0.46	0.95	8	-0.24	-0.22	-0.58	-0.12	-0.58	0.03
83	0.68	0.8	8	-0.60	-0.19	-0.54	0.03	-0.48	-0.15
84	0.86	0.63	8	-0.56	0.06	-0.36	-0.09	-0.59	-0.13
85	0.97	0.46	8	-0.18	0.15	-0.16	0.22	-0.47	0.10
86	1.07	0.16	8	0.22	0.00	-0.07	0.16	-0.42	0.12
87	0.34	0.86	9	-0.36	-0.10	-0.62	-0.18	-0.67	0.14
88	0.53	0.81	9	-0.44	-0.24	-0.47	-0.03	-0.48	0.02
89	0.71	0.65	9	-0.47	0.08	-0.32	0.05	-0.43	-0.16
90	0.82	0.49	9	-0.32	0.08	0.00	0.13	-0.44	-0.06
91	0.95	0.29	9	-0.08	0.18	-0.27	0.08	-0.49	-0.11
93	0.13	0.86	10	-0.46	-0.04	-0.17	-0.25	-0.14	-0.25
94	0.4	0.73	10	-0.25	0.01	-0.30	-0.02	-0.32	0.01
95	0.56	0.62	10	-0.52	-0.11	-0.28	0.06	-0.78	0.10
96	0.67	0.46	10	-0.12	-0.01	-0.24	0.03	-0.58	0.01
97	0.8	0.31	10	-0.13	0.23	-0.32	-0.01	-0.45	-0.02
98	0.85	0.12	10	-0.32	0.08	-0.49	0.00	-0.52	-0.01
99	0.21	0.72	11	-0.29	-0.15	-0.19	-0.14	-0.12	-0.12
100	0.42	0.58	11	-0.23	0.02	-0.26	0.02	-0.25	-0.15
101	0.65	0.31	11	-0.18	0.00	-0.02	-0.12	-0.21	-0.06
104	0.26	0.58	12	-0.01	0.04	-0.18	-0.03	-0.06	-0.16
105	0.49	0.4	12	-0.14	-0.06	-0.27	0.19	-0.14	-0.06
106	0.64	0.13	12	-0.02	0.04	-0.14	-0.07	-0.25	-0.02
107	0.11	0.52	13	0.10	0.07	-0.10	0.05	-0.06	-0.08
108	0.32	0.42	13	0.01	-0.08	-0.14	-0.09	-0.11	-0.03
109	0.47	0.23	13	-0.13	0.11	-0.07	0.04	-0.15	-0.04
111	0.16	0.36	14	0.15	-0.06	-0.15	-0.06	-0.14	-0.08
112	0.31	0.25	14	0.10	-0.02	-0.06	0.03	-0.14	-0.08

Summarized Packing Density - Placement Test According to Designed Grid

Xbloc Designed Grid				Test T1a		Test T1b		Test T1c	
	Placed	%		Placed	%	Placed	%	Placed	%
No.	36.23	100	Row	36.23	100	36.23	100	36.23	100
1			1						
2			1						
3			1						
4			1						
5			1						
6			1						
7			1						
8			1						
9			1						
10			1						
11			1						
12			1						
13			1						
14			2	33.0	91.2	29.5	81.5	27.4	75.5
15			2	26.9	74.4	27.1	74.7	25.8	71.2
16			2	27.1	74.8	30.6	84.5	26.0	71.6
17			2	25.2	69.6	26.8	74.0	24.9	68.6
18			2	31.3	86.3	26.8	73.9	28.6	79.0
19			2	27.6	76.3	29.8	82.1	25.7	70.9
20			2	25.7	71.0	32.0	88.3	29.9	82.5
21			2	36.5	100.7	39.1	107.8	37.4	103.2
22			2	32.9	90.9	30.3	83.6	26.9	74.3
23			2	27.4	75.5	29.9	82.5	29.8	82.3
24			2	26.7	73.8	32.2	88.9	26.7	73.6
25			2						
26			3						
27			3	38.0	104.9	39.4	108.8	47.0	129.6
28			3	44.6	123.2	38.4	106.0	43.2	119.3
29			3	52.1	143.9	48.4	133.6	39.1	107.9
30			3	36.4	100.5	58.6	161.7	35.1	97.0
31			3	30.9	85.3	45.6	125.9	39.6	109.3
32			3	41.3	114.1	39.0	107.6	48.5	133.9
33			3	42.0	116.1	45.3	125.2	49.9	137.8
34			3	34.8	96.1	49.3	136.0	59.3	163.7
35			3	38.1	105.1	51.3	141.5	64.9	179.0
36			3	40.8	112.7	40.6	112.1	41.3	113.9
37			3			0.0		0.0	
38			4	35.2	97.2	41.4	114.2	30.4	83.9
39			4	37.4	103.2	36.2	100.0	33.9	93.7
40			4	33.4	92.2	37.4	103.3	29.1	80.2
41			4	31.6	87.3	35.7	98.5	46.1	127.2
42			4	34.7	95.9	30.7	84.8	39.4	108.7
43			4	33.6	92.7	38.4	106.1	32.6	90.1
44			4	25.0	69.1	35.5	98.0	36.4	100.6
45			4	30.2	83.5	32.4	89.4	36.9	102.0
46			4	35.0	96.7	32.1	88.6	33.6	92.8
47			4	29.0	80.1	32.8	90.6	33.4	92.3
48			4						
49			4						
50			5						
51			5	34.1	94.1	32.2	89.0	30.7	84.9
52			5	32.1	88.6	36.5	100.7	41.3	114.1
53			5	19.6	54.0	20.2	55.9	21.7	59.9
54			5	32.6	90.1	39.8	109.8	45.0	124.3
55			5	40.7	112.5	42.3	116.9	44.8	123.7

56			5	21.0	58.1	22.6	62.3	16.9	46.7
57			5	36.1	99.6	32.9	90.9	37.9	104.5
58			5	44.8	123.6	35.5	97.9	35.6	98.4
59			5						
60			6	31.9	88.0	35.5	97.9	41.5	114.5
61			6	37.5	103.4	27.8	76.8	32.6	89.9
62			6	39.0	107.6	24.2	66.9	33.7	93.1
63			6	38.2	105.5	32.1	88.6	33.2	91.6
64			6	39.7	109.5	35.9	99.0	35.4	97.6
65			6	39.0	107.8	31.8	87.8	46.1	127.3
66			6	33.7	93.1	31.5	87.0	39.2	108.1
67			6	33.0	91.0	38.0	105.0	33.7	92.9
68			6						
69			6						
70			7						
71			7	48.9	135.0	48.0	132.6	43.3	119.6
72			7	37.0	102.2	46.9	129.3	39.4	108.8
73			7	45.3	125.0	43.0	118.8	37.5	103.4
74			7	56.7	156.6	48.9	134.9	48.3	133.4
75			7	46.7	129.0	38.9	107.2	42.1	116.1
76			7	45.4	125.2	38.1	105.2	41.2	113.8
77			7	30.8	85.1	35.5	98.1	51.6	142.3
78			7						
79			7						
80			8						
81			8	29.0	80.1	40.8	112.6	37.7	104.0
82			8	20.3	55.9	26.9	74.2	19.2	53.1
83			8	41.9	115.6	38.8	107.2	32.7	90.3
84			8	38.2	105.4	36.0	99.3	38.9	107.3
85			8	19.1	52.6	17.6	48.7	17.9	49.5
86			8						
87			9	33.7	92.9	35.2	97.1	29.9	82.7
88			9	36.9	101.8	30.0	82.8	29.2	80.7
89			9	32.7	90.4	30.6	84.6	33.5	92.5
90			9	37.0	102.2	32.6	89.9	31.6	87.2
91			9						
92			9						
93			10	19.8	54.7	20.4	56.2	20.8	57.3
94			10	27.6	76.2	26.9	74.3	30.4	83.8
95			10	29.9	82.5	28.0	77.4	34.1	94.2
96			10	28.0	77.3	35.1	96.8	30.3	83.7
97			10	27.4	75.7	38.8	107.1	32.6	89.9
98			10						
99			11	32.4	89.4	34.1	94.2	26.8	74.0
100			11	17.1	47.2	15.5	42.8	12.3	34.0

APPENDIX C

Placement Test 2 results - Placement with Coherent Judgement

Contents: **Page**

C.1. Photographs of Placement for TEST T2a AC2
C.2. Photographs of Placement for TEST T2b AC4
C.3. Photographs of Placement for TEST T2c AC4
C.4. Computer Model Grid Position and Placement Test Grid AC5
C.5. Unit Deviations AC7
C.6. Placement Results AC10

APPENDIX C – Recommended Placement Tests Placement with Judgment - Test 2

C.1. Photographs of Placement for TEST T2a

Row1-Row4

Placements made in this row are pretty much easy and did not behave differently as in first placement test.

Row 5

Some difficulties encounters with this row where the horizontal distances are tight. Many units touch the breakwater underlayer using legs. The units start to be repositioned and could not follow the designed grid.

Row 6

The units covering the left out unit are repositioned to the lower levels to cover the large gap created by the left out unit. Many units were repositioned to lower levels to have connection with the two base units. The units that are touching only one base unit below and not stable are rolled to the front.

Row 7-Row 10

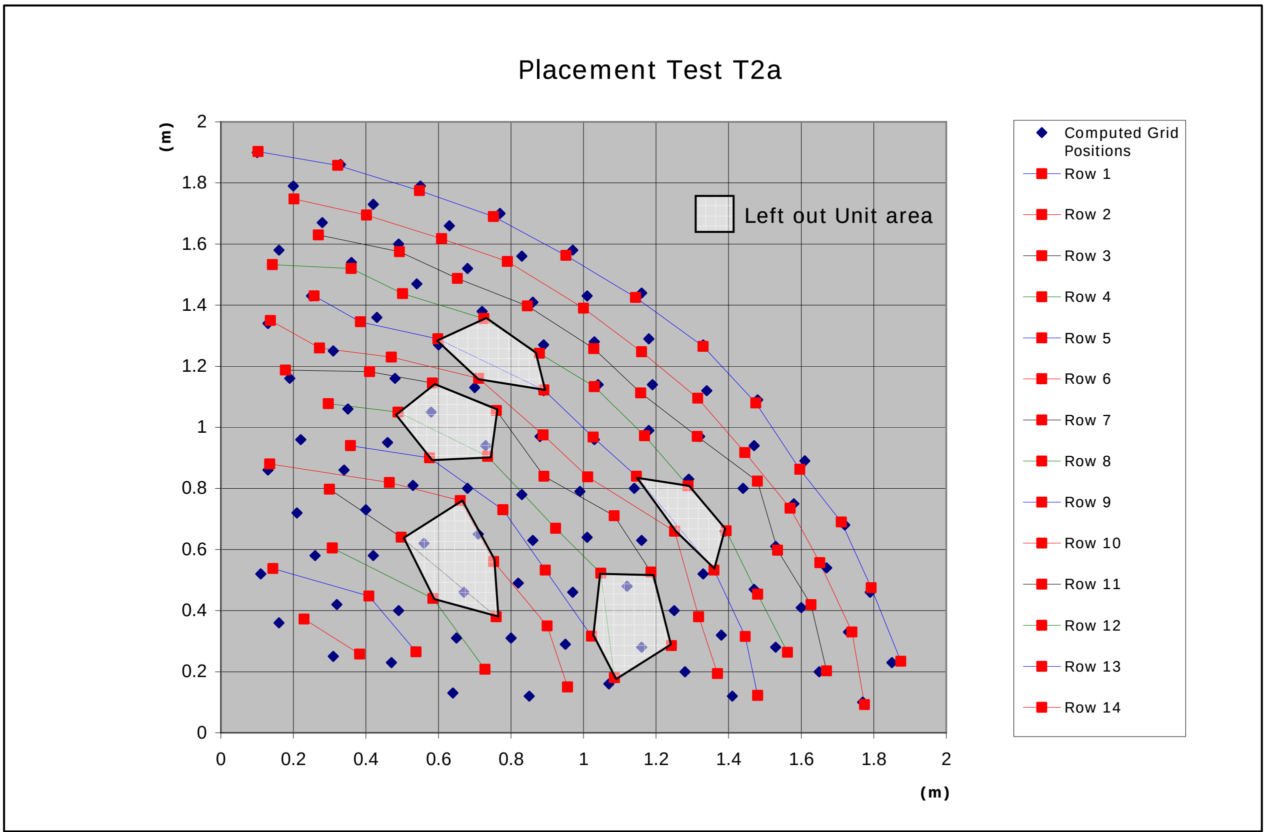
Units were again many to be repositioned to the lower level for better fittings. These rows of placing the units experienced larger repositioning to the lower level are due to the cumulative lower upslope deviations in the row downslope. Some of the units were again rolled to front for a better stability. The units covering the left out unit area are repositioned further lower than the designed grid.

Overview of Placement Test T2a

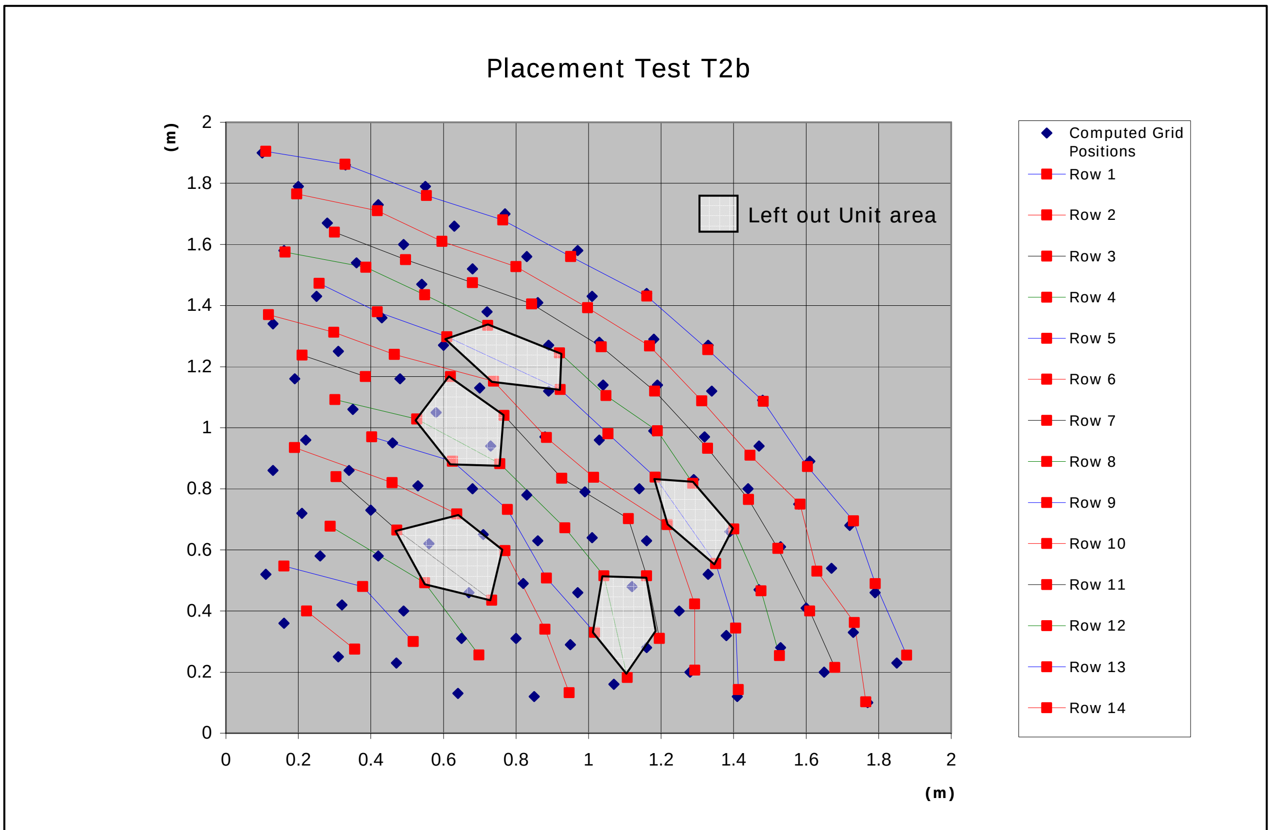
C.2. Photographs of Placement for TEST T2b

C.3. Photographs of Placement for TEST T2c

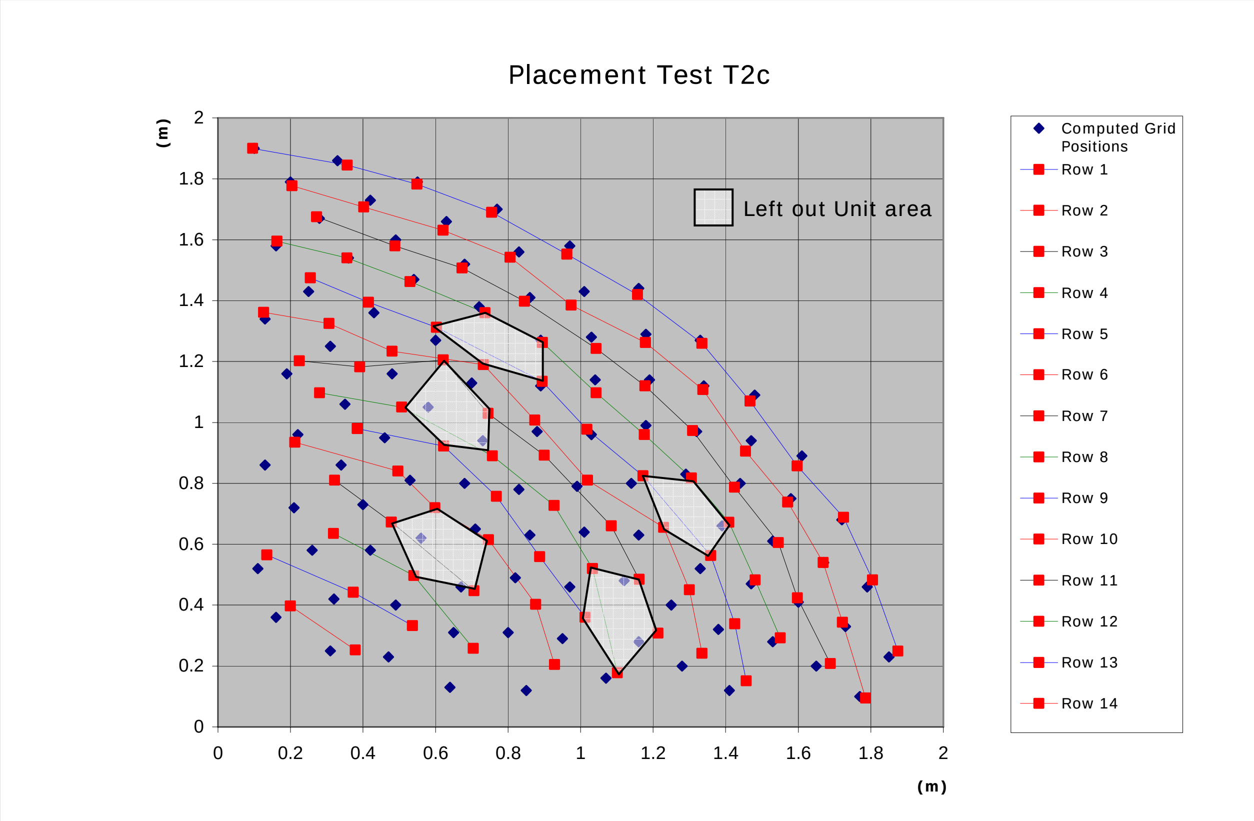
C.4. Computer Model Grid Position and Placement Test Grid



a) Measured Positions Test 2a



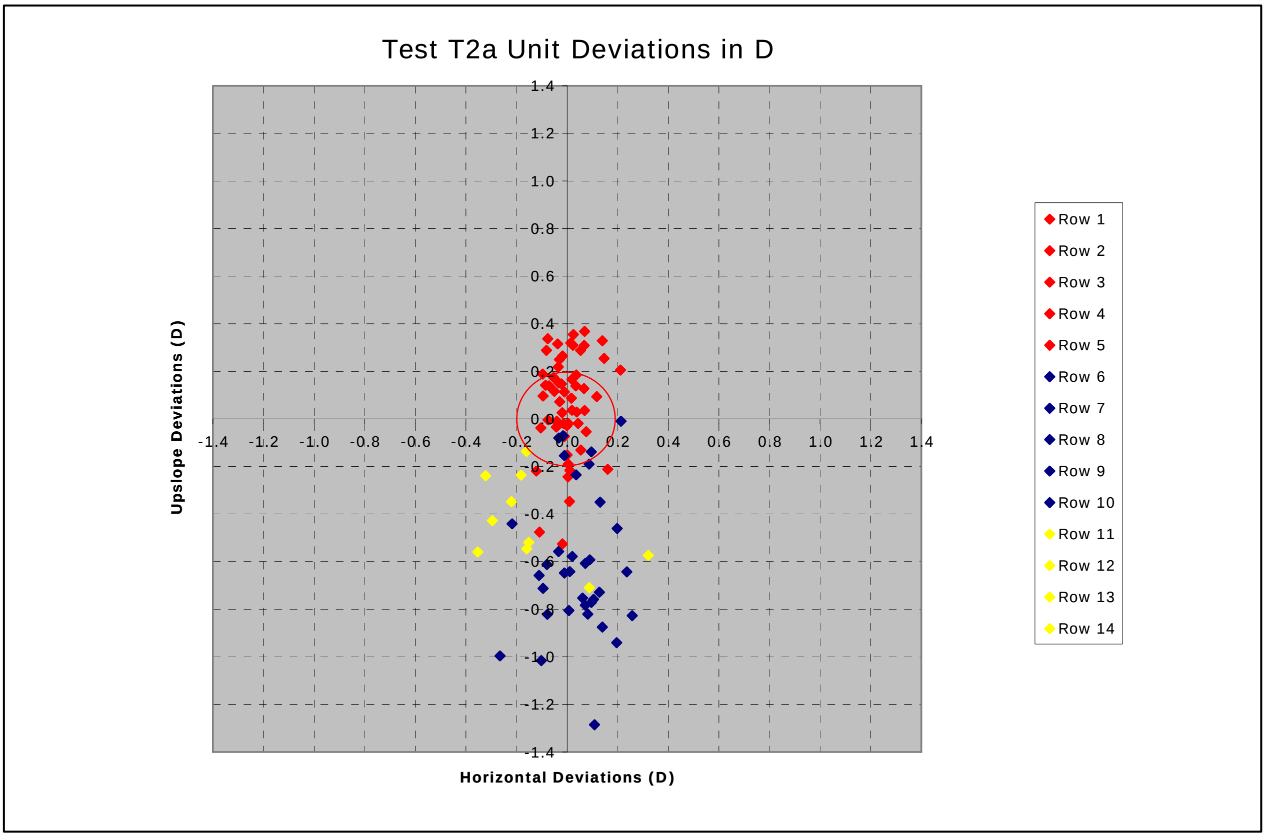
b) Measured Positions Test 2b

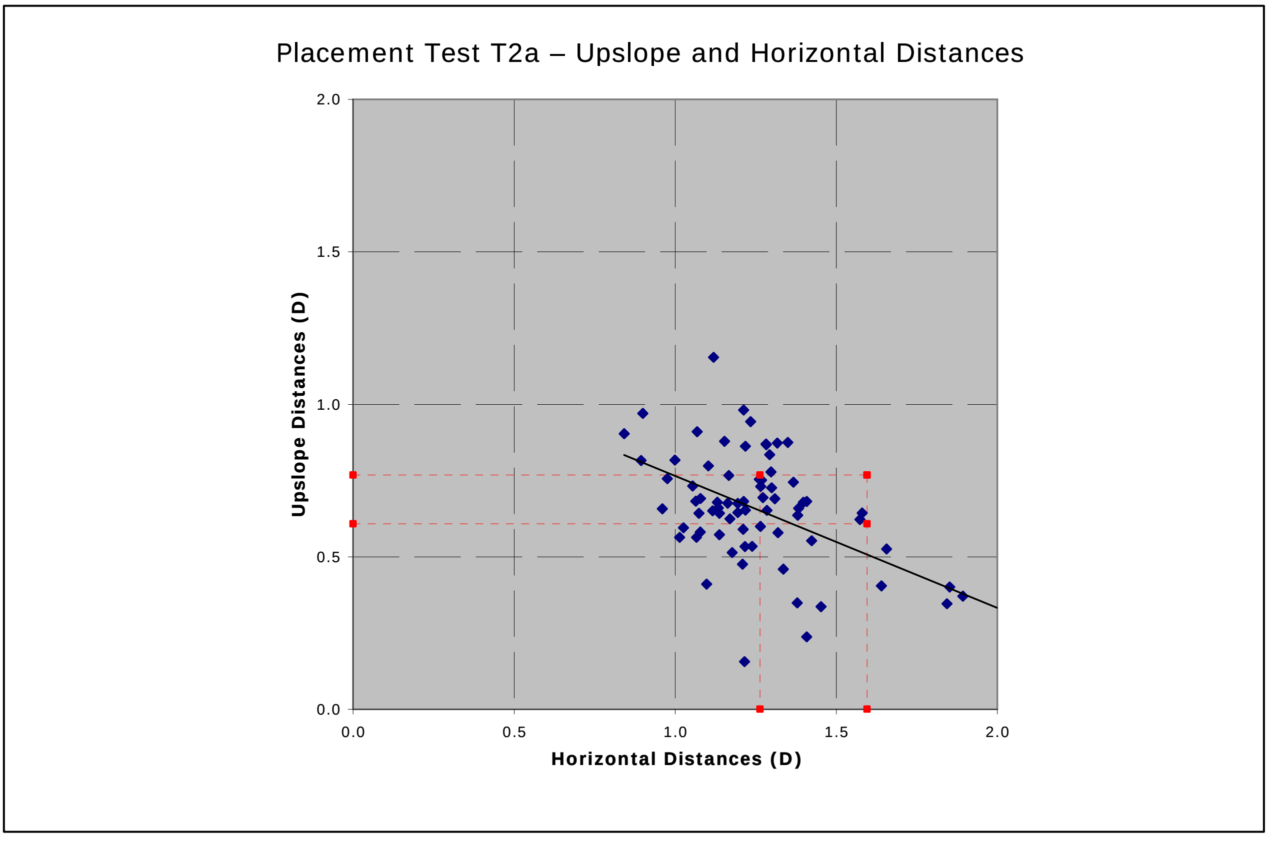


c) Measured Positions Test T2c

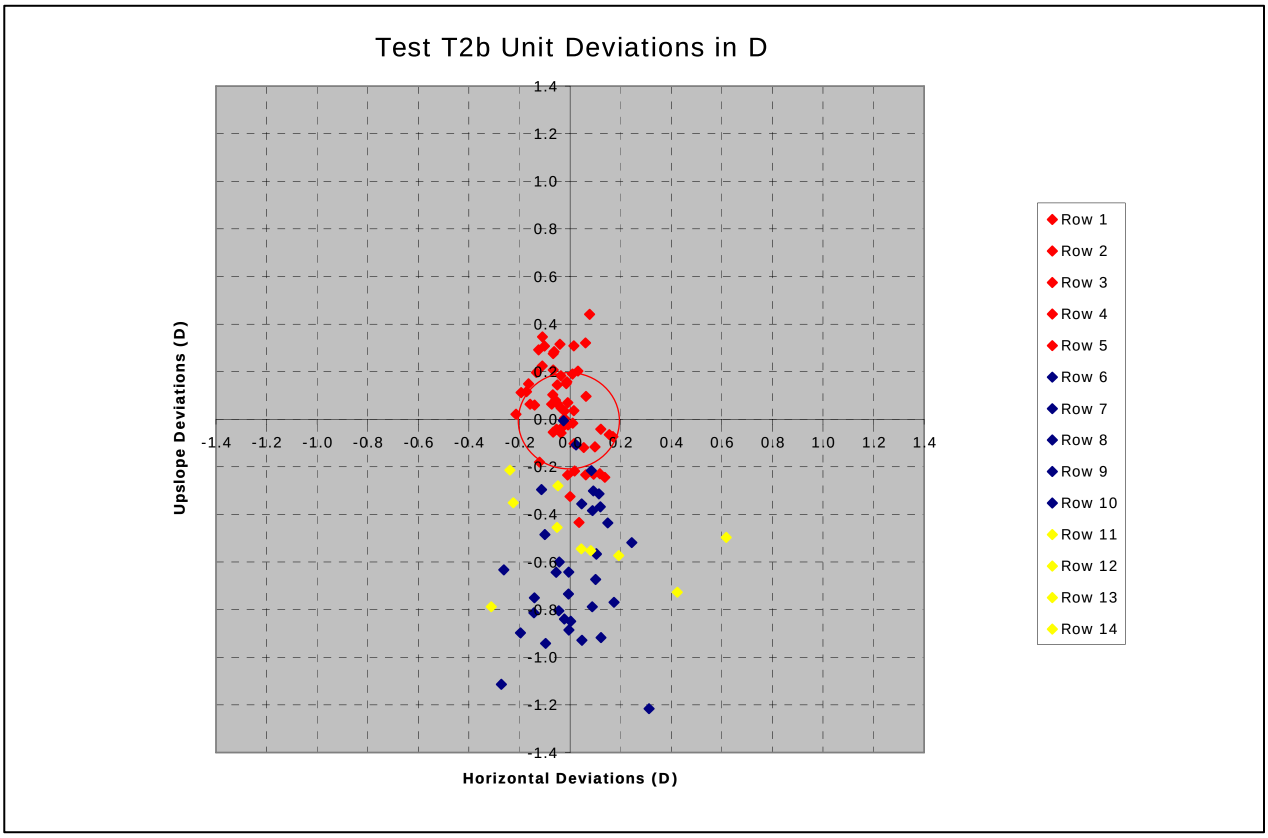
C.5. Unit Deviations

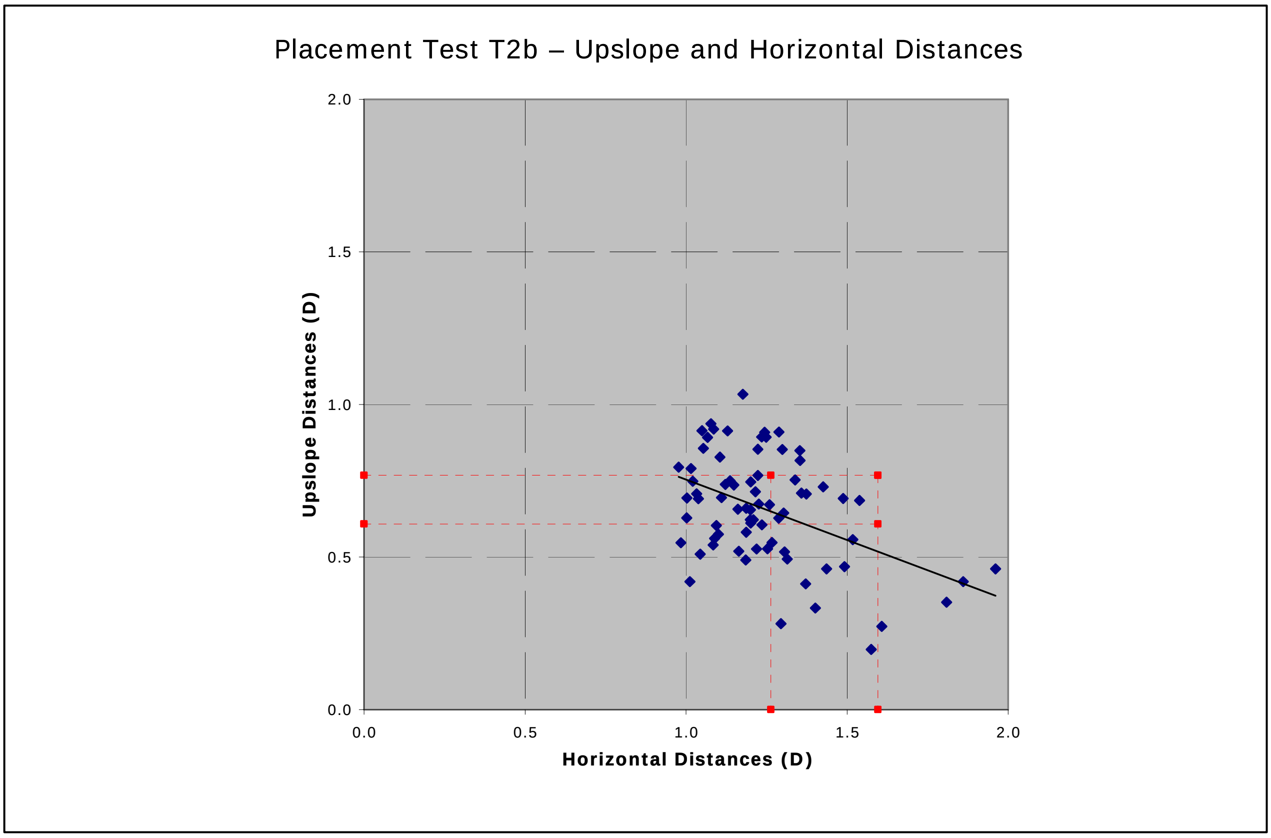
Deviations on Design Position – Test T2a



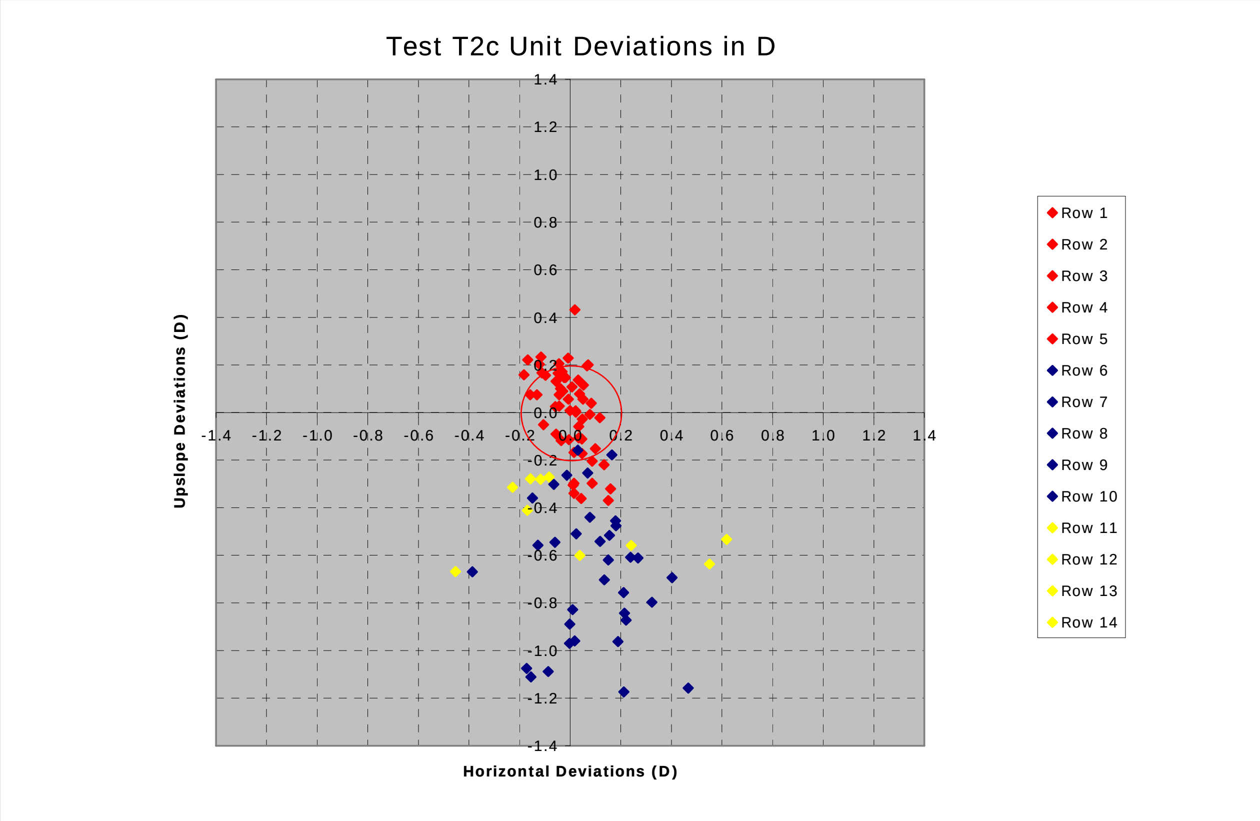


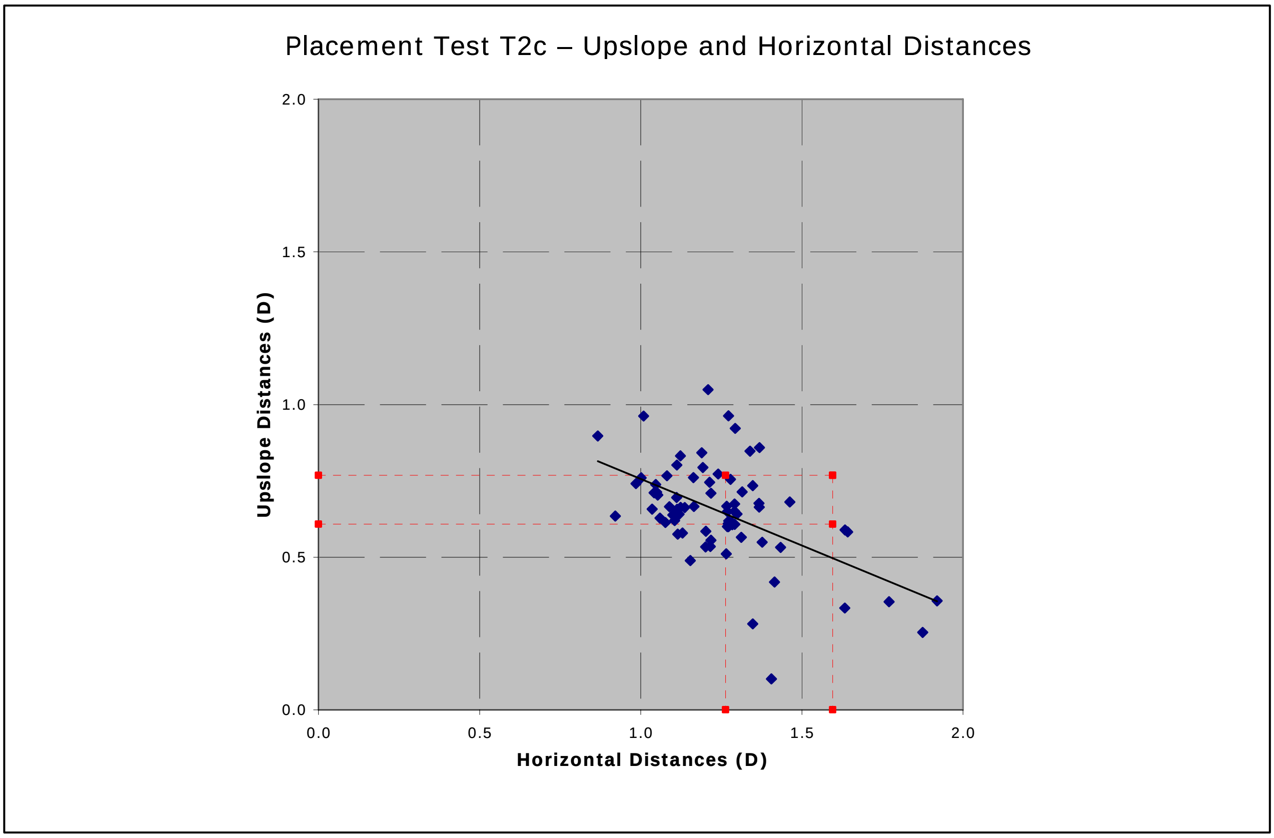
Deviations on Design Position – Test T2b

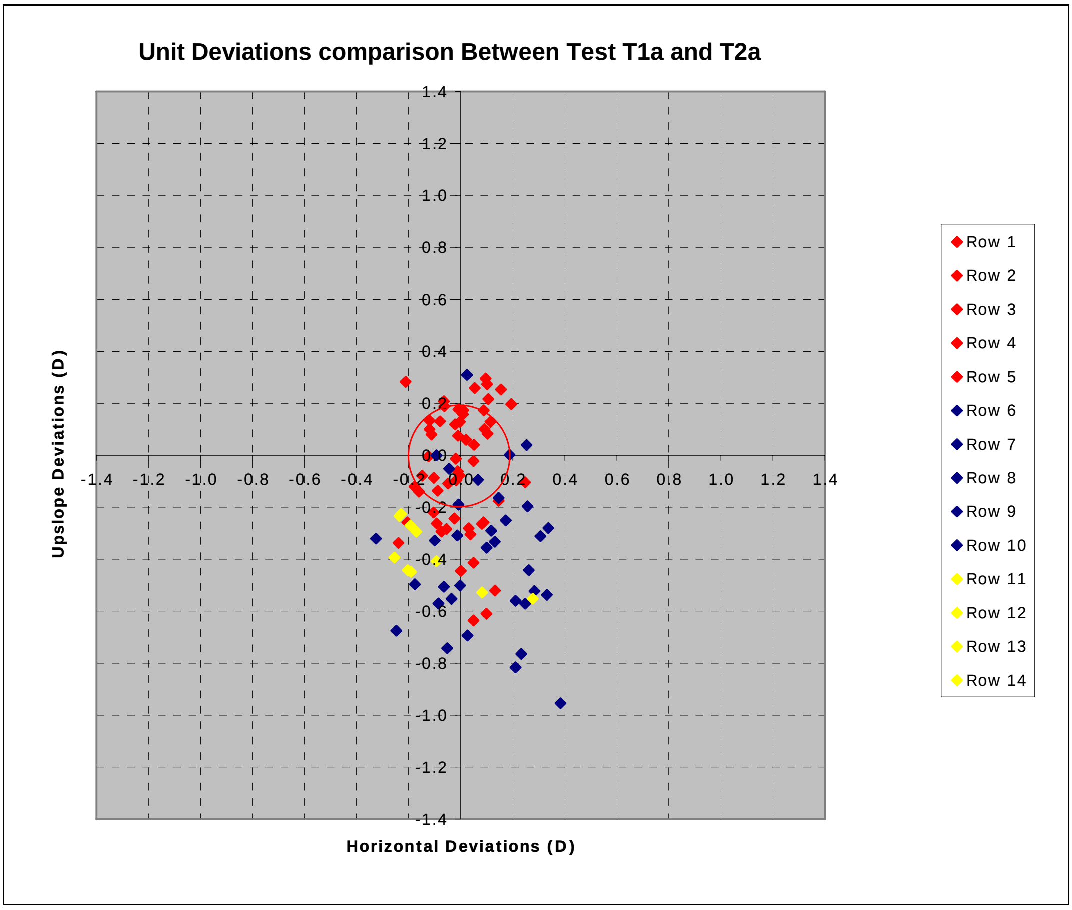


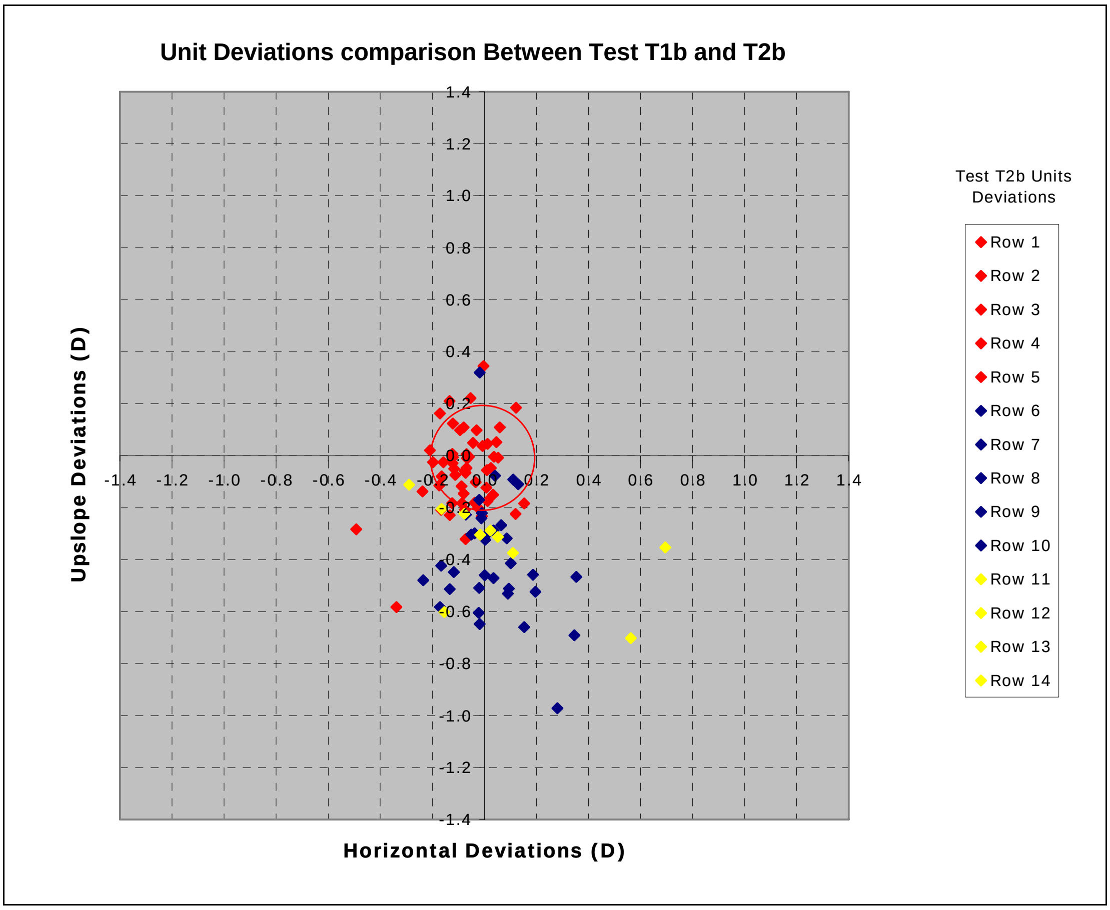


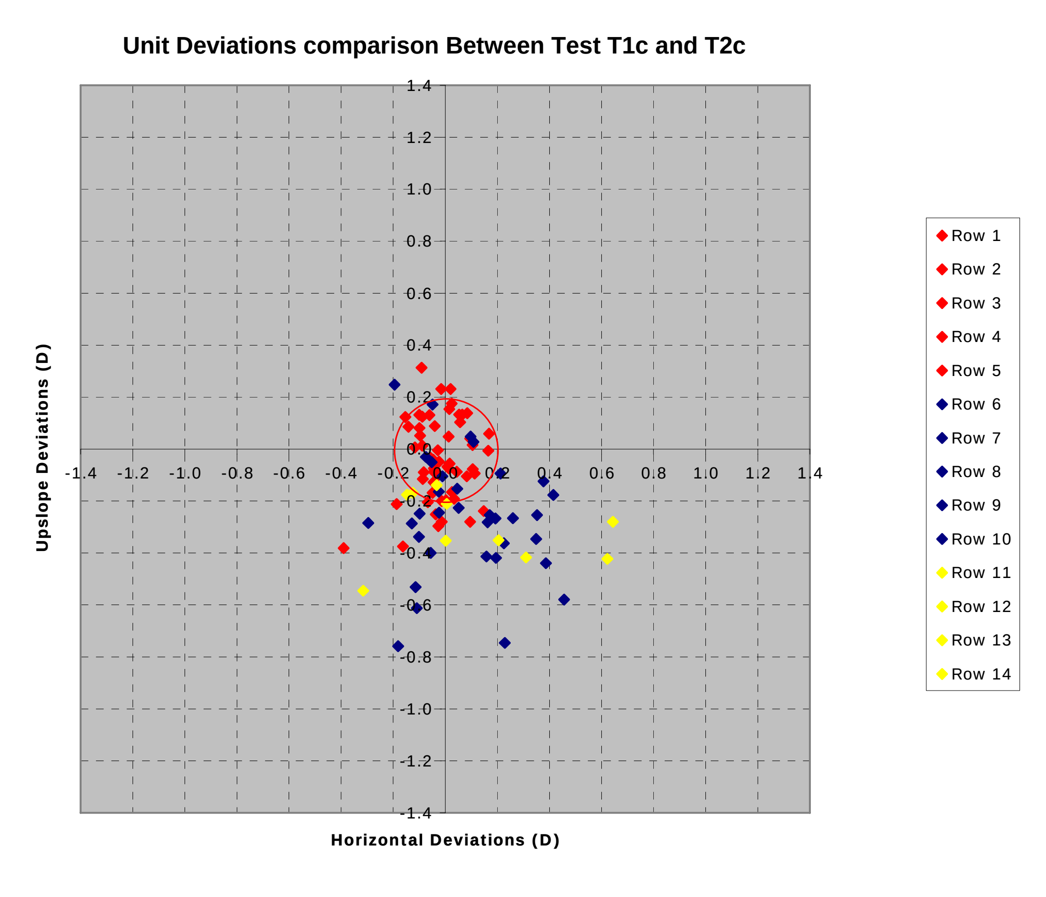
Deviations on Design Position – Test T2c






Unit Deviations comparison Between Test T1a and T2a
Upslope Deviations (D)
Horizontal Deviations (D)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
Row 1
Row 2
Row 3
Row 4
Row 5
Row 6
Row 7
Row 8
Row 9
Row 10
Row 11
Row 12
Row 13
Row 14


Unit Deviations comparison Between Test T1b and T2b
Upslope Deviations (D)
Horizontal Deviations (D)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
Test T2b Units Deviations
Row 1
Row 2
Row 3
Row 4
Row 5
Row 6
Row 7
Row 8
Row 9
Row 10
Row 11
Row 12
Row 13
Row 14


Unit Deviations comparison Between Test T1c and T2c
Upslope Deviations (D)
Horizontal Deviations (D)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.4
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Row 1
Row 2
Row 3
Row 4
Row 5
Row 6
Row 7
Row 8
Row 9
Row 10
Row 11
Row 12
Row 13
Row 14

C.6. Placement Results

Summarized Xbloc Placement Grid - Placement According to Designed Grid with judgements

				Test T2a		Test T2b		Test T2c	
Xbloc Designed Grid				Placement Test		Placement Test		Placement Test	
No.	x-pos 2	y-pos 2	Row	x-mid	y-mid	x-mid	y-mid	x-mid	y-mid
1	0.1	1.9	1	0.103	1.903	0.110	1.905	0.096	1.900
2	0.33	1.86	1	0.323	1.858	0.329	1.863	0.357	1.845
3	0.55	1.79	1	0.548	1.775	0.554	1.760	0.549	1.783
4	0.77	1.7	1	0.752	1.690	0.764	1.680	0.755	1.690
5	0.97	1.58	1	0.952	1.563	0.951	1.560	0.963	1.553
6	1.16	1.44	1	1.144	1.425	1.161	1.431	1.157	1.420
7	1.33	1.27	1	1.330	1.265	1.330	1.255	1.335	1.260
8	1.48	1.09	1	1.476	1.080	1.482	1.087	1.468	1.070
9	1.61	0.89	1	1.597	0.863	1.604	0.873	1.597	0.858
10	1.72	0.68	1	1.711	0.690	1.731	0.695	1.725	0.689
11	1.79	0.46	1	1.794	0.475	1.791	0.490	1.805	0.483
12	1.85	0.23	1	1.875	0.234	1.878	0.255	1.875	0.249
13			1						
14	0.2	1.79	2	0.202	1.748	0.196	1.765	0.204	1.778
15	0.42	1.73	2	0.402	1.695	0.418	1.710	0.402	1.708
16	0.63	1.66	2	0.609	1.618	0.596	1.610	0.621	1.631
17	0.83	1.56	2	0.791	1.543	0.800	1.528	0.806	1.543
18	1.01	1.43	2	1.000	1.390	0.998	1.393	0.974	1.385
19	1.18	1.29	2	1.160	1.248	1.169	1.268	1.179	1.263
20	1.34	1.12	2	1.315	1.095	1.313	1.088	1.338	1.108
21	1.47	0.94	2	1.445	0.918	1.446	0.910	1.455	0.906
22	1.58	0.75	2	1.570	0.735	1.584	0.750	1.571	0.738
23	1.67	0.54	2	1.652	0.557	1.630	0.530	1.669	0.540
24	1.73	0.33	2	1.740	0.330	1.734	0.362	1.722	0.344
25	1.77	0.1	2	1.775	0.093	1.765	0.103	1.786	0.095
26			3						
27	0.28	1.67	3	0.269	1.630	0.300	1.640	0.272	1.675
28	0.49	1.6	3	0.493	1.575	0.496	1.550	0.489	1.580
29	0.68	1.52	3	0.652	1.488	0.680	1.475	0.673	1.508
30	0.86	1.41	3	0.845	1.398	0.844	1.405	0.846	1.398
31	1.03	1.28	3	1.029	1.258	1.035	1.265	1.043	1.243
32	1.19	1.14	3	1.158	1.113	1.183	1.120	1.178	1.120
33	1.32	0.97	3	1.314	0.970	1.329	0.933	1.309	0.973
34	1.44	0.8	3	1.480	0.824	1.442	0.765	1.425	0.788
35	1.53	0.61	3	1.536	0.598	1.522	0.605	1.545	0.605
36	1.6	0.41	3	1.628	0.419	1.610	0.400	1.598	0.424
37	1.65	0.2	3	1.670	0.203	1.680	0.215	1.689	0.208
38	0.16	1.58	4	0.143	1.533	0.164	1.575	0.163	1.595
39	0.36	1.54	4	0.360	1.520	0.386	1.525	0.356	1.540
40	0.54	1.47	4	0.501	1.438	0.549	1.435	0.530	1.463
41	0.72	1.38	4	0.725	1.356	0.722	1.335	0.737	1.360
42	0.89	1.27	4	0.879	1.243	0.920	1.245	0.895	1.263
43	1.04	1.14	4	1.030	1.134	1.049	1.105	1.043	1.098
44	1.18	0.99	4	1.169	0.973	1.190	0.990	1.176	0.960

45	1.29	0.83	4	1.289	0.809	1.288	0.818	1.306	0.818
46	1.39	0.66	4	1.394	0.662	1.401	0.669	1.409	0.672
47	1.47	0.47	4	1.481	0.454	1.476	0.466	1.482	0.483
48	1.53	0.28	4	1.563	0.264	1.527	0.254	1.551	0.293
49			4						
50			5						
51	0.25	1.43	5	0.258	1.430	0.258	1.473	0.255	1.475
52	0.43	1.36	5	0.385	1.345	0.418	1.380	0.416	1.395
53	0.6	1.27	5	0.599	1.290	0.610	1.298	0.603	1.313
54	0.89	1.12	5	0.891	1.123	0.922	1.125	0.894	1.135
55	1.03	0.96	5	1.027	0.968	1.054	0.980	1.018	0.978
56	1.14	0.8	5	1.146	0.840	1.184	0.839	1.172	0.825
57	1.33	0.52	5	1.360	0.533	1.351	0.555	1.359	0.563
58	1.38	0.32	5	1.446	0.315	1.406	0.344	1.425	0.339
59	1.41	0.12	5	1.480	0.123	1.414	0.143	1.457	0.152
60	0.13	1.34	6	0.137	1.350	0.118	1.370	0.127	1.362
61	0.31	1.25	6	0.273	1.260	0.298	1.313	0.307	1.325
62	0.48	1.16	6	0.470	1.230	0.465	1.240	0.480	1.234
63	0.7	1.13	6	0.711	1.160	0.738	1.153	0.732	1.190
64	0.88	0.97	6	0.889	0.975	0.884	0.968	0.874	1.008
65	0.99	0.79	6	1.012	0.838	1.015	0.838	1.019	0.810
66	1.16	0.63	6	1.252	0.660	1.217	0.683	1.229	0.655
67	1.25	0.4	6	1.318	0.380	1.293	0.423	1.300	0.451
68	1.28	0.2	6	1.370	0.194	1.294	0.207	1.335	0.242
69			6						
70			7						
71	0.19	1.16	7	0.179	1.188	0.211	1.238	0.225	1.203
72	0.35	1.06	7	0.410	1.183	0.385	1.168	0.391	1.183
73	0.58	1.05	7	0.584	1.145	0.620	1.168	0.622	1.205
74	0.73	0.94	7	0.760	1.055	0.768	1.040	0.745	1.030
75	0.83	0.78	7	0.891	0.840	0.927	0.835	0.900	0.893
76	1.01	0.64	7	1.085	0.710	1.110	0.703	1.085	0.660
77	1.12	0.48	7	1.186	0.526	1.161	0.515	1.162	0.485
78	1.16	0.28	7	1.243	0.285	1.196	0.310	1.214	0.308
79			7						
80			8						
81	0.22	0.96	8	0.297	1.078	0.301	1.093	0.281	1.098
82	0.46	0.95	8	0.489	1.050	0.527	1.029	0.507	1.050
83	0.68	0.8	8	0.736	0.905	0.756	0.883	0.757	0.890
84	0.86	0.63	8	0.924	0.669	0.935	0.673	0.927	0.728
85	0.97	0.46	8	1.048	0.523	1.043	0.515	1.033	0.520
86	1.07	0.16	8	1.086	0.180	1.107	0.183	1.102	0.178
87	0.34	0.86	9	0.358	0.940	0.403	0.970	0.384	0.980
88	0.53	0.81	9	0.576	0.900	0.625	0.890	0.623	0.923
89	0.71	0.65	9	0.778	0.730	0.777	0.733	0.768	0.758
90	0.82	0.49	9	0.895	0.533	0.885	0.508	0.888	0.559
91	0.95	0.29	9	1.023	0.316	1.017	0.330	1.013	0.360
92			9						
93	0.13	0.86	10	0.135	0.880	0.190	0.935	0.213	0.935
94	0.4	0.73	10	0.465	0.819	0.459	0.820	0.496	0.840
95	0.56	0.62	10	0.660	0.760	0.637	0.718	0.599	0.720

96	0.67	0.46	10	0.753	0.560	0.770	0.598	0.746	0.615
97	0.8	0.31	10	0.900	0.350	0.880	0.340	0.876	0.403
98	0.85	0.12	10	0.956	0.150	0.947	0.133	0.929	0.205
99	0.21	0.72	11	0.300	0.798	0.304	0.840	0.322	0.810
100	0.42	0.58	11	0.498	0.640	0.472	0.665	0.479	0.673
101	0.65	0.31	11	0.760	0.380	0.733	0.435	0.706	0.448
102			11						
103			12						
104	0.26	0.58	12	0.308	0.605	0.288	0.678	0.319	0.635
105	0.49	0.4	12	0.585	0.440	0.548	0.493	0.540	0.498
106	0.64	0.13	12	0.729	0.208	0.698	0.256	0.705	0.258
107	0.11	0.52	13	0.144	0.538	0.160	0.548	0.135	0.565
108	0.32	0.42	13	0.409	0.448	0.378	0.480	0.373	0.443
109	0.47	0.23	13	0.539	0.265	0.517	0.300	0.537	0.333
110			13						
111	0.16	0.36	14	0.230	0.373	0.223	0.400	0.200	0.398
112	0.31	0.25	14	0.383	0.258	0.355	0.275	0.379	0.253
113			14						

Summarized Upslope and Horizontal Distances - Placement According to Designed Grid with Judgements

				Test T2a				Test T2b				Test T2c			
Xbloc Designed grid				Upslope	%	Horizontal	%	Upslope	%	Horizontal	%	Upslope	%	Horizontal	%
No.	x-pos 2	y-pos 2	Row	x.xxD	0.12	x.xxD	0.24	x.xxD	0.12	x.xxD	0.24	x.xxD	0.11648	x.xxD	0.24
1	0.1	1.9	1		0.64		1.33		0.64		1.33		0.64		1.33
2	0.33	1.86	1												
3	0.55	1.79	1												
4	0.77	1.7	1												
5	0.97	1.58	1												
6	1.16	1.44	1												
7	1.33	1.27	1												
8	1.48	1.09	1												
9	1.61	0.89	1												
10	1.72	0.68	1												
11	1.79	0.46	1												
12	1.85	0.23	1												
13			1												
14	0.2	1.79	2	0.94	147.36	1.23	92.77	0.85	133.32	1.22	91.96	0.68	106.41	1.46	109.99
15	0.42	1.73	2	0.87	136.35	1.32	99.00	0.71	110.83	1.36	102.14	0.80	125.28	1.11	83.61
16	0.63	1.66	2	0.86	134.75	1.22	91.57	0.89	139.59	1.23	92.84	0.77	120.74	1.24	93.29
17	0.83	1.56	2	0.73	113.48	1.30	97.70	0.77	119.87	1.22	91.97	0.66	103.77	1.37	102.84
18	1.01	1.43	2	0.78	121.66	1.30	97.56	0.82	127.55	1.35	101.82	0.92	144.06	1.29	97.23
19	1.18	1.29	2	0.88	136.75	1.35	101.52	0.75	117.62	1.34	100.66	0.71	111.49	1.32	98.88
20	1.34	1.12	2	0.83	130.39	1.29	97.23	0.89	139.53	1.25	93.89	0.60	93.77	1.27	95.69
21	1.47	0.94	2	0.74	116.33	1.37	102.82	0.85	132.65	1.35	101.77	0.68	105.73	1.37	102.81
22	1.58	0.75	2	0.64	100.47	1.14	85.53	0.62	97.22	1.20	90.17	0.67	104.14	1.16	87.58
23	1.67	0.54	2	0.73	114.12	1.27	95.14	1.03	161.41	1.18	88.44	0.75	116.46	1.21	91.30
24	1.73	0.33	2	0.68	106.04	1.40	105.10	0.71	110.34	1.37	103.26	0.85	132.41	1.34	100.71
25	1.77	0.1	2												
26			3												
27	0.28	1.67	3	0.66	103.17	1.13	85.22	0.67	104.92	1.26	94.69	0.49	76.35	1.15	86.76
28	0.49	1.6	3	0.53	83.41	1.22	91.51	0.74	115.35	1.12	84.35	0.61	95.26	1.27	95.64

29	0.68	1.52	3	0.69	107.95	1.08	81.13	0.62	97.21	1.21	90.91	0.58	90.50	1.13	84.91
30	0.86	1.41	3	0.55	86.38	1.42	107.05	0.49	77.03	1.31	98.83	0.51	79.84	1.27	95.13
31	1.03	1.28	3	0.51	80.30	1.18	88.51	0.52	81.11	1.16	87.51	0.57	88.29	1.31	98.66
32	1.19	1.14	3	0.67	105.43	1.19	89.83	0.55	85.52	1.27	95.23	0.71	110.83	1.22	91.59
33	1.32	0.97	3	0.48	74.29	1.21	90.89	0.53	82.24	1.22	91.63	0.61	94.71	1.28	96.54
34	1.44	0.8	3	0.16	24.40	1.22	91.38	0.66	102.56	1.16	87.29	0.64	100.03	1.12	84.17
35	1.53	0.61	3	0.58	90.80	1.08	81.06	0.60	94.53	1.24	92.89	0.53	83.55	1.22	91.45
36	1.6	0.41	3	0.46	71.84	1.34	100.46	0.54	84.23	1.08	81.52	0.66	102.59	1.11	83.68
37	1.65	0.2	3	0.58	90.41	1.32	99.18	0.46	72.00	1.44	107.99	0.42	65.42	1.42	106.41
38	0.16	1.58	4												
39	0.36	1.54	4	0.60	93.71	1.26	95.09	0.49	76.64	1.19	89.10	0.64	100.25	1.30	97.67
40	0.54	1.47	4	0.82	127.68	1.00	75.16	0.60	94.29	1.09	82.28	0.67	103.92	1.09	81.89
41	0.72	1.38	4	0.62	97.57	1.17	87.98	0.79	124.12	0.98	73.48	0.66	103.61	1.12	84.52
42	0.89	1.27	4	0.75	117.42	1.27	95.35	0.64	100.66	1.30	98.00	0.55	85.78	1.38	103.56
43	1.04	1.14	4	0.56	88.02	1.07	80.18	0.75	117.11	1.14	85.45	0.76	118.74	1.00	75.31
44	1.18	0.99	4	0.68	105.57	1.16	87.44	0.52	80.74	1.31	98.17	0.77	119.78	1.08	81.34
45	1.29	0.83	4	0.98	153.37	1.21	91.17	0.69	108.50	1.11	83.47	0.58	91.36	1.20	90.38
46	1.39	0.66	4	0.87	135.93	1.28	96.39	0.55	85.48	0.98	73.99	0.53	83.37	1.20	90.35
47	1.47	0.47	4	0.80	124.74	1.10	82.96	0.67	105.27	1.23	92.16	0.66	102.73	1.04	77.86
48	1.53	0.28	4	0.68	106.54	1.21	91.15	0.92	143.64	1.09	81.64	0.67	105.41	1.29	97.10
49			4												
50			5												
51	0.25	1.43	5	0.64	100.76	1.19	89.80	0.53	82.30	1.25	94.21	0.62	96.90	1.11	83.11
52	0.43	1.36	5	0.97	151.56	0.90	67.67	0.75	116.88	1.02	76.74	0.74	115.34	1.05	78.69
53	0.6	1.27	5	0.69	107.82	1.31	98.47	0.57	89.76	1.10	82.73	0.67	104.25	1.27	95.24
54	0.89	1.12	5	0.60	92.99	1.03	77.10	0.51	79.60	1.04	78.51	0.56	86.77	1.22	91.57
55	1.03	0.96	5	0.77	119.80	1.17	87.74	0.63	98.17	1.00	75.33	0.70	109.96	1.05	79.17
56	1.14	0.8	5	0.65	101.73	1.12	83.95	0.56	87.59	1.09	81.86	0.63	98.10	1.06	79.69
57	1.33	0.52	5	0.53	83.49	1.24	93.14	0.58	90.80	1.19	89.21	0.58	89.86	1.11	83.82
58	1.38	0.32	5	0.57	89.38	1.14	85.49	0.65	102.30	1.20	90.23	0.70	108.70	1.11	83.58
59	1.41	0.12	5												
60	0.13	1.34	6												
61	0.31	1.25	6	0.90	141.18	0.84	63.30	0.79	123.44	1.02	76.35	0.74	115.75	0.99	74.09

62	0.48	1.16	6	0.59	92.16	1.21	91.08	0.74	115.01	1.15	86.33	0.83	130.02	1.12	84.44
63	0.7	1.13	6	0.40	62.61	1.85	139.25	0.46	72.01	1.96	147.46	0.25	39.57	1.88	140.99
64	0.88	0.97	6	0.68	106.04	1.13	85.05	0.94	146.32	1.08	81.01	0.64	99.69	1.10	82.68
65	0.99	0.79	6	0.66	102.72	0.96	72.19	0.86	133.73	1.05	79.24	0.79	124.04	1.19	89.68
66	1.16	0.63	6	0.15	22.96	2.06	154.77	0.35	54.91	1.81	136.03	0.35	55.25	1.77	133.15
67	1.25	0.4	6	0.65	101.97	1.29	96.62	0.61	95.53	1.20	90.28	0.61	95.84	1.28	96.47
68	1.28	0.2	6	0.64	100.37	1.07	80.76	0.83	129.31	1.11	83.10	0.71	111.12	1.04	78.34
69			6												
70			7												
71	0.19	1.16	7	0.82	127.47	0.89	67.20	0.69	107.97	1.04	78.06	0.96	150.33	1.01	75.88
72	0.35	1.06	7	0.41	64.13	1.10	82.53	0.69	108.28	1.00	75.40	0.61	95.85	1.08	80.94
73	0.58	1.05	7	0.35	54.48	1.38	103.68	0.20	30.78	1.58	118.43	0.10	15.79	1.41	105.68
74	0.73	0.94	7	0.24	37.09	1.41	105.92	0.28	44.01	1.29	97.36	0.60	93.77	1.27	95.40
75	0.83	0.78	7	0.56	88.03	1.01	76.22	0.42	65.50	1.01	76.10	0.28	43.94	1.35	101.34
76	1.01	0.64	7	0.40	63.18	1.64	123.32	0.33	51.96	1.40	105.35	0.53	83.14	1.43	107.83
77	1.12	0.48	7	0.64	100.54	1.58	118.84	0.69	108.05	1.49	111.85	0.84	131.52	1.19	89.43
78	1.16	0.28	7	0.68	106.64	1.06	79.99	0.66	103.05	1.19	89.24	0.76	118.89	1.16	87.51
79			7												
80			8												
81	0.22	0.96	8	0.69	108.42	1.27	95.66	0.71	110.46	1.03	77.67	0.63	99.11	0.92	69.28
82	0.46	0.95	8	0.76	118.17	0.98	73.33	0.91	142.07	1.29	96.88	0.96	150.46	1.27	95.68
83	0.68	0.8	8	0.66	102.94	1.38	104.01	0.73	114.01	1.43	107.18	0.66	103.49	1.14	85.44
84	0.86	0.63	8	0.87	135.57	1.28	96.48	0.91	141.94	1.24	93.50	0.59	92.01	1.63	122.88
85	0.97	0.46	8	0.88	137.32	1.15	86.71	0.89	139.39	1.07	80.22	0.71	111.39	1.05	78.90
86	1.07	0.16	8												
87	0.34	0.86	9	0.91	142.19	1.07	80.33	0.63	98.07	1.29	96.84	0.65	101.40	1.27	95.41
88	0.53	0.81	9	0.62	97.18	1.57	118.32	0.47	73.22	1.49	112.20	0.33	52.06	1.63	122.80
89	0.71	0.65	9	0.53	82.12	1.66	124.52	0.56	86.97	1.52	114.13	0.61	94.98	1.29	97.15
90	0.82	0.49	9	0.73	114.36	1.05	79.29	0.91	142.85	1.05	78.89	0.75	117.93	1.28	96.17
91	0.95	0.29	9	0.37	57.94	1.89	142.36	0.42	65.45	1.86	139.88	0.36	55.73	1.92	144.34
92			9												
93	0.13	0.86	10												
94	0.4	0.73	10	0.65	101.97	1.22	91.56	0.85	133.15	1.30	97.68	0.73	114.73	1.35	101.35

95	0.56	0.62	10	0.34	52.51	1.45	109.23	0.75	116.59	1.20	90.28	1.05	163.92	1.21	90.88
96	0.67	0.46	10	0.75	117.88	1.26	94.83	0.41	64.33	1.37	103.11	0.62	96.62	1.27	95.72
97	0.8	0.31	10	0.64	99.35	1.38	103.80	0.71	111.56	1.22	91.38	0.65	101.60	1.29	97.08
98	0.85	0.12	10												
99	0.21	0.72	11	0.35	54.10	1.84	138.64	0.27	42.59	1.61	120.86	0.58	91.05	1.64	123.52
100	0.42	0.58	11	1.15	180.41	1.12	84.17	0.91	142.63	1.13	84.86	0.90	140.16	0.87	65.20
101	0.65	0.31	11	0.68	106.47	1.41	105.90	0.68	107.02	1.54	115.68	0.86	134.25	1.37	102.91

Summarized Unit Deviations - Placement Test According to Grid with Judgement

Xbloc Designed Grid				Test T2a		Test T2b		Test T2c	
No.	x-pos 2	y-pos 2	Row	Upslope,D	Horiz,D	Upslope,D	Horiz,D	Upslope,D	Horiz,D
1	0.1	1.9	1	-0.02	-0.01	-0.04	-0.05	0.00	0.02
2	0.33	1.86	1	0.03	0.04	-0.02	0.01	0.07	-0.16
3	0.55	1.79	1	0.11	-0.01	0.21	-0.07	0.06	-0.01
4	0.77	1.7	1	0.13	0.07	0.16	-0.01	0.11	0.05
5	0.97	1.58	1	0.18	0.04	0.20	0.03	0.21	-0.04
6	1.16	1.44	1	0.17	0.02	0.05	-0.04	0.13	-0.06
7	1.33	1.27	1	0.03	-0.02	0.08	-0.06	0.02	-0.06
8	1.48	1.09	1	0.07	-0.03	0.00	-0.02	0.16	-0.05
9	1.61	0.89	1	0.19	-0.10	0.10	-0.07	0.20	-0.12
10	1.72	0.68	1	0.03	0.07	-0.12	0.05	-0.06	0.03
11	1.79	0.46	1	-0.05	0.08	-0.06	0.16	-0.15	0.10
12	1.85	0.23	1	-0.19	0.00	-0.23	0.12	-0.20	0.09
13			1						
14	0.2	1.79	2	0.32	-0.04	0.19	0.01	0.09	-0.03
15	0.42	1.73	2	0.29	0.05	0.15	-0.02	0.20	0.07
16	0.63	1.66	2	0.35	0.03	0.44	0.08	0.23	-0.01
17	0.83	1.56	2	0.25	0.15	0.32	0.06	0.20	0.07
18	1.01	1.43	2	0.29	-0.08	0.28	-0.06	0.43	0.02
19	1.18	1.29	2	0.34	-0.08	0.18	-0.04	0.16	-0.10
20	1.34	1.12	2	0.26	-0.02	0.31	-0.04	0.07	-0.04
21	1.47	0.94	2	0.25	-0.03	0.28	-0.07	0.23	-0.12
22	1.58	0.75	2	0.12	-0.05	-0.02	-0.01	0.10	-0.04
23	1.67	0.54	2	0.09	0.12	0.31	0.02	0.01	0.00
24	1.73	0.33	2	-0.07	-0.01	-0.07	0.17	0.04	0.08
25	1.77	0.1	2	-0.03	-0.04	0.04	0.02	-0.12	-0.04
26			3						
27	0.28	1.67	3	0.31	0.02	0.20	-0.13	-0.03	0.05
28	0.49	1.6	3	0.17	-0.05	0.35	-0.11	0.15	-0.02
29	0.68	1.52	3	0.31	0.07	0.31	-0.10	0.11	0.01
30	0.86	1.41	3	0.14	0.03	0.10	0.06	0.14	0.03
31	1.03	1.28	3	0.14	-0.07	0.06	-0.07	0.16	-0.18
32	1.19	1.14	3	0.32	0.01	0.14	-0.05	0.17	-0.03
33	1.32	0.97	3	0.04	0.02	0.11	-0.19	0.06	0.05
34	1.44	0.8	3	-0.35	0.01	0.12	-0.17	0.15	-0.02
35	1.53	0.61	3	0.00	-0.07	0.07	-0.01	-0.09	-0.06
36	1.6	0.41	3	-0.22	0.01	-0.05	-0.07	-0.01	0.08
37	1.65	0.2	3	-0.15	0.00	-0.23	0.06	-0.30	0.02
38	0.16	1.58	4	0.37	0.07	0.03	-0.02	-0.11	-0.01
39	0.36	1.54	4	0.15	-0.02	0.06	-0.16	0.01	0.02
40	0.54	1.47	4	0.33	0.14	0.22	-0.11	0.08	0.04
41	0.72	1.38	4	0.14	-0.09	0.29	-0.12	0.07	-0.13
42	0.89	1.27	4	0.22	-0.03	0.02	-0.21	0.03	-0.04
43	1.04	1.14	4	0.09	0.02	0.15	-0.16	0.22	-0.17
44	1.18	0.99	4	0.15	-0.03	-0.06	-0.04	0.17	-0.11
45	1.29	0.83	4	0.10	-0.09	0.07	-0.05	-0.05	-0.11
46	1.39	0.66	4	-0.03	0.00	-0.10	0.02	-0.17	0.01
47	1.47	0.47	4	-0.04	-0.10	-0.03	-0.03	-0.11	0.05
48	1.53	0.28	4	-0.22	-0.12	0.06	-0.14	-0.17	0.05
49			4						
50			5						
51	0.25	1.43	5	-0.01	-0.04	-0.32	0.00	-0.34	0.02
52	0.43	1.36	5	0.21	0.21	-0.12	0.10	-0.22	0.13
53	0.6	1.27	5	-0.13	0.05	-0.22	0.02	-0.30	0.09
54	0.89	1.12	5	-0.02	0.00	-0.18	-0.12	-0.11	0.03

55	1.03	0.96	5	-0.02	0.04	-0.23	-0.01	-0.02	0.12
56	1.14	0.8	5	-0.21	0.16	-0.43	0.04	-0.30	0.01
57	1.33	0.52	5	-0.24	0.00	-0.24	0.14	-0.32	0.16
58	1.38	0.32	5	-0.48	-0.11	-0.23	0.09	-0.36	0.04
59	1.41	0.12	5	-0.53	-0.02	-0.04	0.12	-0.37	0.15
60	0.13	1.34	6	-0.08	-0.03	-0.22	0.08	-0.16	0.03
61	0.31	1.25	6	-0.01	0.21	-0.44	0.15	-0.54	0.12
62	0.48	1.16	6	-0.46	0.20	-0.52	0.24	-0.52	0.16
63	0.7	1.13	6	-0.24	0.04	-0.30	-0.11	-0.51	0.02
64	0.88	0.97	6	-0.07	-0.02	-0.01	-0.03	-0.18	0.16
65	0.99	0.79	6	-0.35	0.13	-0.37	0.12	-0.26	-0.01
66	1.16	0.63	6	-0.71	-0.10	-0.57	0.10	-0.55	-0.06
67	1.25	0.4	6	-0.44	-0.22	-0.36	0.05	-0.48	0.18
68	1.28	0.2	6	-0.66	-0.11	-0.11	0.02	-0.46	0.18
69			6						
70			7						
71	0.19	1.16	7	-0.19	0.09	-0.60	-0.04	-0.36	-0.15
72	0.35	1.06	7	-1.02	-0.10	-0.85	0.00	-0.97	0.00
73	0.58	1.05	7	-0.64	0.24	-0.92	0.12	-1.17	0.21
74	0.73	0.94	7	-0.83	0.26	-0.77	0.17	-0.61	0.24
75	0.83	0.78	7	-0.64	0.01	-0.81	-0.14	-0.96	0.19
76	1.01	0.64	7	-0.76	0.10	-0.89	0.00	-0.56	-0.13
77	1.12	0.48	7	-0.59	0.09	-0.38	0.09	-0.30	-0.06
78	1.16	0.28	7	-0.61	-0.08	-0.31	0.11	-0.44	0.08
79			7						
80			8						
81	0.22	0.96	8	-1.00	-0.27	-1.11	-0.27	-1.11	-0.16
82	0.46	0.95	8	-0.77	0.10	-0.75	-0.14	-0.83	0.01
83	0.68	0.8	8	-0.88	0.14	-0.84	-0.02	-0.89	0.00
84	0.86	0.63	8	-0.56	-0.03	-0.64	-0.06	-0.84	0.21
85	0.97	0.46	8	-0.73	0.13	-0.67	0.10	-0.62	0.15
86	1.07	0.16	8	-0.14	0.10	-0.30	0.09	-0.25	0.07
87	0.34	0.86	9	-0.61	0.07	-0.94	-0.10	-0.96	0.02
88	0.53	0.81	9	-0.75	0.06	-0.90	-0.20	-1.09	-0.09
89	0.71	0.65	9	-0.78	0.07	-0.79	0.09	-0.87	0.22
90	0.82	0.49	9	-0.65	-0.01	-0.48	-0.10	-0.70	0.14
91	0.95	0.29	9	-0.58	0.02	-0.57	0.10	-0.61	0.27
92			9	0.00	0.00	0.00	0.00	0.00	0.00
93	0.13	0.86	10	-0.15	-0.01	-0.63	-0.26	-0.67	-0.39
94	0.4	0.73	10	-0.82	-0.08	-0.80	-0.04	-1.07	-0.17
95	0.56	0.62	10	-1.28	0.11	-0.93	0.05	-0.76	0.21
96	0.67	0.46	10	-0.94	0.20	-1.22	0.31	-1.16	0.47
97	0.8	0.31	10	-0.81	0.01	-0.64	-0.01	-0.80	0.32
98	0.85	0.12	10	-0.82	0.08	-0.73	-0.01	-0.69	0.40
99	0.21	0.72	11	-0.56	-0.35	-0.79	-0.31	-0.67	-0.45
100	0.42	0.58	11	-0.52	-0.15	-0.54	0.04	-0.60	0.04
101	0.65	0.31	11	-0.71	0.09	-0.73	0.42	-0.64	0.55
102			11						
103			12						
104	0.26	0.58	12	-0.24	-0.18	-0.55	0.08	-0.41	-0.17
105	0.49	0.4	12	-0.55	-0.16	-0.57	0.19	-0.56	0.24
106	0.64	0.13	12	-0.57	0.32	-0.50	0.62	-0.53	0.62
107	0.11	0.52	13	-0.14	-0.16	-0.21	-0.24	-0.27	-0.08
108	0.32	0.42	13	-0.43	-0.30	-0.45	-0.05	-0.28	-0.16
109	0.47	0.23	13	-0.42	0.01	-0.41	0.23	-0.59	0.35
111	0.16	0.36	14	-0.24	-0.32	-0.35	-0.22	-0.28	-0.12
112	0.31	0.25	14	-0.35	-0.22	-0.28	-0.05	-0.31	-0.23

Summarized Packing Density - Placement Test According to Designed Grid with Judgements

Xbloc Designed Grid				Test T2a		Test T2b		Test T2c	
	Placed	%		Placed	%	Placed	%	Placed	%
No.	36.23	100	Row	36.23	100	36.23	100	36.23	100
1			1						
2			1						
3			1						
4			1						
5			1						
6			1						
7			1						
8			1						
9			1						
10			1						
11			1						
12			1						
13			1						
14			2	27.2	75.0	29.0	80.1	33.1	91.3
15			2	28.0	77.3	32.5	89.7	30.8	85.0
16			2	31.8	87.9	29.0	80.2	33.7	93.1
17			2	29.5	81.5	29.8	82.1	29.7	82.0
18			2	29.3	80.9	29.2	80.6	28.0	77.2
19			2	27.0	74.6	28.8	79.5	34.5	95.3
20			2	29.3	80.9	26.5	73.1	36.5	100.8
21			2	36.7	101.2	35.8	98.7	39.9	110.2
22			2	37.2	102.8	29.0	80.0	33.8	93.4
23			2	32.2	88.8	31.1	85.9	31.4	86.7
24			2	33.7	93.1	29.8	82.2	25.2	69.5
25			2						
26			3						
27			3	40.5	111.9	35.2	97.3	44.2	122.1
28			3	46.9	129.5	42.8	118.0	43.7	120.7
29			3	38.1	105.2	46.9	129.4	44.0	121.5
30			3	42.9	118.5	47.1	130.0	47.1	130.1
31			3	45.3	125.0	44.7	123.4	40.0	110.5
32			3	43.7	120.5	45.1	124.4	37.5	103.5
33			3	82.5	227.8	46.6	128.6	42.3	116.8
34			3	64.7	178.5	39.0	107.6	42.6	117.5
35			3	50.1	138.2	50.8	140.4	44.2	122.0
36			3	42.7	117.8	44.8	123.7	44.9	123.9
37			3						
38			4	42.1	116.3	49.1	135.6	42.6	117.5
39			4	40.1	110.8	53.4	147.5	42.5	117.4
40			4	36.6	101.0	41.0	113.1	37.4	103.3
41			4	37.4	103.1	34.4	95.1	44.0	121.4
42			4	40.3	111.2	39.0	107.8	38.1	105.2
43			4	45.2	124.8	43.0	118.8	37.6	103.9
44			4	32.0	88.2	43.2	119.3	39.1	108.0
45			4	26.6	73.4	48.3	133.4	52.4	144.7
46			4	32.0	88.4	43.2	119.2	42.3	116.8
47			4	33.6	92.8	32.3	89.1	42.0	115.9
48			4						
49			4						

50			5						
51			5	39.1	107.9	42.0	116.0	43.8	120.8
52			5	33.1	91.2	41.8	115.3	37.9	104.7
53			5	21.9	60.4	24.6	68.0	21.8	60.1
54			5	38.1	105.3	53.5	147.7	44.1	121.8
55			5	36.6	101.1	48.8	134.7	38.9	107.5
56			5	22.6	62.3	26.6	73.4	23.7	65.4
57			5	45.0	124.2	39.8	109.8	40.3	111.1
58			5	49.1	135.6	41.7	115.2	41.7	115.0
59			5						
60			6	37.4	103.2	36.8	101.6	40.4	111.5
61			6	42.1	116.2	39.7	109.7	37.7	104.2
62			6	38.0	104.9	31.6	87.2	36.9	101.8
63			6	34.9	96.2	29.0	80.0	43.4	119.8
64			6	45.0	124.2	33.1	91.4	35.9	99.0
65			6	45.7	126.1	35.1	96.9	34.1	94.0
66			6	46.2	127.5	37.8	104.3	42.1	116.2
67			6	40.0	110.4	35.7	98.4	38.6	106.5
68			6						
69			6						
70			7						
71			7	52.2	144.0	44.3	122.2	37.8	104.3
72			7	77.6	214.3	57.5	158.7	81.6	225.1
73			7	67.1	185.1	80.8	222.9	58.8	162.3
74			7	59.0	162.8	78.4	216.4	59.0	162.8
75			7	52.7	145.4	72.4	199.7	62.5	172.4
76			7	34.1	94.1	42.8	118.2	33.5	92.5
77			7	35.4	97.7	33.9	93.5	34.3	94.5
78			7						
79			7						
80			8						
81			8	35.6	98.2	34.2	94.5	33.2	91.6
82			8	18.7	51.7	16.2	44.7	16.5	45.4
83			8	31.2	86.1	28.4	78.5	34.4	94.9
84			8	28.2	77.8	28.0	77.3	33.7	93.1
85			8	18.1	50.1	18.2	50.2	22.1	60.9
86			8						
87			9	29.4	81.2	38.3	105.8	39.2	108.1
88			9	30.4	84.1	40.6	111.9	46.8	129.2
89			9	38.7	106.8	31.2	86.0	32.4	89.4
90			9	32.7	90.4	31.1	85.9	36.1	99.5
91			9						
92			9						
93			10	25.1	69.2	22.0	60.8	25.0	69.1
94			10	42.1	116.2	29.4	81.2	30.2	83.3
95			10	42.3	116.8	43.3	119.6	32.4	89.4
96			10	32.9	90.7	42.7	117.8	36.8	101.5
97			10	41.6	114.8	35.3	97.4	41.3	114.1
98			10						
99			11	29.0	80.0	38.2	105.3	31.6	87.3
100			11	13.3	36.8	15.2	41.9	17.3	47.8