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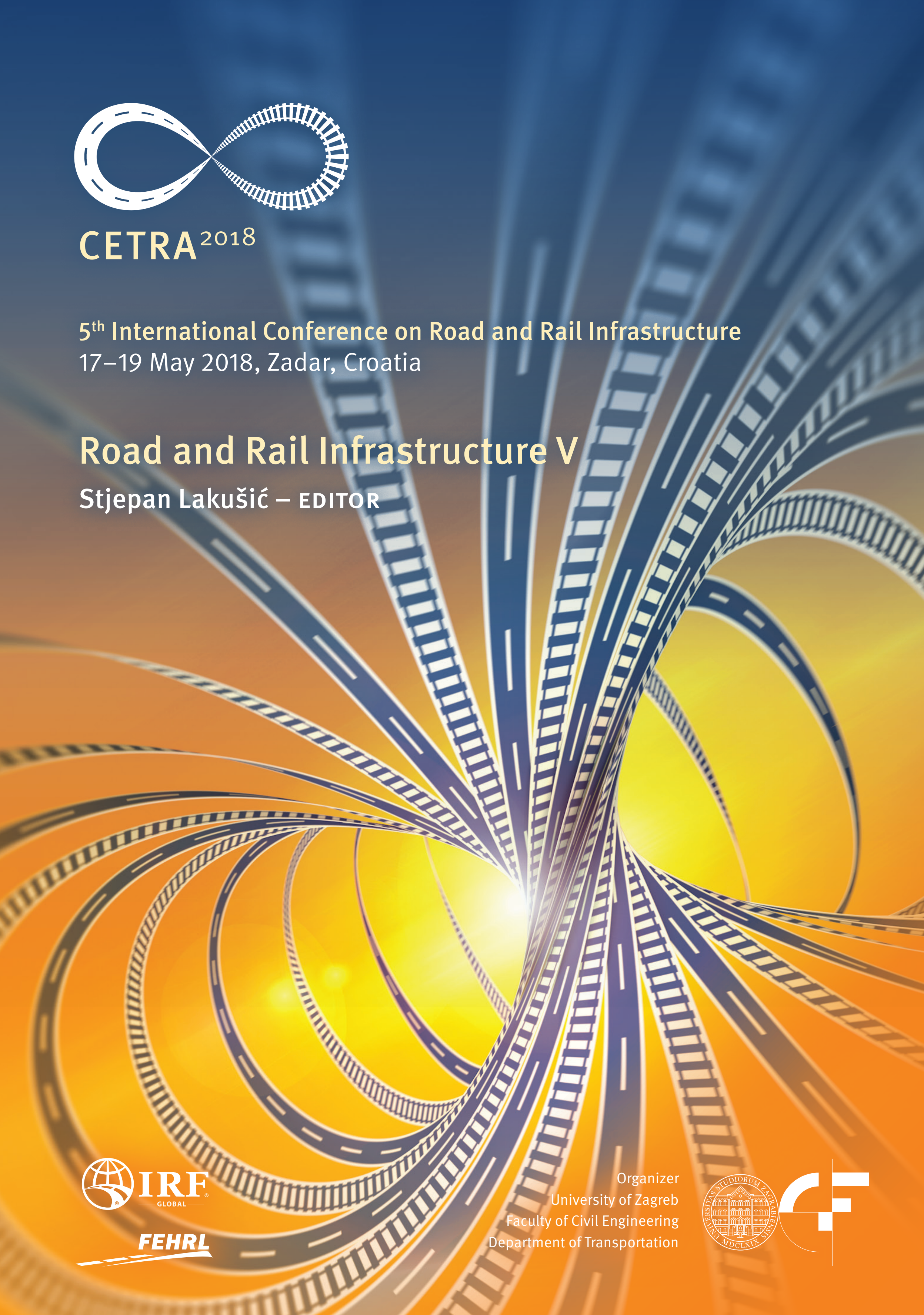

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LIFE CYCLE MANAGEMENT MODEL FOR TUNNELS

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Abstract

Tunnels are a vital link in transport networks which represent a significant investment in all life cycle phases from planning, investigation works, construction and operation. Decisions through the whole life cycle of a tunnel should be based on solid facts and reliable data especially in the context of considerable impacts on both the environment and society. The calculation of total life time costs for different design alternatives, maintenance options and societal impacts can be used to compare different technical solutions and select the optimal design and maintenance alternative. Generally problems related to tunnel degradation can be divided into those caused by external pressure and those caused by the deterioration of materials. These problems are gradually increased through all life cycle stages of a concrete structure such as a tunnel, therefore decisions about the timing and the type of maintenance should be based on degradation prediction models and monitoring of the structure performance or degradation processes. Uncertainties in the decision making process can be decreased by using information from monitoring which are used to establish triggering thresholds for the structure passing certain performance levels. In this paper the use of monitored tunnel deformations in a life cycle management model for a tunnel is presented. The monitoring data gives information about tunnel long term deformations that are used in the decision making process, in order to prevent occurrence of tunnel damage and consequently large maintenance costs.

Keywords: tunnels, maintenance, life cycle management model, decision making

1 Introduction

Tunnels, are vital part of many transport infrastructure networks, and represent a significant financial investment with a very high influence on both environment and society. This type of structure is designed and built for a very long life cycle of which a major part is the operational phase with all related maintenance activities. Inadequate and untimely planning of maintenance and repair activities can cause immense costs, both financial and environmental.
Ageing is a general ubiquitous process but deterioration mechanisms and environmental impacts are different regarding type of structure. At present day there are millions of civil engineering and building structures, where design service life is usually defined in the range of 70 – 120 years. [1, 2] The required service life of a structure, especially as one as important as a tunnel, can often be much longer than it was initially designed for. But severe structural defects that often occur in the service life can highly increase the overall life time cost.

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2 Problems related to tunnels

When it comes to underground structures there are specific problems regarding the environmental influences on the structure and external loads which are very much dependant on the surrounding soil or rock mass. The primary phase of the actual construction process of a tunnel is excavation which leads to stress redistribution and changes in soil stiffnes. This eventually leads to short-term and long-term deformations that can cause local cracks or micro cracks on the concrete lining surface, [1]. Figure 1 shows some problems appearing in tunnels such as cracks and leaking through tunnel lining.

Figure 1 Heavy leaking through tunnel lining and water on the pavement as a consequence influencing traffic safety; cracks on tunnel ceiling [4]

Generally the causes of deterioration of tunnel lining can be broadly classified into two types, (1) those caused by external pressure, including earth pressure and freezing pressure; and (2) those caused by the deterioration of materials such as the concrete lining, [3]. The implementation of long term monitoring systems, which measure tunnel performance, will decrease the uncertainties included in the life cycle tunnel management decision making processes.

3 Life cycle management

Whole-life costing (WLC) is "the methodology for systematic economic consideration of all whole life costs and benefits over the period of analysis" as defined in the international standard for life cycle costing of buildings and constructed assets [5]. Analysis of the whole life costing is aimed for improving decision making process and does not necessarily mean choosing the longest service life or the minimum costs but rather choosing an optimal solution based on reliable data.

3.1 Life cycle stages

There are a number of phases in the development and use of an asset. Typically the sequence of events through the life of the asset progresses as follows:
- Concept phase – where the owner's basic requirements and needs are established.
- Design – usually involving preliminary and detailed design phases.
- Construction – the process whereby the asset is built.
- Operation and use – through life performance and maintenance of its functionality.
- Disposal – the process by which the asset is either sold, decommissioned or removed.

Figure 2 shows the different phases in the service life of a concrete structure. It incorporates the periods of design and construction, post-construction service life, the remedial intervention process and also post-intervention performance. It shows the general steps and activities involved. Some parameters and other aspects which influence the potential durability and service-life of the structure are listed. Such parameters might provide a basis for modelling the performance of the structure and for developing better acceptance and performance criteria which might be utilised by the owner for through-life management of the structure, [6].

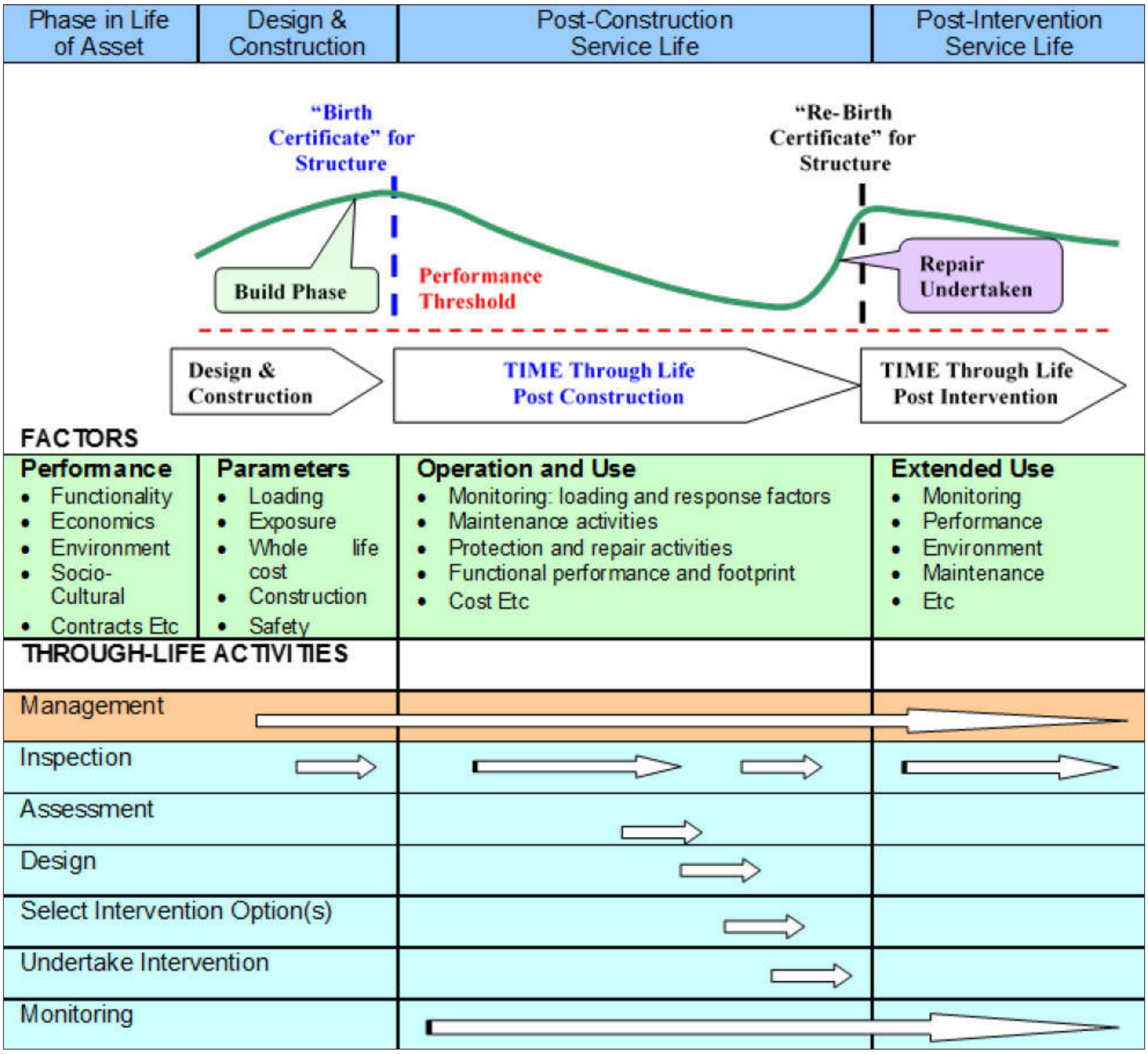

Figure 2 Through-life processes and management of concrete structure [6]

3.2 Tunnels performance modelling and monitoring

When performing any life cycle cost analysis it is necessary to establish a deterioration curve to predict a structure, system or a part of a system passing from one condition state to another. It can be applied for both new and existing structures and considers explicitly the impact of maintenance interventions. First it needs to be determined which are the dominant deterioration mechanisms for the tunnel and the influence the tunnel structural performance as well as the quantifying the geological and hydrogeological conditions.
There are both deterministic and probabilistic models available which can be used to simulate the structural degradation. Since the parameters associated with underground structures such as tunnels are associated with large uncertainty it is recommended in the literature [7] to use probabilistic models combined with measurement data for simulating the degradation of structures subjected to gradual deterioration.

According to [8] a review of the published literature suggests that there are several uncertainties associated failure assessments of tunnel structures that require further research: (i) the stochastic formulation of time-dependent performance functions in tunnel structures has not been fully developed in the previous studies; (ii) time-dependent reliability assessment of tunnel structure, which leads to prediction of remaining lifetime, has not been fully implemented; (iii) in the few reliability-based studies only one failure mode has been considered. But often in practice when it comes to decision making a simple analysis based on expert judgment of experienced engineers is used for the purpose of determining the transition into a lower condition level.

3.3 Monitoring of tunnel long term deformations

Tunnels are not as accessible for inspections as some other types of structures. Although the inside face of the primary lining of a tunnel is directly visible the secondary lining, rock or soil behind it (possibly strengthened) and bonds between all layers cannot be examined visually. Non-intrusive methods (e.g. ground penetrating radar) require interpretations whilst intrusive techniques can compromise the structural integrity. Long-term monitoring provides a viable alternative with which to reduce uncertainties regarding processes of condition assessment and can be used for calibration of existing numerical models.
Long-term deformations can occur over large periods (tens of years resulting from various time dependent processes such as creep, squeezing, swelling, and consolidation of soils. In addition stress redistribution between the primary and secondary lining, creep or degradation of the structural materials can occur, [9]. These deformations can cause local cracks or micro cracks on the concrete surface.

3.4 Life cycle management model for tunnels

A large part of the total cost over whole life of a tunnel are incurred after construction in the operational phase and can highly overcome the initial construction cost of a structure. Choices made regarding different alternatives of initial design for a new asset or maintenance activities for existing assets can result in a very different life-time service cost.
The investigation and assessment processes need to give owners an understanding of the urgency of any interventions required upon the structure, whether this is essential for its structural functionality and the influence such issues may have upon the management of the structure, as well as the choices available amongst the potential options for discharging the owner's specific and wider responsibilities, [6].
Figure 3 shows two types of maintenance approaches in infrastructure management decision practice. Reactive or corrective maintenance imply actions after a fault or a failure already occurs and it relies on data collected mainly through inspections. Proactive or preventive and predictive maintenance is based on probability theory [2] and is based on the economic assumption that it is better to invest now, to prevent structure damage or its advancement, to save money later. Life cycle cost analysis is used to asses these costs through a certain period or whole life of a structure.
Although sudden failures of tunnels do occur rarely they do not present a dominant way of these structures reach their ultimate limit state and eventually end of life. Deterioration of a tunnel is a gradual process through the life of a structure in which routine maintenance and repair actions are performed. While routine maintenance does not improve quality level of a structure but rather keeps it on an operational level repair/remediation works are intended to increase structure performance level. Figure 4 shows how a standard gradual deterioration curve of an ageing structure can be combined with monitoring data to establish threshold values which can then be used for determination of optimal timing for certain measures.

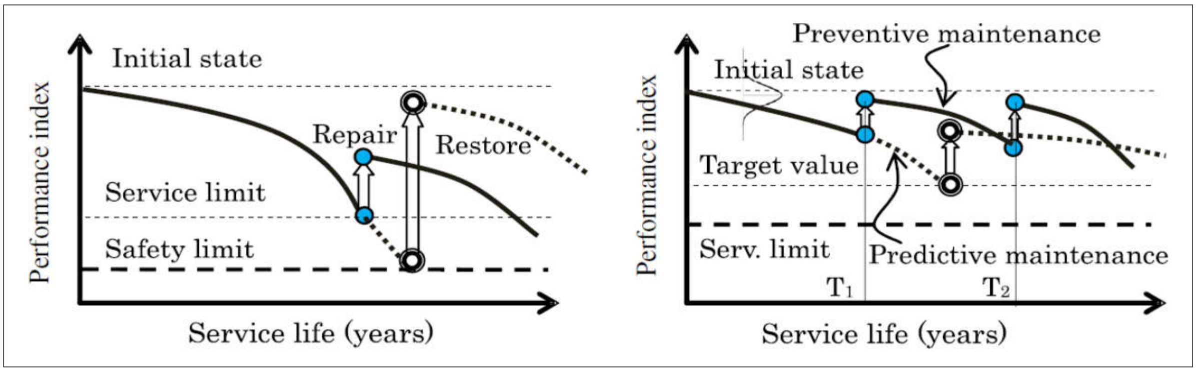

Figure 3 Two types of maintenance philosophies (a) corrective maintenance and (b) preventive and predictive maintenance [2]

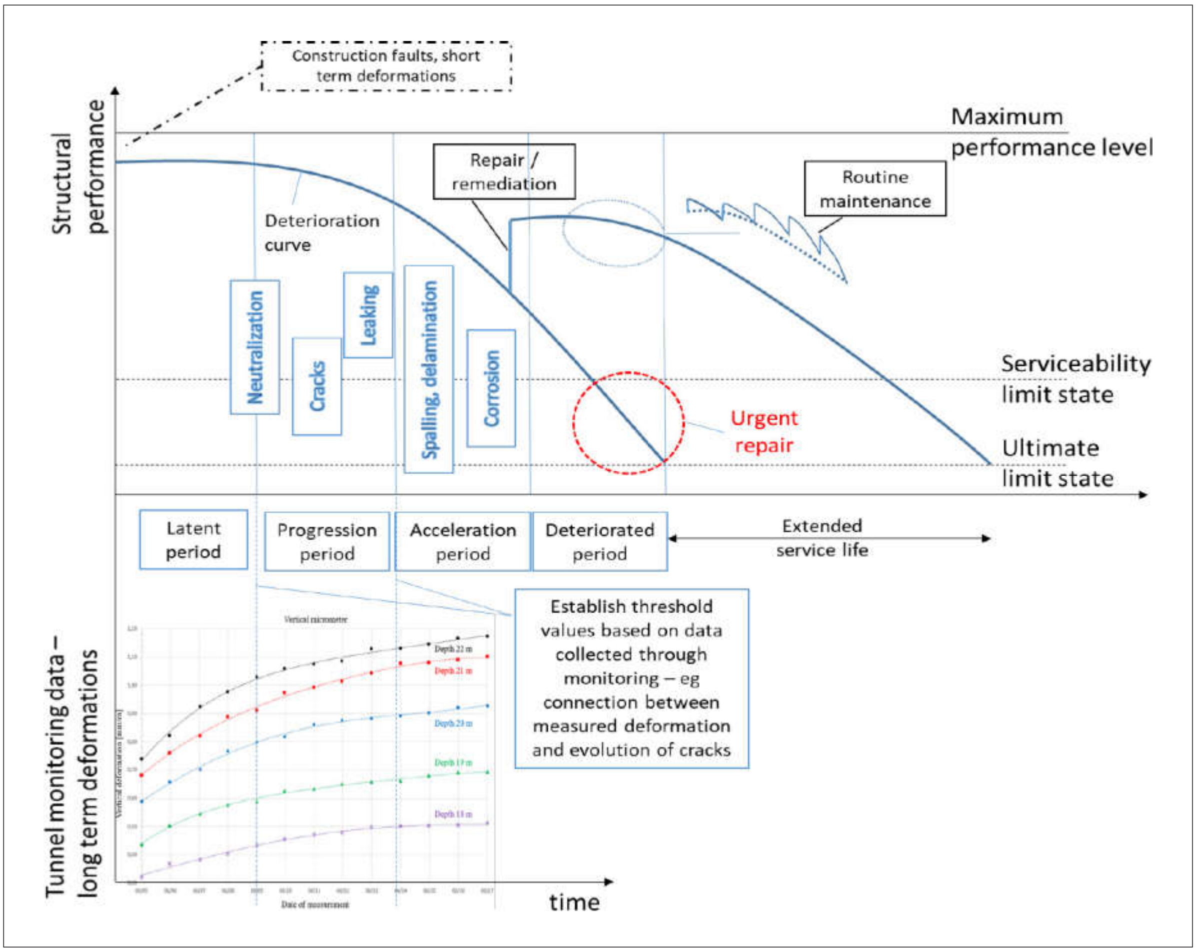

Figure 4 Life cycle of a structure combined with tunnel monitoring data

The Faculty of Civil Engineering in Zagreb installed extensive geotechnical instrumentation in the Bobova tunnel which was constructed in 2005. It is located on the D404 state highway and passes under a part of the Vežica – Sušak town area in Rijeka. Measurements were carried out during excavation works and over the 12 years of operation. The deformation measurements shown in Figure 4, indicate that the largest movements occurred during excavation, however, displacements have continued to the present day, albeit at a continuously reduced rate.
The monitoring results are to be used to test a methodology for estimating rheological parameters for the prediction of long-term deformations using monitoring data for Croatian karst. In this paper monitoring results are suggested to be used in the development of life cycle management model for tunnels as shown in Figure 4.

Figure 4 combines a theoretical gradual deterioration curve of structural performance and ageing. In the first period before neutralization it is easy to maintain a structures performance with routine maintenance. Once progression period begins inclination of deterioration curve is increased and maintaining structures performance requires more costs. Establishing the deterioration curve can help decision makers in choosing optimal time for repair works before structural performance reaches a certain level where costs significantly increase. The curve is valid while there are constant conditions and does not present environmental changes such as floods or earthquakes. Long term monitoring of deformations can be used for determination of the phase in which structure is which is what triggers decisions regarding maintenance or repair activities.

4 Conclusion

This research is the beginning of the optimisation of maintenance strategies by decreasing uncertainties in the analysis of life cycle of a tunnel structure. Monitoring data can be used to establish probabilistic deterioration relationships to determine future costs. Future steps are needed to bring together data about defects and timing of defects with the data about long term deformations collected through monitoring.

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