MASTERING LATENT DEFECTS IN MARITIME AND PORT ENGINEERING THROUGH TECHNICAL RISK MANAGEMENT

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INTRODUCTION

Linear maritime engineering structures are exposed to the highest levels of risk in the construction industry, because of the serial work involved in their design and construction. Systematic design or execution errors can turn these constructions into vulnerable artefacts. At the same time, the economic drive is pushing the long linear structures towards limited levels of redundancy, where failure of individual elements can generate progressive collapse. A global approach to risk is therefore indispensable in the management of coastal engineering projects, in addition to the organization of appropriate quality control systems. The intervention of an independent organization within the framework of this risk management – a well-known traditional concept in many European countries – is an added value in a global risk management of maritime structures.

Awareness has indeed grown that a second performance layer on top of the classic quality control systems is needed to cope with these challenges. Apart from the help that can be expected from working at the level of standardization, progress is mostly expected from measures which instigate project professionalism and collaboration between the different building partners.

QUALITY CONTROL SYSTEMS

During the nineties the construction industry has been criticised for its poor performance and productivity in relation to other industries. Many of the management practices used to organize construction companies have then been challenged. Their clients, active in other industrial sectors demanded improved service quality, faster building and innovations in technology. It was logical that the construction industry has turned to the manufacturing sector as a point of reference and source of innovation. Quality management have since then become increasingly adopted and have nowadays become mainstream in construction companies. The quality that is the subject of these systems is the degree to which the needs of the final customer are being met (customer satisfaction).

However, the implementation of quality control principles and structures has proven to be difficult in the construction sector, mainly due to a number of reasons.

The first one seems to be the nature of the construction process itself. Projects are often multidisciplinary, each project is again a prototype and projects are hardly ever repeated in the same location. The construction process is an environment in which several participants, each with their own interests and perspectives, are brought together to complete a project plan that is typical heavily subject to changes during construction, while each of the parties tries to manage their individual challenges. The construction industry is therefore characterized more by confrontation than by real collaboration between the different parties involved. Even though a common project goal should be shared, participants differ in what they seek to win from their participation in the process. The owner typically strives to spend as little as possible to get the project completed up to the standard they require. Contractors try to provide a product, designed by an engineering office, with an interpretation that allows them to maximize their profit. Designers provide a service to one of them, but not always necessarily to the benefit of the quality of the project. Less can be expected when one descends to the level of the subcontractors (and their subcontractors).

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Another barrier is the lack of standardization. The prototype character of many projects makes it difficult to apply universal standard specifications, that could be expected to lead to the same quality of the result of their application. Changes to the details of a design or a construction method are typical for a standard construction process.

RISK MANAGEMENT

Notwithstanding all of the quality control efforts in an attempt to reach client satisfaction, damage in construction still persists in the 21st century. Some recent bridge collapses are there to testify. We continue to see great losses in construction, which is why over the latest decades an alternative definition of project quality has won grounds, namely its ability to be free from hidden defects. In particular those defects which may give rise to future damages are then being envisaged.

In order to achieve that level of quality, the building team should inevitably engage in a thorough risk management exercise. Although familiarity with risk management principles has risen considerably during the past years, the approach is still very often static and a collaborative approach is missing. One individual aspect of a construction project is covered at the benefit of one intervening party and at one particular stage in the project (one point in time). The designer wants to master his design risks, the contractor his construction risks, the client his financial risks during the investment or during the maintenance period, etc. A traditional linear approach to risk management is represented in figure 1.

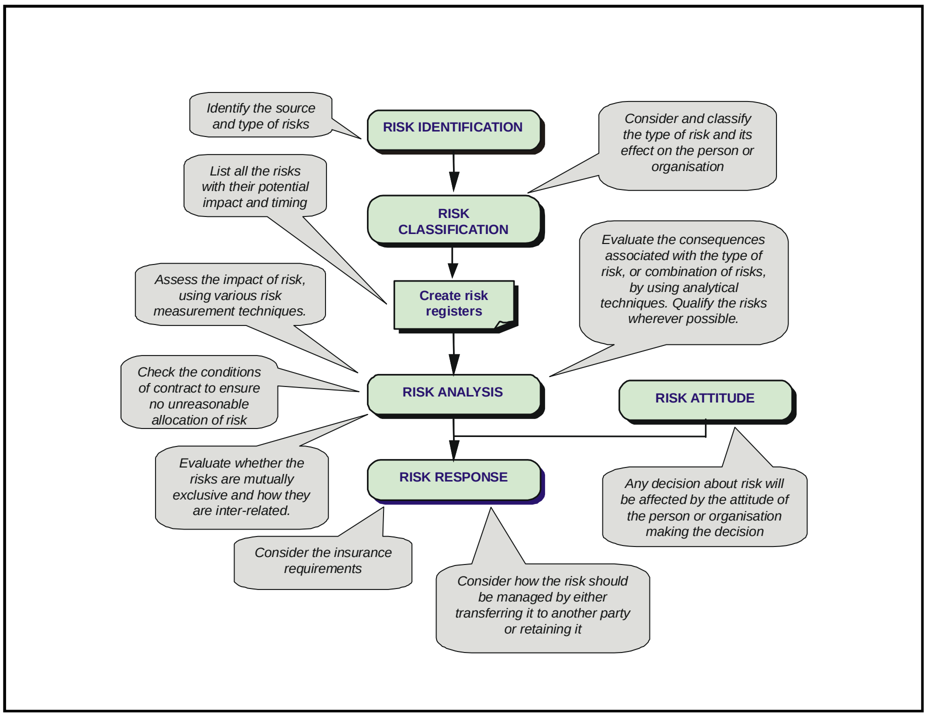

Figure 1: Steps in traditional risk management

A comprehensive risk management programme does not only deal with the individual risks of each intervening party, but tries to comprise the whole project and aims at finding the most economic yet technically perfectly viable answers to the project's strategic brief. Sharing this objective, a technical control agency, independent from the building actors, but actively involved within the preparation and the construction of the project functions as the ideal engine for a continuous project risk exercise. Risk management is turned into a dynamic concept, driven by the active participation of an independent technical inspection service (TIS) from the earliest stages in the project up to the maintenance period. The risk management exercise will profit from the assistance of the TIS at every stage thanks to the experience that they have gained in similar or consecutive projects, turning them into an effective knowledge center for the project. The verification of the design and execution of the works is no longer a systematic, sterile check on the application of specific codes or prescriptions for all construction elements. It is well focused and aims at those aspects that have proven to be crucial for a successful risk reduction. A global risk management is therefore much more efficient than the implementation of a traditional quality system in avoiding damages.

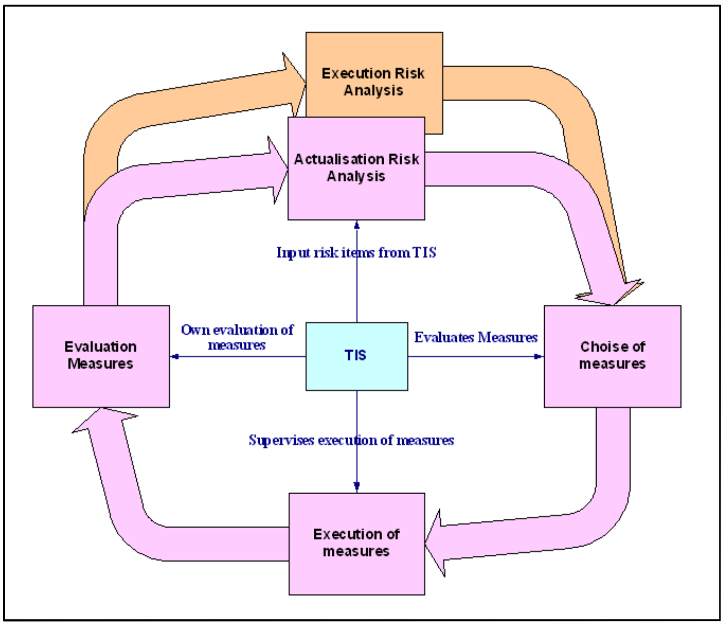

Figure 2: Dynamic risk management with TIS (Technical Inspection Services)

Although a qualitative analysis has become a common tool when dealing with risks in an explicit way, it can - whenever feasible - be combined with a quantitative probabilistic approach to structural failure. In this case the risks involved are evaluated in relation to a well defined 'reliability function'. A typical reliability function compares the likely strength of the design of an element or a construction with the anticipated loading on that element or that construction, taking into account the variation of strength and loading around their most likely values. The numerical possibilities in this respect have become mainstream.

Basic parameters when evaluating the risk of failure are the design conditions and the acceptable damage criteria agreed upon. The introduction of a Life Cycle Management (LCM) policy is indispensable. On the one hand, the design probabilities of failure are influenced by the degree of quality control during the construction works. On the other hand, the real failure probability is defined by the effectiveness of a specific monitoring and maintenance program after construction.

Coastal engineering projects are known to be exposed to the highest level of risks, not only because of the systematics involved in their design and construction processes, but also because of the uncertainty of the environmental actions involved (as well as their effects on the structures and their project environment). A large benefit can therefore be expected from the application of risk management principles.

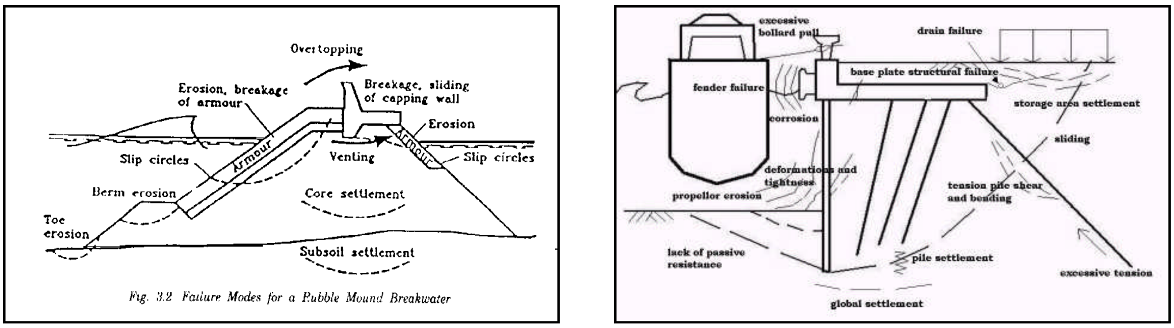

Figure 3: Results of a risk brainstorm exercise for a rubble mound breakwater and a quay wall

4. SOME EUROPEAN PROJECTS AND CONSTRUCTION TYPES REVISITED

Linear structures such as quay walls, seawalls, dikes etc. are very much exposed to risk because of the repetition involved in their construction. Systematic design or execution errors can turn these constructions very vulnerable. At the same time, the economic drive is pushing long linear structures towards limited levels of redundancy. Failure of individual elements can generate progressive collapse. A thorough risk management exercise for these structures is absolutely essential.

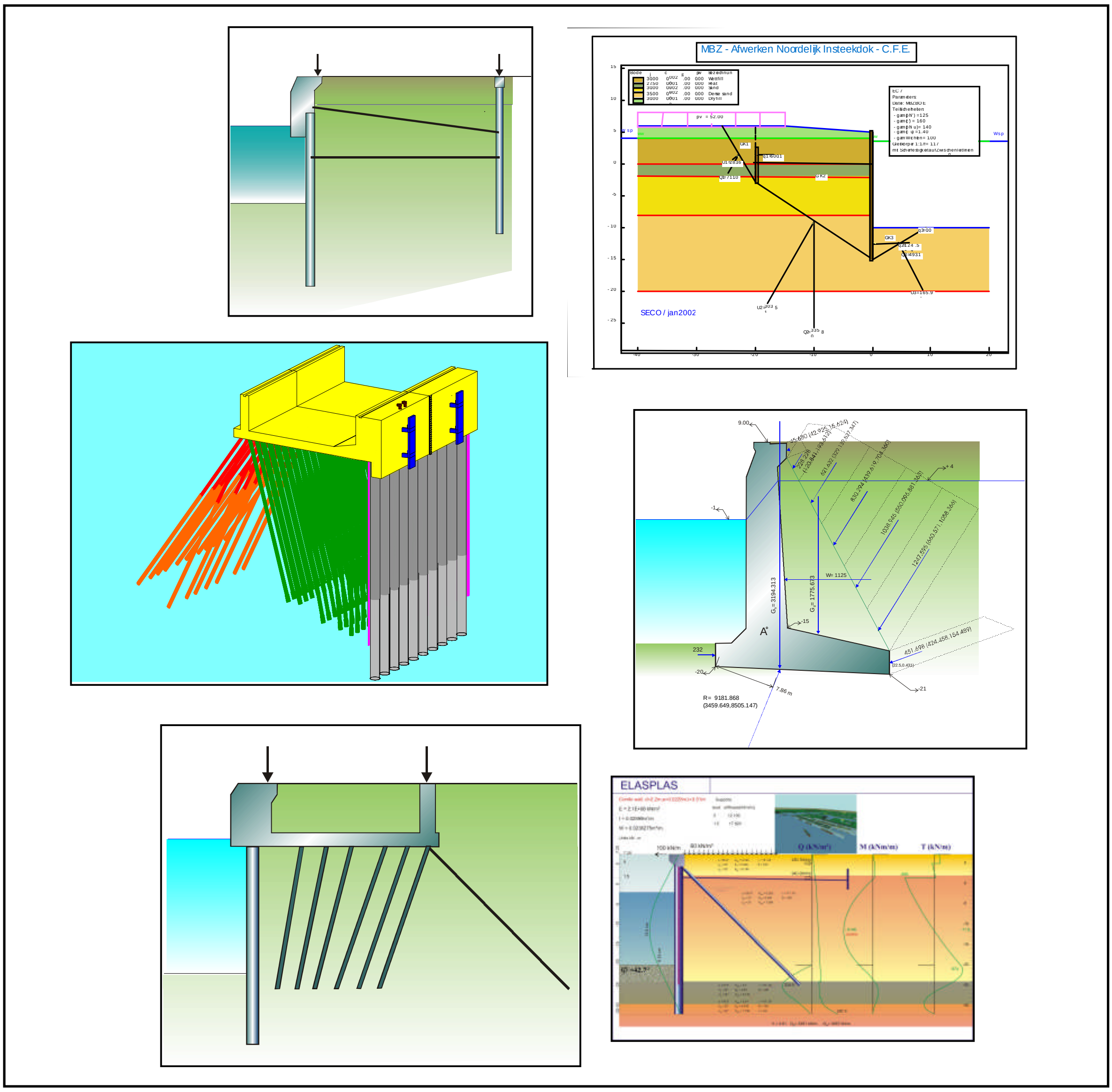

Figure 4: Classification of different types of quay walls

Quay walls can be subdivided in three categories according to two of their main aspects: their level of redundancy and their vulnerability to lack of tightness of the joints (related to the degree of complexity to check these joints). Type 1 structures provide excellent redistribution capacity and complete visual verification of the soil tightness of the joints in the system prior to their service life. Type 3 structures provide none of that. Type 2 quay walls are characterized by only one of the above characteristics. Some examples of quay walls are given in figure 4. A traditional piled platform usually provides excellent redistribution capacity in case of malfunctioning of one of the (numerous) piles. A gravity wall provides complete ability to verify the joints during the construction process. A simple anchored wall is a typical example of a class 3 quay wall. Its redundancy is usually very limited, the possibility to verify the joints is rather limited (although techniques are evolving) and the consequences of soil loss on global stability may be immediate.

The failure of one of the quay wall anchors can lead to the progressive collapse of adjacent stretches. A damage case like this occurred in the harbour of Antwerp in Belgium, where the subsequent zipper effect led to the complete collapse of a stretch of simple anchored wall. Anchors in such wall systems are becoming more and more slender due to the introduction of high yield, but at the same time less ductile steel. Demands for corrosion protection are more stringent for these kinds of anchors, but not always compatible with traditional, rough building practices. Vulnerability of the anchors to ship collisions may also be considerable.

During the latest years a risk management philosophy has developed to verify the design stability of the structure in case of failure of one of the anchors. Even in slender anchored wall types, redundancy e.g. can be attributed to a concrete coping beam on top of the wall. Figure 5 is an example of the verification of the effect of anchor failure on the internal forces in such a coping beam and the forces in the adjacent anchors.

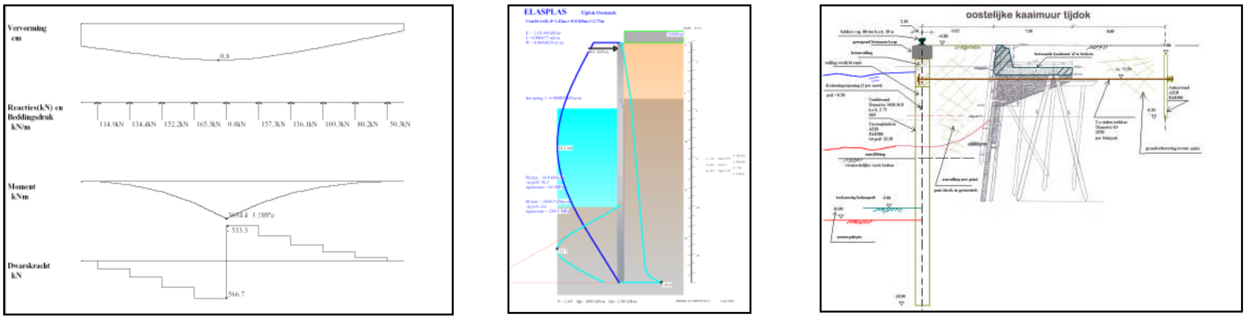

Figure 5: 2D simulation of a stretch of a coping beam on top of an anchored wall with failure of one anchor in the middle of the stretch

In creating redundancy, the existence of ductility may be of the utmost importance. Elastic and plastic elongation has to be generated to mobilise the required redistribution. In France, the extension of a container quay wall in the tidal zone has been covered for decennial liability. A risk identification at the very basis of the technical control led to a successful rectification of fabrication quality problems with respect to the connection principle of transportable lengths of anchors. A picture of a typical section of the project is represented in figure 6. The project comprised a combi-wall anchored at two distinct levels. The level of redundancy is again quite low, although some redistribution capacity is present at the deepest anchor level where a longitudinal steel beam had been installed just behind the wall. A systematic problem occurred at the connections of these passive anchors. The requirement set out upfront -that the connections in the system should be stronger than the standard section of the anchors, permitting ductile behaviour of the anchor – was finally successfully met after corrective measures had been taken.

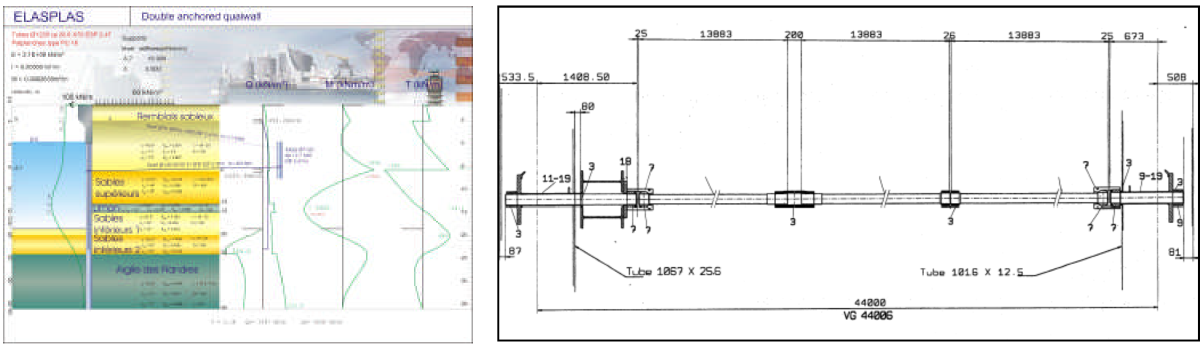

Figure 6: Double anchored wall and principle of the anchor connection system

In Ostend, at the Belgian coast, a new sea defense structure has been built, comprising a series of breakwaters. For the design of these new constructions, hydrodynamic boundary conditions (waves and water levels) had to be determined at different locations near Ostend. The interaction between water level and wind direction had not been examined until recently. This is important as some constructions can only be attacked by a restricted range of wave directions. Since only a limited number of near shore data were available, extreme value distributions at deep water were examined. These were transformed to the Ostend situation with a numerical wave model. The results were interpreted in order to get directional wave and water level distributions. The numerical model was calibrated with the wave data from a local buoy in Ostend.

The redundancy level provided by a double armour layer on the breakwaters was seriously under discussion within the building team. Single layer systems were tested for extreme conditions to provide the extra reliability required for their use. In the model tests some consideration was also given to breakage of elements.

An important aspect of the study was the analysis of all possible uncertainties and their effect on the uncertainty of the final result. There were mainly two types of uncertainties: those of the deep-water statistics and those of the transformation occurring from deep to shallow water in the vicinity of the new constructions. It became clear that the last mentioned uncertainties were the highest – despite the sophistication of the model used and the elaborate simulation exercises being performed.

With the uncertainties in mind, Monte Carlo analyses were performed on the reliability formulae associated with the failure mechanisms (overtopping, hydraulic instability of the armour layers, …). The use of these kinds of statistical models allowed the building team to make a technically justified and financially sound decision on investment and maintenance, not only based on mean (50% reliable) values, but also on the probability of extreme values.

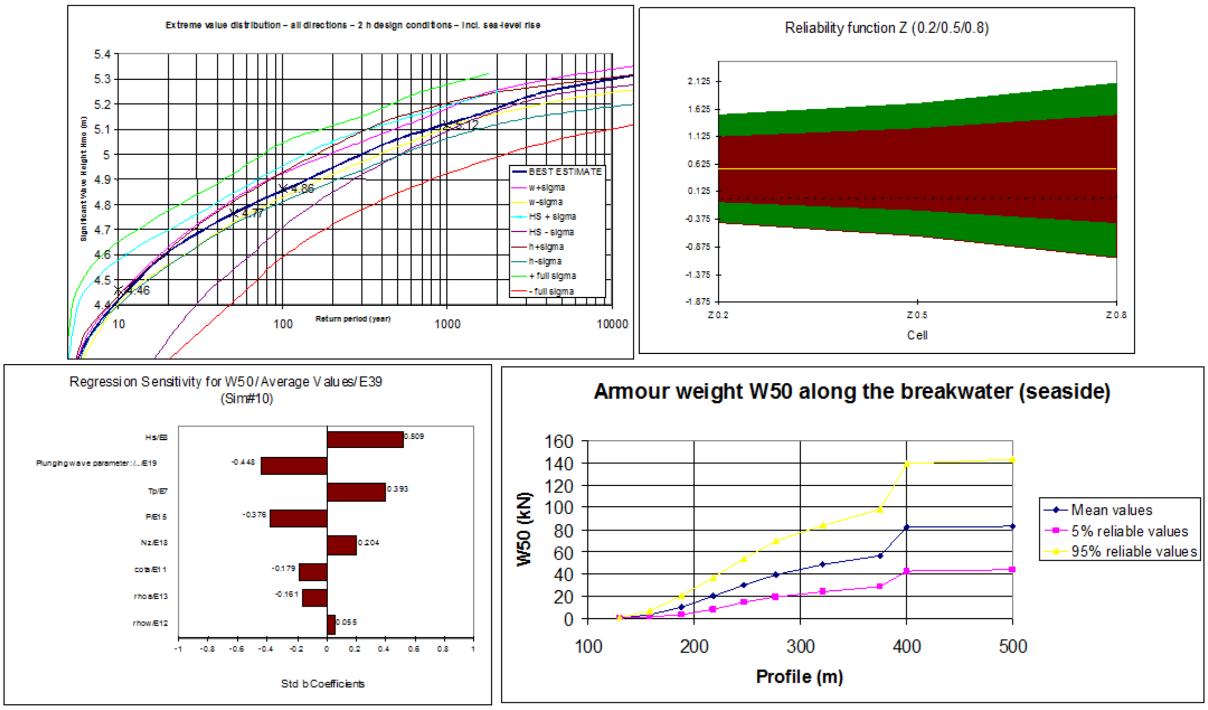

Figure 7: Representation of the significant wave height at an Ostend location after transformation, its use in hydraulic stability formulae and indication of the influence of uncertainty on the main parameters

FOCUS ON A PROJECT IN LATIN AMERICA

The present paragraph will focus on the introduction of this traditional European concept of risk management in the Latin American environment, through a case study of a quay wall project in the port of Montevideo, Uruguay. An alternative calculation model set up independently from the black box model used by the designers, has been used as part of the technical inspection services to establish the sensitivity of the deck-on-pile structure to different sets of load combinations. A representation of the alternative calculation model has been represented in figure 8. Geotechnically, the site consists of an extensive package of mud (typical for the Rio de la Plata estuary) deposited over a number of more consistent clay and sand layers, all on top of a rock horizon (going from fragmented rock to sound massive substance). It has been confirmed that the resistance to the horizontal loads for these type of structures can relatively easily be increased and tuned to the requirements, primarily by efficiently intervening in the connection node of the landward pile row (the one with the most limited free length) at marginal cost.

The alternative model has been used as part of a risk analysis, which has been able to identify and prioritize technical risks, as well as list mitigation measures for each of them, allowing for assistance in the technical management of the project.

The reanalysis of the structure, taking into account the geotechnical uncertainty of the conglomerate subsoil, also showed that a redistribution of the total projected concrete volume of the piles over the 4 pile rows, without any additional concrete consumption, could contribute to an important relief of the geotechnical risk, based on the information available at the start of construction.

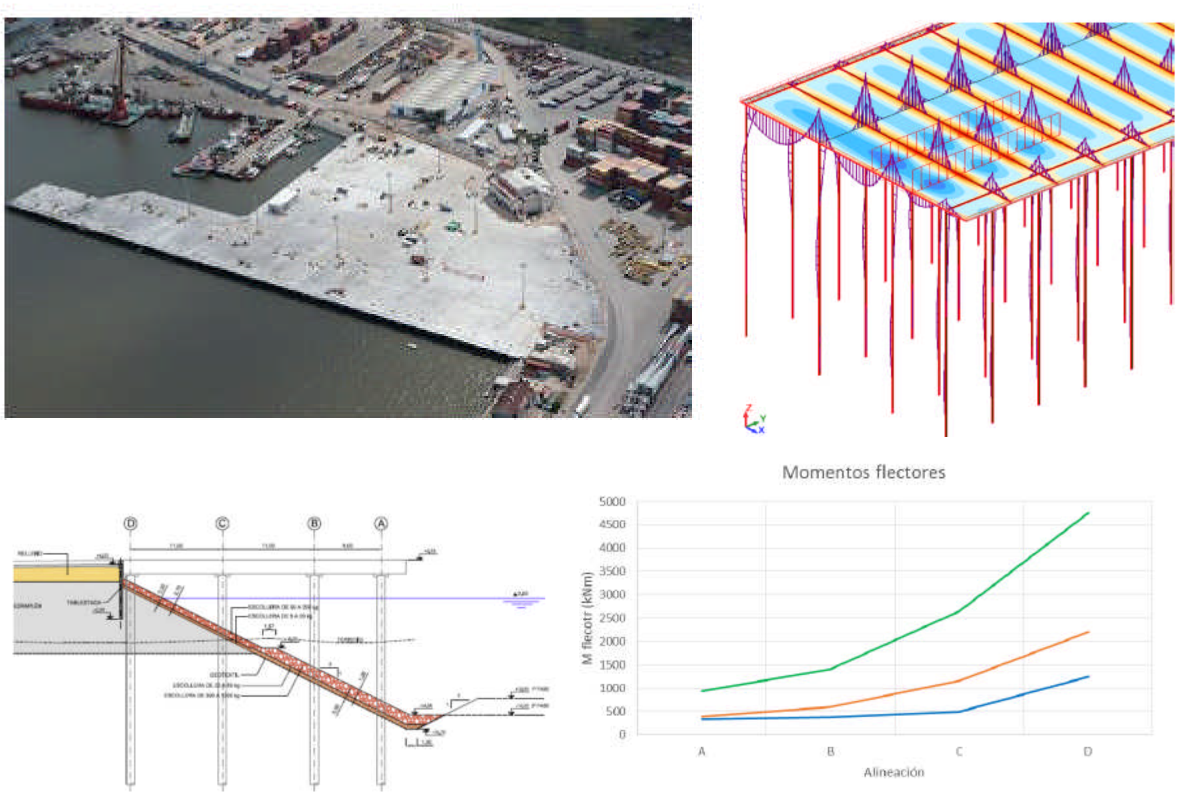

Figure 8: The location of the project, some parallel calculation model output and an overview of the top bending moments in the different piles rows A,B,C,D acc. to different hypotheses

Apart from a sound independent desktop analysis, a complete dynamic risk management process also necessarily includes inspection of the site construction process, an exercise which has proven to be beneficial in demonstrating the need for standardization in the construction methodology and in the specification.

The construction methodology used for the execution of the bored piles for the project has been questioned thoroughly after the detection of probable artesian water in the project area. The artesian water had shown itself at the end of the concreting of the first piles, as if it was an effect of concrete segregation/bleeding. Subsequent sonic testing and coring unfortunately confirmed a specific deterioration of the quality of the concrete executed. Finally, a site specific dedicated execution principle has been developed, as a result of the technical sparring of a series of possible solutions, brought up by the project participants, including the TIS. The finally withheld execution principle tries to take into account an increased respect of standard construction principles (as suggested in applicable construction standards), in connection with a more stringent monitoring campaign as well as a more intensive post-construction quality evaluation (including increased levels of sonic testing and dynamic testing).

CONCLUSION

The intervention of an independent organization within the framework of technical risk management – a well-known traditional concept in many European countries – is an added value in a global risk management of maritime structures. A typical principle that has arisen from this approach is the strife for structural redundancy, even in the most slender and economic of structures. Dealing with uncertainty in an explicit way is another. The TIS (Technical Inspection Services) can play a driving role in the constant review of the risk level within the dynamic risk management environment of a construction project. This can be done in a qualitative or in a quantitative way, depending on the nature and the severity of the risk. The externalization and independency of the service can make for a practical tool to assist in managing the technical project risks and transfer to all parties around the table the necessary confidence in the design and construction process, as well as promote dispute resolution around acceptable technical solutions and innovative alternatives within projects.