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An integrated monitoring and risk management system for civil construction works

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ABSTRACT: The Rotterdam Randstad Rail project comprises building of a bored tunnel and the rebuilding of an underground station from two-track single platform to three-track, two platform configuration, suitable for a light-rail transportation system. Obviously, the building process in the centre of Rotterdam has to meet all kinds of terms and conditions; one major design condition is that public transport in the station is not to be affected during building activities. It was therefore concluded that the technical complexity of the project and the financial control required a risk management system. Risk control by means of monitoring was the heart of the risk management system. The environment, in the broadest sense, has been made key issue for set-up of the monitoring program and selecting monitoring parameters. Consequently, the requirements made by the environment are the boundary conditions for the construction process. This strategy led to a change of view of the role monitoring should play in a construction process and now is the working standard in Rotterdam projects.

1 INTRODUCTION

Randstad Rail is a light-rail connection between the cities of Rotterdam and The Hague. The connection concerns partly existing track and partly a new line. The new part runs by urban area and is approximately 3 km long, of which 2 km is carried out by means of tunnel boring techniques. It is the first bored tunnel in an urban area in the Netherlands. In the centre of Rotterdam the new line connects with an existing line. For this, the existing head station is extended from a two-track single platform to a continuing triple-track layout with two platforms. Important design condition was that the underground railway transport cannot be interrupted during the building process.

Rotterdam public works has looked after both the whole design and the process to the invitation to tender and has been actively involved during construction works.

The demands made on the project ask for technical excellence and a complicated phasing. This entails a high risk profile. To prevent quality loss and damage during construction works and to mitigate financial and time-risks, monitoring and risk control has been explicitly used in the project.

The choice for the parameters and the role which monitoring eventually played at project control and how this led to a new look on the setup of a monitoring plan and its integration in the project is the subject of this paper.

2 PROJECT DESCRIPTION

2.1 *Technical description*

The project consists of the following components:

- Conventional tunnel, constructed using the cut and cover technique, with a length of 0,7 km. Conventional tunnelling has been adopted on spots where ground cover is insufficient for the construction of a bored tunnel. Start and reception shaft pits were delimited with diaphragm walls with a thickness of 1,2 m, reaching a depth of 40 m below ground level.
- Bored tunnel, length 2,3 km. The bored tunnel consists of two tubes with an inner diameter of 6,3 m. For the passage of the holocene soft soils, where tunnel support was insufficient, ground improvement, like MIP, jet-grouting and ground replacement, was used on a large scale.
- A new underground station (20 m depth) with an identical way of construction as was used for the start and reception shaft.
- The reconstruction of an existing underground station. For this reconstruction a building pit was created around the existing station, using diaphragm walls. On the location where the subway tube cuts the building pit the ground was frozen in order to create a watertight wall.

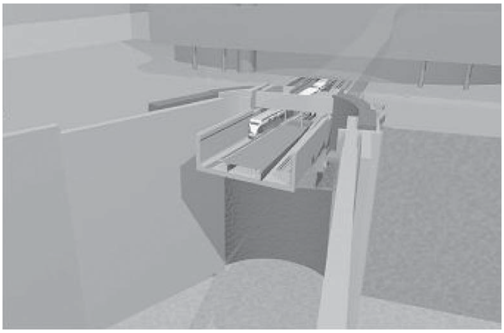

Figure 1. Cross-section of the old station, diaphragm walls and frozen soil for the new station.

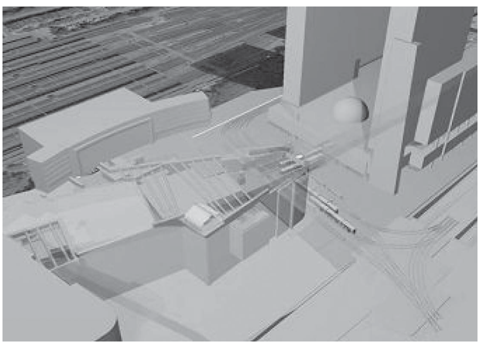

Figure 2. 3D birds-eye view of the position of the old station within the building pit.

2.2 *Project surroundings*

The line crosses several infrastructures, such as the railway track Rotterdam—Utrecht, the 6-lane motorway A20 and the 13 tracks of Rotterdam Centraal Station. It passes at a short distance from houses from the 1930s. The underground station to be reconstructed was built in the 1960s and consists of submerged caissons.

The physical surroundings, like adjacent building and infrastructure, dictated in an important degree the way the construction process has been carried out. Regarding infrastructure, demands were made with regard to both safety and functionality. For adjacent buildings, the acceptable soil deformation was determined by the capacity of the buildings foundations to deal with the loads originating from soil movement.

Accessibility of the train station, traveller security and the fact that the public transport was not to be affected in any way constricted the way the project was build.

Apart from the physical demands made by the surroundings the implementation of a monitoring system is also determined by legal provisions particularly with regard to noise, vibration and spills.

Figure 3. Location of bored tunnel under 13 railway tracks of Rotterdam Central Station.

2.3 *Financials*

The project is financed by a number of agencies of which the central government was one. The project received a one-off contribution from the central government in which the repurchase of all the identified risks were included.

On the condition that proactive risk management would by applied during construction, the project got a considerable discount on the insurance fee.

So, a thorough risk identification is not only important with regards to technical control but contributes substantially to financial feasibility.

The total investment costs are M€ 500.

3 RISK MANAGEMENT AND SURROUNDINGS

Something, which is justified form a technical point of view is not necessarily justified from a social point of view. This consideration forms the base of the centrality of the (social) surroundings, as defined above, in establishing the monitoring programme. The responsibility with regards to the surroundings which the government has during the realisation of large inner city projects, the empowerment of the inhabitants and the claim culture of the society means that project limits do not end with the building pit walls but extend into the "surroundings". This means that a definition of the "surroundings", plays an important role in making a risk management and monitoring programme.

For the monitoring programme risk control (for "whom" are you taking the measurements, what is part of your "surroundings") has been linked to technical monitoring ("what" are you going to do).

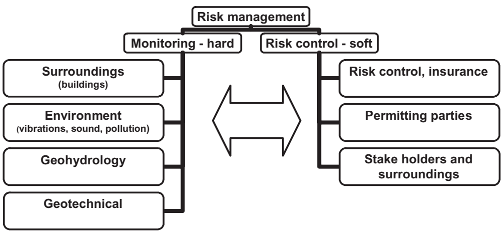

Figure 4. Risk control and monitoring.

By application of account management the project benefits for different stakeholders have been determined and it was determined what, from the stakeholders point of view, made the project a success.

In the preliminary phase a long list with risks was drawn which also contributed to the choice for the monitoring programme, the hazard levels and the frequency of the measurements. For instance:

– For the railway track crossing, lengthy discussions took place with the permitting party about the allowable track deformations. The technical specifications of the monitoring system, hazard levels, and alarm procedure is based upon the discussions. The frequency of the measurements of track deformation is adjusted to the influence of the construction works. During TBM passage a measurement was taken every 15 minutes, whereas during other works a measurement a week was sufficient. Risk control carried out for the track owner led to a tailor made monitoring- and alarm system. This considerably facilitated authorisation of the track crossing.
– For the buildings alongside the bored tunnel the acceptable relative distortion for the 1930's brick buildings was calculated. The location of the monitoring points was chosen in such a way that the results could be easily translated into relative distortion. Because the chance of damage is actively diminished insurance fee was reduced.
– For the reconstruction of the underground subway station stress changes in the subsoil (due to pit digging, change in groundwater levels, ground freezing *etc.*), can cause differential displacements between the old caissons. The displacements are registered on the joints of the caissons. The displacements are a measurement for the displacement of the tracks in the caissons. A fully automated measuring system is incorporated in the tunnel which sends an SMS in case a hazard level is exceeded. Hazard levels and alarm procedure have been setup together with the track owner.

4 MONITORING

Monitoring goes beyond taking measurements. In the perception of the Rotterdam Municipality monitoring comprises taking measurements, testing whether or not the hazard levels have been reached and subsequently decide if the mitigating measure has to be implemented.

4.1 *Monitoring program*

The monitoring program was designed by the Rotterdam Municipality. The measurements are carried out by the contractor. The responsibility for the control of the construction process lies with the contractor, measurements and construction process become this way directly coupled.

Most of the monitoring programme was rather conventional (settlement gauges, inclinometers), only for the measurements on the railway tracks a fully automated system was operational which kept track of some 1200 measuring points.

4.2 *Testing of hazard levels*

In the contract the obligation has been incorporated that the contractor must test the results with regard to the hazard levels and at imminent overshooting must alarm the client. Alarming is done using SMS. For the graphical registration of all measurements an internet application is used.

The S- and I-hazard level are defined as follows:

– The S-level is a value at which raised alertness is necessary and at which mitigating measures can be taken to prevent exceeding of the I-level.
– The I-level is the level above which the damage and calamity chance is unacceptable.

The spacing which is kept between S- and I-level is coordinated on the time which it takes to implement a mitigating measure.

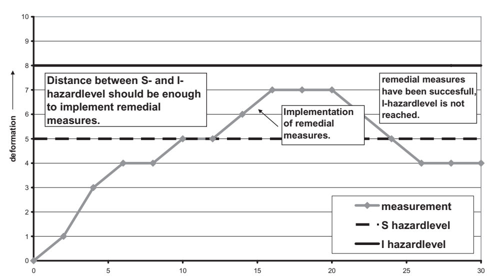

Figure 5. Principle of determining S- and I-hazard level.

4.3 *Mitigating measures*

The way in which monitoring in Rotterdam is now done marks a clear transition form reactive to proactive approach.

The clear choice for S- and I-level actually enforces the undertaking of action when a S-level is exceeded, without having to think what and when to do next. A couple of examples:

- Exceeding the S-level of railway track means that the track owner is informed directly. He decides about the severity of the situation and calls, when necessary, for action. The frequency of measurement is increased and the work process is modified in such a way that deformations come to a halt.
- Exceeding the S-level of a pipe means that steel tension is calculated, when necessary the pipe is raised and replaced in the ground.
- In case of large deformations within buildings there are basic foundation reparation plans ready. For instance the use of ground improvement in the foundation layers, installing jacks to lift the building or, in a worst case situation, installing a complete new foundation. When the S-level is exceeded these are elaborated upon.

By incorporating testing and control within the ideas of monitoring Rotterdam has obliged itself to a proactive approach. What this means for the organisation is subject of the next chapter.

5 ORGANISATION AND RISK MANAGEMENT TEAM

In the organisation a risk and quality management team is created which carries out actively risk management. The team consists of specialists (soil mechanicians, geo-hydrologists, environmental specialists, *etc.*). Their task is to signal risks on the basis of the monitoring results, write a report, propose mitigating measures and make sure someone is responsible for the risk.

Keeping track of the risk and the implementation of mitigating measures is done on a monthly basis, in the presence of all who are responsible for the risk and the project manager.

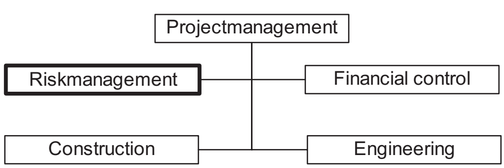

Figure 6. Position of risk management in the project organisation.

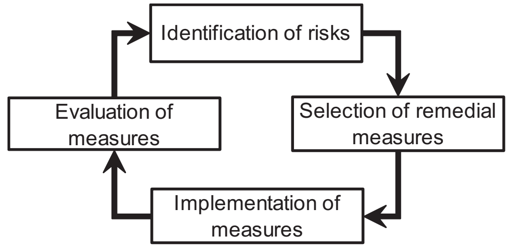

Figure 7. Risk management cycle.

Once every trimester the team reports to the project manager. In the report the original list of risks is updated, the mitigating measures are evaluated and new risks appear. By giving the risk and quality management team a clear position in the project organisation and by clearly delineating the responsibilities it proved actually to be possible to act proactive.

In the trimester report a financial chapter is included in which the budget is compared with the necessary financial reserve for identified risks and costs for implemented mitigating measures. More about this in the next chapter.

6 FINANCIAL CONTROL

Extra project costs arise as a consequence of:

- Scope broadening.
- Omissions and defects in the original plan.
- Risks.

All works not included in the original contract have been labelled according to the above partitioning. The constituent was responsible for financing scope broadenings, for omissions/defects and risks a separate budget was available. How the budget available for risks is calculated is explained in this section.

6.1 *Risk budget*

In the preliminary phase a long list with possible risks was identified. Each risk has been given a possibility (percentage) and, in case the risk should occur the costs for reparation or mitigation have been determined. Using Monte Carlo analysis it was statistically determined how much budget was necessary to be sure that the budget would cover the risk associated costs in 95% of the cases.

Each trimester the list with risks was updated. Risks disappear because of work progress or because of the implementation of mitigating measures. New insights or a change in working method can incorporate new risks. Based upon the

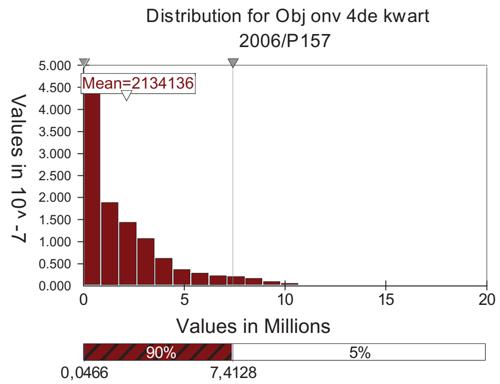

Figure 8. Monte Carlo calculation of necessary reserve for identified risks.

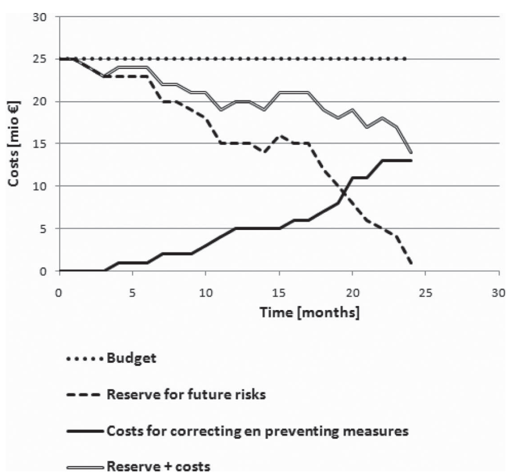

Figure 9. Development of risk related costs.

updated list the necessary risk budget is calculated. As the project progresses the necessary reserve for future risks generally diminishes.

At the same time the original budget is used to finance preventing and correcting measures.

By comparing the sum of costs and reserve with the original budget the financial reserves in the project become clear.

7 CONCLUSIONS

From the Randstad Rail project we have learned that a fully integrated risk and monitoring system contributes to project control. It was also recognised that in nowadays complex society a risk management and monitoring system makes a project more easy to accept for those who live or work next to the construction works.

Lessons learned in the Randstad Rail project with regards to monitoring and risk management have now made the four steps used in the process the standard for Rotterdam civil construction works. To summarise:

1. Determine project surroundings and the demands they put upon the project itself. Acknowledge the success factors of the stakeholders and make them a part of the risk management.
2. Draw the technical outline of the monitoring programme and make the contractor responsible for the measurements. Determine both S- and I-hazard level for each monitoring instrument, taking into account the safety and structural demands made by the "surroundings".
3. Determine, in the preliminary phase of the work, which mitigating measures to take, when a S- or I-level is exceeded (proactive approach). Give a risk- and quality management team a place in the organisation, directly linked to the project manager. Make the team responsible for risk identification, on a cyclic base, and implementation of mitigating measures.
4. Since there is a large financial component in risk management, link the financial and risk control to each other to get a better idea of the development of risk related costs. Also, to make sure that there is a budget to finance mitigating measures, whenever necessary.