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Contributing human and organizational factors for damage of Bos & Lommer plaza in Amsterdam

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Abstract

The Bos & Lommer plaza complex in Amsterdam was completed in 2004. This complex consisted of apartments, shops and a parking for over 500 cars. In 2006, an 11 ton truck was positioned on the plaza deck and caused structural damage. Part of the load bearing structure had failed and the apartments were evacuated, until the deck was strutted.

Forensic investigations showed that detailing of the reinforcement was questionable and the amount of reinforcement was insufficient, or deviated from drawings. The whole complex was evacuated until measures were taken. Subsequently, investigations of the shops and apartments above the parking showed that the design of a 1 m thick transfer floor might have been erroneous.

Profound investigation of this case showed various human and organizational factors, that might have contributed to the failure. The stacking of various functions resulted in a complex load bearing structure. The building process was complex with over 50 subcontractors. The safety culture was not well developed, given heavily economizing on costs and very tight planning, fragmentation and no clear final responsibility. Risk analysis and checking procedures were lacking. Communication and collaboration could have been improved.

This paper will give insight in technical causes of the failure and in underlying contributing factors. These underlying factors will be systematically studied, by using a theoretical framework.

Keywords: Forensic Structural Engineering, Failures, Human and organizational factors

1 Introduction

The multifunctional Bos & Lommer plaza complex in Amsterdam was delivered in 2004. It consisted of apartments, businesses and shops, a two-storey parking lot for more than 500 cars and a market place. In 2006 an 11 ton truck drove on the market place, which was the roof of the parking garage, and caused structural damage. A concrete half-joint underneath the deck had failed. Residents of apartments were evacuated until the deck was strutted and a reduced maximum load on the deck was introduced and enforced.

Investigations on the causes were started. It was concluded that the detailing of the reinforcement was questionable and the amount of reinforcement was insufficient.

Furthermore, at a number of locations in beams and floors the actual reinforcement differed from the by drawings prescribed reinforcement.

Finally, further checking of the project showed that the design of a 1 m thick transfer floor might have been erroneous. Distributed loads on the slab were assumed, but concentrated loads should have been considered, so reinforcement was not placed at the right positions.

Figure 7.1 Recovery activities at Bos & Lommer Plaza (photo: Dick Hordijk)

The authorities decided to evacuate the area until measures were taken.

An investigation committee was established that extensively studied the underlying factors of this case [1,2]. For their investigation, they made use of archive and literature study and they performed interviews with key persons. The committee came up with a number of conclusions and recommendations related to points of attention for public private partnerships, increased integration and quality within the project and improved building control by municipality.

To focus on learning points related to structural safety, it is worthwhile to investigate failure cases with a framework of set parameters.

Terwel set up a framework with possibly influencing factors for structural safety [3,4]. The framework is based on critical success factors derived from management literature and factors from safety science. In the following section the framework will be explained.

This paper will check to what extent human and organizational factors in the building process (as listed in a theoretical framework) might have played a role in the failure case of the Bos & Lommer plaza. The focus is on the involved parties in the primary building process, like engineers and contractors. This paper will not focus on the role of local building control, which was part of the formal investigation report. The current analysis is an extension of chapter 7 of the PhD-thesis: "Structural safety: study into critical factors in the design and construction process" [3].

2 Theoretical framework

2.1 General explanation

The theoretical framework, used to classify various underlying factors, makes a distinction in three levels. On macro level possible underlying external factors are listed. These factors are related to the situation in which a project exists and they are usually hard to influence by any of the project participants. On meso level project factors, company factors and project characteristics are distinguished. Project factors are related to the collaboration of several parties within a project. Company factors take into account that every company brings his own features, like organization, culture, working conditions and habits in a project. The factors that might play a role within companies, might be similar to the factors on project level. Project characteristics are related to type and complexity of the project and the phase of a project. On micro level possible underlying human factors are mentioned.

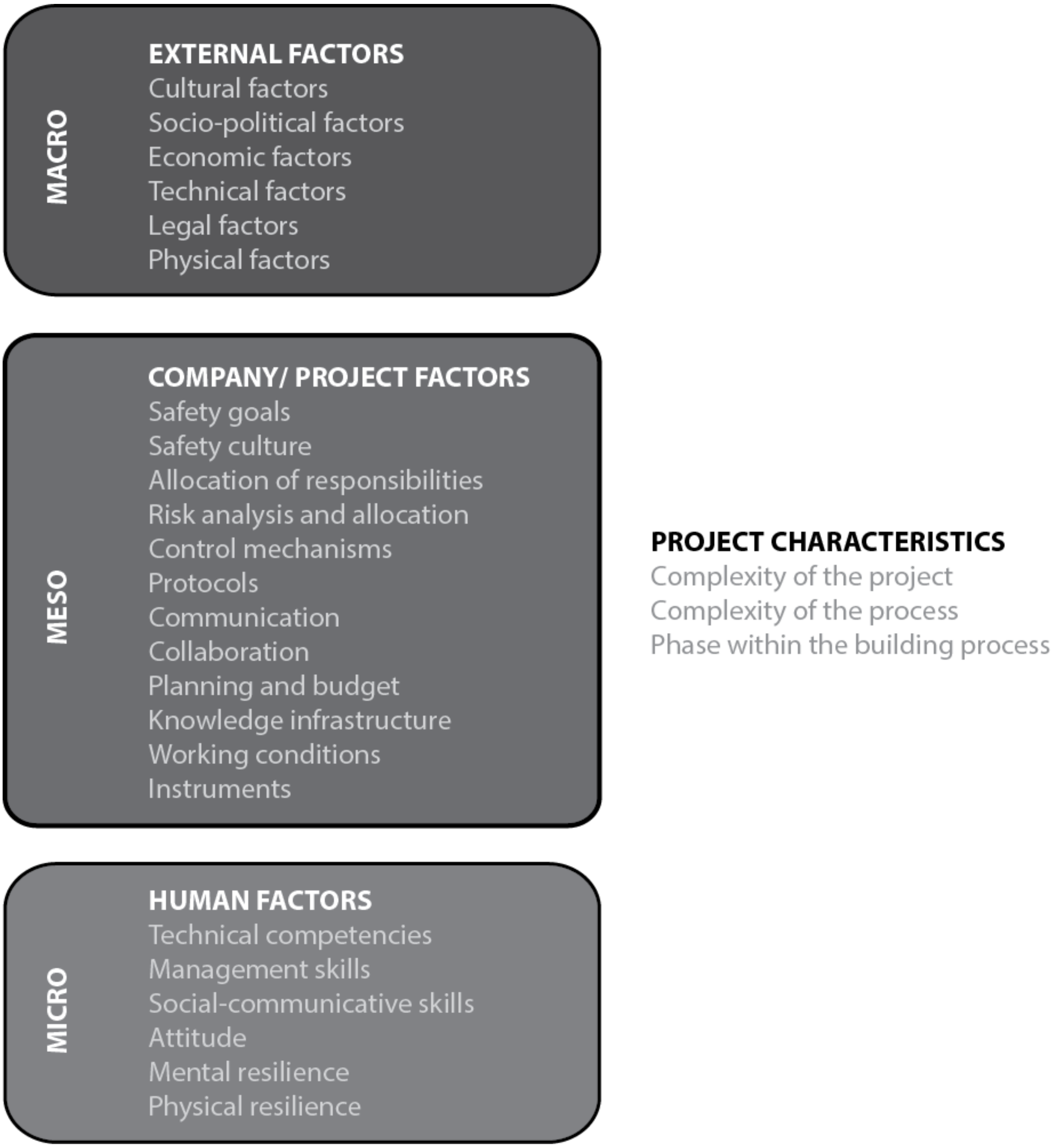

Figure 2: Theoretical framework (derived from [3])

This paper will focus on meso (organizational) and micro level (human) factors. Furthermore, project characteristics are analyzed. The used definitions of these factors are explained in the following sections (for references and background, see: [3,4]).

2.2 Definition project characteristics

Complexity of the project is the extent to which the design and final appearance of the building or structure is regarded to have a complicated nature.

Complexity of the building process is the extent to which the design and construction process is regarded to have a complicated nature.

Phase within the building process is a limited period between the initiation of the project and the delivery of the structure.

2.3 Definition organizational factors

Safety goals are objectives with regard to structural safety.

Safety culture is the total of practices, conventions and habits that affect the way the organization is dealing with risks.

Allocation of responsibilities is the amount or share of responsibility that is given to a person or organization. A good allocation of responsibilities includes a project organization suited to size, complexity and urgency of a project with a clear and suitable assignment of responsibilities.

Risk analysis and allocation is the identification and assignment of risks, associated with structural safety, of the building product and the building process.

Control mechanisms are ways to keep something at the right level/limit. In this case study it will be regarded as the way checking is performed.

Protocols are the rules describing the way tasks should be performed.

Communication is exchange of information within a company or between the various project partners.

Collaboration is the way various project partners cooperate with each other.

Planning and budget are the amount of available hours and budget to deliver a project.

Knowledge infrastructure is presence and availability of technical as well as process knowledge of relevant solutions.

Working conditions are factors related to the influence of the environment on the performance of work.

Instruments are the provided tools (software or equipment) that are necessary to perform the tasks properly.

2.4 Definition human factors

Technical competencies are demonstrated abilities to apply knowledge and skills for the design and construction of a structure.

Management skills are the skills to lead oneself and others.

Social-communicative skills are the abilities with regard to interpersonal communication.

Attitude is someone's opinion or feelings about something. A positive attitude is regarded as a constructive position and commitment towards safety by the various participants of the project.

Mental resilience is the way in which an individual can cope with stress.

Physical resilience is the way in which an individual can cope with long term and heavy physical loading.

3 Analysis of human and organizational factors at the Bos & Lommer plaza case

3.1 Project characteristics

Bos & Lommer plaza is a case where *complexity of the project* was of major importance. It was a large project with multiple functions. The program consisted of 395 houses, 24.000 m^2 offices, 6000 m^2 central functions and 3500 m^2 socio-cultural amenities. In addition, the program was complex with an apartment building on top of shops and a market plaza on top of a parking garage.

This latter kind of complexity is supposed to be one of the contributing factors of the structural problems that were revealed in the apartment building of the Bos & Lommer complex [2]. A grid size of 8,1 m for the retail on the ground floor was chosen while the grid size for the residential part on top of it was only 5,4 m. A conceptual error was reported to be made in the structural design of the redistributing floor on the first level, thus resulting in a structure with questionable safety.

Related to *complexity of the building process* the location of the project, the number of participants and changes in the project can be mentioned.

The structure was developed in a busy city. Subsequent building activities related to underground structures, impeded access to the construction site [1, p.74]. This added to complexity of the building process.

A number of parties was involved in the design phase. Two developers hired three architects and two structural engineering firms which increased complexity of the process. During construction the situation was even worse; over 50 subcontractors were involved, thus making coordination a hard task [2]. In addition, one of the subcontractors went bankrupt, so changes in tasks were necessary [1, p.62].

Furthermore, the preparation phase was described to be dynamic, and thus complex, with a lot of changes in the functional program [2]. At the start of the project the apartments had a similar bay width as the shops (8,1 m). As mentioned before, this change led to the necessity of a redistribution floor, which was inadequately engineered. During construction a number of changes was made in the actually applied reinforcement, thus impeding checking.

It was observed that during every *building phase* mistakes were made that lead to the incident. In the design phase, a systemic error was made in the design of the concrete distribution floor between apartments and shops. In the detailed design phase, errors were made in the calculations of the detailing of reinforcement of concrete half-joints. During construction, many deviations were made in the size and position of reinforcement, compared to shop drawings.

3.2 Organizational factors

On meso level the factors safety goals, safety culture, allocation of responsibilities, risk management, control mechanisms, protocols, communication and feedback, collaboration, reasonable planning and budget, knowledge infrastructure, working conditions and instruments will be discussed. These factors might play a role on company level and on project level (in the interaction between companies).

No information about *safety goals* is provided, although, based on the descriptions of safety culture, it is believed that no common safety goals were set during this project.

Safety culture was not explicitly defined in the investigation report, although the aspects of a poor safety culture were listed: heavily economizing on costs, preparations not internally supervised, fragmentation and no all-encompassing final responsibility [2].

Misplaced trust was also reported, where inspectorate staff trusted to much in the quality of the main contractor and his subcontractors [2].

Allocation of responsibilities was not clear, with two different lead engineers; one engineer for the apartment building and another for the other structures. Neither of both parties had all-encompassing responsibility [2].

No explicit *risk analyses* were performed focusing on structural safety [2].

Control is commonly regarded as an effective measure to reduce failures. However, for this case it was stated: “There is no evidence that an independent inspection was performed either internally or externally” [2], indicating a general lack of control. Checking on the building site was not part of the task description of the involved structural engineers [1, p.62]. The developer appointed a checking agency for a number of checking tasks, but it seemed that the focus was on progress of the work and not on quality control [1, p.66].

Protocols are often part of certification processes, like ISO 9001. Several involved parties were certificated, which did not prevent them from making mistakes. For the main contractor it was reported that he was certified in accordance with ISO 9001. However, after investigation it was concluded the project developer and contractor primary focused on making profit [2]. The contractor did not seem to maintain an adequate quality assurance system [2]. A large gap between pretended activities and actually performed and documented activities regarding quality assurance existed [1, p.67]. In the investigation report this is explained by citing R. Spruit who stated that in general ISO certification holders often use it as a marketing instrument and try to do as little as possible to fulfill the minimum requirements for the certification. In addition, the broad applicability of this certification in various sectors, gives room for personal interpretation, which might impede effectiveness [1, p.66].

Moreover, the case provides some examples why procedures in practice might not always work. For the fixing of the reinforcement procedures seemed to be clear, but a lot of improvising was needed due to: stolen reinforcement, bankruptcy of a company, and unavailability of reinforcement bars in the right size [1, p. 68].

Regarding *communication* the following observations were made. Language problems, because of the presence of foreign labourers, were reported. In this case, the communication between steel-fixer and main contractor was not adequate [2]. Direct communication between steel fixer and structural engineer was believed to be absent [1, p.68]. Furthermore, there was inadequate coordination between main contractor, concrete pourer and steel fixer. Finally, it was highlighted that several structural calculations were lacking explanations and the position and relevance of several calculations was not made clear, which is a type of miscommunication [5].

Communication always takes place in the *collaboration* between various persons or parties.

It was reported that 'the relationship between the main contractor and the sub-contractors was characterized by extremely tough price competition'[2].

Reasonable *planning and budget* are often related, although not always. There was a strong emphasis on cutting costs, with a strict time table for pouring the concrete, resulting in a huge pressure on the assembly of the reinforcement [2].

Information to be able to draw conclusions related to *knowledge infrastructure* was not found in the investigation reports.

Regarding *working conditions*, a limited building site was reported, which impeded logistics and construction. In addition, there was not a sufficient amount of security, which resulted in the stealing of reinforcement from the building site. This resulted in improvising in the choice of reinforcement bars, which impeded checking of the reinforcement [1, p. 68, 154].

Related to *instruments*, the following issue was brought up. For the floor between shops and apartment building it was suggested that to adequately model this situation, it would have been better to use a finite element program, instead of the used simplified modeling. A modeling error is assumed in the investigation report [1, p.83, 84].

3.3 Human factors

The relevance of *technical competencies* is highlighted in this case. A lack of technical competencies was assumed for some structural engineering companies, because of erroneous modelling of the transfer floor between shops and apartments and the structure underneath the plaza floor [1, p.85,86]. It should be noted that the involved engineering company did not agree upon the assumed modelling error [2, p.85]. Furthermore, some steel fixers were not able to read drawings and, thus, were lacking technical skills [2]. Finally, regarding detailing of reinforcement a large national discussion started. It appeared that the designed position and length of reinforcement might have been insufficient [6]. This can be regarded as a lack of technical competency of the designer, although the way it was designed was common practice.

Management skills can sometimes be used to serve competing goals like maximizing profit instead of increasing quality and safety. The management of the Bos & Lommer project was believed to focus on profits on the detriment of safety [2].

Social-communicative skills are necessary for communication. However, in the cases these are not explicitly mentioned.

Regarding *attitude*, it is hard to make general analyses. Although the focus on progress and cost cutting was on the detriment of quality, some interviewed persons from the construction parties showed very competent and professional behaviour [1, p.67].

Mental and Physical resilience was not reported as an influencing factor within this failure case.

3.4 Essential human and organizational factors per sub case

In section 3.2 and 3.3 relevant organizational and human factors were listed for the Bos & Lommer case. Basically, in this case there were two main problems, where measures were needed:

1. Reinforcement was often not according to drawings
2. The actual load bearing behavior of the force distribution floor was expected to be different than assumed in the used structural model

Now, for these sub problems it will be analyzed what human and organizational factors were essential. Essential factors are that factors that if they would have been on a higher level, the specific problem would not have occurred.

Deviations in reinforcement

The failure of the half-joint, which triggered investigation of Bos & Lommer plaza project, was caused by application of insufficient reinforcement compared to the drawings [1, p. 148]. It appeared that on many positions reinforcement was deviating from drawings, although in the majority of situations safety was assured [2, p.161-163].

This general problem of deviations in reinforcement can be regarded as a multi layered problem.

First, *complexity of the process* can be regarded as an essential factor. When the number of changes during steel fixing would have been smaller, checking would have been easier and deviations from drawings would have been smaller.

Second, *safety culture* was not well developed, because there was a focus on *planning and budget*. This resulted in an insufficient *allocation of responsibilities*, with insufficient *checking.* Furthermore, it was not completely clear who was responsible for changes in construction of reinforcement; the steel fixer or the contractor. Clearer *communication* about responsibilities and about the changes could have avoided the problem of deviations in reinforcement. Finally, it can be argued that a *technical competent* individual with the right *attitude* at the contractor could have avoided failure. However, it is doubtable if individual warnings would have let the system change.

Modelling concrete slab

For the modelling of the concrete slab, first of all, *complexity of the project* is an essential factor. When the grid size would have been similar for shops and apartments, no distribution slab would have been necessary. This complexity was provoked by the cost cutting process, so *planning and budget* is an essential factor.

Author wants to stress that complex design of buildings can be very appealing. However, when designing and constructing complex structures, additional measures are needed to assure quality.

A lack of *technical competency* can also be mentioned regarding the assumed modelling error. The involved designer, was believed to be a competent engineer for dwellings. However, because of the difference in grid size between apartments and shops, the redistribution slab was necessary. This was a nonstandard structure, which is more common in civil structures [1, p.86]. Furthermore, more sophisticated *tools or instruments*, like 3D FEM programs could have revealed the different load bearing behavior of the slab, than as it was assumed. These kind of programs were not common practice, at least not in standard type of dwellings at the time of design (approximately in 2004). *Checking* by a different company, experienced in projects with similar complexity, could have revealed the modelling error [1, p. 86]. This lack of checking is rooted in a poorly developed *safety culture,* with a focus on *planning and budget. Allocation of responsibilities* was incomplete by not including external checking.

4 Discussion

This analysis is based on publically available information. It is possible that individual involved parties have another opinion about facts and contributing factors.

It was useful to use a theoretical framework to analyze a failure case, to be able to derive contributing human and organizational factors. It appeared that essential factors were influencing each other; which impedes deriving the relevance of a single factor. However, this complexity resembles reality in a more appropriate way than only a list of single influencing factors.

5 Conclusion

Investigation of Bos & Lommer plaza revealed various problems with design and construction of reinforcement. For every sub problem it was possible to derive essential human and organizational factors that lead to deviations and errors.

For improvements, focus should not be just on human or on organizational level. Improvements are necessary on organizational level (e.g. improved allocation of responsibilities and effective checking) and human level (improved technical skills).

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