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Case Studies
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Chapter 4

Balconies in Maastricht

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This chapter focuses on human and organisational factors that are usually behind the technical cause of failure. This is illustrated by a case of the collapse of five balconies in 2003 in Maastricht (The Netherlands) resulting in two fatalities.

4.1 Introduction

In 2003 a residential building called Patio Sevilla was completed. In the evening of April 24^{th}, 2003, five balconies of this apartment building collapsed, resulting in two fatalities. Several major investigations were started by insurance companies, police, and the criminal court.

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

A framework with possible influencing factors for structural safety has been set up [1, 2]. The framework is based on critical success factors derived from management literature and factors from safety science. In Section 4.3 the framework will be explained.

This chapter will first reveal the technical causes of the failure, and subsequently analyse to what extent human and organizational factors in the building process (as listed in the theoretical framework) might have played a role in the collapse of the balconies of Patio Sevilla in Maastricht. The focus is on the involved parties in the primary building process, like engineers and contractors.

The analysis of the technical, human, and organizational factors of this case is based on: court judgement [3-5], a report from an expert witness [6], various other investigation reports [7, 8], newspaper articles [9, 10], and a book chapter on this incident [11]. This chapter is an adaption of an IABSE conference paper [12].

4.2 Structure and Technical Cause of Failure Resulting from the Investigation Process

4.2.1 Layout of the Structure

The balcony structure was made of prefabricated concrete. On two positions per balcony, a hinged, thermally isolated connection between balcony slab and floor was designed.

To provide a stable structure a steel column, 100 mm * 100 mm was added as third support. This column was supported by a foundation wall beneath (see Figure 4.1 for a top view of the standard balconies).

During construction, cracks were observed in the balcony of the ground floor. It appeared that this balcony was reduced in thickness, and that the position of the column was not aligned with the supporting wall, after a change in design. These changes were not incorporated in the design. Therefore, the pad on the ground floor underneath the column was not supported by the foundation wall. This inadequacy was fixed by applying a steel corbel underneath the concrete pad (see figure 4.2). The height difference between the top of the steel corbel and slab was filled with masonry. In this way, it was assumed that the essential column 100*100 was adequately supported.

4.2.2 Technical Cause of Failure Identified from the Investigation Process

Various parts of the structure were subject to the forensic investigations. Experts agreed that detailing of the reinforcement of the pad at ground floor was inadequate and not according to the codes. Furthermore, the bolted connection of the steel corbel on the foundation wall was not properly constructed and the connection between the steel corbel and the concrete pad was suboptimal.

Finally, it was concluded by experts and court that the combination of a bending moment and a concentrated force on the small pad resulted in failure of the pad at ground

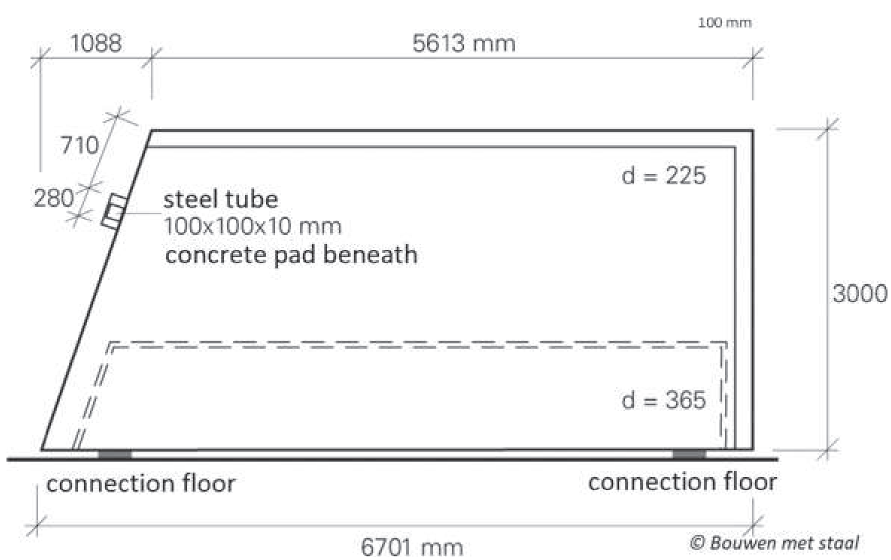

Figure 4.1 Top view of standard balcony with the position of the steel tube column (adapted from [11, 13] with permission). Mind that balcony slab level 1-5 is thicker than slab on ground level (Figure 4.3).

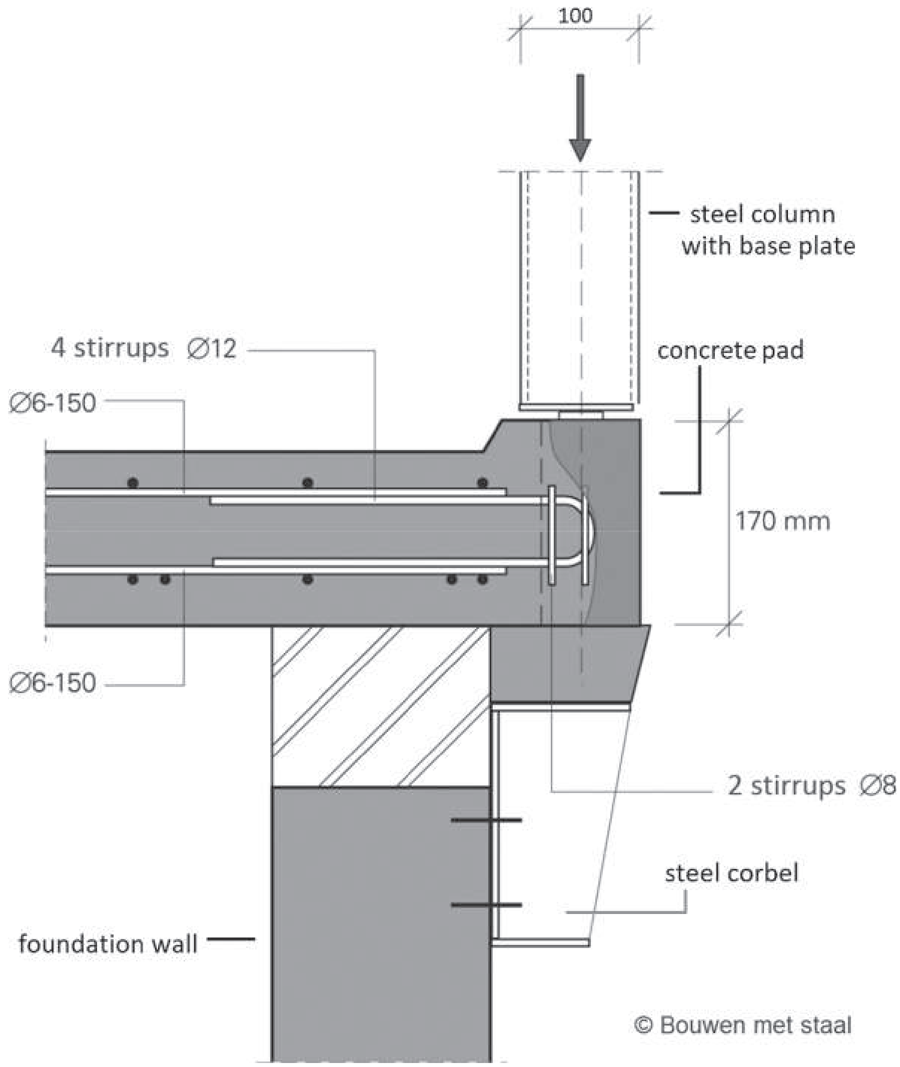

Figure 4.2 Detail of solution with steel corbel ground floor (adapted from [11, 13] with permission).

floor level. This resulted in a progressive collapse of the other balconies (see Figure 4.3) as the columns lacked support [3]. The triggering event was not evident; it was suggested that a relatively warm day resulted in lengthening of the steel columns, or that creep effects of the roof slab might have played a role [4].

It should be noted that not all experts agreed on the technical cause of failure.

The company of the engineer of record had to pay a fine of € 22.500. For the Netherlands this is a remarkable decision, because fatal structural incidents are rare, and therefore it rarely happens that an engineer of record is convicted. The court motivated this fine by stating that the main engineer did not fulfil his checking and coordinating task adequately. The criminal cases against the main contractor and the detailed engineer of the balconies resulted in an acquittal, although their contribution to the failure was acknowledged.

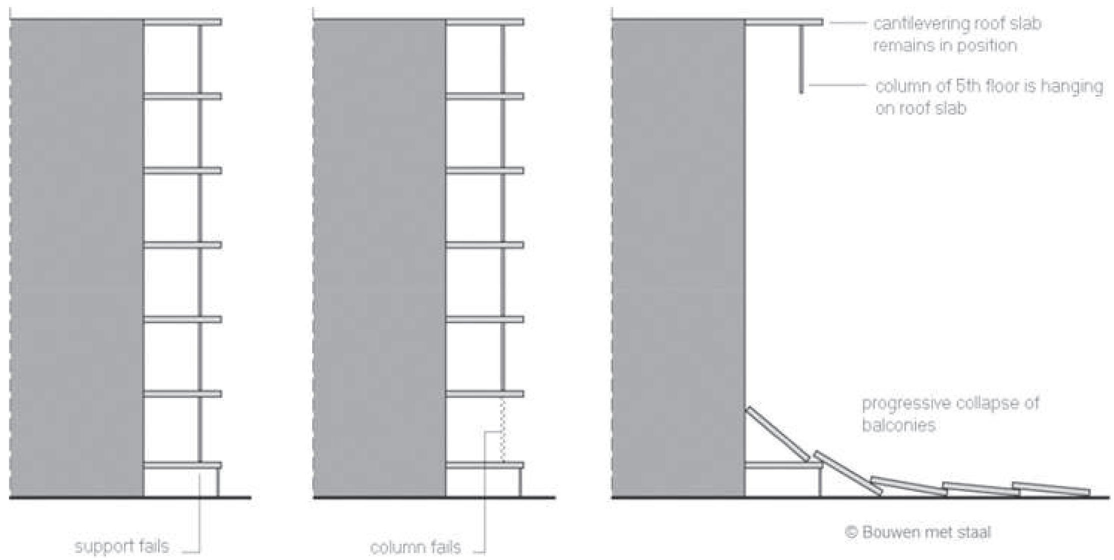

Figure 4.3 Side view of building: initial failure leading to progressive collapse (adapted from [11], with permission).

4.3 Theoretical Framework

4.3.1 General Explanation

A full explanation of the framework is provided in [2]; the definitions in this chapter were explained in [14].

The theoretical framework used to classify various underlying factors makes a distinction on three levels (see Figure 4.4).

On the 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 the 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 its own features, like organization, culture, working conditions, and habits into a project. Project characteristics are related to type and complexity of the project and the phase of a project.

On the micro level possible underlying human factors are mentioned.

This chapter will focus on meso (organizational) and micro level (human) factors. Furthermore, project characteristics are analysed (not included in figure 4.4).

4.4 Analysis of Human and Organizational Factors in the Maastricht Case

4.4.1 Project Characteristics

Most structural engineers will not regard this project as complex in nature. However, because of several design changes the complexity of the structural solution for the balcony support increased during the project.

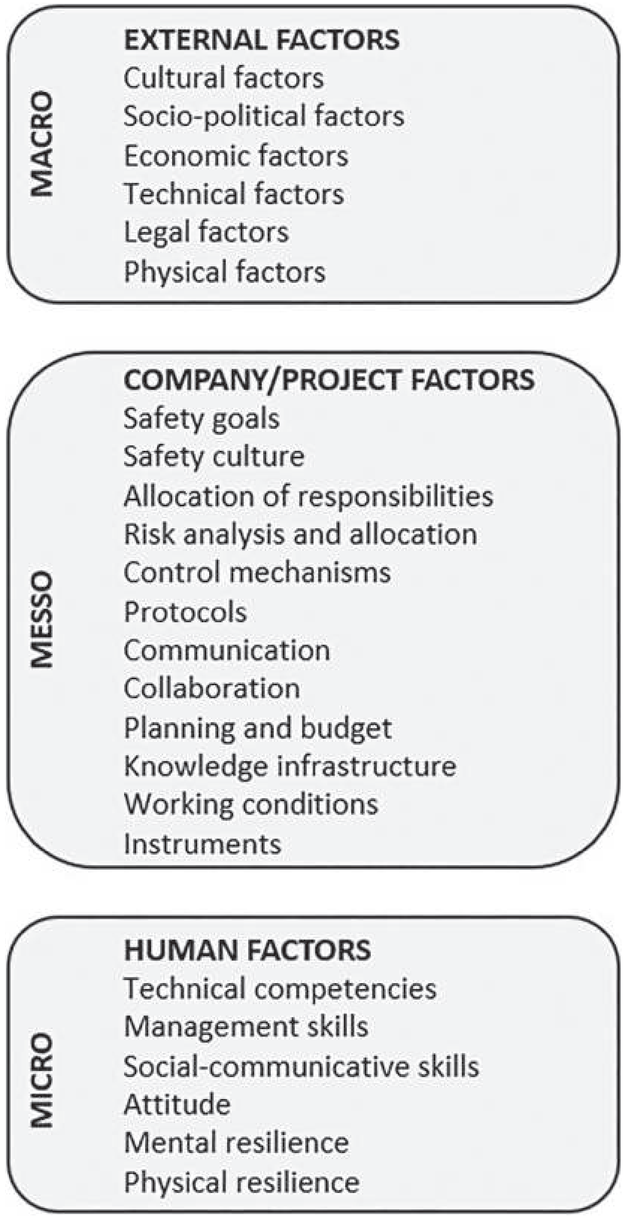

Figure 4.4 Theoretical framework (project characteristics not depicted, adapted from [2]).

First, the column was repositioned towards the boundaries of the slab, to be able to integrate the column with the finishing structure (aesthetical reason [11]). Figure 4.1 clarifies the final, changed position of the column. To be able to support the balcony on a pad at the side of the balcony a slab is required (see also figure 4.1). Second, during preliminary design the engineer designed two moment-resisting connections, between the apartment floor and the balcony slab. During the technical design phase, this was changed by a supplier into two hinged connections [6]. These changes resulted in a less robust solution that was more vulnerable to failure.

The level of complexity of the process can be regarded as medium. First, the various design changes led to miscommunication and inadequate fitting of parts.

Another aspect of the complexity of the process is the number of parties involved. For the design and construction of the balconies, many parties were involved. The client arranged a Design and Construct team composed of various parties [3]. An internationally renowned architect was responsible for the main design, supported by a Dutch architect [7].

For the structural design, an engineer of record was responsible. A main contractor hired subcontractors for the balconies (with separate parties for reinforcement and thermally isolated connections) and the columns. This fragmentation enabled miscommunication in the process.

Related to the project phases, it can be stated that the root of the problems was in the transition of phases. First, according to [6] it was unclear when the technical design phase was finished, resulting in a not fully coordinated set of drawings for the architect and structural engineer. Second, the transition between detailed engineering and the construction stage seemed to have played a role. During detailed engineering, it appeared that the work of the various parties involved was not properly coordinated. During the construction phase, the first warnings popped up (cracking, notification of probably not functioning pad by contractor), but these warnings were not always adequately followed up.

4.4.2 Organizational Factors

Safety goals and safety culture seem not to have been very well developed in this project. Sometimes, when information was unavailable, assumptions were made without adequate checking with the other project partners. A positive exemption is when the contractor warned the structural engineer after discovering cracks, indicating that he felt that the pad structure was insufficient [3].

The unclear *allocation of responsibilities* was often mentioned in the report by the expert witness [6]. A standard allocation of responsibilities was listed in the contract between the engineer and the client. However, this didn't comply with the allocation of responsibilities in the technical specifications, and the applied allocation in the project was also different. Therefore, it was not fully clear who was responsible for design changes. Many parties were responsible for parts of the balcony structure, but no one showed overall responsibility. A single controlling mind was lacking. It was, for instance, reported in the newspaper that the structural engineer would have stated that he was only responsible for the main load-bearing structure (which was the building) and everything else was outside his scope [9]. However, in the legal procedure [4] the structural engineer was regarded as the engineer of record, with the responsibility to determine the starting points for the balcony structure and to perform general checking of the main points of the structure and its detailing (as was written in the technical specifications).

Several subtasks were also not adequately addressed. According to the technical specifications, the contractor was responsible for the engineering of the columns, but the structural engineer determined the size of these columns. The contractor designed base plates for these columns, which were not adequate. No calculations of these base plates could be found, and no proof of sharing the information of these base plates with the structural engineer was present in the files [6].

The studied files gave no proof of proper *risk management*. A risk analysis was not carried out for this project.

Insufficient *checking* was mentioned several times as a contributing factor to the failure. The client did not arrange adequate supervision [6]. The structural engineer did not properly check the integrity of all elements in the structure. He paid adequate attention to the thermally isolated connections, but not to the column-balcony connection [6]. Following the warning signal of cracks in the pad, no proper analysis of the stresses in these pads was performed, thus missing the chance to avoid failure [3].

Related to *protocols*, it was observed that not all paperwork was correct. The contract with the contractor was only signed sometime after the start of construction. A signed contract between the structural engineer and the client couldn't be found [6]. However, it is questionable if these issues would have avoided the failure.

Insufficient *communication and collaboration* seem to be at the root of this failure. First, the results of design changes were poorly communicated. During construction, drawings were used where the changed thickness of the balcony slab on the ground floor was not implemented. For the steel support to resolve the misalignment, the structural engineer used outdated information. This was corrected by the contractor, without communicating this with the structural engineer [3, 6].

Furthermore, the structural engineer seems not to have shared information with the contractor regarding loads on steel columns and balcony slabs [6]. Therefore, the detailed engineer of the balcony slabs is insufficiently aware of the loads that would act on the pads. The detailed engineer of the thermally isolated connections made his own calculation of loads (instead of using the loads by the structural engineer) and changed the support from moment resisting to hinged [6].

Moreover, the contractor failed to provide the structural engineer with detailed calculations and drawings regarding the connection of the columns with the balcony [6].

Finally, the contractor several times informed the structural engineer about cracks in the balconies of various apartments. However, there were also cracks in the pad of the collapsed balconies, but these were not communicated to the structural engineer. The contractor decided, without communicating with the engineer, to apply similar measures as with the other pads [6].

It is not clear if the *planning and budget* were too tight. During the legal case, financial problems of the structural engineer were reported [4]. It is not clear if these were a result of the incident. Time pressure was reported when an alteration needed to be designed for the pads that were not supported. When the problems were discovered by the contractor, the structural engineer designed a solution on the same day and a few hours later the contractor adjusted this solution and ordered the materials [6].

It is not to be expected that a more advanced *knowledge infrastructure* within a company, or in between the companies would have improved the result, as knowledge infrastructure is related to general knowledge of solutions, structural behaviour, etc. One indication of a failing knowledge infrastructure is that when the contractor's employee who had initially warned about the cracks and the pad structure needed to be replaced (because of illness [10]), the new person did not directly apply the same measures as the initial person had done. However, this would not have avoided the failure.

Furthermore, it appeared that within the Dutch building industry, there was no general agreement regarding the real behaviour of the pads and the strategy for secondary load paths with balcony structures. So, knowledge infrastructure on the national level could still be improved [6].

There is no indication that *working conditions* played a role in this case.

If this project was elaborated in a 3D BIM environment (more advanced *instruments*), an inadequate fitting of parts would have been detected earlier. However, this was not common practice at the time of this project. Furthermore, as the structural engineer paid limited attention to the connections, it is questionable that he would have used more advanced 3D calculation software for the situation with the pad if this would have been available.

4.4.3 Human Factors

The overall support system can be regarded as too vulnerable. It would have been more logical if the columns had transferred their loads directly to the foundation, rather than first transferring them through a small pad [6]. Apart from this, it could have been expected that a structural engineer would make a design with adequate detailing according to the codes [6]. These two issues might indicate a lack of technical skills by the engineer of record or the detailing engineer. However, if a skilled person doesn't take the time to check the situation, technical skills might have been present but were not used. Furthermore, it was indicated that both the engineer of record and the detailing engineer worked with incomplete information. So, a lack of technical skills was indicated but not proven.

Although lack of communication and collaboration is mentioned on the organizational level, based on the available information it is hard to conclude if individuals lacked management or social communicative skills or that they didn't use available skills. Furthermore, it is unclear if a lack of mental resilience played a role.

The case doesn't provide proof that a lack of physical resilience did add to the failure.

4.4.4 Essential Human and Organizational Factors

Now, it will be analysed what human and organizational factors were essential. Essential factors are those factors that if they would have been improved, the specific problem would not have occurred.

An incomplete allocation of responsibilities is regarded as the first essential factor. Although an initial allocation of responsibilities was present in the contract phase, during the actual design and building the allocation was not properly followed. Especially, the role of the coordinating engineer or design coordinator, who should have coordinated the various engineers involved, was lacking.

A lack of checking is regarded as the second essential factor. If checking, especially by the engineer of record, would have been more comprehensive, i.e., also checking of connecting parts and disciplines, then it is believed that the failure would not have occurred.

Insufficient communication is regarded as the third essential factor, as this resulted in making choices based on incorrect information.

Other factors may have contributed. However, it can be doubted if these factors would have been on a higher level so that the failure would not have happened.

4.5 Conclusion and Discussion

The technical cause of the progressive collapse of various balconies in 2003 in the Netherlands can be attributed to inadequate detailing of a pad of a prefabricated concrete slab at ground level. Essential human and organizational contributing factors were a lack of allocation of responsibilities, insufficient checking, and inadequate communication.

As this analysis is based on available information from the legal case and additional sources, there will be involved parties who have another opinion about the contributing technical, human, and organizational factors. For instance, some parties suggested that construction errors were made which triggered the failure.

However, without trying to analyse these kinds of failure cases, it is hard to actually learn from failures. This case was a wake-up call for the Dutch building industry, where various initiatives started to improve structural safety.

4.6 Lessons Learnt

Lessons learnt are increasing awareness of the importance of details, especially when various parties are involved. Furthermore, this case was a starting point to focus more on human and organizational factors contributing to failures. Understanding these factors can help reduce the number of failures.

The author would like to thank Dik-Gert Mans who shared his knowledge of this case.

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