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Chapter 8

Roof of FC Twente Stadium

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This chapter focuses on human and organizational factors that are usually behind the technical cause of failure. In this chapter the focus is on the collapse of the extension of the roof of the Football Club Twente stadium in Enschede (The Netherlands) during construction, resulting in two fatalities.

8.1 Introduction

On July 7th, 2011, an extension of the roof of the FC Twente stadium collapsed during construction. This extension would increase the stadium's capacity with an additional 10.000 seats. Additional capacity was needed because of a successful period for the soccer club.

During the assembly of finishing structures for this new roof, a roof truss failed. This resulted in a progressive collapse. Two fatalities and nine injuries were recorded. A collaboration of the Public Prosecution, the Labour Inspectorate of the Ministry of Social Affairs and Employment, and the Dutch Safety Board [1] started an investigation. The Dutch Safety Board reported the outcomes of this investigation to the public [2].

At first, this chapter reveals the technical causes of the failure. Subsequently, it presents human and organizational factors in the building process that might have played a role in the collapse. This case was analysed with the same framework of human and organizational factors as was used in chapter 4. The analysis of the technical, human, and organizational factors of this case is based on a report of the Dutch Safety Board, an earlier paper on technical causes and various newspaper articles [1-5]. This chapter is an adaption of an IABSE conference paper [6].

8.2 Structural and Technical Cause of Failure Resulting From the Investigation Process

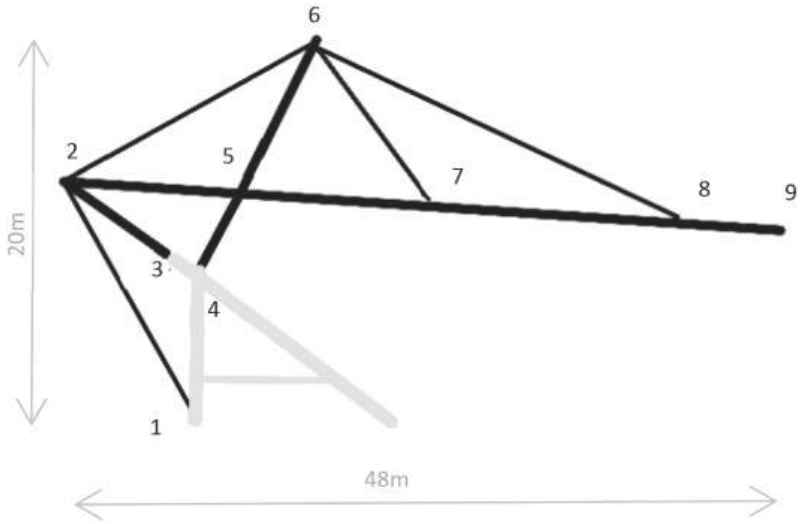
8.2.1 Layout of the Structure

The original FC Twente stadium was constructed in 1998 and extended in 2008. Because of sporting successes, a second similar extension was constructed in 2011.

The structure for the extension of the roof in 2011 consisted of 11 bearing frames. Each bearing frame had a length of approximately 48 m and a height of approximately 20 m (see Figure 8.1). The bearing frame was constructed out of steel tubes. These were mounted on the concrete grandstand structure.

The engineers created stability out of plane by coupling bars and braces at the positions of 2, 5, 6, 7, and 8. The roof, a steel structure with steel sheeting, was positioned below position 2, 5, 7, 8, and 9. All frames were erected when the structure collapsed (Figure 8.2).

However, the structure appeared not to be fully assembled at the moment of collapse. One coupling bar between the nodes 6 of two frames was lacking. Furthermore, several



Black bold = *steel with compression force, when loaded downwards*
Black thin = steel with tensile force
Gray = concrete grandstand

Figure 8.1 Schematic overview of bearing frame (Based on [2]).

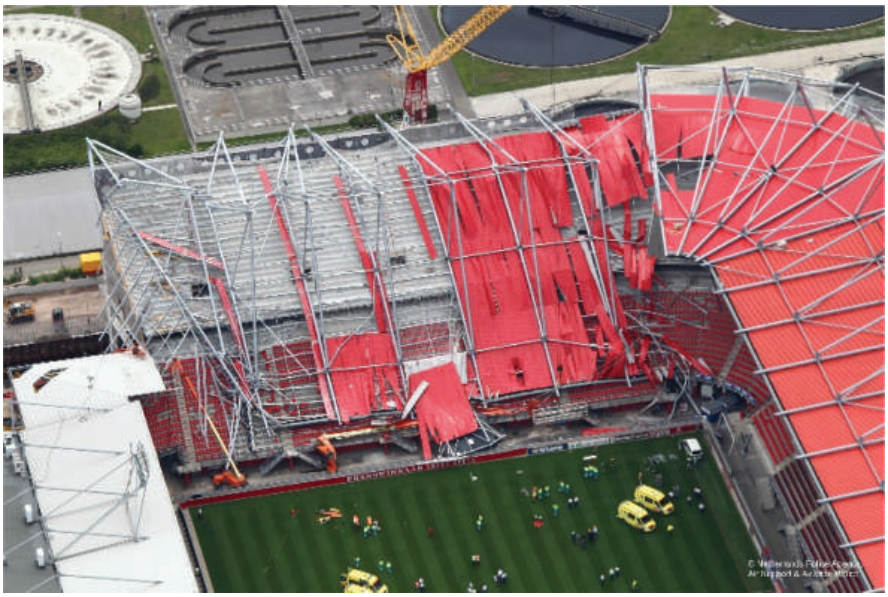


Figure 8.2 Roof of FC Twente stadium after collapse. Reproduced by permission of Netherlands Police Agency, Air support and Aviation Police.

couplings between nodes 2 of various frames were missing to enable easier construction with the tower cranes. Temporary braces were removed to apply safety nets. Part of the steel roofing was already assembled.

Although the structure was not completed, it was already loaded in various ways. Roofing sheets were stacked on the roof waiting for assembly. Labourers were walking on the roof for assembly of the remaining structure. Furthermore, hanging bridges were connected to the roof for assembly, and several days before the collapse a video-wall of 8400 kg was installed at the position of node 9.

8.2.2 Technical Cause of Failure as Found in the Investigation Process

After the collapse, several parties started investigations into the cause of the collapse. The Dutch Safety Board performs investigations of failures in situations where they expect that new lessons can be learned to improve safety, or when they suspect structural shortcomings in a sector related to safety [7]. As this board had already investigated a collapse of a temporary structure with similarities with the FC Twente collapse, they decided to perform an investigation. The aim of this investigation was to determine the cause of failure, but also to investigate what measures within the process were taken to avoid collapse [8]. The Dutch Safety Board was assisted by several companies who assisted in part of the research, like measuring deviations in precast concrete structures and analysing the cause of failure with help of structural modelling. TNO assisted in deriving the technical cause of failure. After a thorough investigation of debris, video material, and numerous finite element analyses, they concluded [1] that:

- the frame where the video-wall was connected collapsed first;
- the main cause of failure was out-of-plane buckling of the outer parts of two frames where the connecting bar at position 2 was missing.

Instability of the structure during construction can be regarded as a sufficient technical cause. TNO calculated a buckling factor n=1.67 for the situation without coupling bars [2, p.74 and annex]. The buckling factor was calculated here as the ratio between the buckling capacity load (Eulers's critical load of a perfect structure) over the actually applied load (no load factors used)[1]. If n>10 no instability issues are to be expected. If n<1 instability is to be expected. A factor of 1.67 means that the structure is very vulnerable for instability, although it will not necessarily result in a collapse if there is hidden capacity. TNO also calculated that without the loads of video-wall etc., the buckling factor of this structure still would be around 2.

In case the coupling bars would have been present, this would result in a buckling factor of n=12. Thus, the presence of these coupling bars would have significantly increased the capacity against buckling as the buckling length would have been reduced. The absence of these bars was therefore regarded to be a major contributing factor.

Initial stresses in the steel structure because of forcing the structure into place may have contributed to the failure. The Dutch Safety Board concluded that these initial stresses had reduced the resistance. However, they didn't clarify if these initial stresses would have been sufficient to let the structure collapse.

The investigation didn't reveal a clear trigger for the event. It seems that the structure was so close to instability, that any action could have been the final trigger[1].

Based on the analysis of the Dutch Safety Board the author assumes that the instability during construction because of the absence of some coupling bars was the essential factor for the collapse. The author assumes that the initial stresses, because of deviations in measurements, and the premature loading of the structure were a contributing factor to the collapse of the FC Twente stadium roof.

This chapter will primarily focus on human and organizational factors, which might have played a role in this incident. In chapter 4, a theoretical framework was introduced with possibly influencing human and organizational factors. This framework will be used again in this chapter to analyse process factors that might have led to the collapse.

8.3 Analysis of Human and Organizational Factors in the FC Twente Case

8.3.1 Project Characteristics

The extension of the FC Twente stadium was regarded to be structurally complex, although a similar extension had been constructed before.

The building process of the extension can be regarded as chaotic and complex. The available time for the extension of the FC Twente stadium was reduced because of scheduled international games that had to be hosted, resulting in a shift from sequential towards simultaneous activities. This was mentioned as a contributing factor of the failure of the roof of this stadium [2].

8.3.2 Organizational Factors

Safety goals and *safety culture* seem not to have been very well developed. It was suggested that clients in general focus on functionality, time, and costs and less on safety assurance. For the FC Twente case the Dutch Safety Board observed a lack of a collective safety approach [2].

The *safety culture* of the FC Twente stadium was characterized by unjustified trust [2]. Because of earlier collaboration [2] the parties trusted each other's competencies, to the detriment of thorough checking.

The same project team was involved for the FC Twente stadium in the failed project as in the successful first extension of the stadium. Nevertheless, the *allocation of responsibilities* was insufficient and was one of the contributing factors of the roof collapse. Pre-arranged tasks, like the measurement of the concrete structure or calculation of stability during construction were not allocated to individuals within

organizations and were neither executed nor communicated [2]. Structural inspections were included in the contract of the structural engineer, but the kind of inspections was not clear [2]. All in all, the Dutch Safety Board concluded that not all responsibilities and tasks of the members of the team were included in an agreement with the various parties [2].

For the FC Twente case no information on *risk management* was provided. However, the outcome of the case showed that risks were not adequately managed.

Control (checking) is commonly regarded as an effective measure to reduce failures. The case of FC Twente revealed various deficiencies in the control processes. Coordination and control during construction was a responsibility of the main contractor [2]. However, sequence and method of construction was insufficiently checked by the main contractor [2]. Furthermore, strength and stability during construction were not adequately addressed. This lack of control was explained by stating that the main contractor was of the opinion that he was not qualified to check the specialized work of the steel [2]. A newspaper reported that the structural engineer visited the building site the day before collapse, but the construction process was not stopped [5]. However, it is not clear whether this person was aware of the deviations, and if so, made any relevant remarks about it.

In the case of FC Twente, the assembly plan was based on the earlier extension. However, this procedure (*protocol*) was incomplete. There was insufficient attention to strength and stability during construction [2] and it did not provide adequate guidance for the sequence of the assembly of stability bracings [2]. Furthermore, initial protocols relating to the sequence of activities were abandoned.

It was also reported that some forms of *communication* were indirect. There was, for instance, no direct communication between structural engineer and steel contractor, because every communication was coordinated by the main contractor. Direct communication might have been beneficial to avoid structural problems [2]. Sometimes the communication seemed to be unclear. The steel contractor was convinced that the main contractor agreed with an adapted assembly plan, while the main contractor stated that he did not order changes in assembly sequence or leaving out structural parts [2].

As stated earlier, the *collaboration* between the participants of the FC Twente stadium could be characterized by unjustified trust.

In this case the *planning* had to be condensed because of the scheduled soccer games [2]. This resulted in time pressure and a simultaneous execution of tasks. The steel contractor had planned to apply the steel structure in six weeks, whereas the main contractor had only reserved two weeks in the overall planning [2].

Related to *knowledge infrastructure*, a lack of knowledge transfer between structural engineer and steel contractor regarding strength and stability during construction can be assumed in the FC Twente case. The assembly plan seemed to lack an analysis of structural safety during construction [2] and there was no direct contact between structural engineer and steel contractor. However, this will be regarded as inadequate allocation of responsibilities in the first place.

Sometimes occupational safety and health has a negative impact on structural safety. In case of the collapse of the stadium roof of FC Twente it was reported that labourers

removed a stability brace to be able to assemble safety nets for roof workers, to improve *working conditions*. These stability bracings were essential for the stability of the roof and this demounting contributed to the collapse of the roof [2].

There was no information available regarding the insufficiency of *tools* (like working equipment) that might have contributed to the failure.

8.3.3 Human Factors

In the FC Twente case, various risks were not adequately addressed. For example, the risk of removing the bracings to apply safety nets [2] to make assembly of the roof sheets easier [2]. Furthermore, the risk of leaving out essential elements to avoid problems with the crane [2]. The removal of bracings was approved because the stability bracing was not under tension [2]. This indicates a lack of technical skills [2]. However, the workers might have been skilled, but they were not fully aware of risks under the influence of time pressure. Nevertheless, when labourers do not fully understand the structural behaviour, they are not expected to take decisions like the removal of (temporary) stability elements.

In the description of the cases, lack of management skills, social-communicative skills, mental resilience (the way a person can cope with stress), and physical resilience (the way a person can cope with long term and heavy physical loading) were not mentioned.

Regarding attitude, within the case of the roof of the FC Twente stadium the various parties had an unjustified trust in each other, resulting in loosening necessary checks in the process.

8.3.4 Essential Human and Organizational Factors

Various influencing factors are mentioned, but would it be possible to determine the essential influencing factors? Essential factors are those factors which in case they would have been improved, the specific problem would not have occurred.

If we focus on instability as the most significant contributing technical factor, the following underlying organizational factors can be regarded as essential in contributing to this technical cause:

- *Time pressure*. This resulted in abandoning sequence of activities, and presumably in making short cuts in temporary stability measures.
- *Insufficient allocation of responsibilities*. Checking the stability of the structure during construction was inadequately addressed.
- *Insufficient communication and collaboration*. It was unclear if temporary situations were checked. Furthermore, knowledgeable persons who could have understood the hazardous effect of the sequence of activities were not always involved.

Although the Dutch Safety Board conducted several interviews, information lacks to strongly conclude on essential human factors.

8.3.5 Consequences

Unfortunately, there were two fatalities and nine injuries. Furthermore, the collapse resulted in significant material damage.

The stadium roof for the extension was finished in October 2011, resulting in an unknown amount of additional cost. In 2014, Dutch prosecutors determined four persons and three companies as suspects. However, it was decided in 2016 that the persons had to wait too long for the legal process and that they were acquitted [4].

Finally, the case for the companies was settled. Contractor and steel contractor both had to pay € 50.000,- and €75.000,-, respectively, to a fund for the victims [3].

8.4 Conclusion and Discussion

Based on the investigation of the Dutch Safety Board, this chapter concludes that instability of the roof structure during construction was the main technical cause of failure. Time pressure, insufficient allocation of responsibilities and insufficient communication and collaboration were listed as essential underlying factors.

Coming to reliable statements regarding causes of failure is not an easy job. First, companies are usually not proud of their failed projects and are reluctant to share information. They often take a defensive position, being aware of possible legal consequences of admitting mistakes. In the case of the FC Twente stadium various parties involved made defensive remarks to the draft version of the investigation report.

Second, in failure cases it is often hard to pinpoint one singular technical cause, as several causes usually contribute to a failure. Experts might not agree on conclusions as was also the case in the FC Twente stadium collapse. Moreover, parties in legal cases sometimes tend to highlight a most likely cause which is beneficial for them. Incomplete information and subjective analyses hamper reliable conclusions on the technical cause of failure.

As human behaviour and technical processes are more complex than technical behaviour, it is clear that deriving reliable conclusions on human contributions is even harder. To come to more reliable conclusions one has to avoid the bias of hindsight [9, 10]. Furthermore, one has to be able to judge the consequence of contracts and to understand what you can reasonably expect from professionals. Moreover, it is necessary to perform relevant interviews with various stake holders. This demands not just technical skills. Therefore, multidisciplinary teams are necessary, an approach that the Dutch Safety Board also advocates.

Finally, the Dutch Safety Board tends to look for causes on an organizational level to avoid blaming of individuals and to allow organizations to learn. The downside of this approach is that it will be harder to address relevant human factors.

It is not easy to come to reliable conclusions regarding the technical and procedural causes of failures. Nevertheless, it is believed that communicating lessons from failures, technical as well as procedural, is very valuable to improve structural safety within the building industry.

8.5 Lessons Learnt

Lessons learnt are related to the essential underlying factors: time pressure, unclear allocation of responsibilities and insufficient communication and collaboration.

In the majority of construction projects time pressure will be present. However, one has to be aware that tasks still need to be properly done and checks need to be performed. Furthermore, it is important to aim for a clear allocation of responsibilities. This can be written on paper, but also needs to be discussed between the project partners. Finally, in many projects there will be the risk of insufficient communication and collaboration. There is a need for a strong role of an engineering coordinator for the various engineering parties and a coordinating contractor for the various subcontractors. There should be a single controlling mind. In addition, it is essential that every project partner is aware of interfaces with other disciplines and other parties.

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