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Contributing human and organizational factors to the collapse of the FC Twente stadium roof

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Abstract

In 2011 the city of Enschede was shocked by the collapse of the roof of an extension for the FC Twente stadium. The structure collapsed during construction and two fatalities and nine injuries were recorded. The cantilevering steel roof structure was covered with corrugated steel sheets and stabilized by bracings. Investigation showed that the structure was already loaded with the finishing structure before it was completed and stabilized. Contributing influencing human and organizational factors to the incident were the tight schedule resulting in a flawed construction sequence. Furthermore, there was too little attention to the way of execution during design, unjustified trust between parties resulting in inadequate coordination, checking and allocation of responsibilities.

Keywords: human and organizational factors, causes of failure, forensic engineering

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 of the soccer club.

During assembly of finishing structures for this new roof, a roof truss collapsed. This resulted in a progressive collapse. To fatalities and nine injuries were recorded.

A collaboration of the Public Prosecution, Labour Inspectorate of Ministry of Social Affairs and Employment and the Dutch Safety Board [1] started an investigation. Dutch Safety Board reported the outcomes of this investigation to the public [2].

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 chapter 3 this framework will be explained.

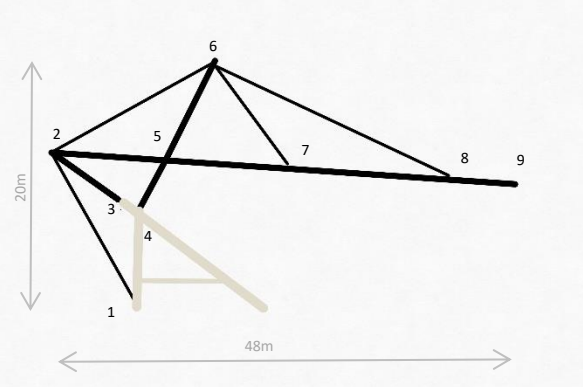
At first, this paper reveals technical causes of the failure. Subsequently, it presents human and organizational factors in the building process that might have played a role in the collapse. The focus is primarily on engineers and contractors who play an important role in the primary building process.

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 news paper articles [1,2,5-7]. 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 Structure and technical cause of failure

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

The structure for the L-extension of the roof consisted of 11 bearing frames. Each bearing frame had a length of approximately 48m and a height of approximately 20m (see fig. 1). The bearing frame was constructed out of steel tubes. These were mounted on the concrete grandstand structure.



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

Figure 1: Schematic overview of bearing frame (Based on [2]).

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.

However, the structure appeared not to be fully mounted at the moment of collapse. One coupling bar between the nodes 6 of two frames was lacking. Furthermore, several 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. Moreover, several days before the collapse a video-wall of 8400 kg was installed at the position of node 9.

After thorough investigation of debris, video material, and numerous finite element analyses, TNO 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

Although there are alternative explanations for the failure, for this paper we stick to the “official” causes as published by Dutch Safety Board.

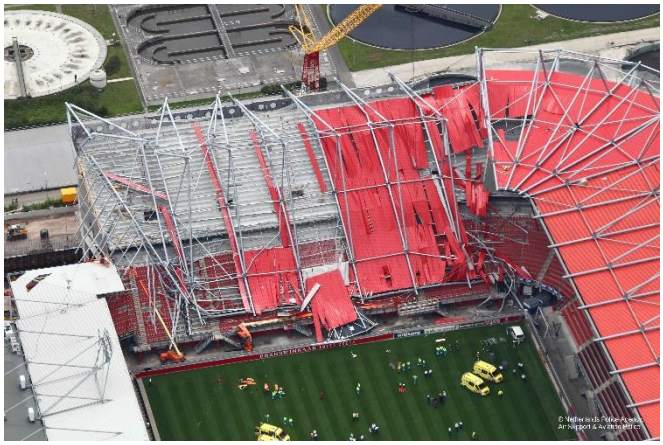


Figure 2. Roof of FC Twente stadium after collapse. Reproduced by permission of Netherlands Police Agency; Air support and Aviation Police

This paper will primarily focus on human and organizational factors, which might have played a role in this incident. Therefore, possibly influencing factors will be listed as a theoretical framework.

3 Theoretical framework

A full explanation of the framework is provided in [4]; the definitions in this paper were explained in [8].

The theoretical framework, used to classify various underlying factors, makes a distinction in three levels, see figure 3.

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. 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.

This paper will focus on meso (organizational) and micro level (human) factors. Furthermore, project characteristics are analyzed (not included in figure 3).

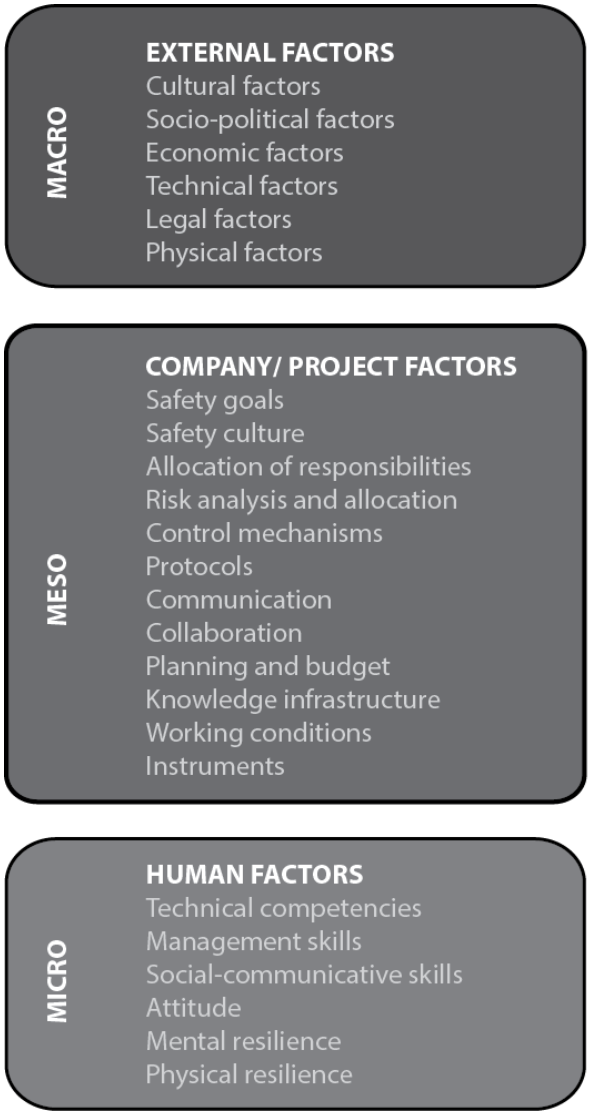


Figure 3: Theoretical framework (project characteristics not depicted, adapted from [4])

4 Analysis of human and organizational factors

4.1 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, p.6].

4.2 Organizational factors

Safety goals and *safety culture* seem not to have been very well developed. It was suggested that clients in general manage on functionality, time and costs and less on safety assurance. For the FC Twente case the Dutch safety board observed a lack of collective safety approach [2, p.6].

The *safety culture* of the FC Twente stadium was characterized by unjustified trust [2, p.30]. Because of earlier collaboration [2, p.4] the parties trusted in each other's competencies, on the detriment of thorough checking.

In case of the FC Twente stadium the same project team was involved 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 not executed or not communicated [2, p.5,37]. Structural inspections were included in the contract of the structural engineer, but the kind of inspections was not clear [2, p.22]. All in all, 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, p.38,44].

For the 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. For instance, the sequence and method of construction was not checked by the main contractor [2, p.5]. 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, p.34]. A newspaper reported that the structural engineer visited the building site the day before collapse, but the construction process was not stopped [7]. However, it is not clear whether this person was aware of the deviations, and if so, made any relevant remarks about it.

In case of FC Twente, the assembly plan was based on the earlier extension. However, this procedure (*protocol*) was incomplete. There was no attention for strength and stability during construction [2, p.5] and it did not provide adequate guidance for the sequence of the assembly of stability bracings [2, p.31]. Furthermore, initial protocols related to sequence of activities were abandoned.

For the FC Twente case it was 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, p.31]. 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, p.32].

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, p.6,30]. 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, p.30].

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, p.5] 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, p.28].

There was no information available regarding the insufficiency of *tools* that might have contributed to the failure.

4.3 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, p.28] to make assembly of the roof sheets easier [2, p.32]. Furthermore, the risk of leaving out essential elements to avoid problems with the crane [2, p.31]. The removal of bracings was approved because the stability bracing was not under tension [2, p.28]. This indicates a lack of *technical skills* [2, annex 10]. However, the workers might have been skilled, but they were not fully aware of risks under influence of time pressure. Nevertheless, when labourers do not fully understand the structural behaviour, they are not expected to take decisions like removal of (temporary) stability elements.

In the description of the cases, lack of *management skills, social-communicative skills or mental/physical resilience* 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.

4.4 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.

First, it is important to determine the most presumable technical cause or causes.

Instability of the structure during construction can be regarded as a sufficient cause. TNO calculated a buckling factor n=1,67 for the situation without coupling bars [2, p.74 and annex]. This means the structure is very vulnerable, although it will not necessarily result in a collapse if there is hidden capacity or if the actual loads are lower. TNO also calculated that without the loads of video-wall, etc. the buckling factor still would be around 2.

In case the coupling bars would have been present, this would result in a buckling factor n=12. So the reduction in capacity is significant when these bars are not present, and is 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. Dutch Safety Board concluded that these initial stresses had reduced the resistance. However, they didn't make clear if these initial stresses would have been sufficient to let the structure collapse.

Based on the analysis of Dutch Safety Board we assume instability during construction because of absence of some coupling bars the essential factor for the collapse. We assume the initial stresses because of deviations in measurements and the premature loading of the structure as a contributing factor.

If we focus on instability as the most significant contributing technical factor, the following

underlying 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.

4.5 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 [6].

Finally, the case for the companies was settled. Contractor and steel contractor both had to pay €50.000,- and €75.000,- to a fund for the victims [5].

5 Conclusion and discussion

Based on the investigation of Dutch Safety Board, this paper 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 case of 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 like also was the case in the FC Twente stadium collapse. Moreover, parties in legal cases sometimes tend to highlight a most presumable 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 you have to avoid the bias of hindsight [9,10]. Furthermore, you have 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 only for technical skills. Therefore, multidisciplinary teams are necessary, an approach that Dutch Safety Board also advocates.

Finally, Dutch Safety Board tends to look for causes on organizational level to avoid blaming of individuals and to allow organizations to learn. The backside 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 building industry.

6 Acknowledgements

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