Exploring improvements for structural safety

Karel Terwel

Delft University of Technology, Delft, the Netherlands
Coenraedt B.V., Rotterdam, the Netherlands

Dik-Gert Mans

Meged Engineering & Consultancy, Zoetermeer, the Netherlands

Contact: k.c.terwel@tudelft.nl

Abstract

Research has shown that 80-90% of failure cases is caused by human and organizational factors, like communication errors. A national survey in the Netherlands revealed that critical factors within Dutch building process are: safety culture, communication and collaboration, allocation of responsibilities, risk management, control and knowledge infrastructure. This paper explores how the critical factors within building industry might be improved for both design and construction stage.

Keywords: structural safety, building process

1 Structural safety: is improvement necessary?

The last few years the Dutch building industry has been shocked by some major structural failures, often during construction, for instance with the collapse of a temporary scaffold for construction of the floor of the B-tower in 2010 and the partial collapse of the roof of an extension for the FC Twente stadium in 2011 resulting in several injuries and fatalities [1].

Fortunately, the number of fatalities caused by structural collapses is currently very limited in the Netherlands, resulting in probabilities of dying for workers in the construction sector of $7.5 \times 10^{-6}$ to very low probabilities of dying for residential end-users ($1.1 \times 10^{-8}$) [2]. These numbers are low, although the risk of dying should be limited to a level that is As Low As Reasonably Practicable (ALARP).

Apart from the number of fatalities and injuries, a reduction of failure costs can be an important driver to improve structural safety. The failure costs in the Netherlands are estimated at 10% of the yearly turnover, which results in a total sum of approximately 5 billion euros. This number needs
improvement. In addition, parties are willing to improve structural safety because of moral reasons (feeling personal responsibility, professional pride: striving for quality) mixed with financial reasons (shareholders value, reputation and trust).

Research on over 700 failure cases showed that 80-85% are caused by human and organizational factors [3]. This is in line with international research [4].

Therefore, it is important to know what factors in the design and construction process are critical; that is: make a difference between a successful project and less successful project regarding structural safety. Critical factors within Dutch building processes are: safety culture, communication and collaboration, allocation of responsibilities, risk management, control and knowledge infrastructure [5].

When critical factors are known, it is important to determine measures that might lead to improvement of these factors in the building process.

This paper will describe the possible measures that were proposed in various publications, which are deemed to improve the critical factors for structural safety. In addition, the results of a workshop with participants from the building industry is presented which lead to an action list to improve structural safety.

2 Exploring improvements

In the Netherlands a lot of measures are suggested, but usually not based on a thorough analysis. By using the derived critical factors as a starting point, it is deemed easier to select relevant measures.

Possible measures have been selected from various sources:

- Eurocode describes briefly some measures to assure safety
- Convenant Highrise was set up in the Netherlands, because the normal codes are not applicable for buildings of over 70m. This convenant includes procedural measures [6]
- NEPROM, the Dutch association for Project developers has issued a Code of Conduct with measures to improve quality [7]
- Compendium Structural Safety has been drafted by various parties from the building industry to assure safety in various stages of the building process [8]
- Interviews with building experts have resulted in possible measures
- A comparison with other industries has led to ideas for improvements [9]

The following subsections highlight some of the proposed measures.

2.1 Measures to improve safety culture

Improving safety culture starts with awareness. It might be important in a fragmented building industry to have a central organization that coordinates activities regarding structural safety, like mandatory failure reporting.

The building industry can be inspired by other industries, like offshore, aviation and process industry, where the safety approach is more developed and integrated in daily practice. In aviation and process industry the importance of control, risk analysis and failure analysis is higher [9].

Furthermore, the building industry might develop an assessment system, to rate projects on the vulnerability of failures. A first proposal to do this has been presented in [10].

Within companies support of management for safety related issues is important. A constructive attitude with regard to structural safety should be stimulated. For young engineers it might be very fruitful to experience openness in speaking about failures without a focus on blaming and shaming when an error was made.

Moreover, companies should be very attentive when warnings are present. In many failure cases, the structure already warned before full collapse occurred [11]. In addition, within the process often persons warn. A structural engineer should be welcoming critical remarks by a contractor, when these remarks improves the safety of the structure.
2.2 Measures to improve allocation of responsibilities

Figure 2 presents various ways to improve allocation of responsibilities.

The current situation can be characterized by a lack of coordination.

This can be improved, especially when the number of participants is limited, by maximum coordination where every project partner communicates with each other. In this situation contracts might have to be improved with regard to a clearness in roles of various participants. There are software tools like VISO, where all contractual agreements are listed, that might facilitate this clearness [12].

When many parties are involved, coordination should be involved in the task demarcation. Although clients are usually responsible for the content of the contracts, it might be beneficial to give more transparency in the content of the contracts to the various parties, for easier detecting gaps (or overlaps) between the contracts.

Within Dutch building industry there has been a long debate on the necessity of appointing a mandatory single point of responsibility regarding structural safety (central coordination). However, the government is reluctant to make this a legal obligation, because it is expected to be a responsibility of the market. Authors believe, that especially for complex projects, the appointment of an engineer of record with authority on the construction site will be beneficial for structural safety. In addition, it might be wise for such projects to demand certification for the engineer of record, based on competence and experiences.

When the complexity of projects can be reduced, it is believed that it will be easier to assure structural safety. A maximum number of project participants (especially subcontractors) can reduce the complexity. Furthermore, integrated contracts can make the process easier, because no strict cut between design and construction is made.

2.3 Measures to improve risk management and control

Risk analysis is common within the building industry, but usually not with a focus on structural safety. Therefore, guidance is needed for a method for this specific structural risk management. The Institution of Structural Engineers (IStructE) has issued a generic risk management approach that can be customized for every project [13]. This is also relevant and useful for countries outside Great Britain.

Within Eurocode risk analysis is recommended for CC3 structures (where failure possibly results in high consequences, like high rise buildings). It might be useful to be more strict and make a full risk analysis mandatory for CC3 structures and a light qualitative version mandatory for CC2 (with possibly medium consequences, like midrise office buildings) to improve proactive risk awareness.

Everyone knows, that control (checking) is important. However, in the rush of daily practice it is sometimes omitted or too limited. Therefore, the relevance of checking should be highlighted: everyone has the right to be checked.
For CC3 structures it is advised that a second opinion by an independent third party will be performed. A Technical Inspection Service can be used for this purpose.

When the liability of engineers and contractors will be increased, the need of checking for these parties will be higher. In the Netherlands, the liability of engineers is usually limited to the consultancy costs. A limited liability might stimulate engineers to be more accurate and alert, keeping in mind that claims after failure cases can result in an increase termination of the insurance policy, an increase of insurance fees or an increase of the deductible.

When checking is more integrated in the process, it will increase quality. More standardized ways of building, like prefab structures are promising with this regard.

2.4 Measures to improve communication and collaboration

Many failures occur, because a limited transfer of information between design and construction phase. Therefore, a review of the design by the contractor is advised. Within successful projects with integrated contracts, this review is an important aspect. When chain integration is stimulated, suppliers are more involved in the design, which might increase the constructability of structures. Furthermore, for larger projects a site engineer is recommended to be able to construct as it was intended in the design.

BIM is often mentioned with regard to communication and coordination, because virtual prototyping, interface management and clash control can be performed.

When project parties can trust each other’s competencies, successful collaboration can be the result. Other important factors for successful collaboration are: understanding, communication, humor, tolerance and respect [14].

2.5 Measures to improve knowledge infrastructure

Within companies and projects proper HR management is essential to maintain a high standard of knowledge within the company, especially when persons are retiring. For larger companies and projects, knowledge management is important, which is “the discipline that promotes an integrated approach to identifying, capturing, evaluating, retrieving, and sharing all of an enterprise’s information assets [15].

Within countries the level of technical education is relevant. Lectures by professionals from the building industry are relevant and stimulating for students. Involvement of building practice when developing study goals for education curricula should be stimulated.

A more elaborate explanation of the possible measures is presented in: “Structural safety: study into critical factors in the design and construction process” [3].

From the introduction it is clear that the majority of the listed measures has been mentioned before. In practice it seems harder to implement these measures than to develop them. For real change, involvement of building professionals is key. Therefore, within the Netherlands a workshop was set up with participants from the building industry to set up an agenda to improve structural safety.

3 Setting the agenda

3.1 Organizing a workshop

From 2008 to 2014 the Platform Structural Safety, a cooperation of contractors, engineering firms, governmental bodies and clients, undertook several activities to improve structural safety in building projects. Evaluating the activities it was concluded that the awareness of the risks related to structural safety has increased, but that for a wider dissemination of this awareness and for further improvement new activities were necessary. The strategy to achieve this goal is to develop a program that will be supported and executed by the top of the leading construction companies and structural engineering firms. The motivation for this strategy is that they are willing to improve the performance in the projects in which they are involved, that they can enforce other project partners to cooperate in improved processes and that their way of working can
become an example for other organizations and project teams.

To develop a program with meaningful activities a workshop was organised. In addition to representatives of the top of the leading construction companies and structural engineering firms, representatives from governmental bodies, from clients and some specialists were invited. In the group of 32 participants experience in residential, office and industrial buildings, in bridges and tunnelling were more or less equally present.

3.2 Input for the workshop

As introduction for the workshop there were three presentations. The first presentation was a retrospect on passed activities and set preconditions for an agenda. This preconditions are that the activities must lead to proven better performance in terms of less incidents, less failure costs and retraceable structural safety. The second presentation explained the results of the study into critical factors, as described in the first part of this paper: safety culture, allocation of responsibilities, risk management & control, communication & collaboration and knowledge infrastructure. The third presentation focussed on safety incidents and analyses in other industries.

3.3 Brainstorm and discussion

As follow up of the presentations every participant did proposals for improvement. Some of the proposals focus on a limited part or phase of a building project, other proposals cover a broader area. The proposals were assigned to the six groups of critical factors and prioritizing was done by rating the proposals by the participants. After this was done, discussions in small groups were held about the proposals. After a plenary discussion the results were summarized. Table 1 gives an overview of the results.

<table>
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<th>Safety culture</th>
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<tr>
<td>- promote management focus on safety, not only on time and money</td>
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<td>- organize discussion of incidents in project meetings</td>
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<tr>
<td>- apply evaluations of (the assuring of) structural safety after each stage of the project</td>
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<td>- facilitate not only top down but also bottom up communication about structural safety</td>
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<tr>
<td>- make sure the parties involved have the same expectations about managing the risks</td>
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<td>- legislation and enforcement (law and order) are important</td>
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<tr>
<th>Communication and collaboration</th>
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<tr>
<td>- use 3D drawings for complex knots and structures</td>
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<tr>
<td>- give more attention to the transfer from design to execution, e.g. by oral explanation</td>
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<tr>
<td>- involve the designer in the control of the production and execution</td>
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<tr>
<td>- organize consultations about structural safety with the parties involved</td>
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<tr>
<td>- reduce the number of parties for easier communication and coordination</td>
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<td>- show leadership in structural safety matters</td>
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<th>Allocation of responsibilities, accountability</th>
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<tr>
<td>- develop standards for demarcation of tasks and responsibility for engineering by (sub)contractors</td>
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<tr>
<td>- make one person responsible for approval, coordination and communication of all structural engineering</td>
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<tr>
<td>- make and check project quality plans and execution plans</td>
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<tr>
<td>- choose logical cuts in engineering and delivering</td>
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<th>Knowledge infrastructure</th>
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<tr>
<td>- stimulate learning organizations</td>
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<tr>
<td>- give attention for technical education</td>
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<tr>
<td>- develop and use checklists with engineering tasks from design to execution stage</td>
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<tr>
<td>- give attention to risk files, design files and as built files</td>
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<th>Risk management &amp; control</th>
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<tr>
<td>- apply risk management, organize checks based on risks</td>
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<tr>
<td>- systematic checking of processes and products, e.g. by developing checklists</td>
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<tr>
<td>- apply second opinions and/ or do independent checking by competent engineers</td>
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3.4 Program of activities to improve assuring structural safety

Based on the results of the workshop it was concluded that a more systematic way of assuring structural safety should be achieved. Too often the different parties involved in a building project have their own expectations of assuring structural safety but there is no common view and strategy, and as follow up, no commonly agreed way of assuring structural safety. The transfer of information throughout the project is mentioned as one of the very important subjects. The transfer from design to production and execution (often with different engineers) seems to be the most critical. Therefore special attention is asked for this type of transfer.

Based on these findings four subjects are chosen for follow up by activities.

- **Best practices**
  
  Best practices, based on experience and proven good results, can help to improve and standardize working methods. Different building projects (i.e. bridges, industrial buildings, and residential housing) and different collaborations and contracts (traditional, D&C, other integrated contracts) will lead to different risks. So best practices can be coupled to specific projects and contracts and can describe parts of the design and construction process or cover the whole process.

- **Practical methods for risk management**

  Applying risk management in large scale projects is common. But the attention for risks related to money and time sometimes overrule the risks related to structural safety. In smaller projects, risk management is not a separate discipline; it will be part of quality management or just integrated in the tasks of project management and/or specialists. Goal of this activity is to develop tools and examples for risk management in a practical way.

- **The transfer of information from design to production and execution**

  The number of participants in a building project increases significantly in the transition from design to production and execution. The organization should be chosen in such a way that the risks of miscommunication and incompleteness of allocation of tasks are manageable. Building information modelling or just 3D modelling of complex joints can help to improve the communication about structural safety issues. Task assignments based on historically developed working methods should be evaluated. How should designers, purchasers, engineers and executers cooperate to get reliable results?

- **Reporting and communication about incidents.**

  Learning from incidents can be done on the level of the building industry, on the level of project organizations and on the level of the companies involved in building projects. A system of reporting on the level of the building industry have been executed in the Netherlands from 2008-2012 [16]. Doing this in a way that this leads to less incidents and better profit is the challenge of this activity.

4 Conclusions

Within the Netherlands, an action agenda to improve structural safety is based on thorough, scientific analysis of critical factors. It is expected that the critical factors: safety culture, communication and collaboration, allocation of responsibilities, risk management, control and knowledge infrastructure are relevant for various countries.

Various measures to improve the critical factors are available. However, setting up plans is easy, implementing measures is tough.
5 References


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