FAILURE OF STEEL STRUCTURES: RETHINKING SOME OF THE AFTERMATHS

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Abstract. Steel structures are the most ductile systems; however they are prone to instability phenomena due to their inherent slenderness. Looking at the real events of over 50 years, it was observed that steel structures, when they are subjected to seismic actions, respond, relatively, in an acceptable way, avoiding a global collapse. In case of quasi-static loads, such as snow, overloading, due to earth infill in case of green roofs, or indirect actions, coming from geometrical imperfections or lack of bracing, fail under a sudden way. A failure should be approached by any type of combination of cumulated errors in design, construction, operation and maintenance. The paper is focused on failures, in quasi-static loads, of the first stage in the design and construction phase of a project. It attempts through a technical classification and presentation of case studies to unveil relevant causes of collapses. From the engineering point of view, the lack of redundancy, robustness and ductility are the main factors of structural collapse. Indeed, the human nature represents the central core for any structural failure, and this is attributed to a coupling of the lack of knowledge, as well as management and organizational inefficiencies.

Key words: collapse, lack of knowledge, management, ultimate state, case studies.

1. Introduction

Generally, structures are unique products, each one with distinctive characteristics. Hence, they are not such as other technological products, (e.g. machines), where high grade of industrialization and QC & QA (quality control and quality assurance), policies could be applied. Certainly, current European Norms prescribe some clauses for the quality management as well as the management of structural reliability (Gulvenesian *et al.*, 2002; Marek *et al.*, 1999); it is a substantial effort in order to mitigate the probability of failure. Nevertheless, the content of any procedure is based on the level of the knowledge of stakeholders for both technical and managerial issues, and one way is to learn from past failures (Petroski, 1994). The trial-and-error method, widely used by engineers, is the simplest example. Moreover, failure is an excellent learning experience, providing the vulnerability of a structural system, while success provides the capacity/demand ratio of a structural system, when is subjected to corresponding external actions.

Focused on steel structures, one can observe the following two aspects:

1. Steel is a material with high quality control as compared with other basic construction materials (e.g. the concrete).
2. Steel components (e.g. beams, columns, bracings), are realized, partly, as prefabricated elements where quality control could be developed.

A steel structure, as a final product, is dictated not only by the material and components, but by the design, fabrication, erection, operation and maintenance. It is a complex process which requires technical, organizational and management awareness. Evidently, the construction of steel structures is also connected with the human factor, and as such the human error plays a central role to any kind of structural failure. It is interesting to present the opinion of Petroski (2006), where ''*Structural failures occur in part because the design process is subject to all the flaws and failings of human intelligence and human nature.*''

Concentrating on the root causes of a structural failure we remark that according to Kletz (1992), an ''*Accident investigation is like peeling an onion. Beneath each layer of causes and recommendations lie other layers. The outer layers deal with the immediate technical causes, the middle layers with ways of avoiding the hazards and the inner layers with the underlying weaknesses in the management system.*'' In addition, Turner (1978), investigating the nature of the disaster, stated that ''*There is an accumulation over a period of time of a number of events which are at odds with the picture of the world and its hazards represented by existing norms and beliefs.* ''. Therefore, there is period of incubation until an uncontrolled cause, which finally, will trigger the failure.

Generally, steel structures have adequate strength and ductility. This merit provides earthquake-resistant steel structures, as demonstrated by strong seismic actions like Northridge (1994, USA), Kobe (1995, Japan) and Christchurch (2010, 2011, NZ). Practically, this behavior influenced the structural engineering community of New Zealand, where different steel structural systems are mostly applied for the post-earthquake reconstruction of Christchurch (Bruneau and McRae, 2019).

However, steel structures due to their inherent slenderness and lack of stiffness in the absence of proper bracing, are vulnerable to instability phenomena, becoming prone to failure at the erection phase or, in many cases, due to snow loads.

New construction technologies, such as green roofs with earth infill, when they are not well defined, may trigger unexpected failures. Moreover, new construction processes, such as erection techniques and technologies, may develop conditions to cause collapse.

Taking into account all the aforementioned, the present study is focused on failures coming from quasi-static loads, which are directly connected with the statements of Kletz (1992) and Turner (1978). Firstly, in order to set in explicit way the combined technical and managerial goals, at the incipient phase, the paper attempts to point out and classify the structural failure. Secondly, through some case histories, it is unveiled that managerial errors along with an incubation period stand behind a large number of failures, even in the case that seems to be that when failures are provided from other types of errors like, for instance, the inefficient design.

2. Classification of failure focused on steel structures

Classical studies in the field of structural safety classify the structural failure as follows (Pugsley, 1951; Blokley, 1980; Turner, 1978):

- Due to errors in design, or construction.
- Due to unforeseen high values of loading.
- Due to poor understating of how to use the existing materials, and construction or other type of technologies.
- Due to improper understanding of the structural behavior of a system.
- Due to improper use of a structure.
- Due to improper handling of information among the stakeholders.
- Due to violation of procedures, specifications and/or codes.

All the above depicts the general framework of failure causes, which are valid for all types of structures. On the other hand, one can observe that the projects of the steel structures are somewhat different as compared with the reinforced concrete structures; this is related to fabrication and erection process. The first one is connected with a series of activities like: surface cleaning, cutting, bending, rolling, straightening, drilling, punching, welding, fitting, coat finishing and transporting. The second one is associated with the lifting of steel components into a position, (although without full connection, only temporarily holding in position), suitable bracing ensuring stability until the full connection of the system, bolting and welding on site, alignment, final installing and permanent joining of the steel components, application of the final coat, on site, and attachment of the cladding. The fabrication procedure is a construction phase where quality control, QC, is applied. Certainly, QC is developed and implemented by human beings; therefore, under such circumstances, the human error would occur. The erection activities, due to their nature, they do not always respect any quality control and quality assurance. They represent a decisive execution stage, for the following reasons:

- The whole stability of the structural system would be ensured.
- The health and safety of the stakeholders present on site would be ensured.

2.1. Failure based on the construction life cycle

Briefly, from structural point of view, we can distinguish three main stages of a construction life cycle: the design, the construction and the operation phase as well. Towards this conceptualization, for each phase, there is a possibility that structural failure occurs (Table 1).

Table 1. Failure due to construction life cycle.

Failure type	Cause
Failure due to design	Designers incompetence
	Structural design code inefficiency
	Load code inefficiency
	Computer-aided design incompetency
Failure due to construction (execution)	Fabrication (e.g. defective process, improper workmanship)
	Erection (e.g. lack of bracing, inefficient joining/assembling of elements)
Failure due to service loads	Quasi-static loads (e.g. dead or live load, snow)
	Dynamic loads (e.g. fatigue, seismic actions)
Failure due to operation	Lack of inspection and maintenance (e.g. corrosion, accumulation of dust adding extra load)

In this paper the demolition phase or any type of rehabilitation are not considered, because they are not make part of common structural failure definition.

Definitely, all the aforementioned types of failure, presented in Table 1, provide the external cause. Therefore, when the external cause interacts with the gross human error along with management inefficiency in design, construction, inspection and maintenance, then a structural failure would appear (Fig. 1).

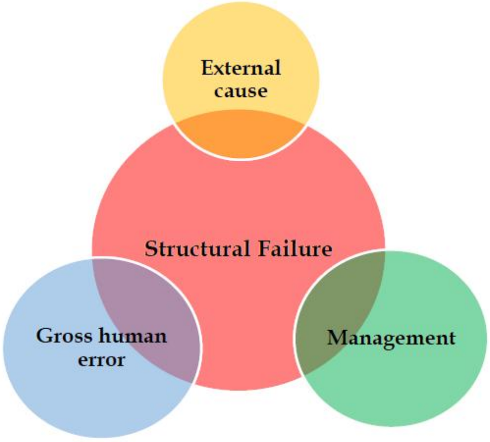

Fig. 1. Schematic view of interaction factors.

2.2. Failure based on the main structural characteristics

Firstly, among the structural systems, there are some that are more susceptible to failure than others. For instance, a moment resisting frame with long span is more prone to failure as compared with one that is braced. Moreover, a truss space frame is more robust, as a roof cover, than a grillage of beams, and so on. Therefore, a basic factor that must be considered against the possibility of failure is the type of structural system. To this end redundancy, ductility (e.g. alternative load paths and capacity for stress redistribution), overstrength, robustness, provided by continuity and member connectivity, and diaphragmatic action as well, are the main factors avoiding structural failure (Table 2).

Secondly, the primary use of a structure and the modality of operation would introduce the possibility of structural failure. One can observe that, for example, steel crane structures, steel bridges, steel roofs covering stadiums, exhibition halls, auditoriums or other industrial facilities with long spans, are sensitive to failure due to loading conditions (e.g. crane overloading, snow accumulation, impact on a bridge pier). This is because of inappropriate settings of loading restrictions and inefficient management actions to control such overloading situations, Table 2.

Table 2. Failure due to structural characteristics.

Failure type	Cause
Failure due to structural system deficiency	Lack of redundancy
	Lack of robustness
	Lack of overstrength
	Lack of continuity and connectivity
	Lack or incomplete diaphragmatic action
Failure due to use and operation	Overloading
	Inefficient management measures

3. Case studies

Failure is an excellent way to learn (Nastar and Liu, 2019). In addition, another mode to learn is from the experience of others. However, human beings have short memory and forget historical or other important failures. Consequently, by any means, it is of paramount importance, to present the aftermaths of any type of structural collapse.

It is interesting to provide the dictum of Santayana ''*that those who do not remember the past are condemned to reap it*'' (extracted from the book of Petroski, 1994).

3.1. Roof collapse at the stadium of FC Twente, Holland

On July 7th, 2011, suddenly and at the time of construction, part of the roof at the De Groslch Veste stadium of FC Twente, Holland, collapsed, killing two workers and seriously injured (nine others). At the time of the failure, about 12 workers were working above and below the roof, Fig. 2 and 3. The collapse occurred in the afternoon, in an advanced phase of the works.

Work had begun in February of that year and was an extension of the existing roof, following a previous extension that began around 2008. The project was undertaken by a general contractor who then outsourced two subcontractors; the first one commissioned to execute the reinforced concrete works and the second one the execution (fabrication and erection) of the structural steelwork. It is noteworthy that the aforementioned subcontractors had also dealt with the work carried out in 2008.

A year later, a commission was set up to investigate the incident, and it was concluded that the failure was due to technical as well as human factors (Onderzoeksraad Voor Veiligheid/Dutch Safety Board, 2012). In general, the failure is obviously due to insufficient support of the roof part and in particular to the following technical factors:

- The temporary support measures, which consisted of metal cables, and ensured the stability of the system during construction / erection, were detached before the installation of the permanent support system and the stiffening of the whole structure.
- Prior to the completion of the construction, the contractor allowed to set up, locally, in the subdivision of the structural system which collapsed, the installation of a video wall, a suspension service deck and a roof cladding section. The aforementioned introduced an additional load which would have to be undertaken from the whole and not from a part of a roof.
- Structural deviations were recorded between the concrete elements as well as those made of structural steelwork, resulting in the 'forcible' placement of the latter, which led to the development of additional stresses, while at the same time reducing the margin of calculated strength.

Fig. 2. Global view of the collapsed roof (http://newcivilengineer.com/archive/engineering-errors-led-to-twente-collapse-stadium-12-07-2012).

Regarding human factors, these can be summarized as follows:

- The general contractor, without permission and due to time pressure changed the construction plan and while initially there was a sequential erection and partial planning, finally all the works were performed simultaneously. Therefore the contractor did not properly assess the situation, by erecting the construction without revising the design.
- Subsequently, the general contractor did not record the dimensions of the concrete elements, in order to inform the relevant subcontractor (related to

structural steelworks), about the tolerances. At the same time the subcontractor of the steel constructions fabricated the steel elements without checking the concrete elements. As a result, there was no proper communication between the involved parties, nor was there a clear hierarchy of roles and responsibilities.

- It is noteworthy that the lack of communication, based on the findings of the committee, may have resulted from the past establishment of bonds of trust and cooperation between the parties involved (general contractor and subcontractors).

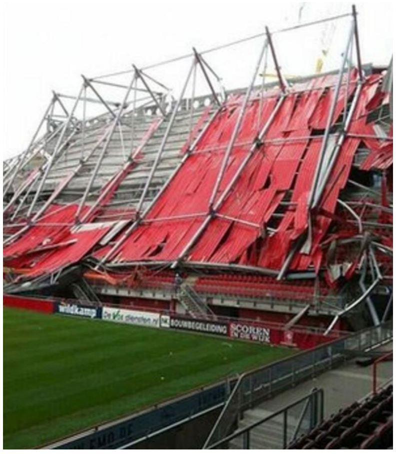

Fig. 3. Local view of the collapsed roof (http://www.bbc.com/news/world-europe-14063640).

It is obvious that during the construction of such structures the erection plan should exist and rigorously implemented, without modifications, while for possible changes, the stakeholders and the respective construction managers should be informed. At the same time, the control and communication between all parties must be governed by specific procedures and implemented to the letter, even if all the partners work together for many years. Moreover, a suggestion for the designers is to develop highly redundant and robust structural systems, through continuity of elements and use of bracings. In addition, construction tolerances, even from the initial design, are necessary, because the fabrication and erection are not perfect.

3.1. Roof collapse at Maxima supermarket, Zolitude, Latvia

The Maxima supermarket, in Zolitude, a city near Riga, Latvia, was a building completed and delivered for use on November 3, 2011. It had an area of about 4,750 m^2. The main structural system for the roof, bridging a span of 16.0 m, was made by steel trusses, connected between them with prefabricated perforated slabs (hollow core prefab slabs). On its roof the construction of a "green roof" cladding of about 20-30 cm thick was under execution. However, on 21 November 2013, the roof of the Maxima store collapsed, while the market was in operation killing 54 people, Fig. 4, and Fig. 5. In addition, this disaster led to the fall of the Latvian government.

The duration of the legal process was long. Finally on February 18, 2020, eight from nine defendants (the architect, the construction manager, the construction supervisor, the project construction expert, three officials from the Riga building and construction inspectorate and an employee of Maxima as well), were acquitted, and only the responsible building civil engineer was accused of *"making gross errors in the structural calculations, which directly led to the collapse"* (https://eng.lsm.lv/article/society/crime/verdicts-delivered-in-zolitude-tragedy-case.a348764/).

The legal opinion it is not always technically sound, when facing a fatal construction failure.

For instance, one can observe that the construction history of the corresponding building was really very complex. (https://en.wikipedia.org/wiki/Zolit%C5%ABde_shopping_centre_roof_collapse#cite_note-51). Generally, in such cases, not only the design error but also a combination of causes coming from the pressure on the construction budget, relationships between the investment partners, the maintenance and the management, as well, are responsible for a catastrophic failure in construction.

Fig. 4. Global view of the Maxima collapsed roof (http://dailymail.co.uk/news/article-2511652-Latvia-supermarket-roof-collapse-kills-37-Riga.html).

According to Gusta (2015), the Maxima disaster was due to error in design, errors in construction and inspection process, failure to manage an emergency situation as well as the lowest construction cost, which finally led to the lowest quality of construction. In other words the private profit was over the public safety. This attitude is ethically unacceptable. Certainly, the authorities must discourage such actions, through peer reviewing in case of building facilities with crowd accumulation.

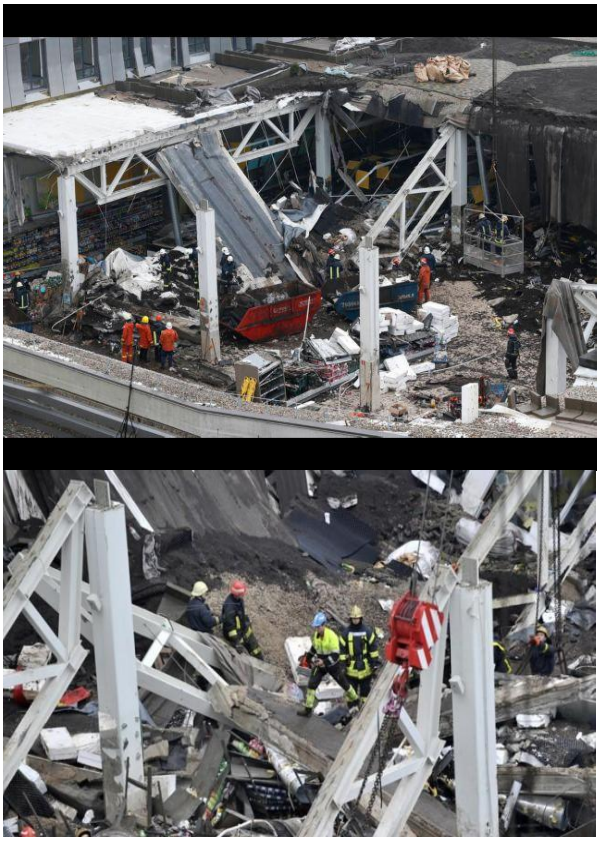

Fig. 5. Local view of the Maxima collapsed roof (https://www.abc.net.au/news/2013-11-22/latvia-supermarket-roof-collapse-kills-dozens/5112572).

Concerning this failure case, an important technical remark would be made related to the change of a classic roof to a ''green roof''. For the Maxima supermarket it seems that such loads was not taken into account or not computed correctly (loads in the order of 400-600 kgr/m^2, due to the fact that previously there was relative rainfall which clearly worsened the load condition of the roof; case of wet soil). Also, the possible unilateral overload led to the failure in combination with the previous ones. This is because the construction of the green roof was in progress, thus changing the intensive situation that probably could not have been foreseen as a distinct construction phase. Therefore, the overload, and the position of the load during the execution, caused by such a cladding, must be taken into account. Moreover, the improper connection between the trusses (lack of purlins, bracing ties, and a horizontal bracing system), created a system with reduced redundancy, not allowing the formation of a 3D effect of a space structure, which allows force redistribution. For the Maxima supermarket the aforementioned structural solution was not the proper option, possibly for purposes of reducing the construction cost. Therefore, once again it should be pointed out that the redundancy develops alternative load paths, the ductility allows for the force redistribution, and finally, the robustness ensures the integrity of the system. These structural properties save lives and properties as well.

3.3. Girder collapse of the Groat Road Bridge, Edmonton, Canada

The failure was occurred during the execution phase (at the erection stage), and it is related to four girders of welded double-T cross section with a height of about 4.20m in a bridge with a span of around 100.00m. In Figure 6 the aerial view of the bridge, after failure, is presented (https://edmonton.ctvnews.ca/damaged-girders-on-102-ave-bridge-repaired-to-be-reinstalled-1.2375088).

A web camera system was put in place in order to monitor the execution process of the project. By the virtue of the above mentioned system, the failure was recorded in real time. According to that, we distinguished the following stages.

The girders were erected by the steel fabricator on March 15, 2015. Around the first morning time and at 2:00 a.m. (March 16, 2015), as recorded by the web cameras in the project, there was no any sign of failure (Fig. 7). The beams are still straight.

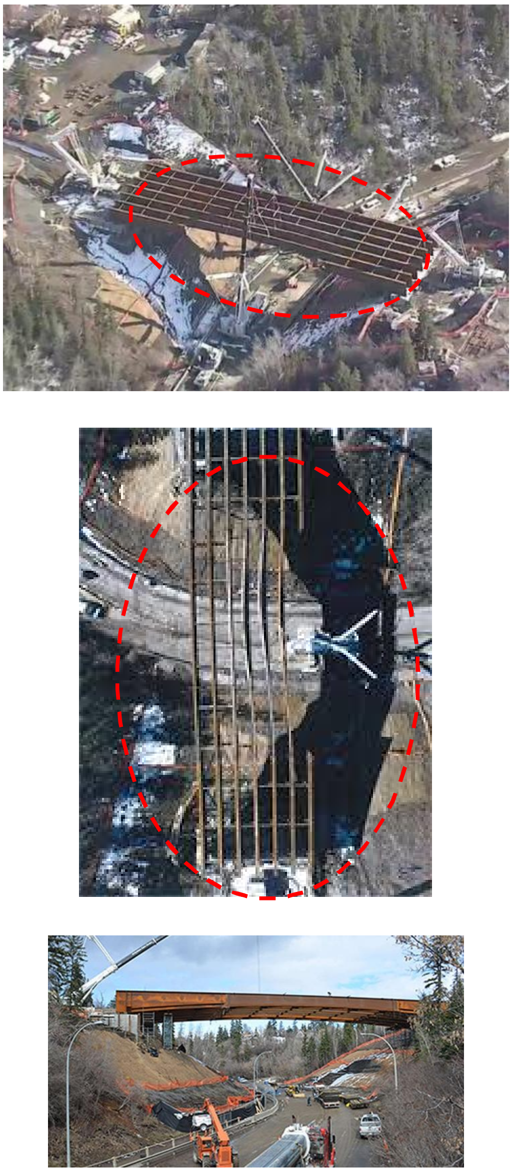

Fig. 6. Aerial view of the beams under a failed position (https://edmonton.ctvnews.ca/damaged-girders-on-102-ave-bridge-repaired-to-be-reinstalled-1.2375088).

A quarter later at 2:15 a.m. four of the beams are buckled. There were no casualties or injuries but only financial losses (Fig. 8).

This was a typical failure of flexural torsional buckling, which is a characteristic type of failure for bridge girders of such height and span, when they stay unrestrained (Edmonton Journal, 2015; Zhao *et al.*, 2009) (Fig. 9).

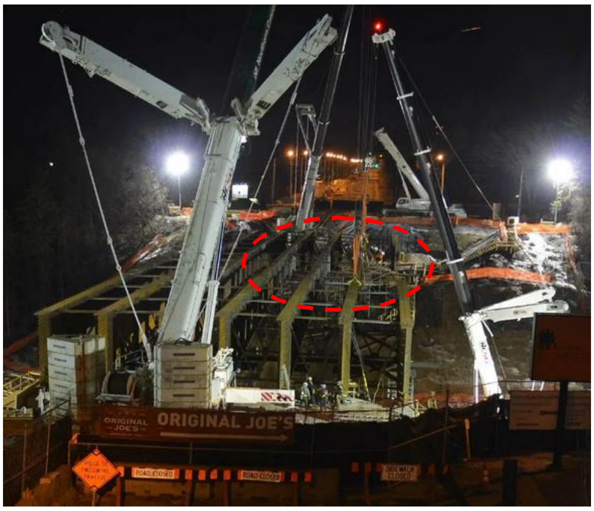

Fig. 7. Beams are straight at 2.00 a.m., on 16 March 2015 (https://globalnews.ca/news/1887233/groat-road-to-remain-closed-for-three-weeks-for-curvy-girder-repairs/).

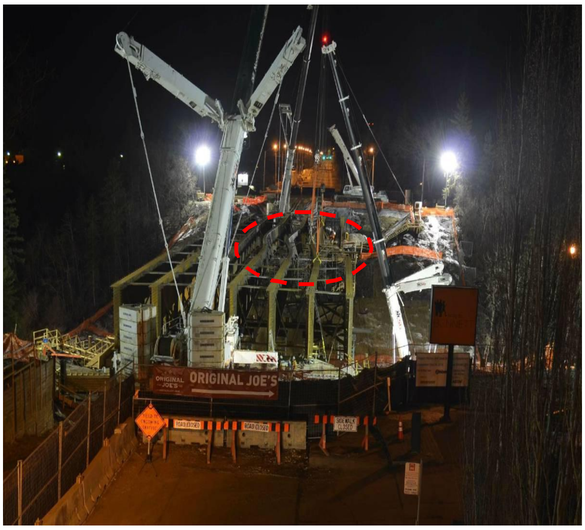

Fig. 8. Beams failed at 2.15 a.m., on 16 March 2015 (https://globalnews.ca/news/1887233/groat-road-to-remain-closed-for-three-weeks-for-curvy-girder-repairs/).

Given the fact that the corresponding phenomenon is of primary concern at the erection stage and a well-known cause of failure, in this case it was found that at the design stage, as well as at the construction stage, the correct measures were not implemented. Moreover, the construction manager had not taken the proper measures, leaving the crane ropes to stabilize the beams, without any type of temporary or/and permanent bracing. Thus, errors in design, erection and management in construction occurred.

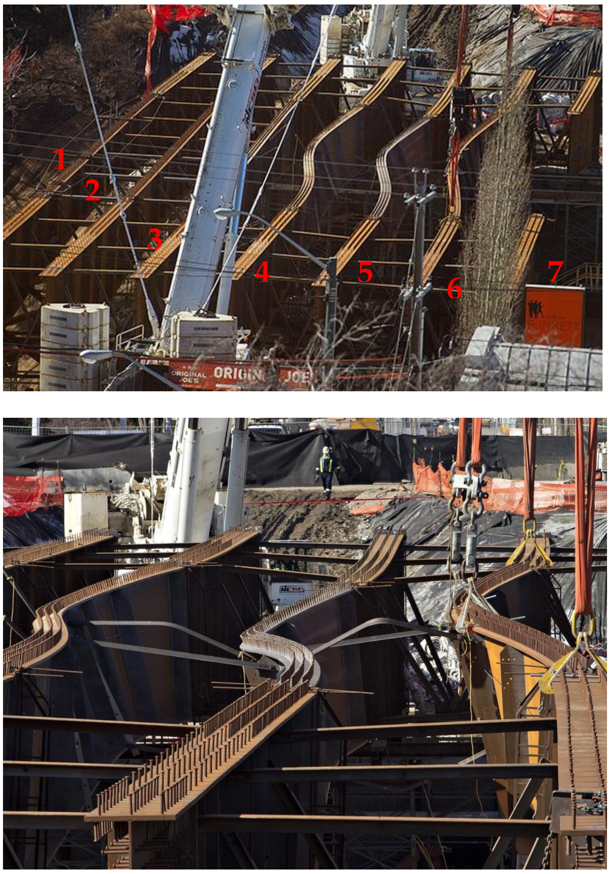

Fig. 9. Flexural torsional buckling of the main girders (the 4th, 5th, 6th) (https://globalnews.ca/news/1887233/groat-road-to-remain-closed-for-three-weeks-for-curvy-girder-repairs/).

An in depth qualitative analysis reveals the following results:

- In the failure area in question, e.g. between the 4th-5th-6th beam, the transverse support system (permanent or temporary for construction purposes) was not fully installed after the completion of the construction works on March 15.
- The 6th and penultimate beam of the system, out of the total of 7 beams of the bridge, remained incomplete and also unilaterally supported, after the completion of construction works.
- All the of the failed beams show deformations in the same direction. Therefore in the following hours, after the end of the work, due to the incomplete support of the girders the compressed side, probably under the dead weight of

the beam and /or secondary effects that developed after the end of the construction works (e.g. from geometric eccentricities, some type of a gust of wind striking surface of this girder), caused the deflection of the 6th and last installed beam which in turn diverted the other two, in a domino-type failure.

- Furthermore, it can be seen that during the construction, the transverse joints were not fully placed on the beams that failed, as respectively they seem to have been placed and exist between the 1st-2nd and 3rd girder. Certainly, the improper placement and connection of the bracing system contributed to the failure, even in the assumption that the study envisaged unilateral beam support, however with the complete installation of the transverse bracing system for the prevention of out-of-plane translational and especially torsional deformations.

In any case, it is very interesting to present the results of the remediation works. It was estimated that the replacement of the girders and the completion of the project would cause a delay of 9 to 12 months. However due to the requirements of the project clauses (approximately $ 15,000/day) the girders were not replaced but repaired on site, after being dismantled by the bridge under construction, by applying heat straightening methods and cold procedures at the construction site (Fig 10). Such methods are widely applied in bridge construction (Avent and Brakke, 1996; Avent and Mukai, 2001). It is known, of course, that hot straightening, depending on how it was applied in combination of the quality of the steel, alters the mechanical properties of the material and can cause a number of problems, such as accumulation of stresses, reduction of the modulus of elasticity, increase of the yield limit state by about 20%, a relatively smaller increase in tensile strength, decrease of about one third of ductility, decrease of fatigue limit, decrease of fracture toughness (Avent *et al.*, 2000).

Fig. 10. State of the girders before and after repair (https://www.cbc.ca/news/canada/edmonton/groat-road-bridge-twister-bender-or-bucky-edmontonians-suggest-names-1.3079412).

The contractors of the project guaranteed the quality execution of the repair, so at the end they proceeded with the repair despite any initial disagreements and voices to the contrary.

Overall, the following observations were identified:

(a) In any project, even from the design phase, the thorough examination of the construction stages is of paramount importance. The designer must take into account the real on-site conditions of the project, as well as the applied construction practices and technologies.

(b) The importance of the elaboration of the erection plans, especially for structures with long span and slender steel elements.

(c) The rigorous implementation by the construction team of the construction plans and described procedures.

(d) The knowledge, by the construction manager, of the behavior of steel structures. This deals with the fundamental instability phenomena, especially with the lateral torsional buckling. The redundancy and robustness, through the application of X or V type bracings, are of paramount importance. Furthermore, it is very important the well tightening of the bolted connections, ensuring continuity of the key-stability elements.

(e) The possibilities for real-time communication between the design team and the construction team, via web cameras.

(f) Structural monitoring, at the construction stage, as well, via web cameras.

4. The nature of failure in practice

From a structural point of view, the stiffness, strength and ductility are the mechanical properties ensuring the system capacity. From the other side, redundancy, robustness and ductility are the main structural characteristics that provide the collapse resistance. Certainly, the progressive collapse should be avoided (Starossek, 2007). This is achieved with proper bracing (lateral bracing and torsional bracing).

However, failures present an excellent way to learn from the experience of others, and especially from some historical structural failures (Morin and Fischer, 2006; Martin and Delatte, 2006; Biegus and Rykaluk, 2009; Wojnowski *et al*, 2002; Hao, 2009). A method to approach engineering problems is to use the trial-and-error method or the back-analysis procedure. For both the aforementioned methods, the past failure experience represents the benchmark point in order to ensure the structural safety.

Unfortunately, in civil and architectural engineering education there is a lack of a course aimed to inform students, systematically, about the historical disasters and failures of different structural systems. There are proposals to implement such a curriculum in the university education (Delatte, 1997; Delatte and Rens, 2002; May and Deckker, 2009); nevertheless the large majority of faculties had not introduced similar courses.

For practitioners there is the Structural-Safety organization (www.structural-safety.org), with two entities, namely, the Standing Committee of Structural Safety, SCOSS, and the Confidential Reporting of Structural Safety, CROSS; it is an excellent effort, however with limited international impact.

Definitely, after a failure, the collection of independent information and data is very difficult due to confidential nature of any process (Brady, 2014). Despite this, not only quantitative, but also qualitative observations and remarks are of paramount importance. There are many occasions in which legal decisions are influenced by parameters other than the technical investigation or any other root cause analyses reports. As a function of the catastrophic effects of a disaster, it is possible that political and social pressure lead to deviations from the real technical causes. Hence, any type of documented information is welcome in the engineering community.

A survey of experienced structural engineers illustrated several of the above mentioned conclusions, which are presented in the case studies in this paper

(Klasson *et al.*, 2018). The nature of structural failure is more than a calculation error; it is related to the holistic management, the capacity to organize and administrate the design, construction and maintenance process. Thus, the human mind, engineering culture and education could not be replaced by any type of detailed code or even by a sophisticated calculation (also performed by the aforementioned human mind).

The human mind, through a human error in design, execution, use and maintenance, provides the hazard, while the structural system, through its geometrical and mechanical characteristics, provides the vulnerability.

Qualitatively, in order to minimize the risk of failure, the tools we have are the education, culture, ethics and professionalism. The engineering judgment, which can ''*combat*'' the structural failure, is cultivated by the four above mentioned values.

Consequently, there is an urgent need to educate students and practitioners, through universities and professional associations; from failure, to learn, about the vulnerability of a system, and from success, to estimate the capacity of a system.

5. Concluding remarks

The paper presented three different case studies focused on steel structures subjected to quasi-static loads; each one with its adding value. For instance:

1. The roof collapse at the stadium of Twente FC, Holland, 2011, unveiled that the inefficient communication between different subcontractors would lead to a structural failure. This was due to management and on site work organization incompetence. Finally, beyond any technical issue, the clear definition and allocation of responsibilities and duties between the involved parties is the most important matter for a safe construction.
2. The roof collapse at the Maxima supermarket, Latvia, 2013, mainly revealed that the investor's pressure on the construction budget, as well as design and management along with inspection inefficiencies would be the decisive factors for a catastrophic failure. Another aftermath of the Maxima roof collapse was the warning sign of developing green roofs to existing structures not designed for such loads. Soil retains water, therefore, wet soil introduces additional loads not foreseen creating failure conditions. In addition along with a combination of snow loads, definitely, becoming hecatomb of deaths. Green roofs, due to environmental benefits, will be used more frequently in existing structures, hence specific attention should be paid in such cases with the reconsideration of the loading conditions as a function of a type of green roof (extensive, ~ 70 Kgr/m^2, biodiversive, ~ 200 Kgr/ m^2, intensive, more than 200Kgr/m^2). In case of a roof transformation, from the conventional one to a green roof, special attention must be paid on unilateral loading cases. Moreover, a distinct loading case considering the weight of depositing materials, on the roof, and in a concentrated area, must also be taken into account.
3. The girder collapse at the Groat Road Bridge, Canada, 2015, demonstrated once again, this time during the erection stage, that the basic root cause is inefficient management. Another cause is the lack of knowledge, from the construction manager, related to

the basic behavior of the steel structures. This is because the type of failure is most characteristic for long span, slender steel girders, which remain unrestrained. Consequently, for such structures the elaboration of a detailed plan of erection, associated with the erection drawings, methodology and sequence of erection is imperative. Focused on the erection sequence, the rule of thumb is to create a bracing unit, or in other words a stiff box. Furthermore, the stabilization of the assembled steel components must be completed at the end of each working day, thus ensuring redundancy and robustness.

Practically, the structural failure does not originate from only one source. It is a process of cumulated causes; at a critical and under suitable conditions, they form the state of collapse. Furthermore, in steel construction industry there is a long chain of stakeholders (investors, designers, fabricators, workers, inspectors, etc); all of that with different interests and level of knowledge. Thus, it is of paramount importance to recognize what we can learn from past failures, and based on that to educate, cultivate engineering judgment, ethics and professionalism in the engineering community.

Achieving the aforementioned goals, namely the technical excellence, we can further create management systems that will ''*trap*'' the human error and then minimize the probability of failure and maximize the structural safety.

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