Causes of some steel structures failures

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Origine de la ruine de quelques constructions métalliques

Ursachen des Versagens einiger Stahlkonstruktionen

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SUMMARY

This paper contains some short reports about several steel structure failures that happened on the territory of Croatia in Yugoslavia between 1967 and 1982. These failures are considered from the quality assurance's standpoint. Also, some personal opinions about the role of quality assurance within the building process are given.

RESUME

L'article traite de quelques cas de ruine de constructions métalliques qui ont eu lieu entre 1967 et 1982 sur le territoire de la Croatie, en Yougoslavie. Ces écroulements ont été analysés au point de vue de l'assurance de la qualité. L'exposé est suivi de quelques considérations de l'auteur sur le rôle de l'assurance de la qualité dans le processus de la construction.

ZUSAMMENFASSUNG

Dieser Artikel enthält knappe Berichte über das Versagen einiger Stahlkonstruktionen, die in Kroatien (Jugoslawien) von 1967 bis 1982 vorgekommen sind. Diese Versagensfälle werden hier vom Standpunkt der Qualitätssicherung analysiert. Einige Überlegungen über die Bedeutung der Qualitätssicherung im Bauwesen werden angefügt.

1. CAUSES OF SOME STEEL STRUCTURE FAILURES

Series No.	Structure discription	Failure	Place	Year	Load in moment of failure
1.	Sugar Silo D-45 m, H-30 m	Collapse during erection, H-22 m	Vrbas	1979	Wind cca 30 m/sec.

Insufficent stability of the cylindrical shell without wind girder and any erection assurance, with a big unstiffened opening on mantle (6x18 m) on the windside.

Series No.	Structure discription	Failure	Place	Year	Load in moment of failure
2.	Corn Silo D-8,28 m, H-32m (6 cells)	Collapse of one cell in use during lateral unloading (after 3 years of limited use)	Daruvar	1980	Cell filled with wheat

The cause of the failure was not officially determined, but there were three obvious defects of structure: insufficent stability of cylindrical shell, increased initial geometrical imperfections, shortage of loadbearing capacity of longitudinal bolted connections (The hole diameter greater than bolt diameter by 2 mm, thread length equal to bolt length).

Series No.	Structure discription	Failure	Place	Year	Load in moment of failure
3.	Cement Silo (Capacity 10 MN)	Collapse in use (after 2 years of use)	Split	1981	Silo filled (70%)

The official report says that there were several different design defects and also possibility of a "shake down" effect in the place where the shell is supported.

Series No.	Structure discription	Failure	Place	Year	Load in moment of failure
4.	Water tank, 2200 m^3 (on a water-tower above a restaurant). The tank was designed as two ventricle inside two concentric cylindrical shells, with free upper edge.	Collapse of inner empty cylinder in use	Vukovar	1970	The inner ventricle was empty, and the outer was full of water

Insufficent stability of cylindrical shell under outside pressure because of: increased initial geometrical imperfections, residual welding stresses and poor design (inadequate edge conditions).

Series No.	Structure discription	Failure	Place	Year	Load in moment of failure
5.	Corn Silo (capacity 100 MN)	Collapse of one cell in use	Podravska Slatina	-	Cell was filled

Insufficent stability of cylindrical shell because of: inadequate appreciation of loading conditions, inadequate appreciation of edge conditions of vertical stiffeners, poor design of stiffener splices without continuity on the level of horizontal shell splices.

Series No.	Structure discription	Failure	Place	Year	Load in moment of failure
6.	Tanks D-32 m H- 8 m	Collapse of 5 tanks during erection	Obrovac	1974	Strong wind

Insufficent assurance during erection.

7.	Single story industrial building with steel roof trusses. Area 840 m^2, Span 20 m.	Collapse in use	Gerovo	1972	Snow 2-3 kN/m^2
	Poor workmanship of butt welds in a lower chord tension member.				
8.	Single story industrial building with steel roof trusses. Area 2000 m^2, Span 24 m.				
	Poor workmanskip of butt welds in lower chord tension member.				
9.	Single story industrial building with steel roof trusses Area 2000 m^2, Span 20 m.	Collapse in use	Virovitica	-	Snow cca 1.8 kN/m^2
	Load above the standard (0.75 kN/m^2). Also inadequate treatment of supposed statical system.				
10.	Single story warehouse with steel roof trusses. Area 600 m^2, Span 10 m.	Collapse in use	Skradin	1976	Snow cca 1.0 kN/m^2
	Serious mistake in erection. The tie rods of main roof girders were connected with bolts M12 instead of M14, as it was designed. The bolt holes were made by burning.				
11.	Roadway bridge with trusses above floor	Collapse in use	Karlovac	1981	Special transport
	Special cargo hitched on a truss member. Precaution measures were not strict enough.				
12.	Roadway bridge with trusses above floor and lateral bracing between upper chords	Collapse in use after a special cargo hitched on a member of bracing.	Ličko Lešće	1980	Special transport
	Precaution measures were not strict enough.				
13.	Lamp posts	Collapse in use	Zagreb	-	Wind
	Underestimation of wind effects. Neglected influence of the dynamics. Difference between workshop drawings and original drawings.				
14.	Steam generator for nuclear power plant (NPP)	Overturned in transport	Between Zagreb and Rijeka	-	-
	Transportation procedure was not prepared professionally enough.				
15.	Stator of turbine for NPP	Overturned during transport	Krško	-	-
	Underestimation of influence. Precaution measures were not strict enough.				

16. River dam (water suply for NPP)	Collapse of all seven gates	Krško	-	High water wave

Grossly inadequate execution of operational procedure, and poor design.

17. Steam generator (NPP)	Excessive vibrations of U-tubes	Krško	-	Prestarting operations

Inadequate appreciation of real behaviour of structure.

18. Reactor make up water storage tank (NPP)	Rupture during filling	Krško	-	Pressure too high

Inadequage execution of filling procedure.

19. Auxiliary feedwater system (NPP)	Deformation of pipes	Krško	-	Pre-starting operations

Poor design.

20. Condensate pump (NPP)	Erosion on rotor and stator	Krško	-	Pre-starting operations

Poor workmanship.

Note:

Failures described under 14 to 20 happened either durign building phase or prestarting operations, between 1977 to 1982. During all that time quality assurance was implemented against USA Model of QA for NPP.

2. QUALITY ASSURANCE WITHIN THE BUILDING PROCESS

2.1. Experience gained from the failures described

Most of the described failures occured also because of gross human errors, that happened in different phases of building process. Most of them could have been discovered with a little additional checking, or in some cases without any additional checking, if there exised a more efficient QA system. Referred are only the cases of collapses or failures that have caused unforeseen costs and delays (e.g. the causes in NPP Krško), but not very many causes where gross errors have been noticed on time, either in planning phase or in construction phase, after wich corrective actions have been taken.

Phase	Design	Construction	Design and constructi-on	Use	Design and use	Total
Description case No.	3,5,13,17, 19	1,6,7,8,10,14 12,2o	2,4	11,12,18	10,16	
Number of cases	5	8	2	3	2	20
%	25	40	10	15	10	

Table 1 Phase of building process in which gross error has occured

	Possibilities of discovery	Case	%
a)	Discovery probable with additional checking		
	in phase of:		
	Planning:	3,5,9,13,14,15,16,17,19	45
	Construction	4,8,10,20	20
	Use	11,12	10
b)	Discovery probable without any additional checking	1,2,6,7,17	25

Table 2 Possibilities of Error Discovery

Described cases of failures refer to the structures that could be classified as "middle or low level of technology".

Gross human errors occured because jobs were entrusted to the people with insufficient knowledge or negligent attitude to the job. That was possible because of absence of effective QA.

Most countries already have some kind of a more or less effective "classical" QA system within the industry and within the building process. The question is, are there good reasons for some changes, particularly in construction? I think the answer is yes, both in technicaly developed countries as well in those which are not.
It would be a mistake if a country, through its technical regulations, implemented a QA system completely against Appendix B to 10CFR 50 /USA/ in the construction field, because this system as a whole, as a society game, is necessary and tolerable for the components of highest technology, e.g. nuclear industry, but the same system would be an unadequate and unnecessary handicap in civil engineering. Within the building process, a QA system against a new concept would be useful and necessary, in the form of regulations and guidances, but this should be an appropriate and simplified level of QA programme. However, in the internal policy, rules and organization of a construction firm, it is reasonable and useful to implement and accept all the principles and concepts of the 18 criteria, Appendix B, which has already been done by many world known firms and manufacturers outside nuclear industry, for competition and economic reasons.

However, everyone should be aware that efficiency of the QA system would essentially oscillate in different countries depending on their national system of contract and legal liability, motivation and technical level. The danger in implementation of QA lies in formalism and bureaucracy of the process. It could be expected that in some countries firms taking part in building process will accept QA principles and establish quite perfect QA manuals, procedures and organization,but only formally. Actually they will not implement it truly against known principles, and for example quality assurance will not have sufficient authority and will not be independent from production, etc.

IABSE, because of its international respectability should prepare a document on QA. This document could be a model for a national standard on QA. It shall contain only principles and aims. Good examples are standards: BS 5750 Part 1,2 and 3 CSA Z 299.1 to Z 299.4. These are standards for general industrial use, with three or four basic levels of quality programs, including guidelines for selection of appropriate level of quality program in each individual case.

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