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Remarks on Failure of a Reinforced Concrete Cooling Tower

Considérations sur la ruine d'une tour de refroidissement en béton armé

Bemerkungen über den Einsturz eines Stahlbetonkühlturms

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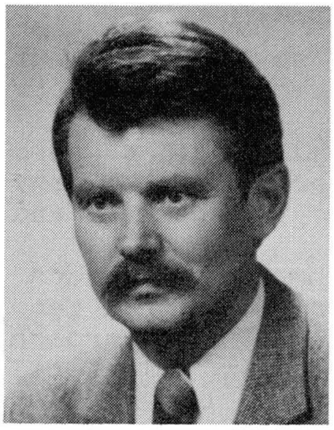

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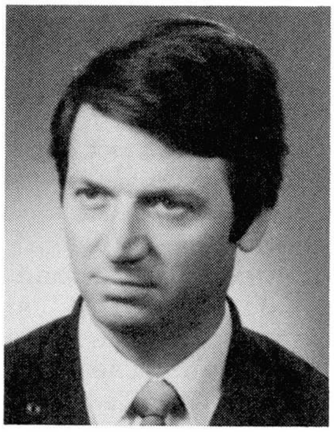

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SUMMARY

In February 1987, a reinforced concrete cooling tower, 100 m high, collapsed at the power station Turow in the Lower Silesian region. As the process of the collapse, its effects and the results of later research on its cause revealed a series of interesting findings and conclusions, we decided to describe them in our paper.

RÉSUMÉ

C'est en février 1987 que le tour de refroidissement en béton armé de la centrale thermique de Turow (Basse Silésie, Pologne), haute de 100 m, s'effondra brusquement. Le processus de l'écroulement, ses effets et les résultats de la recherche qui s'ensuivit afin d'en déterminer les raisons, ont apporté une série de remarques intéressantes ainsi que certaines conclusions. Ces considérations font l'objet du présent article.

ZUSAMMENFASSUNG

Im Februar 1987 ist ein 100 m hoher Stahlbetonkühlturm des Kraftwerks Turow eingebrochen. Der Verlauf des Unfalles, seine Auswirkungen und die Ergebnisse späterer Forschungen über die Ursachen waren so interessant, dass wir uns entschlossen haben, sie in dieser Arbeit zu beschreiben.

1. Introduction.

Increasing in the last years computing abilities and intensive research in modeling and structure analysis, brought the formulation of the new idea of concrete structure definition a term called structural concrete. The term called total structural designing is tightly with this term connected. What is understood by these terms, we may find in the works of Bruggeling [1], Breen [2] and others.
First it is necessary to introduce a definition of the structural concrete. Bruggeling [1] gives the following definition of this term; "Structural concrete" refers to any structure built from concrete, and non-prestressed and/or prestressed reinforcement which can resist, in controlled way, all the actions exercised on these structures by loads, imposed deformations and other influences. Moreover, these structures must be constructed in the safe and economical way. In that definition, the article in a controlled way says about our possibility to control, for instance: some deformations, cracks, or durability during the designing process.
Breen [2] says that a structural concrete that is the term describing a wide range of concretes used for building any structure, involving plane concretes, normally reinforced and prestressed concretes.
The basic idea of what is termed the "Structural Concrete Approach" is to eliminate distracting and artificial barriers which tend to compartmentalize the designer's thinking. In the new approach it's necessary to emphasise more global attention to total load paths and resisting elements.That means that at the base of that definitions there lies a wish at overcoming the existing division of concrete structures on normally reinforced and prestressed. In other words it is a wish to enable an analysis of freely chosen structure independently of the way of its reinforcing and a type of acting loads.
Introduction of these definitions and satisfactionary description of computing methods opens the way to the total structural design. Under this term it's necessary to take into account, building of special kind of structure model, (it may particularly refer to the concrete structure), connected with environment through all existing influences. Model like that may be totally analyzed,and the picture we receive of its internal work, gives the possibility of its effective and active forming and constructing. This process maybe repeated up to the moment of receiving optimal characteristic of designed structure. Especially important is the fact, that using this method, a designer is reducing (minimizing) a material usage and is controlling the work of the structure all the time. Using this method, it is possible to calculate and design any type of structure independently of the type of loads.So the principle of total design lies down now in looking on the structure as a whole, not as at the system of separated elements.
Scordelis [3] describes a process of total designing that may be fulfilled and presented as a collection of the following stages:
- first stage it is a conceptual stage,
- second is a predesignig,
- third: structure analysis,
- fourth: structure synthesis,
- fifth: a drafting stage.

Especially important is the third stage that means observations of

structure behaviour under the wide range of influences. Designing process on this stage may be realized in two ways:
First relays on calculating the internal forces and further on using the received results in detailing of structure. This way is a kind of imitation of traditional methods, fulfilled at the general look at the designing structure. Second way relays on examining the internal forces flow in structures involved in the wide range of influences connected with active and effective forming of this structure during the process.
There opens a wide range of possibilities and it is enough to show here only one of them that is possibility of modeling the process of structure collapse.
As an example the case of cooling tower collapse was analyzed.

2. THE COLLAPSE AND ITS EFFECTS.

On the 7th of February 1987 at the power station TUROW in Lower Silesia Region in Poland, there collapsed one of nineexisting there cooling towers. On the hight around 43 m over the ground level, that means between 38 and 39 m of tower shell, almost horizontally, the shell was cut and fell down into the tower.
The construction of tower and its remains after the collapse are shown in fig. 1.

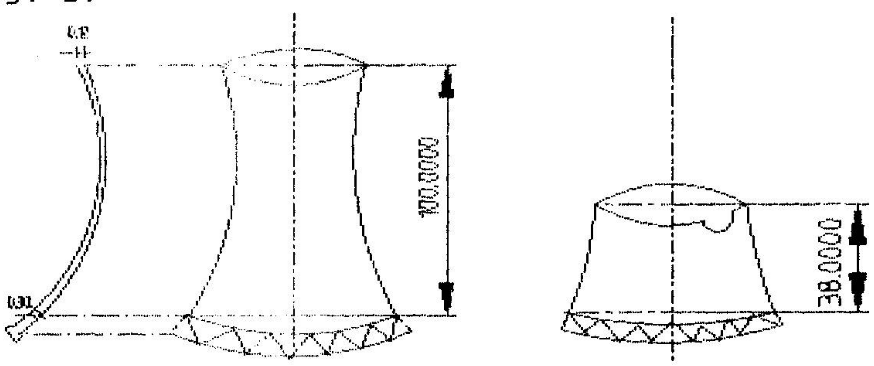


Fig.1
Cooling tower before and after collapse.

The discussed cooling tower was built in 1963. The Main part of this structure make the reinforced concrete double curved shell, dimensioned as follows: total high 100 m (cover shell 95 m), cover shell dimension 74.6 m, shell thickness in the lower ring 0.30 m and it is decreasing to 0.12 on the level of 30 m, further thickness is constant. The shell is reinforced by nets of bars on the distance 0.20 x0.20 m.
For over 25 years of exploitation, the discussed structure was very often controlled and examined and never any damages were found.That is why the researches on the collapse were very difficult.
There were many tests made of which most important were:
- tests of strengths characteristic for used materials,
- tests of physical and chemical properties of used materials,
- geodesic tests of the real geometry of the remaining part of the shell and comparison of the results with the ideal shell geometry,
- analysis of changes in the shell state during exploitation caused by the failures during the shell building,

- analysis of the influence of super loads on the shell work,
- analysis of correctness of designing solutions applicable to the tested shell.

Generally it was established that:
- concrete was generally technically good, that means its strength and quality coefficients were containing in the range demanded by codes of practice,
- position and quality of reinforcement was good,
- most sensitive points of the shell were the places of work breaks made during the shell concreting. It was established that reinforcement bond was decreased in these places. Also the corrosion of concrete developed there and it was increased by diffusion of the water through concrete. The weakest point developed in the region of 38th stripe of concreting. Moreover the stripe of the weak concrete developed on the great length. The increasing lixiviation of cement from concrete caused probably some rising of horizontal slit in the shell. This led further to a change of the static scheme, local overload of the structure and finally to a collapse.

The following hypothesis about the mechanism and causes of collapse were formulated:
- the post building imperfections of the wall-shell,
- the technological and technical disadvantages referring to the concreting process,
- a very bad quality of technological breaks during the concreting,
- the destructive influence of the environment eq.
  - strong wind blasts,
  - local erthquake caused by mine exploitation existing around,
  - thermal influences etc.

After the detailed analysis of the causes listed above, the main reason of the collapse was found. It was the destruction of concrete on the 30 m long stripe of shell circumference, caused by long term lixiviation of cement from concrete. There appeared a long slit in the wall, which changed the static model of the shell structure.

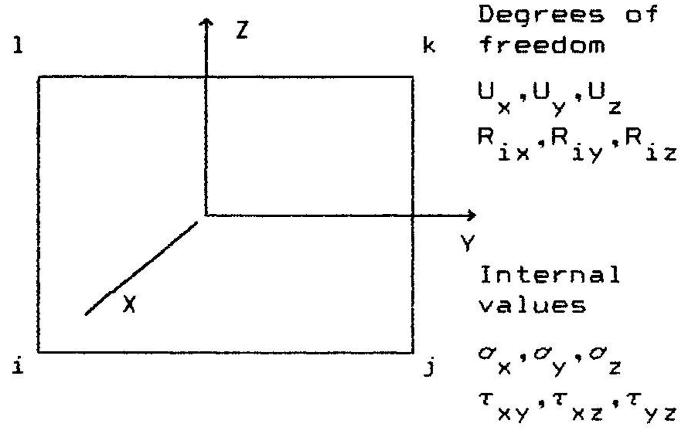
3. MODELING OF THE SHELL WORK.

To check the hypotheses about the cooling tower collapse, mentioned in the previous section, the analytical model of structure was built. There was A series of Computer Programs for Static Finite Element Analysis of Structures called STRAINS used [4]. System STRAINS works on the base of the following assumptions:
- there exists the continuity of the matter,
- stresses in the structures develop in the moment applying some forces,
- the matter is linear,
- the state of stresses in examined point is marked by a state of deformations in this point,
- displacements and deformations are small,
- it is possible to use Saint-Venan's principle.

To build the model of the discussed structure thre were used plane surface elements as shown in. Fig. 2a . The received node mesh is shown in fig. 2b.

On the shell surface, the horizontal slit was modelled. The length of the slit was changeable. The model was loaded by wind forces and several times examined while changing the slit length.

The results of the calculations are shown in figure 3a,b,c.



a. Used shell element

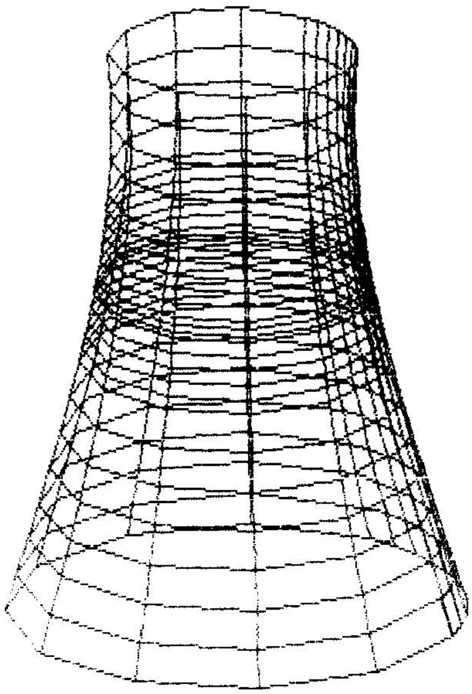
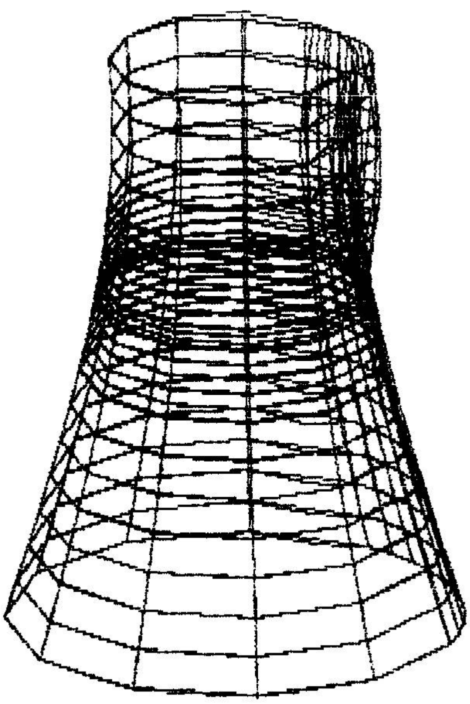
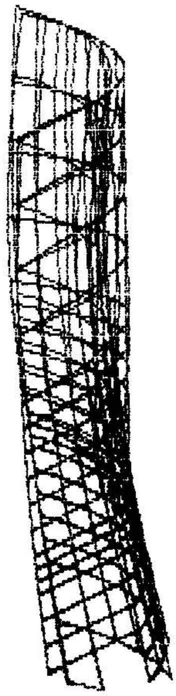


Fig. 2 a,b.
Finite Element model of the discussed cooling tower.

b. FEM modell of the shell





a. Displacements of the shell under the wind load. Length of the slit 40 m

b. Zoom of the deformed place

fig. 3 a,b
Results of the computer calculations.

On the base of the upper listed results it was possible to establish the limited length of the slit which gave enough values of the displacements to cause destruction of the shell.

During the calculation process the limitations of used computer program were seen. Mainly they may be listed as follows:

- it was possible to use (in the applied system STRAINS) only 500 elements. It was only enough to cover the tower coat, by the mesh dimensioned 6x6m. Only around the slit, the mesh had smaller dimensions 0.20x0.2 m. The mesh like that was to rare and received results were only a far approximation of reality,
- there were used only isotropic elements (concrete) to build model of the reinforced shell. In the used system there were no special reinforced concrete elements,
- the used system was't connected with dimensioning systems, so it was necessary to transfer data handy.

Instead so many limitations and disadvantages the gained results make the evidence that such method of structure analysis has significant future.

4. CONCLUSIONS

The presented way of the total structural design of structures, lead to a wider evaluation of their work. That is a way of connecting in the one system, on the same level, methods of structure analysis and synthesis, with the possibility of the data exchange. During the process of the structural designing it is possible to take into account many new aspects and observe a structure response. Also it's possible to design wanted features of structure, e.g, material, shape or ways of reinforcing.

In the presented example the structural analysis of work of the cooling tower shell work with slit permitted to check several hypotheses about collapse reasons.

This way of structure analysis is possible only while using computers. Growing calculation power of computers gives a lot of hope about progress in that field. This trend is bound to continue.

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