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FUNDAMENTAL ASPECTS CONCERNING THE SAFETY OF REINFORCED CONCRETE STRUCTURES

BY

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Abstract. In this work the problem of structural safety of buildings made of reinforced concrete is discussed, with special emphasis placed on the influence of the quality of execution.

The shortcomings of the current analytical evaluating procedures of buildings safety, in general, and of those made of reinforced concrete, in particular, are presented, as they determine, in the end, the over sizing of the load-bearing elements.

Key words: safety; risk; damage; execution errors; geometric deviations; experimental actions.

1. Introduction

Exploitation safety of a building, in various forms known in practice (structural safety, serviceability of equipment and installations, safety against accidental or extraordinary events: explosions, fires, glissades or rock fall, earthquakes, etc.), is considered as an objective attitude to be used without having to be a serious risk.

A construction is safe when it can preserve its structural and functional attributes for a certain period of existence in relation to predetermined performance criteria, which usually represents a major limit state.

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Being parts of calculating methods, the various performance criteria are used to assess the level of safety and of anticipating the behaviour of the constructions in terms of bearing capacity and deformability, depending on the operations performed, the geometric characteristics of the elements, and the physical-mechanical properties of the materials incorporated (Buchman, 1986).

In this sense we resort to the structural design, a creative complex process which aims at setting the parameters meant to ensure construction safety and efficiency, under conditions dictated by its functionality and aesthetics, the nature and type of the site, as well as the specific implementation technology.

In practice we accept the idea that a construction safety is guaranteed, when achieving a state of stable balance between the effects of stresses, regarded as destructive elements, and the consequences of the factors that determine the strength, rigidity and durability of the building as stabilizing elements.

The loss of this can result in tearing of one or more load-bearing elements, the development of efforts or deformations which are incompatible with the requirements of a normal exploitation or the emergence of a state of excessive cracking. To a large extent, such situations arise as a result of exceptional actions, which consume most of the resistance of the buildings reserve. Among these, one can mention frequently: earthquakes of high intensity, the violent effects of extreme climatic factors (heavy rainfall strong air currents, striking and repeated differences of temperature), glissades and rockfalls, malfunctions arising in the process of exploitation due to the failure of machinery and equipment, occurrence of explosions and fire, etc.

This kind of actions can often get out of control, which is why it requires special measures of prevention and protection.

In our country, the seismic action is the most important risk factor, by the size of the territory affected, the frequency of occurrence and intensity, being are the main source of damage and collapse for structures.

The overall level of safety of a structure depends not only on the design conception and the calculation method used, but also on the execution conditions (materials, technologies, correspondence between geometric characteristics or types of design supports and those actually carried out on the site), operating conditions (the interplay of stresses during the lifecycle of the building, changing of the internal structure of concrete in tension and between concrete and reinforcement, due to the rheological properties of materials and deterioration of adhesion), and as a result of climatic factors.

During construction time there appear inherently technical nonconformities (exceeding the design allowable workload intensities, introducing materials of qualities that differ from the expected ones, geometrical characteristics variation in relation to the project, more severe loading conditions than those anticipated, sometimes on static schemes that differ from those allowed in calculation) or due to human nature (insufficient technical documentation, deficiencies in training, or in the conduct of staff, changes in the initial concept of the composition or the introduction of inadequate technical solutions by unauthorized persons) (Ferry Borges, 1974).

Admitting a particular risk factor in the designing practice based on probabilistic concepts should not leave the impression that it deliberately accepts the existence of mistakes in design or execution. On the contrary, it starts from the idea that these processes are conducted fairly, in accordance with the technical regulations in force, thus justifying the risk by the possibility of events that cannot be controlled or rigorously controlled.

Discussing this kind of problems, one should not lose sight of the fact that people agrees to take chances in various occasions of life, but could not accept the idea that the building where he works or rests might collapse (Bekett & Alexandru, 1997).

Considering that the construction risk is conditioned only by the design and execution of the structure is a simplistic way to approach the issue, because the shortcomings encountered in the process of operation and maintenance, including any consolidation measures adopted over time are due, not infrequently, to these issues.

It is difficult to specify how low should an *apriori* risk level be accepted, although theoretical studies examining the values of 10^{-4} ... 10^{-5} may be mentioned (Florea, 1993).

In terms of safety degree which would have to be achieved, one should highlight the special significance of weighting the risk taken, in relation to the seriousness of the consequences which may result in damage to a particular item.

Thus, in a reinforced concrete multistoried frame structure, if the collar beams are oversized by 50%, one can record an increase of seismic safety of 10%...15%, with a possible less favourable situation as a result of migration of critical sections towards the poles. However, their oversizing by 50% is likely to lead to an increased seismic safety by over 100%, noting that in such structures, the cost of the pillars is, generally, lower than that of the beams (Bekett & Alexandru, 1997).

Because both the parameters that determine the level of loading and the factors that determine construction safety are not, as yet, sufficiently well controlled in order to reduce the risk level, there is a tendency to achieve through design an oversizing of load-bearing elements, resulting in for safety reserves difficult to assess the entire structure (Ferry Borges, 1974).

2. The Influence of Execution Errors and Defects

The research studies on structural safety lead to the conclusion that there is no certainty concerning the adequacy of buildings behaviour during construction.

There is, instead, a certain degree of risk (probability of degradation or damage), accepted by the society, if the predictable consequences do not exceed predetermined limits. This is the result of the random or systematical occurrence of defects and conforming errors in the make-up of the structure, following construction errors rather than a faulty design or operation.

Information systematization relating to the damage observed in construction, based on rigorous criteria, resulted in a major data base concerning the causes, nature and frequency of the occurrence of errors and defects, as sources of the deterioration and destruction of a number of elements and structures.

The results of an investigation carried out over 800 cases of damage states recorded in construction in Europe, show that

a) 52% of damage states occurred in civil constructions and only 22% in industry;

b) 63% of damage states were yielding structures, and 37% were the result of deformations or cracking state, located above the allowable limits;

c) 36% of design errors and 54% of runtime errors have occurred as a result of insufficient technical knowledge;

d) 63% of damage states originated in the violation of general execution and exploitation rules and 16% were due to non-compliance with specific requirements.

The favourable effect of the additional checks and verifications carried out in order to avoid gross errors is highlighted by the following findings:

a) 52% of construction errors have been detected during execution, 45% during exploitation and 3% after demolition;

b) 55% of the errors can be found by additional control, 32% without such control, and in 13% of cases it was not possible to identify the mistakes committed.

The findings and observations recorded on the site in various circumstances, confirms the results of the research undertaken, highlighting the fact that most of the disruptions in construction are based on deficiencies in various stages of execution.

Committing mistakes of conception or design is less probable, because the specific tasks, which these stages will have, follow a well developed tracking and control. As a result, any deviations from the requirements and composition can be traced easily and corrected in a timely manner, that is, before the commissioning of the objective.

The deficiencies and imperfections in execution are many and varied and have a number of peculiarities that make it difficult to highlight them at an early stage.

During a normal operation, the elements of reinforced concrete structures are less stressed and in most situations, do not reveal any defects in the internal structure, as it happens in the case of installations. In the case of the structural elements or units, there are, quite often, hidden defects which remain unseen. In such situations, the damage can be triggered by a minor influence that has the adverse effect of aggravating hidden vices generated by the improper execution or unreasonable use of the materials (concrete or reinforcement of lower levels of quality than those stipulated in the project, inadequate recipes for concrete preparation, the use of inappropriate methods of work, etc.).

In the category of execution defects (errors), a special importance should be given to geometric imperfections of the elements or of the structure as a whole. They can exert negative influences on bearing capacity, can modify the intensity or even the nature of the stresses, they can disrupt the functioning of the objective, thus influencing the quality of services provided and the costs they incur.

The influence of geometric deviations of a finished structure against the design through effects constitutes a problem dealt with sporadically in the literature. There are few studies on this topic, and those published do not abound in information and explanations concerning the collection, storage and processing. The results communicated differ much among each other as a result of the differences between the requirements of (normal) design and execution in different countries, between the technologies used and the degree of professional training and labour discipline, which are essential factors in ensuring the quality and accuracy of execution.

Geometric errors occur not only at the section and element level, but also at that of the entire structure when by using a wrong location or positioning against the design specifications, they may generate very dangerous additional stresses.

In the case where, in the same section or element the negative effects of several types of deviations, are the decrease of the cumulated bearing capacity or local stability (general) can achieve high rates, endangering not only the safety of the elements but also of the structure as a whole.

Uncertainties relating to the shape and dimensions of the concrete section and those relating to the amount and position of the reinforcement (the section width variation – Δb; the section height variation – Δh; variation of stretched and compressed reinforcement section area – Δaa and $\Delta Aa'$; variation of the concrete cover thickness of stretched and compressed reinforcement – Δa and $\Delta a'$; length variation – ΔL; variation of element's real axis position in relation to the theoretical axis – Δax) will influence in a different way the bearing capacity of reinforced concrete elements, depending on their type and purpose of the behaviour.

The following are some of the conclusions relating to the topic, as presented in the research studies.

The research on situation of eccentric stressed elements reveal that the pillars having low amounts of reinforcement are the most affected by the existence of errors of execution, reducing the bearing capacity from 20% to 60%, much higher than in the case of components with a high content of reinforcement. As the influence exerted by the section width variation (Δb) is insignificant in relation to the effects of other deviations it may be neglected.

It was found that the poles with small cross-sections (30 × 30 cm), are the most affected by execution errors. Thus, admitting for irregularities Δh, Δax, Δa, Δa' values of 1.0 ... 2.0 cm (situation encountered often in practice), it was established, that analytically the bearing capacity decrease is averaging 7%...12%, when taking into account separately that Δh and Δax are 4%...7% and if the Δa and $\Delta a'$ are considered.

By cumulating the irregularities, these effects lead to a reduction in the bearing capacity of 25...30% which represents a noteworthy value.

Gross execution mistakes are often made when the relative deviations ($\Delta b/b$, $\Delta h/h$, etc.) are 0.1...0.15 and the resistance capacity decrease reaches 20%...30% for a single deviation.

In terms of the effect of geometric deviations on the stress state sensitive differences have been found between the magnitude of the stress induced to statically determinate structures, in relation to the statically indeterminate.

Therefore, the need to differentiate the safety coefficients for various situations is stringent.

In all cases, the effects of geometric deviations on the shear force can be negligible in relation to the effects caused by *M* and *N*.

This observation contradicts the current mode of considering uncertainties by tests coefficients, currently used, and which leads to the same level of safety for all three efforts (*M*, *N*, *T*).

A possible solution would be to damage sectional efforts with specific differentiate safety coefficients, resulting in a probabilistic analysis, which certifies the scientific character of the process.

For statically indeterminate structures the following conclusions can be formulated:

a) the effects of geometric deviations are closely related, both in the columns and beams;

b) the structure shape influences too insignificantly by the effects of inaccuracies; the road bridge structures are little affected by geometric deviations because the piles eccentricity effect, does not intervene;

c) the effect of geometric deviations on efforts occurring in the structures made up of bars, cannot be neglected even in the case of large-section elements, since the sizes, Δl, Δax, do not depend on the magnitude of their stiffness.

It can be concluded that the principles of calculation using the limit state method does not take into account the variability of geometrical characteristics of the elements and structure as a whole, because the measurements concerning the errors and uncertainties (which in reality do not allow for effective realization of the structure), are insufficient and inconclusive in terms of quality. Accordingly, the information in this area does not allow the establishing of statistical laws of distribution.

3. Conclusions and Proposals

Degradation of reinforced concrete internal structure is characterized by a progressive evolution in time, the possible damage state can be notified in a timely fashion and consequently prevented.

For this reason it is necessary to carry out systematic and competent controls (inspections) on the behavior of structures throughout their existence (especially in the case of major interest objectives, when constructive solutions or new materials are applied, for which not enough experience has been accumulated or in the case of constructions which raise suspicious as to their quality).

An objective and, therefore, a truly effective control, cannot be carried out other than outside the sphere of interests of the institutions or individuals, that are not impartial, subordinated to the factors involved in achieving that goal (designer, contractor or beneficiary).

The control should not relate only to the concrete quality (as is done routinely), as quite frequently serious deviations from the correct way of reinforcements layout are found, especially in terms of rectangular frames of pillars and beams, when these cannot be found in the position and in the amount provided by the design project.

Monitoring the quality of construction works should not relate only to the execution itself, the process will include the materials used, with the exception of the concrete, partially purchased through the centralized stations, which are external to the site.

It is necessary to pay attention to all state parameters and not only the mechanical resistance of the material, because in some steels (semi tough), the issue of limit strain is of special importance although it is often ignored or considered as insufficient.

In time, the buildings are subject to a multitude of factors influencing them, which is why they should be supervized and upgraded. The failure to do the repair works or consolidation in due time may lead to serious damage of buildings, equipment and installations the worsening of safety and comfort conditions, leading to a considerable increase of the cost of the rehabilitation works.

Following the earthquakes of the past quarter century, the problem of adopting appropriate measures, in order to preserve the safety of the existing built patrimony, has been seriously raised. The actions results may be considered satisfactory, especially under theoretical aspect, aimed at improving the technical specifications.

On the other hand, the efforts for the implementation of the rehabilitation measures expected by specialists are far less consistent, very few consolidation projects drafted in recent years being materialized, due to underfunding.

The need to ensure a higher quality of construction works becomes evident, in order to achieve safety in operation, together with the efficient use of resources, materials and design, the high quality, being able to generate considerable economic benefits.

In order to achieve an increased safety and durability of structures, it is advisable to resort to:

a) using concretes with a high degree of impermeability;

b) using cements resistant to aggressive physico-chemical actions;

c) convenient setting of concrete cover layer thickness of the reinforcement;

d) providing protective plasters, based on cements resistant to aggressive actions;

e) applying of peliculogene layers of protection on elements surfaces exposed to corrosive attack.

In order to reduce, as much as possible, the number and importance of the consequences of the defects, it is necessary

a) strict adherence to details and indications set out in technical documentation;

b) introduction in the work of the materials (concrete and reinforcement) of the qualities and in the quantities prescribed by the designer;

c) treating properly visible surfaces, in elements exposed to aggressive attack.

Restoring the structural safety of buildings that have suffered damage or deterioration expected to be obtained through the above mentioned measures, must be accompanied by

a) informing a wider circle of specialists about the causes that favoured various types of defects, in order to identify them and prevent their recurrence in the future;

b) reducing the costs of design and rehabilitation expertise in terms of costs of materials and labor, by applying the most effective state of the art solutions;

c) improving the quality of design and execution works, as well as of the computing and composition requirements, in order to ensure optimal sustainability and comfort.

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ELEMENTE FUNDAMENTALE PRIVIND SIGURANŢA STRUCTURILOR DIN BETON ARMAT

(Rezumat)

Este discutată problema siguranţei structurale a construcţiilor din beton armat, insistându-se asupra influenţei pe care o exercită calitatea execuţiei.

Sunt prezentate neajunsurile procedeelor actuale de evaluare analitică a siguranţei construcţiilor, în general, şi a celor din beton armat, în special, care determină, în cele din urmă, supradimensionarea elementelor portante.