Safety of the "Tabularium and Palazzo Senatorio" monuments

Autor(en): **Croci, Giorgio**

Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **46 (1983)**

PDF erstellt am: **23.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-35831

Safety of the «Tabularium and Palazzo Senatorio» Monuments

Sécurité des monuments «Tabularium et Palazzo Senatorio»

Die Sicherheit der Monumente «Tabularium» und des «Palazzo Senatorio»

Giorgio CROCI
Professor
University of Rome
Rome, Italy

Giorgio Croci, born in 1936, received his civil engineering degree and is now professor of Tecnica delle Costruzioni with the Faculty of Engineering at the University of Rome. He has carried out a large number of projects for strengthening monumental works, and has organized courses and conferences on the subject.

SUMMARY

This paper discusses a methodology for examining the safety of monuments and of old buildings in general. In fact, the way uncertainties are dealt with in these structures plays an essential role in the evaluation of their safety as they are, and thus in defining the necessary investigations and the criteria for the restoration operation.

RESUME

Une méthodologie est proposée pour l'étude des monuments et des constructions anciennes en général. Dans ces ouvrages, la manière de traiter les incertitudes joue un rôle essentiel dans l'évaluation de la sécurité à l'état actuel et, en conséquence, dans la détermination des enquêtes nécessaires et des critères d'intervention.

ZUSAMMENFASSUNG

In diesem Beitrag wird eine Methodologie zur Untersuchung der Baudenkmäler und der Altbauten im allgemeinen beschrieben. Bei diesen Bauwerken spielt nämlich die Behandlung der Unsicherheitsfaktoren eine bedeutende Rolle für die Einschätzung der Sicherheit im derzeitigen Zustand und demzufolge für die Feststellung der erforderlichen Untersuchungen und der Kriterien des Eingriffs.

1. INTRODUCTION

Evaluating the safety of a building is tied to the investigations that have been made and to the operations planned on to be made. The evaluation must first be made taking things as they are, using as support all the data that is immediately available.

Should this evaluation reveal inadeguate safety margins, two things may be done, either alternatively or together: extend and deepen the investigations so as to reduce uncertainties and better clarify the facts, or plan operations for the reinforcement and adaptation of the structure.

The choice of the level of knowledge at which to stop the investigation and go on to the planning of any operations depends on a number of aspects. Among these are: the economic (comparison of the cost of further investigation with the cost of operations, taking into account the possibility that further studies may not reduce operations); the risk-factor (to be evaluated is the probability that further damage may develop, or that the building may even collapse, during the longer time taken for investigation); and the building's artistic value (any changes made by investigations or operations must be kept limited).

2. RELIABILITY AND CREDIBILITY

2.1 Two things condition a safety evaluation:
- the uncertainties in the magnitudes, laws, models, hypotheses etc. involved in the study;
- how far the phenomena or actual situations may be adequately represented mathematically.

2.2. Reliability

The dealing with uncertainties, that is, with the random nature of the quantities and magnitudes involved, in the object of probabilistic and semi-probabilistic analyses.

In applyng this method to existing constructions, and in particular to those that are damaged or weak two kinds of difficulties present themselves: the definition of the characteristic parameters, and the problem of how to deal with uncertainties in structural behaviour.

Regarding the characteristic parameters (material's strengths, indirect forces induced by ground settlement, etc.), it is in fact hard to follow standardized procedures, without introducing subjective content. The result is that the partial safety coefficients γ mean very little in themselves, and thus only the ensamble of γ and characteristic value has real meaning: the more precautionary figure the former is set at, the smaller may be the value of the latter, and conversely.

Regarding structural behaviour, the most reasonable appearing path to follow is to use several models for reference, it being in general quite difficult to establish which of them will be the "worst case" a priori.

Furthermore, and quite otherwise from the case of a building that is a yet to be built, in studying an already-existing structure it is worthwhile taking even magnitudes or situations having slight or no reliability at all into account, should it come about that their actual existence will mean a less favorable structure behaviour. Doing so, investigations may be so oriented as to find that the probability of these situations coming about has increased, or even become a certainty.

From these remarks it appears obvious that if it is desired to keep a rational approach to the application of the semiprobabilistic method, without recurring to higher-level probability analyses (a thicket of difficulties), the uncertainties in magnitudes, laws, hypotheses and models adopted must be brought out in some way; the "reliability index" in fact answes to this purpose, and lets account be taken of the precautions taken in formulating an opinion on the building's safety (see Section 3).

2.3. Credibility

The limits of scientific knowledge and the incompleteness of the available data (this relative too to how far the investigations have been taken) do not often permit of adequately knowing and representing the true phenomena and behaviours. Typical examples of this problem can be found in the soil-structure interaction phenomena, in the laws according to which the development of certain phenomena can be predicted, in the models of structure behaviour after cracking, crushing, deterioration, induced stress states, etc.

These aspects can find no place in a semi-probabilistic analysis, nor indeed even in a higher-level probability analysis. Even the characteristic crushing strength becomes a quantity that is essentially defined on subjective bases, thick with wrtitrary assumptions, when only a few unhomogeneous tests are available (sclerometric tests, ultrasonic tests, core-borings, etc.), which themselves are difficulty correlated on the basis of standard rules.

But these problems have anyway one aspect in common: if high reliability is wished, then severely conservative magnitudes, laws, models and hypotheses, representing limit situations that are often quite far frome reality, must be adopted. And at times this can be difficult to do, since it is not always possible to foresee what direction the approximations must take so as to have the highest reliability.

In conclusion, the designer may find himself in the fix of having to make "reliable" evaluations of safety only by veering far away from "reality" or from the "average values" and this can lead to excessively conservative opinions, making structural operations appear necessary that in fact are not.

So as to bring out these situations, as the study phases go ahead it is necessary to develop too, together with an indication of their "reliability", a "judgement" on the "credibility" of the values chosen, ad is summarily indicated in the description of the study phases (Section 3) and in the attached table.

This kind of judgement is something new relative to traditional, whether deterministic or probabilistic, analyses, since it lets the subjective and the objective, the empirical and the theoretical, all find their places within a single methodology, throwing into sharp relief the scant significance that theoretical analyses can have when not even further investigation can clarify the facts.

2.4. Safety, investigations and interventions.

The "theoretical verification" of a building's safety in its as-is state is fully meaningful, and lets a favorable or definitive opinion of it be formed, only when the corresponding indices of reliability and of credibility are high. But this is not always the case.

As already mentioned, it is worthwhile taking situations of low reliability into account, the purpose of this being to have an indication of more favourable and economic operational criteria. In fact, by modying strengths, constraints, etc., these operations will make reliable situations that originally were not so.

However, it is often indispensable to take situations of low credibility into account, and not only because some complex phenomena may never be fully understood, but especially because it is expedient to begin the study with the few data initially available and go on, taking advantage of the information deriving from the investigations to improve credibility, thus rendering situations reliable and hence less serious than initially assumed.

The logic is similar to that followed in the branch of probability theory making use of the Bayesian criterion.

This, starting from a priori distribuion functions based on a small amount of original data and on subjective assessments, changes the "a priori distributions" little by little as new objective date becomes available, into "a posteriori distributions". For equal reliabilities, this lets the partial coefficient γ be corrected.

In a limit-state analysis -- which is operationally a deterministic analysis -- a deeper knowledge, that is, an improved credibility on the relevant mecanical quantities and on structural behaviour allows on to modify the characteristic values and structural behaviour models. For equal reliability, the partial coefficients γ may remain unaltered.

When credibility remains very low, despite the carrying out of the investigations that appeared suitable within a technic-economic context, the judgement may be deemed acceptable only if the safety is "theoretically verified"; if it is not, this doesnt necessarily imply that the construction does not possess adequate safety margins in reality. In this case, the safety assessment must rely on a proper balance between theoretical verification and judgements of empirical and intuitive nature; their relative weight depends on the difference between the degrees of reliability and of credibility.

3. THE ORGANIZATION OF THE STUDY

The study of the Palazzo Senatorio and Tabularium was repeated several times, account being taken first of only the immediately available data, wider-ranging investigation programs then being gradually defined, within the spirit of what has just been said, ad the checking out of the safety in the as-it-is state manifested inadequate margins.

The study was organized into the five phases to be set forth below; in the penultimate column (as shown in the attached table) is indicated the "credibility" of the mathematical representations, the interpretations, the assumptions, the hypotheses, the schemes, the values, etc., that is, the correspondence between the choices made and the reality of the phenomena and thus the credibility of the results. In the last column is indicated the "reliability" of those same choices listed above, that is, the prudence and precaution taken regarding safety when the reliability can be a priori defined.

I. DESCRIPTION OF THE WORKS

This is summarized in six items (see the table); each of these, is the result of the investigations made and is characterized by a greater or lesser "credibility". The "reliability", instead, is introduced only in the later phases (figs. 1 and 2).

II. THE MODELLING OF THE FORCES, OF THE MATERIALS CHARACTERISTICS AND OF THE STRUCTURAL BEHAVIOUR

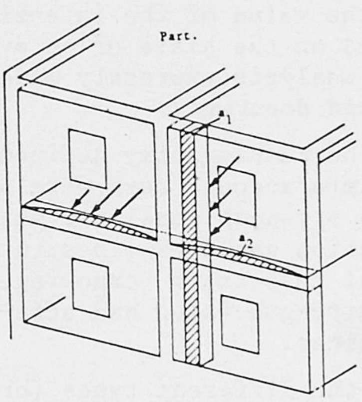
With reference to the facade facing on the Forum, the salient aspects the model necessary for making the computations are defined.

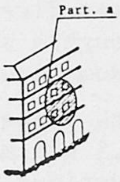
Rearding the forces and materials, their characteristic values are defined and the corresponding partial coefficients are assigned (see phase IV). Three modes of collapse were considered (fig. 3) for the structural behaviour:

a) "local" behaviour of the individual facade portions lying between floor structures and cross walls;

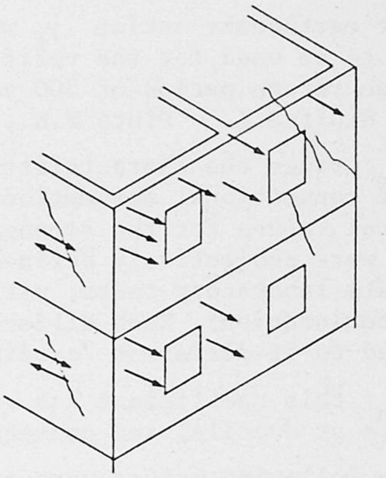
Fig. 1 - Facade looking on the Forum

Fig. 2 - Facade looking on the P.zza del Campidoglio.





b) Facade connections with walls and floor structures behind



a) Local behaviour of individual facade porzion.

a_1 Combined compression and bending in the vertical strips tied to the floor structures.

a_2 Arch effect in the horizontal strips tied to the cross walls.

c) Overall behaviour depending on the shear strength of the cross walls.

Fig. 3 - Collapse possibilities for the Facade looking on the Forum.

b) the breaking-off of the Facade as a whole from the floor-structures and cross walls behind it;

c) a behaviour as "a whole" that involves the shear breakage of the cross walls.

III. COMPUTATIONAL PROCEDURES

The computation procedures refer back to the theory of elasticity, local plasticization being allowed in individual cross-sections.

The material was considered homogeneous, isotropic, and continuous.

The forces and moments, N, M, T are found, and then the stresses, σ_v (vertical) and τ_o (horizontal).

In analyzing the bearing capacity of the walls due to the arch effect, just as in analyzing the shear-walls, their ultimate capacity is first computed; in this way the maximum value of seismic action they can take is determined.

IV. THEORETICAL SAFETY VERIFICATION

The theoretical safety evaluation is done by combining, according to the code the stresses calculated in Phase III and checking that the following inequality is met:

(1) $S_K \cdot \gamma_f \leqslant \gamma_n \quad R_K / \gamma_m \longrightarrow S \leqslant R$

Since compound stresses are being dealt with, a check is made that the point representing the force or stress-state S (M, N, ..., or σ_v, τ_o ...) falls within the corresponding domain R (M, N, ... σ_v, τ_o).

The choice of values to be assigned to the coefficients is closely tied to the schematizations made and to the calculation procedures; in this particular case the following criterion was adopted:

γ_f: because of its reference lifetime - in a monument this must be measured in centuries - and because of the unknown redistribution of the forces to craks diffusion, successive alterations, soil settlements, etc. ..., owing γ_f was taken as 1.7 for the permanent and live loads.

For earthquake action γ_f was instead taken as 1 since the value of the intensity to be used for the verifications was directly obtained on the basis of an avrage return period of 500 years, through a seismic risk analysis expressly made by Giuffrè A. - Pinto P.E., for the Rome area (unpublished document).

γ_m: since the characteristic strength values could not be meaningfully defined, the conventional assumption of γ_m = 1.5 was made; taken into account here were several values for the strengths (and various forms of the strength domains), which were subjectively defined on the basis of the information gathered (in situ tests laboratory tests, ultrasonic testing) and of visual inspection (cracking, deterioration). Each different kind of domain and each strength value had attached to it different "credibility" and "reliability" indices.

γ_n: this coefficient has been used here to account for the different types (brittle or ductile) and consequences of collapse.

The following values were assigned, for the facade giving onto the Forum:

γ_n: 0.8, for facade breakaway (II, b)

γ_n: 0.9, for local failure of the facade (II, a)

γ_n: 1, for shear-breakage of the cross walls (II, c)

The various structural models considered and calculation procedures were also affected by the "credibility" and "reliability" indices.

V. THE SAFETY EVALUATION

When looked at from the point of view just expressed, it turns out that the theoretical verification of safety, as traditionally understood, has in general no significance, since the same structural element will have a range of different values of S and R tied to it - some of which will satifsfy equation (1), and others will not.

This is pointed up graphically by different strength curves and different stress points: some fall within all the domains, others fall outside them all, while still others fall within some and outside the rest (fig. 4).
It follows that an evaluation of safety cannot but derive by a proper consideration of the ensamble of all stress points and domains, indices of credibility and

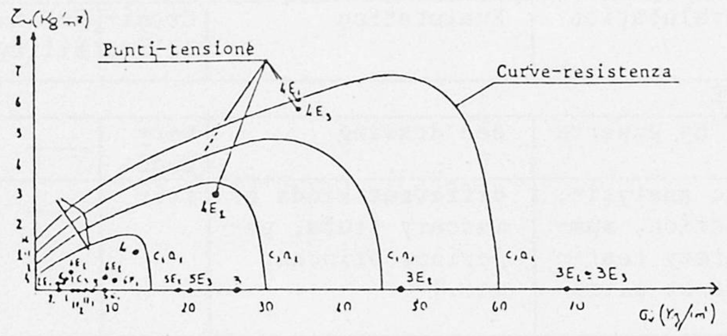


Fig. 4 - Strength domain

of reliability being tied to them. These indices themselves being defined by the linking in a subjective way of the same indices as establisched for the individual elementary operations. Only more advanced probabilistic analyses will be able to reduce or eliminate these subjective contributions - and efforts are being made in this direction.

Stress- points beyond the strength curves in general correspond to high realibility indices, but to rather low credibility indices, so that such a situation does not always mean true danger, or anyway no immediate danger.

Therefore, the following evaluations ar actually subjective, and further investigation is needed to define any intervention operations, whether provisional or definitive:

a) the local behaviours of the facade looking on the Forum display fair safety margins, so that urgent operations are not needed. But the situation is different for several columns of the Gallery, which are working very hard relative to their present deteriorated state.

b) the overall connection of the Facade to the structures behind it is very precarious, so that even a weak earthquake could cause the Facade to break away and collapse. Therefore, urgent operations along the lines of those indicated by previous checks are needed.

The installation of chains causes the credibility of most of the stress-points falling outside the breakage domains to vanish, and thus eliminates them from consideration.

c) overall behaviour, which involves the shear strength of the cross walls, is fair; though the problem of their reinforcement must be faced, no need is seen for emergency operations.

4. INTERVENTION CRITERIA

A this point in the study, and in light of the safety evaluations that have been made earlier, a number of priority or emergency intervention operations have been singled out for the Facade giving on the Forum. These concern:

- the shoring of several columns and their strengthening by cement-mortar grouting;
- the restoration of at least a minimum level of connection between the Facade and the structures behind it by consolidating strips of it to which pretensioned cross-chaincs may be anchored (fig. 5).

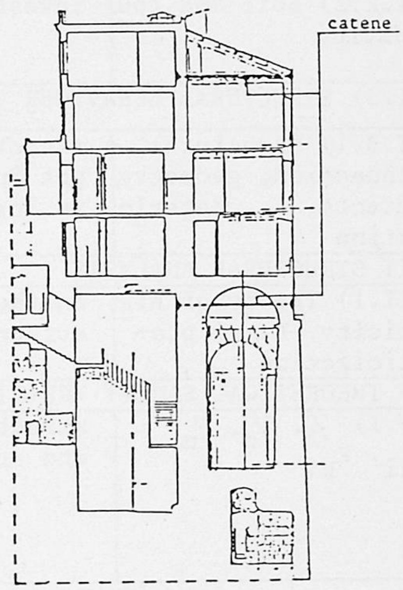


Fig. 5 - The emergency interventions.

Factors determining safety	Source of evalutation	Evalutation	Credibility	Reliability
I DESCRIPTION OF THE PRESENT STATE				
I.1) Geometrical survey	carried out by experts	see drawing	very good	____
I.2) Identification of the material	petrographic analysis, sight inspection, samples laboratory testing, in situ test ultrasonic tests	different kinds of masonry (tufa, peperino, brincks, etc.)	fair	____
I.3) Interpretation of the local failures, degradation	sight inspection, observations	crushing, spreading deterioration, out of perpedicularity, ...	fairly good	____
I.4) Identification of foundations and soil	sight inspection, samples laboratory testing	lacustrine alluvional sediments, tuff, ...	good	____
I.5) Strenghtenings and pre-exstent changes, structural connection	sight inspection, samples	inefficient strenghtnings, different tamperings	fairly good	____
I.6) Developing trend of phenomena	levelling, investigations	slight movement deteriorating	fairly good	____
II MODELLING				
II.1) Actions → γ_f				
II.1.1) Direct action: forces	geometrical survey and Normativa	caratteristic values, γ_f	good	very good
II.1.2) Indirect action: settlements, etc.	investigations	negligible	good	average
II.1.3) Indirect action: earthquake	analysis of a seismic risk	response spectrum	good	good
II.2) MATERIALS → γ_m				
II.2.1) Strength domain	investigations	different caratteristic values γ_n adopted	varies accor ding the adopted values	
II.2.2) Soil and foundation	investigations	deformability only on sismic actions	good	good
II.3) STRUCTURAL BEHAVIOUR → γ_n				
II.3.1) Structural connection, geometry, effects, ... deterioration	structures samples sight inspection, surveys interpretation, etc	different assumptions (see 3.II, fig. 3)	varies according the adopted values	
III STRUCTURAL ANALYSIS				
III.1) Theory of elasticity. Local plasticization	on the basis of the strength of materials	stresses in the structure	awerage	good
IV THEORETICAL SAFETY VERIFICATION				
IV.1) γ_f, γ_n, γ_m S_{ki}, R_{ki}	structural analysis and strength domain	$S_k \gamma_f \lesseqgtr \gamma_n R_k/\gamma_m$ (see fig. 4)	varies according the adopted values	