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The Seismic Assessment of the Curia in the Roman Forum through Simplified Models

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Abstract The knowledge of historical buildings represents the necessary condition for obtaining a reliable evaluation (even if simplified) of their structural safety, especially in relation to the seismic assessment. In the case of archeological finds, the knowledge of the building modifications, due to anthropic or natural events, assumes a particular importance. The Curia, placed in the archaeological site of the Roman Forum in Rome, represents, under this point of view, an emblematic case. The several transformations suffered by the building during the centuries determine the need of a seismic evaluation able to take into account the different structural conformations and the different boundary conditions.

Keywords: Archeological find, masonry building, collapse mechanism

Introduction

Why should we be worried about the structural safety of archeological heritage, since its a-thousand-year-old history attests a structural efficiency?

If we observe the archeological finds of Roman Forum or of Palatino in Rome it seems evident that this assumption, connected to a sort of common sense, can go in crisis, firstly, for two aspects. On the one hand the physiological deterioration can cause architectonical elements significant compromise for the natural decay of the mechanical properties of the materials. This aspect characterizes, in particular, the archeological finds constituted by single structural elements. The mortar degradation, if it is present, or the superficial attack of an aggressive air solution for the pollution that characterizes our time, causes the possibility of local collapses in structures, in which the simpler maintenance rules have been ignored. On the other hand, for the archeological finds that can be assimilated to a building, a selective vision of the history, that have characterized the transformations carried out at the beginning of the last century, has determined buildings for which the concept of structural test, that could be assumed in relation of their a-thousand-year-old history, is, in great part, disregarded.

There is, therefore, a sort of resetting of structural history, in particular, if we take into account a seismic event. There are several examples in the area of Roman Forum: from the Curia (version: St. Adrian Church) that suffered a “restoration” intervention during the twenty years of Fascism in Italy, that re-transformed in Curia (version: Senate Building), to the Titus Arch “liberates” in 1800 from the annexed buildings, or to the recent excavations coordinated by Boni (1900) that have dug up constructions buried by several stratifications. In these last cases (e.g.: St. Maria Antiqua Church or the Oratory of XL Martyrs) the successive completion interventions have created a new architectonical complex.

If, under a formal point of view, there is a scrupulous distinction between “ancient” and “rebuilt” parts, that allows us an immediate lecture of the original building, under a structural point of view, there is a total commixture between the different portions that constituted a new structural system.

Historical Mentions and Building Description

The Curia, or Senate Building, placed in the archaeological site of the Roman Forum in Rome, was built in its actual form by Diocletian in the III century AD. From the VII century, the building was transformed in a church and was consecrated to St. Adrian (Fig. 1a, b). In XIII century it suffered significant restoration interventions: the original floor of the ancient Roman Senate was lifted up of 3 m (in relation to the raising of the external countryside level due to the collapse and the burying of adjacent buildings) and two aisles (with ancient columns) were built. After a period in which the building was not used, in XVI century, the Curia was another time restored and a Convent was annexed to the church (Fig. 1c).

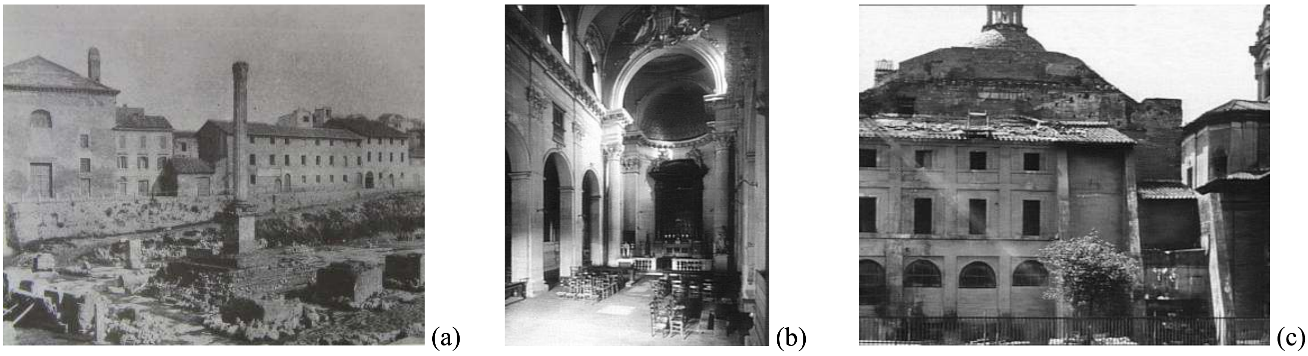

Figure 1: *St. Adriano Church: (a) Roman Forum at the end of XIX century; (b) internal view of the Church; (c) external view of the Convent (Photographic Archive ICCD)*

The church was used until the '30s when, during an excavation in the Roman Forum, it was decided to bring the building back to its original appearance by depriving it of all later additions at the time Diocletian (Fig. 2). The drastic nature of the intervention, that has destroyed all the account of an era, is clearly evident in the historical images following reported (Fig. 2). In figure 2e and 2f, in particular, the ancient masonry walls are identifiable by the rebuilt or consolidated parts. The two facade gables have been almost completely rebuilt, as well as the roof covering system, the back facade and part of the two side-walls.

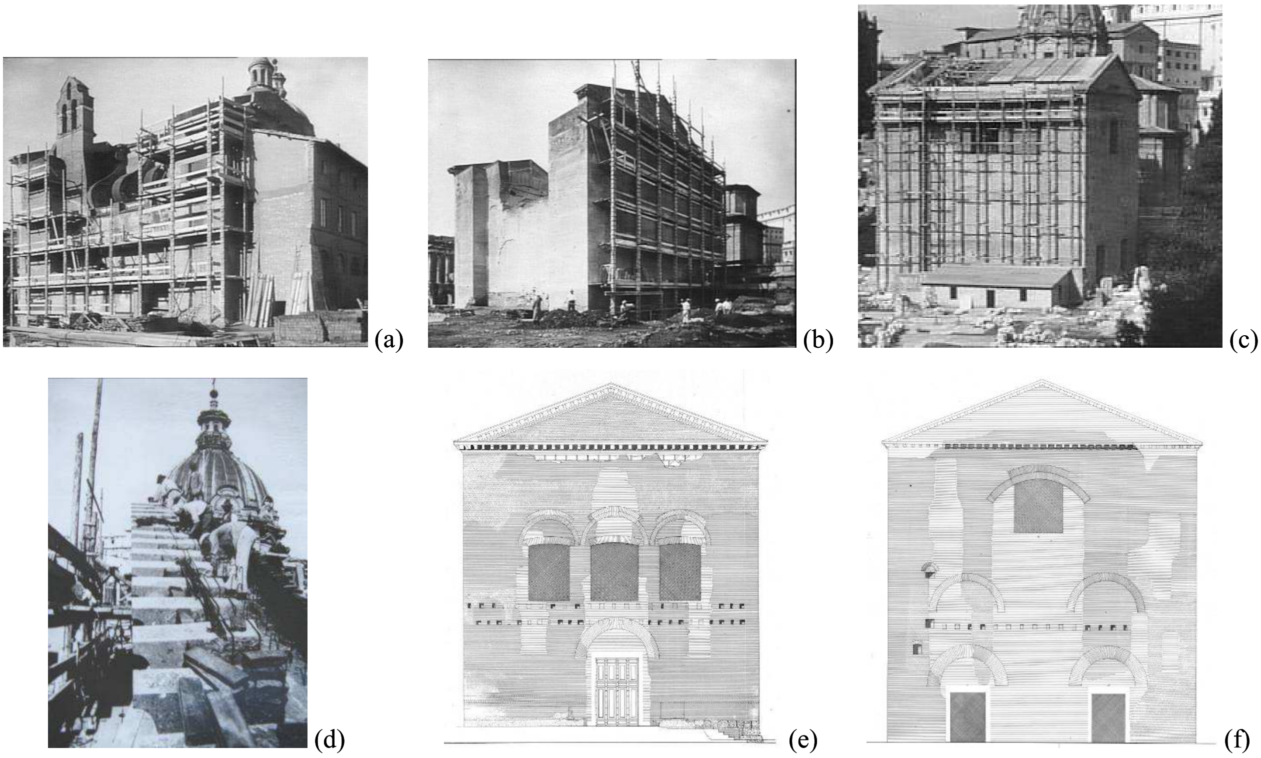

Figure 2: Curia: (a), (b), (c) ,(d) historical images taken during the 1903's restoration works (Photographic Archive ICCD); (e), (f) individuation of rebuilt masonry parts in 1930, respectively the top and back facade (Morselli C. e Tortorici E., 1989).

In its actual conformation, the fabric has a rectangular shape with maximum dimensions equal to 25 meters wide and 28 meters in length with a height of the façade equal to 24 meters. In the corner of the buildings four big masonry pillars are present (Fig. 3).

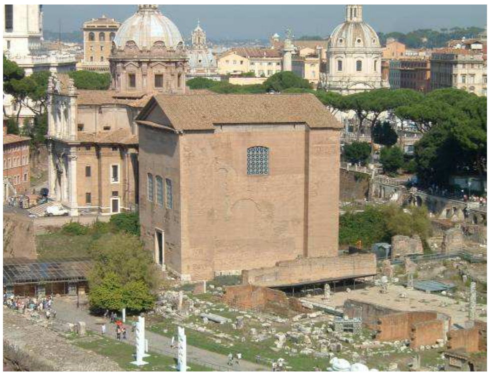 

Figure 3: External view of the Curia in its actual conformation

The roof covering is not visible inside, since a wooden false ceiling is present. From an image taken during the 1930's restoration interventions, it is possible to notice that the roof covering system (Fig. 2c, d) is constituted by reinforced concrete trusses. In particular the position of the first truss, in correspondence of the masonry gable, puts in evidence how the secondary warping of the roof is not directly connected to the façade gable. The reinforced concrete tie-beam, built on the top of the façade, connects the stone elements positioned on the crowning of the façade gable (Fig. 2d).

Local Damage Mechanisms

An adequate knowledge level represents the fundamental assumption in order to obtain a reliable evaluation of the seismic vulnerability of a cultural heritage like the Curia. An appropriate knowledge of the structural details allows, moreover, to individuate the most reliable evaluation model in this specific case. For historical buildings (i.e.: Curia), which have suffered, down the centuries, several transformations and rebuilding of whole structural parts, it is firstly necessary to consider the activation of the local damage mechanisms. The individuations of the collapse mechanisms to analyzed cannot, in particular, prescind from the historical analysis of the transformations. A kinematism model, applied without taking into account the constructive characteristics of the building cannot be able to predict the real structural behavior.

This aspect agrees with the *Guidelines for the evaluation and the reduction of the seismic risk of cultural heritage* (Directive PCM 12/10/2007- O.S. n. 25 – O.B. n. 24 – 29/01/2008).

The *Guidelines*, in fact, propose simplified models to evaluate the global seismic vulnerability of some types of monumental buildings, underlining, nevertheless, the importance to analyze the presence of those constructive details able to favour the activation of eventual local damage mechanisms. The knowledge level obtained for the Curia has allowed, in particular, to individuate, among the several potential damage mechanisms, the more vulnerable one. The kinematisms have been chosen taking into account the actual conformation of the building, the damage pattern (surveyed during a visual inspections) and the historical phases of the building, with particular care to the masonry parts rebuilt during the 1930's restoration interventions. These parts, in fact, have yet not suffered severe intensity earthquakes, and therefore the test of a significant seismic event cannot be assumed. The analyzed collapse mechanisms are reported in Fig. 4.

The kinematisms 1 and 2 have been chosen because the facade openings cause an important reduction of the masonry section; a cylindrical hinge can be localized in this point determining the consequent overturning of the upper masonry part. Moreover, the definition of the kinematism has been studied on the basis of the surveyed damage pattern.

The kinematism 3, as mentioned before, has been individuated in relation to the transformations of the building. Analyzing the historical images, it is possible, in fact, to observe how the modifications of the Curia in church have determined the demolition of the top parts of side walls, rebuilt during the 1930's restoration works (Fig. 2 a, b, c). For this reason this masonry portion can be assumed limited connected to the original one and therefore very vulnerable regarding to an overturning collapse mechanisms.

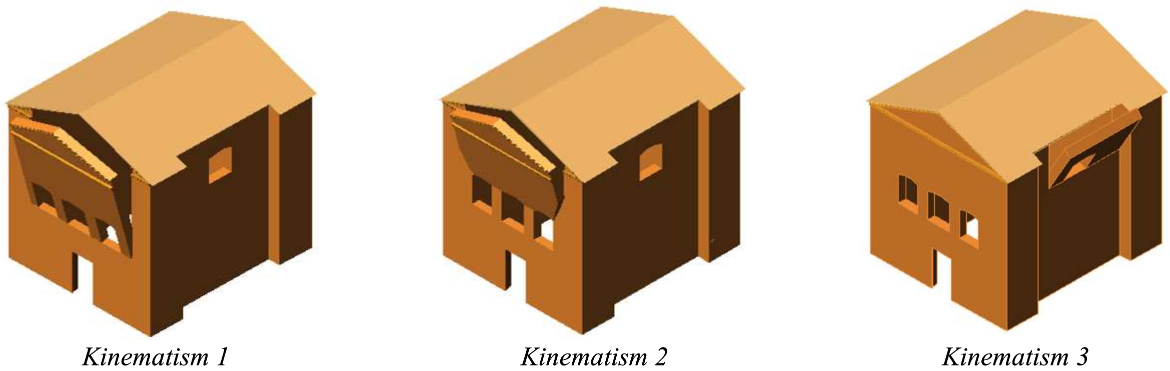

Figure 4: Collapse mechanisms analyzed for the seismic behaviour study

The position of the cylindrical hinge has been moved from the external surface of the wall to the internal part (20 cm) for the collapse mechanisms 1 and 2, while in the kinematism 3 the hinge has not been rearward. For the original masonry the partial collapse of the external brick masonry curtain appears possible: this damage mechanism is, in the past, attested by the several structural integrations. In the rebuilt parts, instead, we have assumed that the transversal connection has been conveniently carried out, and therefore the exfoliation of the external brick curtain is not possible.

The safety checks have been carried out regarding the linear and non linear kinematic analysis methods (Guidelines – pt. 5.4.3.) described, in details, in the Annex C8A.4 of the Circular n° 617 02/02/2009 – Instructions for the application of the Italian Building Technical Code (M.D 14/01/2008). Regarding the seismic action, we have assumed the seismic input equal to the seismic hazard expected by the actual Italian Technical Code, assuming a reference life LR equal to 50 years (nominal life LN equal to 50 years and a use coefficient CU equal to 1), soil condition equal to C and topographic effect equal to T1 in compliance with the Italian Technical Code (Table 1) .

Table 1: Parameters of seismic input for the damage limit state(DLS)and the ultimate limit state(LLS)

	DLS	*LLS*
a_g - peak ground acceleration of the site	0.53 m/s^2	1.15 m/s^2
S - soil condition coefficient	1.5	1.5

The safety check according the kinematic linear analysis is based on the comparison between the spectral acceleration (capacity) a_0*, that activated the different collapse mechanisms, with the seismic demand for the limit state of the live protection (ultimate limit state – LLS) and for the damage limit state (DLS). In table 2 the results are reported with reference to the two different limit states.

Table 2: Linear kinematic analysis results respect to the limit state DLS and LLS

Kinematism	a_0* (m/s^2)	*Demand DLS* (m/s^2)	*Verification DLS*	*Demand LLS* (m/s^2)	*Verification LLS*
1	0.38	0.78	No	0.86	No
2	0.61	1.00	No	1.22	No
3	1.04	1.12	No	1.37	No

The results of the collapse mechanisms analyzed with the non linear kinematics approach are reported in table 4. The non linear kinematic analysis allows to individuate the displacement capacity of the damage mechanism as far as the collapse. In contrast to the linear kinematic analysis, in which the safety check is performed taking to account the force, the non linear method calculates the check in terms of displacement, through a comparison of the ultimate displacement capacity d_u^* of the structure with the displacement demand Δ_d, in correspondence of the secant period T_s.

Table 4: Non linear kinematic analysis results respect to respect to the ultimate limit state (LLS)

Kinematism	d_u*(m)	*Demand* Δ_d (m)	*Verification*
1	0.13	0.11	Yes
2	0.13	0.10	Yes
3	0.17	0.10	Yes

Simplified Vulnerability

In addition to the local vulnerability, a global safety check of the building has been carried out through the application of the simplified model proposed in the *Guidelines* for the typology of "Palace and Villas and other structures with bearing walls and horizontal diaphragms". The aim has been the evaluation of the safety check, in relation to the structural changes due to the architectonic modifications of the original parts. The model proposed by the *Guidelines* allows us to evaluate, even if through a simplified approach, the acceleration value that causes the structure collapse. It is based on the assumption of a global response of the building taking into account a in-plane behavior of the masonry walls. It is, therefore, necessary to define, over the values of the applied loads and the geometry of the resistant panels, also the mechanical characteristics of the masonry (i.e.: shear strength). Since none diagnostic campaign was carried out, in the analysis we have adopted the reference strength values proposed in the Table C8A.2.1 of the Circular n° 617 – 2 February 2009 (Instruction for the application of the Technical Italian Standard for Constructions – M.D. 14 January 2008). The mechanical parameters used in the seismic safety evaluation have been, in particular, obtained by the strength values proposed for the masonry typology "brick and lime mortar", adopting the minimum value of the range reported in the Table C8A.2.1 and assigning the corrective parameters connected to a mortar of good quality and a good transversal connection (Table C8A.2.2). In order to consider the knowledge level, the mechanical properties of the masonry have been subdivided for a confidence factor *FC,* assumed, in this case, equal to 1.21.

The application of the simplified model to the Curia has highlighted that the more vulnerable direction is parallel to the two façade, partly due to the presence, in these two sides, of a great number of openings. In this direction, the acceleration value of the ultimate limit state, a_{LLS} is equal to 0.95 m/s^2. The corresponding value of the return period is, instead, equal to 258 years. In order to obtain a synthetic index representative of the building seismic risk, the ratios between the capacity and the demand of the structure have been calculated. This index has been evaluated with reference to the ultimate limit state (LLS) both as ratio of return periods (I_S – safety index), and of peak ground accelerations (f_a). The results are reported below:

$$I_{S,LLS} = \frac{T_{LLS}}{T_{R,LLS}} = 0.54; \quad f_{a,LLS} = \frac{a_{LLS}}{a_{g,LLS}} = 0.81 \tag{1}$$

In this kind of evaluation plays a fundamental rule the obtained knowledge level. An accurate knowledge of the constructive characteristics (e.g.: the masonry typology or the roof covering system) has both a direct influence on the applied load definition and, indirectly, on the individuation of the confidence factor. With reference to this aspect, the results of the simplified evaluation, hypothesizing an accurate level of knowledge, FC equal to 1, are reported. The reduction of the confidence factor (from 1.21 to 1) determines new values of safety indices equal to: $I_{S,LLS}$ = 0.76 e $f_{a,LLS}$ = 0.91.

In order to put in evidence the importance of the knowledge phase, the seismic evaluation through the simplified model previously used, has been calculated varying the values of the masonry mechanical properties. Three different masonry typologies, adopting the values of the range proposed in the Table C8A.2.1 (Circular n° 617 – 2 February 2009) for "brick and lime mortar" typology are taken into account. The compressive and shear strength of the masonry, has been, in particular, evaluated on the basis of the average value assigned by the Circular to the adopted typology.

Moreover, the presence or the absence of eventual corrective elements has been performed. The three different masonry typologies used in the following analyses are:

1. good quality masonry: mean values of strength and corrective coefficients connected to the presence of a mortar of good quality and a good transversal connection.
2. mean quality masonry: mean values of strength and corrective coefficient connected to the presence of a mortar of good quality.
3. poor quality masonry: mean values of strength without corrective coefficients

In Table 5 the corresponding values of safety indices are reported.

Table 5: Safety indices

Masonry	$I_{S,LLS}$	$f_{a,LLS}$
1	1.18	1.05
2	0.73	0.90
3	0.52	0.81

Conclusions

The results highlight how a reliable knowledge of historical buildings represents the main condition for a seismic vulnerability evaluation, both to individuate the constructive details which may affect the structural response and sequentially to individuate the most reliable evaluation model.

With reference to local damage mechanisms, the knowledge level obtained for the Curia has allowed to evaluate, among the several potential kinematisms, the more vulnerable ones. Moreover a good knowledge of constructive and geometrical characteristics (e.g.: the masonry typology), permits to obtain a more reliable evaluation of the structural response also adopting the global model proposed by the *Guidelines*; the parametric analysis has allowed us to individuate the influence of different parameters on the final results. Under this point of view, although an knowledge increase is desirable, we can conclude that the Curia shows a low seismic vulnerability, despite the transformations suffered in the 1930's restoration works. It is worth noticing that, through a multidisciplinary approach, we are able to recognize those parameters that influence the seismic behaviour of the buildings. In this specific case the masonry quality does not affect only the mechanical strength but, the definition of the transversal connection level between the different curtains could allow a final judge of the structural safety more reliable.

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