10. SEISMIC ASSESSMENT OF R.C. STRUCTURES: CASE STUDIES IN CATANIA

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10.1 Introduction

The research activity was carried out having as basic aims to study in detail and to extend the present knowledge about the evaluation of seismic vulnerability of existing reinforced concrete structures. The actual response and the possible failure mechanisms, also taking in account the influence of infills, was analyzed. The study concerns those structures of Catania's area built in absence of seismic provisions.

In order to reach the above aims, firstly some existing buildings that can be considered as representative of a wide typology were selected in Catania. The choice was based on a screening procedure conducted by some investigations in the archives of Genio Civile and of IACP. In the end two buildings, denominated in the following "Monterosso" and "IACP", were selected and their design drawings were found and analysed.

The detailed analysis of the vulnerability of these buildings, considered representative of a wide part of the building patrimony of Catania's area, was simultaneously carried out by the three following Working Group: Roma "La Sapienza" (coordinator L. Decanini), Catania (coordinator G. Oliveto), Napoli "Federico II" (coordinator E. Cosenza). These groups worked using different and independent methodologies of approach so that also the variability of predictions can be evaluated.

10.2 The analysed buildings

The two analysed structures (Figs.10.1 and 10.2) belong to building complexes of the late '70, and, hence, they were built without any seismic provision. Both buildings, with four and eight storeys, are characterized by reinforced concrete frames; their infills are composed by a double row of perforated bricks with an interposed air chamber.

The building with 4 storeys, called "Monterosso" (Fig.10.2), has a rectangular lengthened plan with a symmetry axis in the transverse direction; in elevation it has three storeys and a basement. Its plan has dimensions of 40x10 m and its height is about of 12 m. The first three storeys have the same plan, whereas the top storey is clearly smaller than those, having only the function of end for the stairwell.

The building with 8 storeys, called "IACP" (Fig.10.1), has a regular plan with dimensions of 11x22 m and it has eight storeys and a total height of 24 m; its foundations are made by a plane system of beams. Three longitudinal frames and three cross-frames define the structural configuration. The building skeleton is formed by columns with lengthened rectangular section and by beams with rectangular section, with strong axis of column in the cross-frames and weak axis in the longitudinal ones. The slabs are made of concrete and perforated bricks, having a thickness equal to (160+40) mm; they have the same orientation and load the longitudinal frames.

The geometric dimensions of the elements, the materials characteristics, the structural masses and the loads were referred to the original design drawings. The declared values were adopted for steel and concrete strength, *Steel* FeB38K f_{yk}=380 N/mm^2, *Concrete* R_{ck}=25 N/mm^2.

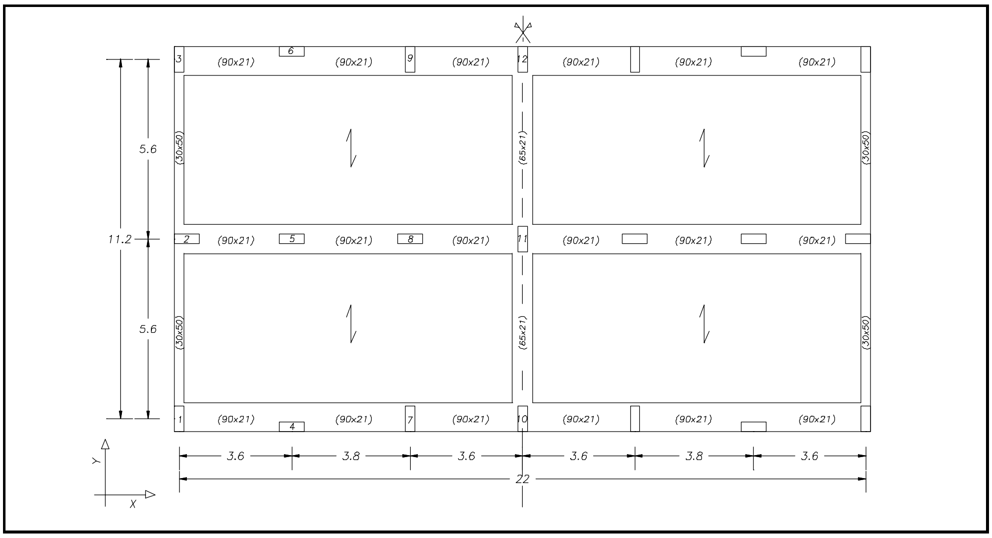

Figure 10.1 - Eight storeys building: typical plan

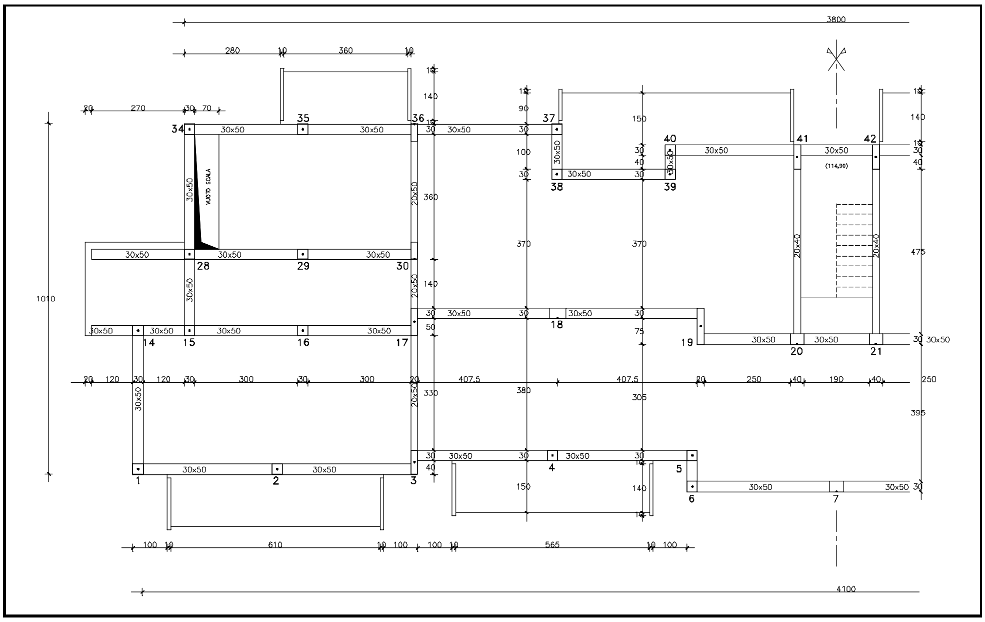

Figure 10.2 - Four storeys building: typical plan

10.3 The static model of the buildings

The work of the different groups was developed independently, in order to underline the differences between the adopted models, evidencing realistic but different approaches in the operative steps. The solutions used for every building are briefly reported below.

10.3.1 *Storeys building "Monterosso"*

Naples WG: Only frames with columns connected directly to beams make the building skeleton chosen by this group (Cosenza et al., 1999). Because of the small mass of the top floor a two-dimensional model of only three storeys was adopted. This is the most conservative model because it does not take in account the contribution of the floors.

Rome WG: The building skeleton of this group is not only based on frames with columns directly connected by beams, but also on cross-frames having isolated columns and equivalent beams which simulate the stress transmission due to the flexural behaviour of the slabs (Bruno et al., 1999).

Catania WG: The model of skeleton is the same of Rome WG, but there is a difference regarding the frame of the stair where Catania Group added an inclined beam to simulate the effect of the slab (Oliveto et al., 1999). This is the most resistant model because it takes in account all the possible linking elements.

10.3.2 *Storey building "IACP"*

Rome WG: The building skeleton is composed by all the plane frames that they can be identified in the carpentry.

10.4 The used numerical models

The models for the analysis used by the different groups are as follows:

Naples WG: In the studies it was developed a fiber model to analyse reinforced concrete frames, with spread plasticity and cracking. The model considers explicitly the steel-concrete bond relationship and it allows to simulate the most important mechanical phenomenon influencing the non-linear behaviour of reinforced concrete frames: cracking, plasticity spread, fixed end rotation, presence/variation of the axial force or P-Δ effect. For its characteristics this model allows to define the ductility of section, of element and overall deriving them from constitutive laws. In the push-over analysis it was considered the loads distribution connected to the first mode of vibration in the analysed direction. The contribution of the infills was not taken in account. The linear dynamic analysis was carried out using the SAP program.

Rome WG: The numerical model of the structures was based on ANSR program for non-linear analysis. Using some elements with concentrated plasticity at the ends the behaviour of columns and beams was modelled. The push-over analysis was developed by a triangular distribution of side loads.

Catania WG: The numerical model adopted by this group considered concentrated plasticity. The plastic hinges took in account the axial force in the columns for gravitational loads. The total or local ductility of the elements had a conventional definition. The push-over analysis was characterized by the load distribution connected to the first mode of vibration in the considered direction.

10.5 Dynamic properties of the buildings

Using a modal analysis performed on the relevant three-dimensional model, some dynamic parameters of the building, as periods of vibration and excited masses, were evaluated.

The elastic first periods in the cross-direction (the smallest dimension of the plan), determined by the different working group, are shown in the following Table 10.1:

Table 10.1: Periods of vibration in the cross-direction

4 STOREYS BUILDING	Bare frames	Infilled Frames	Bare frames with stairs
	T (s)	T (s)	T (s)
Catania WG	0.47	-	0.40
Naples WG	0.57	-	-
Rome WG	0.58	0.42	-
8 STOREYS BUILDING	Bare frames	Infilled Frames	Bare frames with stairs
	T (s)	T (s)	T (s)
Rome WG	1.76	0.86	-

10.6 Push-over analysis

Naples WG: In the push-over analysis the load distribution connected to the first period of vibration in the analysed direction was considered. The computer program allows to have a refined evaluation of the local ductility demand. By a ε_u ranging from 0.5% to 1.0% the changes in the behaviour of the compressed concrete influencing on the squashing failure of the columns was taken in account.

Rome WG: The push-over analysis was developed applying a triangular distribution of side loads. Also the influence of the infills was considered.

Catania WG: The push-over analysis was characterized by the load distribution connected to the first mode of vibration in the considered direction.

The obtained results which are summarized in the Table 10.2, where some parameters allowing an immediate physical interpretation and being commonly used in the technical literature are considered: the shear force below V_b and the seismic coefficient C_b. These results are referred to the direction having the lowest resistance.

Table 10.2: Results of push-over analysis (Values referred to ultimate load)

4 STOREYS BUILDING	Bare frames		Infilled frames	
	C_b	V_b (kN)	C_b	V_b (kN)
Catania WG	0.127	-	-	-
Naples WG	0.063÷0.070	760÷840	-	-
Rome WG	0.088	1070	0.128	1550
8 STOREYS BUILDING	**Bare frames**		**Infilled frames**	
	C_b	V_b (kN)	C_b	V_b (kN)
Rome WG	0.031	590	0.062	1150

10.7 Spectral analysis

The Naples WG carried out the seismic verification of the selected buildings by a spectral comparison based on suggestions of ATC 40 (1996) and of SEAOC BlueBook (1998).

The aim of this verification was to define the mechanical properties of a SDOF system equivalent to the analysed structure on the basis of the push-over curves provided by the non-linear analysis. For the 4 storeys building the period T_{eq}, the strength V_{eq}, the mass M_{eq} and the equivalent ductility μ_δ are summarized in Table 10.3; they were calculated on the basis of the analysis conducted by Rome and Naples groups and employing the Fajfar and Gaspercic (1996) criterion to obtain a bilinear model.

These results are referred to ultimate strength values and they provide a realistic range of strength and available ductility. It can be observed that the available ductility changes depending on the different models; this topic needs further researches and studies.

Table 10.3: Properties of the equivalent systems

4 STOREYS BLDGS	Bare frames				Infilled frames			
	T_{eq} (s)	V_{eq} (kN)	M_{eq} (kN)	μ_δ	T_{eq} (s)	V_{eq} (kN)	M_{eq} (kN)	μ_δ
Naples WG	0.86	585	709	4.42	-	-	-	-
Rome WG	0.70	685	623	2.01	0.52	992	623	2.20

Besides the results were compared with the inelastic spectra (Cosenza and Manfredi, 1999) obtained using the synthetic records generated by Priolo (1999). In the Figure 10.3 a range of the possible seismic actions and strength is given; it shows the variations of the values depending on the different hypothesis of model for the particular case of the synthetic expected records of Catania defined SEG_04.

It can be remarked that the capacity of the structure is largely lower than the expected actions. In order to obtain actions comparable with strength it is necessary to reduce on average the expected records of about three times.

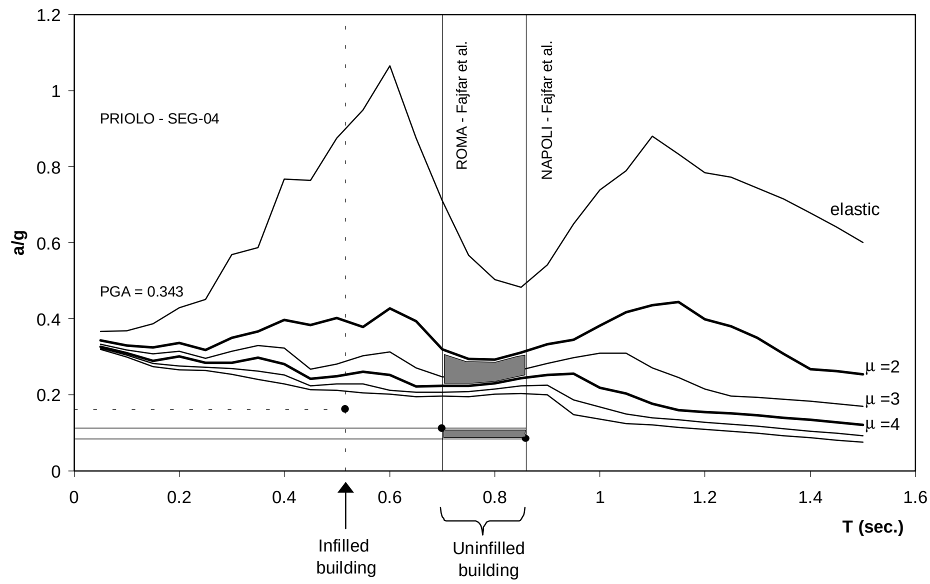

Figure 10.3 - Results of the spectral analysis on the building "Monterosso"

10.8 Dynamic analysis

On the same selected buildings the Rome group carried out some non-linear dynamic analysis. The Priolo record (1999) was scaled up to obtain the seismic failure of the building. For the 4 storeys building the values of PGA leading to failure are reported in Table 10.4. It can be observed that also the capacity of the structure calculated with the dynamic analysis is largely inadequate; in order to obtain comparable quantities it is necessary to reduce the records about five times.

Table 10.4: Collapse acceleration (scaled record SEG_04).

	Bare frames	Infilled Frames
PGA (g)	0.07	0.13

Generally push-over and dynamic analysis provided comparable results, either as possible failure mechanisms or strength values (i.e. base shear force). The difference regarding the displacements was confirmed and it underlined that this topic needs further researches.

10.9 Conclusions

The analysis developed by three independent research groups on reinforced concrete buildings, designed and built in the Catania's area without any seismic provision, confirm the high vulnerability of those structures.

Particularly it can be stated that the analysed structures are not adequate to survive the seismic events which some simulations of other research groups defined: the expected PGA values are about equal to 0.3-0.4 g, whereas the seismic strength is in the order of 0.1 g.

As to the evaluation of seismic strength, it can be underlined that some resistant elements (infills, stairs and effective width of resistant slabs) are of importance, and that modelling of those elements is not too developed in the literature. Moreover the comparisons show that there are more problems in evaluating the structural displacements than the strength, either for ultimate or for intermediate conditions.

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