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Seismic isolation of the ancient Bell-Tower of Melfi

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ABSTRACT: The problems of protecting monuments from earthquake is shortly reviewed and the conditions that make the adoption of base isolation feasible are described. The choices needed to design the base isolation system of the ancient Bell-Tower of Melfi are described. Particular attention is devoted to the constructions phases and to the maintenance of the isolation system. The paper show that, if certain conditions are fulfilled, base isolation is a viable means to protect monuments from earthquake without altering their structural materials and texture.

1 INTRODUCTION

Protecting monuments is a great challenge for the future of Earthquake Engineering, in countries with a long and important history like Italy. Different approaches can be adopted for this sensitive problem.

The first approach is based on old traditional techniques, which have no or only small impact on the ancient construction. Among them the technique of partial reconstruction of masonry to repair cracks and improve the quality of masonry, the application of steel tie rods and so on. Unfortumately this approach is often expensive or requires skilled labor. Moreover in many cases it is not enough effective to give a good protection against strong earthquakes.

The second approach is based on more modern techniques, such as cement or resin injections reinforced with steel bars. R/C structural elements, like slabs and beams, are also used to substitute old deteriorated masonry and wooden elements. With this approach the nature of the original masonry is completely and irremediably altered. For this reason much criticism has arised against this approach.

In the last decade some modern techniques for earthquake protection have been developed and are being used for structures of buildings, bridges, tanks etc.. They are referred to as base isolation and passive energy dissipation, and make use of elastomeric or steel-teflon bearings to decouple the movement of the soil from that of the structure. Steel, friction or hydraulic devices are used to dissipate energy and reduce relative soil-structure displacements. It is obvious that designers involved in strengthening of monuments are attracted by these techniques since, if suitably applied, they could solve the problem of providing an adequate earthquake protection without altering the monument. In fact the application of base isolation requires only interventions at the foundation level. The dramatic reduction of seismic forces determined by base isolation avoids, in most cases, any needs for strengthening the elevation. Unfortunately base isolation cannot be always applied, but some prerequisites must be satisfied: the fundamental period of the structure must be low and the foundation soil must be stiff. Moreover the construction should be compact, to avoid expensive foundation substructure, and detached from other constructions.

In this paper the design of base isolation of the ancient bell tower of Melfi is presented. This intervention is now being realized and represents one of the first applications of base isolation to monuments.

2. THE BELL-TOWER OF MELFI

Melfi is a town of Southern Italy, very important during the middle age. Its better period, in fact, was during the XI-XII centuries, under the Norman domination. In that period many important monuments were built, among which the Castle and the Cathedral with its bell-tower.

The history of Melfi is characterized by several destructive earthquakes, as it is located in a highly seismic area. In the current seismic classification of Italy, Melfi is rated as 1st, i.e. the highest, category zone. In the last three centuries at least four earthquakes (1694, 1731, 1851, 1930), whose intensity was greater than or equal to 8 MCS, caused heavy damage to the buildings and monuments of Melfi. According to Postpischl (1985) the following macroseismic M.C.S. intensities have been estimated in Melfi: 9 for the Campania-Lucania Earthquake of September 8, 1694, 8 for the Foggia Earthquake of March 20, 1731, 10 for the Melfi Earthquake of August 14, 1851, which is also the most destructive in Melfi (see fig. 1), 8 for the Irpinia Earthquake of July 23, 1930.

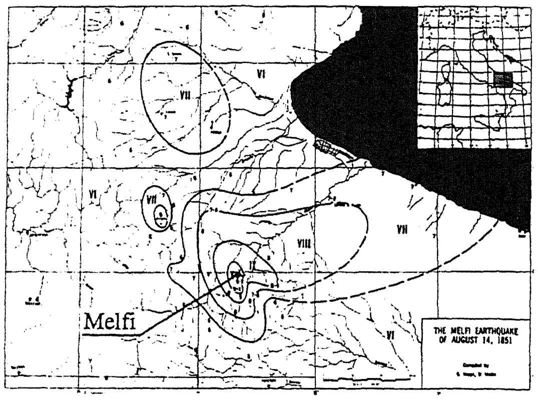

Fig. 1 - Isoseismal lines of the 1851 Melfi Earthquake.

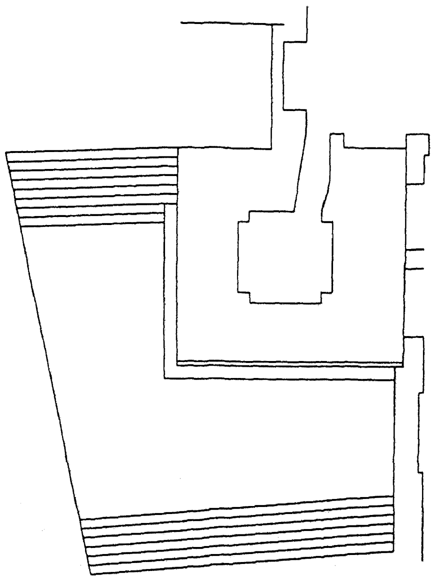

Fig. 2 - Plan of the Bell-Tower.

According to these data a return period of approximately 80 years can be estimated for eartquakes with intensity greater than or equal to 8 M.C.S..

The Bell-Tower of Melfi was built in 1153 by Noslo di Remerio. Also the cathedral was built in the same period, but it was almost completely rebuilt in 1723, because the Campania-Lucania 1694 earthquake produced the collapse of many its parts. At present the two constructions are structurally independent, although they are in contact along one side and half of the Bell-Tower, as can be seen in fig. 2.

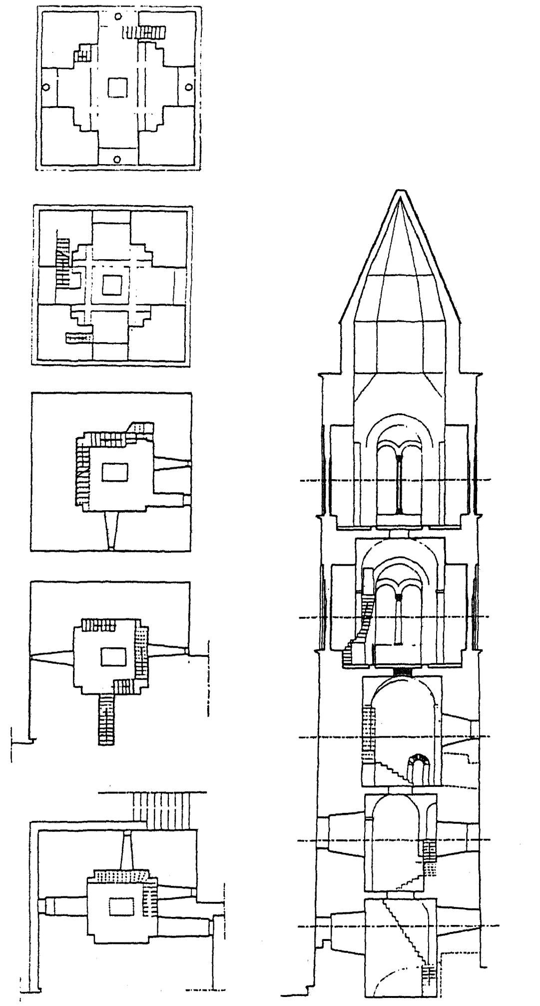

Fig. 3 - Horizontal and vertical sections of the Bell-Tower.

In fig. 3 there are shown the horizontal and vertical sections of the tower. As can be seen the tower has a symmetrical squared horizontal section, whose side is about 9.20 m long. The thickness of the wall at the base is approximately 2.50 m, and it reduces along the height. At the second and third levels there are two orders of mullioned windows, which characterize the Bell Tower from an artistic point of view but which also weaken the structure. The height of the tower is about 47 m, included the optagonal termination. However the mass center is only 17 m high.

The soil is a rocky soil of volcanic origin. The foundation of the tower does not have any enlargement with respect to the elevation and is about 1.70 m deep.

The choice of base isolation as a suitable technique to protect the Bell tower from earthquakes was supported by a preliminary dynamic analysis of the tower fixed at the base. The modal shapes are shown in fig. 4. The type A spectrum (stiff soil) of the Eurocode n. 8 (1988) was assumed as design earthquake spectrum, according to the nature of the soil under the tower. A fundamental period equal to 0.42 secs. was calculated. The first three modes are depicted in fig. 4. Under the design earthquake and for the hypothesis of linear elastic behavior the top displacement would be 75 mm, while the maximum base shear and bending moment would be 18400 KN and 537200 KNm; the masonry would experience a maximum shear stress equal to 0.27 N/mm^2, a compressive stress of 4.8 N/mm^2 and a tensile stress of -3.5 N/mm^2, which are clearly unbearable.

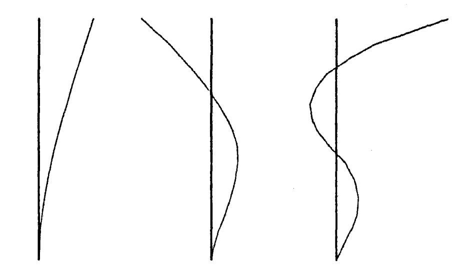

Fig. 4 - Modes of vibrations of the tower fixed at the base.

At the same time a dynamic analysis of the Bell Tower, base isolated with elastomeric bearing of suitable stiffness was performed, in order to establish the feasibility and the advantage of base isolation. The results are shown in fig. 5. The horizontal stiffness of the bearings was chosen such that the fundamental period is equal to 2 secs. With the conservative assumption of a 5% equivalent damping, the maximum base shear and bending moment would be 7250 KN and 13740 KNm; the masonry would experience a maximum shear stress equal to 0.10 N/mm^2, a compressive stress of 1.7 N/mm^2 and a tensile stress of -0.4 N/mm^2. With a no-tension hypothesis the maximum compressive stress would be 2 N/mm^2. The maximum displacement at the base is equal to 170 mm while at the top it is 185 mm. If an equivalent damping equal to 10-15% is assumed, a further 25-40% reduction can be obtained for seismic stresses and displacement, so that the all section is compressed and displacements are limited within 150 mm. The dramatic reduction of stresses makes interventions on the masonry of the Bell-Tower unnecessary, so that the original masonry characteristics are preserved.

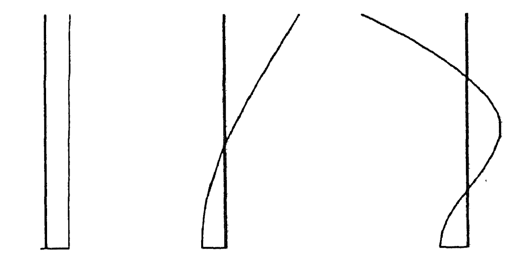

Fig. 5 - Modes of vibrations of the tower with base isolation.

It should be also underlined that the separation from the Cathedral eliminates any dangerous interaction and, therefore, improves also the seismic safety of the Cathedral.

3. BASE ISOLATION SYSTEM

The seismic isolation is obtained essentially by the elongation of the fundamental period. At this aim laminated elastomeric bearings of suitable flexibility are adopted. In order to limit displacements under seismic actions and avoid vibrations under wind actions, a dissipation system is considered in the design.

The interventions necessary to the realization of the isolation system are limited to the foundation of the bell-tower, as shown in figs. 6 and 7. The new foundation structure is made of a R/C ring around the tower and a R/C plate inside the tower. Under the tower a 2.30 m thick anular R/C plate, 13.80 by 13.80 m in plan, is deputed to transmit the vertical and horizontal loads to the foundation structures, through the elastomeric pads of the isolation systems. The new foundation has the advantage of enlarging the base of the tower and, therefore, to better redistribute the stresses due to the overturning moment.

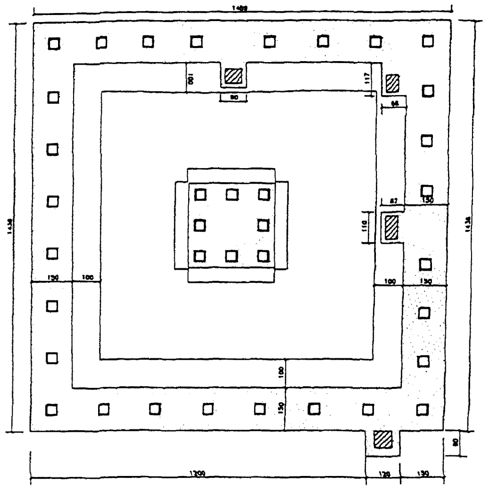

Fig. 6 - Plan of the new foundation structure and location of the elastomeric pads.

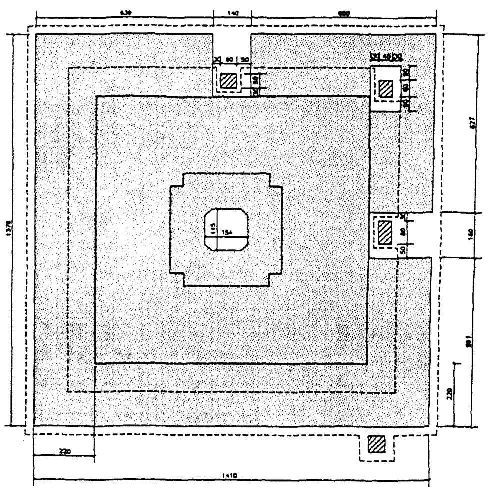

Fig. 7 - Plan of the R/C plate.

To get the final structural configuration the following construction phases must be carried out:

1) Separation of the structure of the cathedral from the bell-tower;
2) Strengthening of the masonry at the base of the Bell tower;
3) Construction of the new foundation structure;
4) Construction of the R/C plate at the base of the bell-tower;
5) Positioning of the hydraulic jacks for lifting and of the elastomeric bearings;
6) Lifting of the bell-tower (20 mm);
7) Loading of the elastomeric pads by means of flat jacks incorporated into the bearing devices.

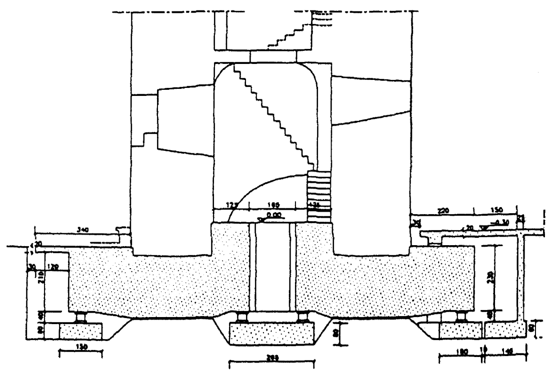

Fig. 8 - Vertical section.

Particular attention is devoted to the possibilities of inspection, substitution and restoring the original fixed base situation. Enough room is left all around the foundation structure to inspect and carry out any kind of intervention on the isolation system. The substitution of the elastomeric devices can be performed by simply lifting the tower, with the same operations carried out for the installation. To eliminate the base isolation it is only sufficient to eliminate the bearing devices and lower the tower. However the new enlarged foundation could be still used to better transmit the overturning moment to the soil.

REFERENCES

C.E.C. (Commission of the European Community) 1988. *EC8 Eurocode n.8.*

Postpischl,D. 1985 *Atlas of Isoseismal Maps of Italian Earthquakes.* Bologna: C.N.R..