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RESILIENZA DELLE CITTÀ D'ARTE AI TERREMOTI
ENHANCING RESILIENCE OF HISTORIC CITIES TO EARTHQUAKES

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VADEMECUM FOR THE SEISMIC VERIFICATION OF EXISTING BUILDINGS: APPLICATION TO SOME RELEVANT BUILDINGS OF THE TRIESTE PROVINCE

The procedure we developed and applied to several relevant buildings of the Trieste Province (Provincia di Trieste, 2015) shown in Figure 1, leads to the seismic verification of a building by: a) use of a scenario based neo-deterministic approach (NDSHA) for the calculation of the seismic input, and b) control of the numerical modeling of an existing building, using free vibration measurements of the real structure. The key point of this approach is the strict collaboration of the seismologist and the civil engineer, from the seismic input definition to the monitoring of the response of the building in the calculation phase. The vibrometry study allows the engineer to adjust the computational model in the direction suggested by the experimental result of a physical measurement.

1. NDHSA seismological elaborations

A reasonable estimate of the hazard at a site of interest can be obtained by calculating the seismic input associated with a series of "scenario earthquakes": a set of seismic sources located within the seismogenic zones is considered, assigning, within each zone, a focal mechanism representative of the tectonic regime. The seismic moment (which is a quantity indicative of the energy released by an earthquake) associated with each source is estimated considering the maximum magnitude inferred

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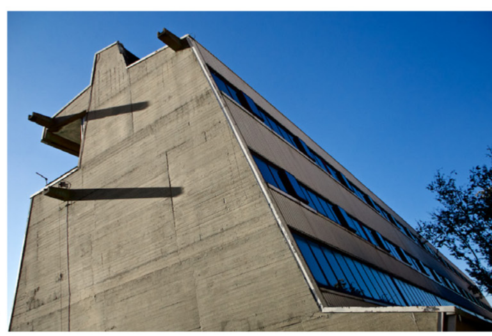


c)

d)

Fig. 1 – The relevant buildings of the Trieste Province to which the proposed procedure has been applied.

from the seismic history of the area of interest, supplemented by additional information available, such as the seismic potential of the active faults (e.g. DISS, 2010) and the morphostructural analysis (e.g. Gorshkov et al., 2013). The magnitude value must be considered close to the Maximum Credible Earthquake (MCE) for the area concerned, which, in the case of uncertainties, can be assessed through a dedicated parametric study, quite easily done using NDSHA.

The seismological and morphostructural analyses allow for the definition of the "scenario earthquakes", i.e. of the strong earthquakes that may take place in the region of interest. For those earthquakes, a database of accelerograms is obtained by the realistic modelling of the ground motion,

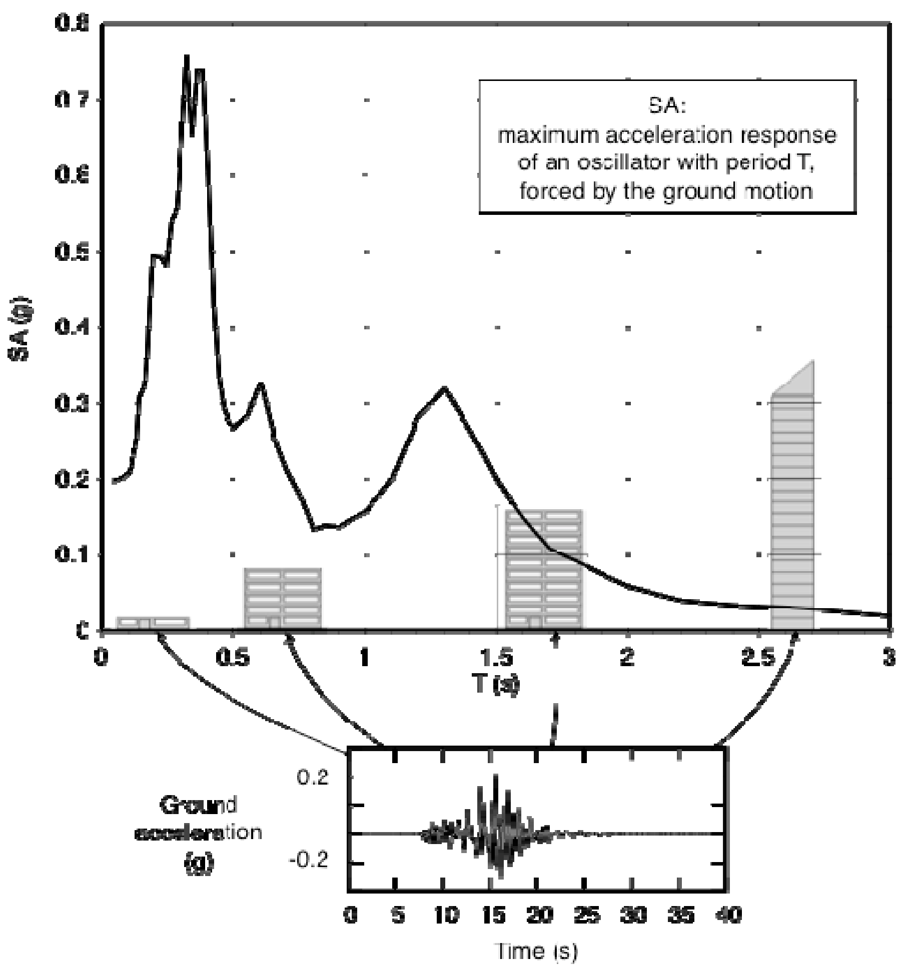


Fig. 2 – NDSHA response spectrum.

carried out using the physical-mathematical principles that are at the basis of the generation, propagation and local amplification of the seismic waves (fully described in Panza et al., 2012), as suggested by the NTC 2008 Italian regulation (C.S.LL.PP., 2008) at § C3.2.3.6 and § 3.2.3.6.

The seismological modelling provides parameters that, transformed into engineering terms (e.g. see Figure 2), may allow for a reliable and proper assessment of the load to be borne by the structures of particular relevance (e.g. bridges, dams, industrial areas at risk, hospitals, schools and buildings of considerable historical interest) in case of a strong earthquake, allowing for the verification of the suitability of the design of the structures present in the study areas and of the sites where they insist.

The engineering analysis to estimate the full non-linear response of specific structures, in fact, requires an appropriate description of the ground motion through complete time histories, while the traditional methods for the seismic hazard assessment only provide peak values and they are difficult to generalize.

2. Engineering analysis

The phase of numerical modelling of the building is partly made in advance and in part accompanied by the survey of the geometry, of the structural characteristics and of the materials that compose it. This phase, in line with the level of knowledge required or achievable, in the case of Italy, is described in detail in Circular 617/2009 of legislation rules. It may also condition the type of numerical analysis that can be performed, by imposing certain limitations among linear, non-linear, static or dynamic ones.

However, in the correct modelling of existing buildings it cannot be ignored, alongside the traditional approach of numerical modelling, the careful vibrometric analysis of the building. Vibrometry allows the engineer to adjust and refine the computational model in the direction suggested by the experimental result of a physical measurement (Figure 3).

The vibrometric study should better be accompanied by the NDSHA determination of the site-specific seismic input, adequately contemplating all scenarios resulting from different source mechanisms. Thus, the approach can a) work in the direction of getting models with the dynamic behaviour as near as possible to the real one, and b) apply to the models the most conservative accelerations for the verification phase.

Figure 4 can be read as a summary of the process: the engineer can "enter" in the spectrum by adopting the correct range of periods, I_E, and then "get out" with realistic values of acceleration, I_A, to be applied to the

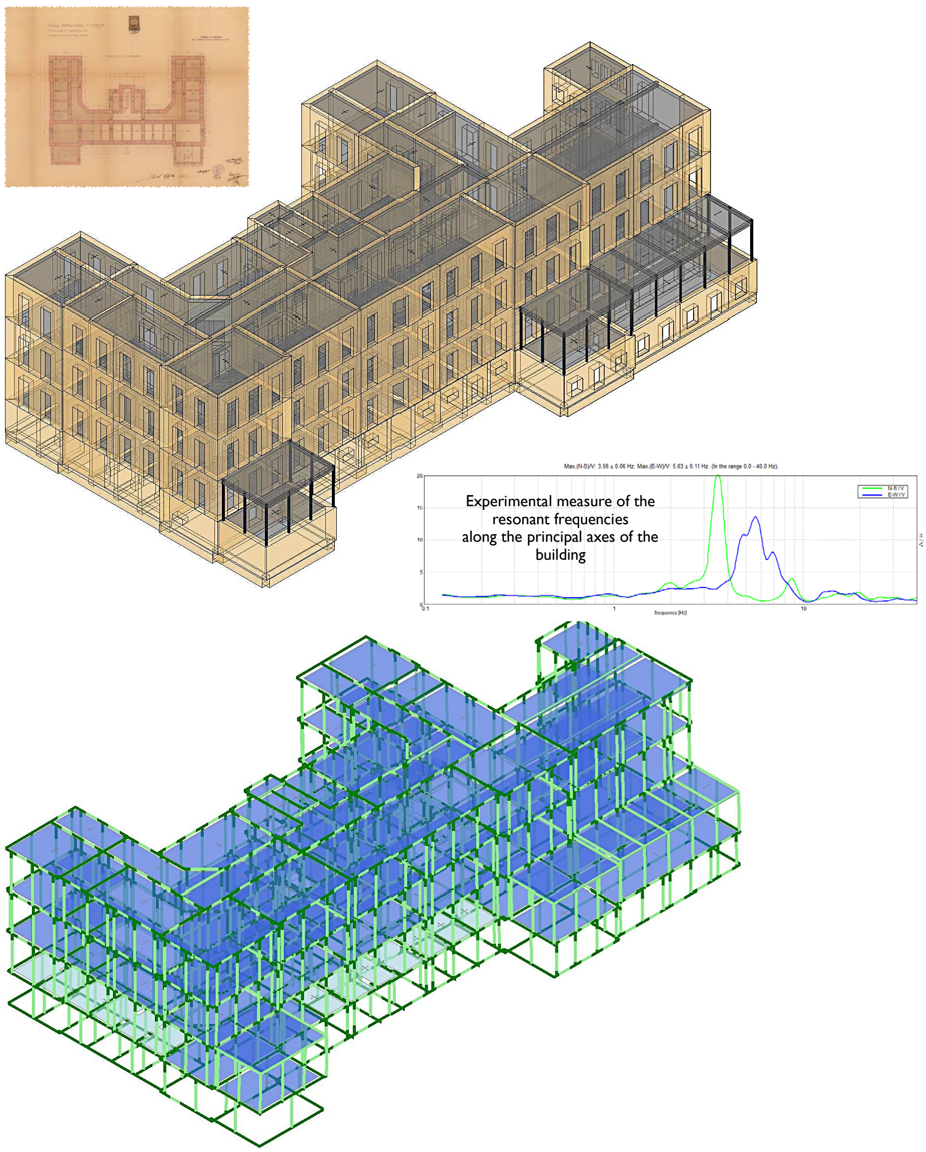


Fig. 3 – From the initial to the final building model: an example for the building shown in Figure 1d).

calibrated model. This is obtained taking into account the appropriate amplification given by the scenario input.

The interval I_E realistically represents the free periods of types of masonry buildings, three/five floors, characteristic, for example, in the area of Borgo Teresiano in the center of Trieste. This interval, for the building

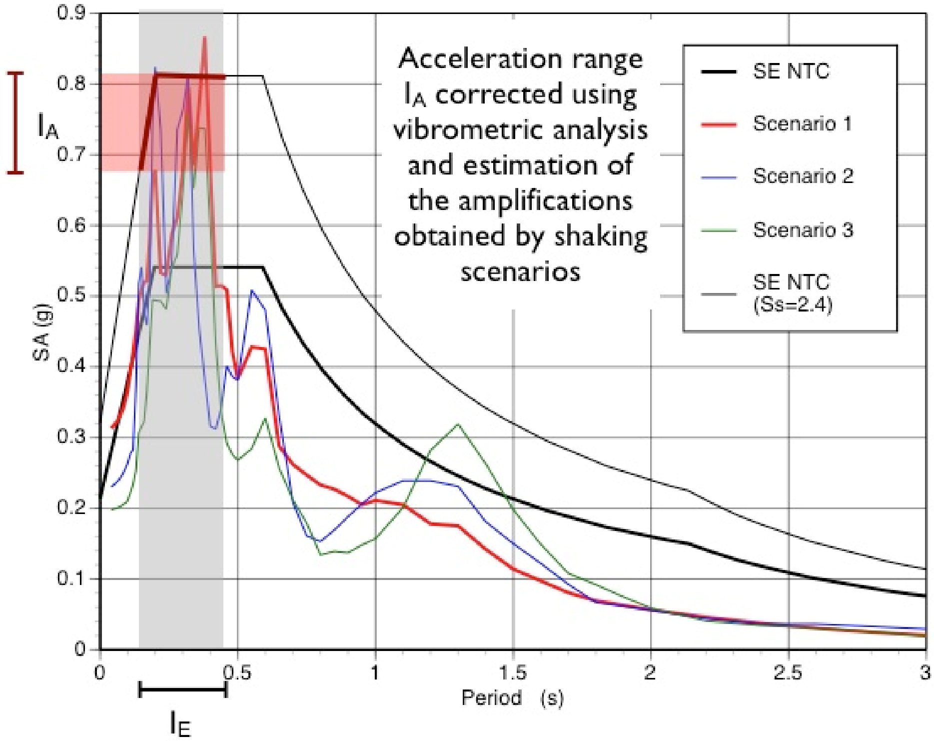


Fig. 4 – Summary of the procedure.

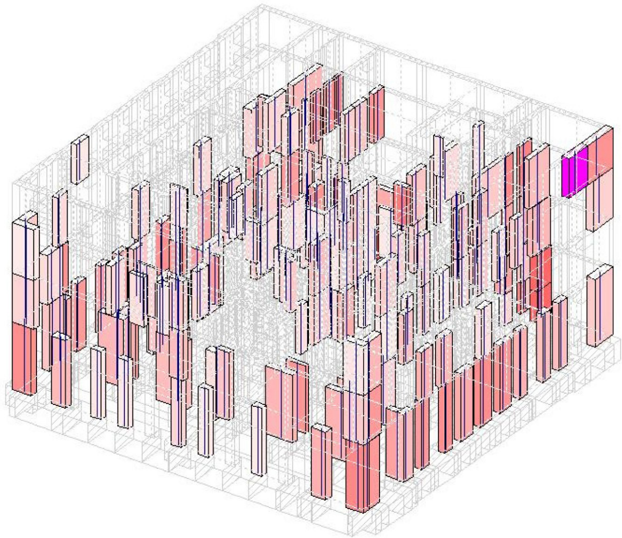
being tested, can be identified by an engineering study (i.e. calculation model and modal analysis), but, although not specifically required by law, must be validated through a vibrometric study and properly adjusted, if necessary.

Generally, but not necessarily, the "scenario" spectra lead to higher accelerations than those deduced by taking the spectra from NTC 2008 (Nekrasova et al., 2015). The task of the verifier engineer is to decide how to act so that the solution of the verification is conservative and realistic.

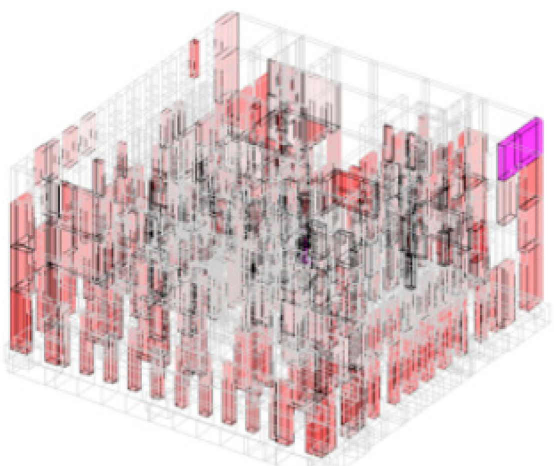
One possibility is to amplify the regulatory spectra through the stratigraphic amplification coefficient (Ss) so as to mediate the difference in accelerations that is obtained from the comparison between the spectra (Figure 4).

In Figure 5 below the use of the scenario input gives an 11% increase of the not verified finite elements.

The analysis of the building in Figure 1d) shows that the adoption of the scenario input leads to a moderate increase of not verified finite elements (Figure 6).



28% of not verified finite elements in bending using NTC spectrum (building of Figure 1a. Ss=1.6.

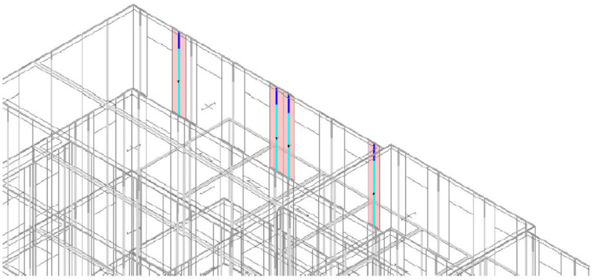


39% of not verified finite elements in bending using the scenario spectrum. Ss=2.4.

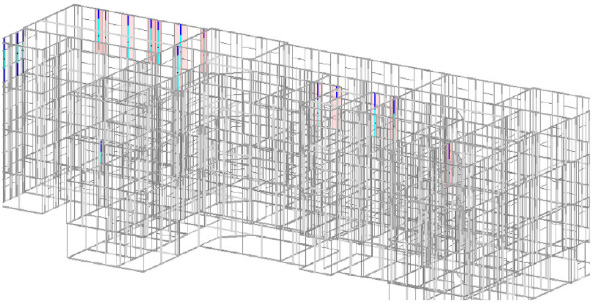
Fig. 5 – Effect of the adoption of the scenario input in the case study for the building shown in Figure 1a).

In order to adopt the scenario spectra, another possibility, instead of using the Ss scaling factor, is to use as input the scenario spectra directly in the calculus code. Considering the building of Figure 1b) it can be observed (right panel of Figure 7) that only in a small range of periods the scenario spectra is higher than the standard spectra; therefore, it is more reasonable to study the effect of the specific spectrum on the structure.

This method of calculus lead to an increase of 15% in the number of not verified finite elements in the structure model.



0.5 % of not verified finite elements in bending using the NTC spectrum (building of Figure 1d). Ss=1.2.



1.5% of not verified finite elements in bending using the scenario spectrum. Ss=1.75.

Fig. 6 – Effect of the adoption of scenario input for the building shown in Figure 1d).

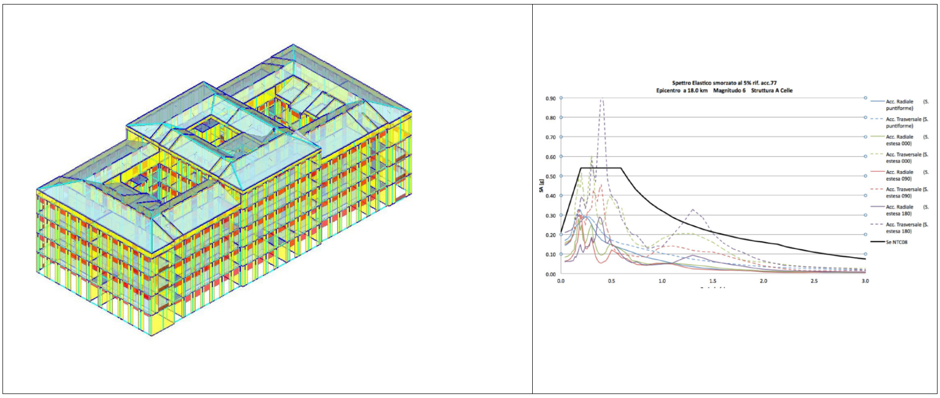


Fig. 7 – Effect of the direct adoption of the scenario input for the building shown in Figure 1b).

In conclusion, the adoption of the scenario input gives in most of the cases an increase of critical elements that have to be taken into account in the design of reinforcements. Furthermore, the higher cost associated with the increase of elements to reinforce is reasonable, especially considering the important reduction of the risk level.

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