Vademecum for the seismic verification of existing buildings

edited by

Giuliano Panza

Full Professor
Dipartimento di Matematica e Geoscienze, Università degli Studi di Trieste
panza@units.it

Fabio Romanelli

Researcher
Dipartimento di Matematica e Geoscienze, Università degli Studi di Trieste
romanel@units.it

Franco Vaccari

XeRiS Project Manager
eXact lab Srl
info@xeris.it, http://www.xeris.it

Giorgio Altin

Professional engineer
Ordine degli Ingegneri della Provincia di Trieste
galtin@altingiorgio.191.it

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Introduction

This document aims to describe the process that leads to the seismic verification of a building by use of a neodeterministic approach (NDSHA, Panza et al, 2001; 2012) for the calculation of the seismic input, with control of the phase of numerical modeling of the building using free vibration measurements of the real structure.

The Italian legislation rules referred to are the technical standards for buildings: Norme Tecniche per le Costruzioni (NTC 2008) Ministerial Decree of date 01/14/2008, and the Circular 617 of date 02/02/2009.

Originally the required seismic verification for buildings of a strategic nature and of significant interest was introduced in Italy by Ordinance 3274/2003.

An effective strategy for mitigation of seismic risk depends essentially on three factors:

a) the reasonable estimate of seismic hazard, i.e. the realistic description of expected earthquakes and of the effects related to the propagation of seismic waves;

b) assessment of the vulnerability of the structures and infrastructures in the study region, depending on their technical-structural characteristics and on the expected ground motion in case of a strong earthquake;

c) exposure assessment of these facilities and infrastructures (i.e. their "value", taking into account the contents in terms of both human lives and objects).

To significantly reduce the risk associated with earthquakes iit s necessary to use advanced seismological methods for the realistic estimate of seismic hazard, as suggested at the point C3.2.3.6 of Italian Circ. 617/2009 of legislation rules.

This approach, however, if not combined with the appropriate monitoring of the response of the building modelling and calculation phase, which commonly is conducted by the engineer, could not adequately exploit the hazard model, no matter how accurate it is.

Scenario based Seismic Hazard Assessment (NDSHA)

A reasonable estimate of the hazard at the site of interest can be obtained by calculating the seismic input associated with a series of “scenario earthquakes”: considering a set of seismic sources located within homogeneous seismogenic zones and assigning, within each zone, a representative type of seismic source (focal mechanism). 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 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 value of magnitude must be considered close to the Maximum Credible Earthquake (MCE) for the area concerned, which, in the case of uncertainties, can be assessed by a parametric study ad hoc, quite easily done using NDSHA.

The seismological and morphostructural analyses then allow for the definition of the “scenario earthquakes", i.e. of the strong earthquakes that may take place in the region of interest, and then for the modelling of the seismic input at predetermined places. The seismic sources thus defined are in fact used to generate a database composed of accelerograms obtained by the realistic modelling of the ground motion, carried out using the physical-mathematical principles that are at the basis of the generation, propagation and local amplification of the seismic waves, as suggested by the Italian regulation (§ C3.2.3.6 and § 3.2.3.6). The seismological modelling provides parameters that, transformed into engineering terms, 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 seismograms, while the traditional methods for the seismic hazard assessment only provide peak values and they are difficult to generalize.

The realistic modelling of ground motion, coupled with an adequate representation of the behaviour of structures, may allow preventive estimation of the global physical damage, allowing for the identification of the structural measures useful to the consolidation, where possible, and to the safeguard of the civil works and urban settlements, including innovative technologies such as seismic isolation and energy dissipation.

Modelling and seismic verification of the building

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 you want and can achieve, in the case of Italy, is described in detail in Circular 617/2009 of legislation rules. It will also condition the type of numerical analysis which can be performed by imposing certain limitations among linear, non-linear, static or dynamic.

In the correct modelling of existing buildings it can not be ignored, alongside the traditional approach of numerical modeling, the careful vibrometric analysis of the building. The vibrometry study allows the engineer to adjust and refine the computational model in the direction suggested by the experimental result of a physical measurement. If this is accompanied by parallel neodeterministic study (NDSHA) of the site-specific seismic input, adequately contemplating all scenarios resulting from different source mechanisms, then the approach can work both in the direction of getting models with the dynamic behaviour as near as possible to the real one and in that to apply to the same models the accelerations that result in the verification phase most conservative. For a better understanding of these concepts see Figure 1, where it is represented a regulatory response spectrum obtained from NTC 2008 legislation rules, which is used as seismic input.

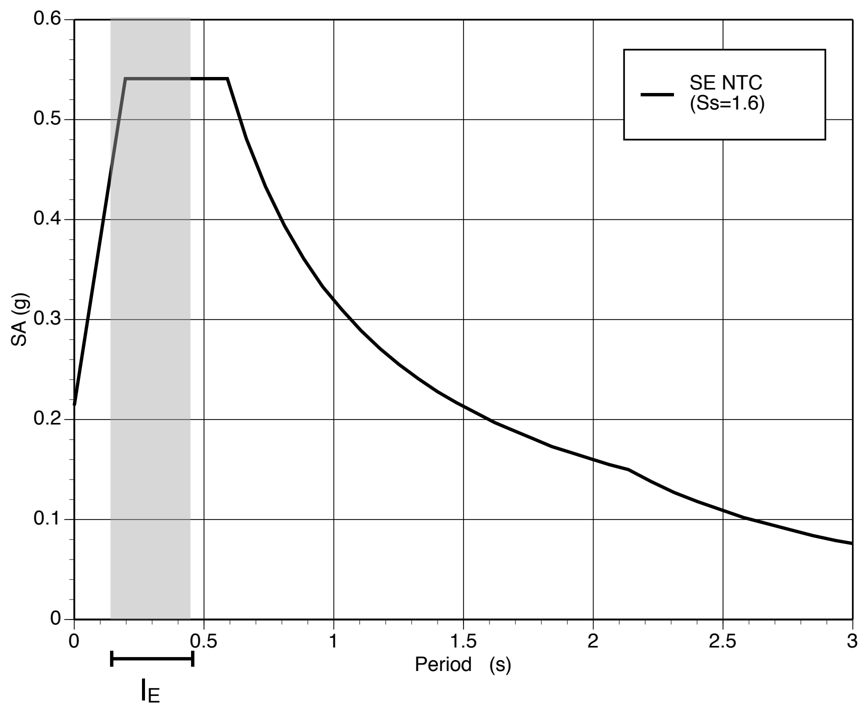

Figure 1. Example of regulatory response spectrum from the Italian legislation rules, where the highlighted interval I_E refers to vibration periods typical of masonry buildings.

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 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.

As it is evident, this interval represents the input zone on the horizontal axis which allows to obtain the value of the accelerations to be used as input for the masses of the structure.

The NDSHA method as already said allows to define, for the building site, a series of "scenario" spectra whose spectral acceleration, with particular reference to the range I_E, generally do not coincide with those that are obtained using the standard spectrum. The example of Figure 2 shows the "scenario" spectra for a site in the center of Trieste, precisely in Borgo Teresiano, and the range of accelerations I_A which would input the structures with the adoption of such spectra. This suggests that the interval I_A defines the possible deviations of acceleration with respect to the spectrum obtained from the INGV gridded values.

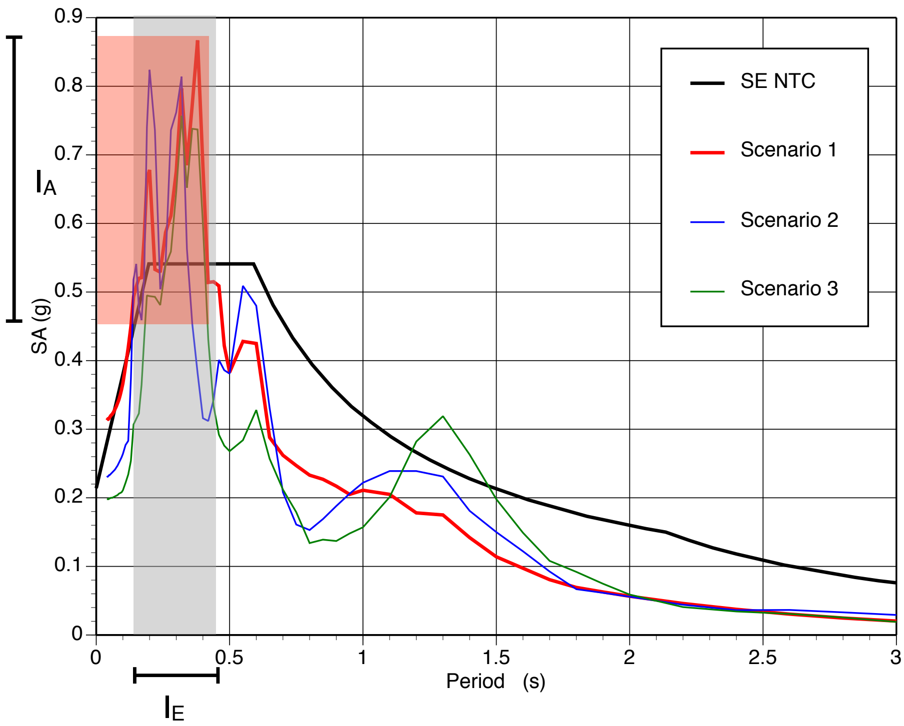

Figure 2. Acceleration range I_A which would affect the buildings characterized by free periods corresponding the interval I_E.

Generally, but not necessarily, the “scenario” spectra lead to higher accelerations than those which are 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 spectrum through the stratigraphic amplification coefficient (Ss) so as to mediate the difference in accelerations that is obtained from the comparison between the spectra. In this case, the acceleration peaks are neglected but at the same time in the numerical models will be used acceleration values higher than those of the spectra from legislation rules.

Figure 3 can be read as a summary of the process: once calibrated the model by vibrometric analysis, you can “enter” in the spectrum by adopting the correct range of periods and then "get out", through appropriate amplification that takes into account “scenario” input, realistic values of acceleration to be applied to the calibrated model.

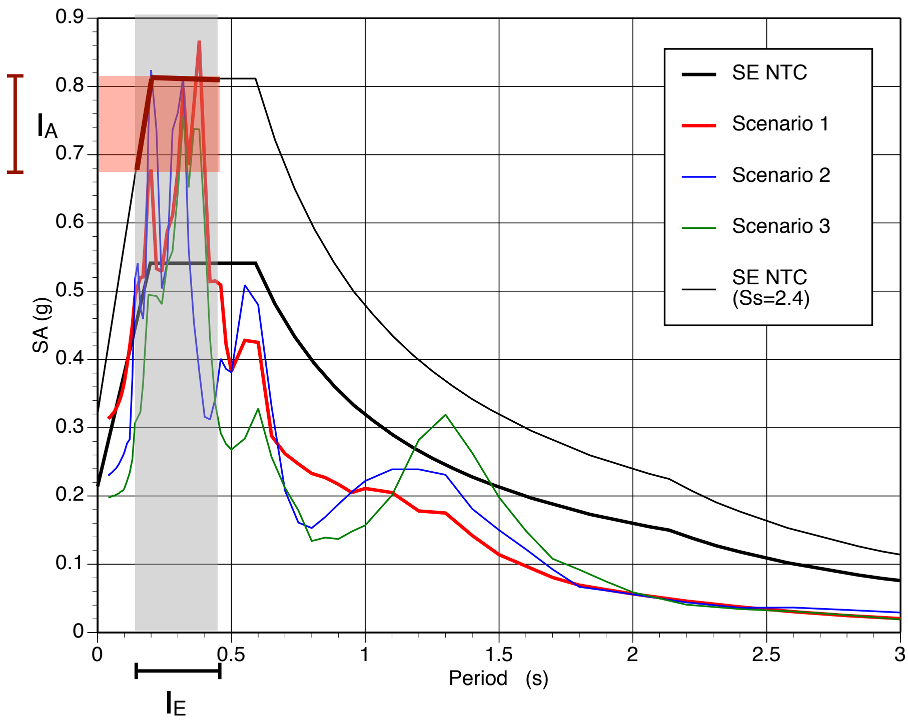

Figure 3. Acceleration range I_A corrected using vibrometric analysis and estimation of the amplifications obtained by shaking scenarios

References

DISS Working Group (2010). Database of Individual Seismogenic Sources (DISS), Version 3.1.1: A compilation of potential sources for earthquakes larger than M 5.5 in Italy and surrounding areas. http://diss.rm.ingv.it/diss/, © INGV 2010 - Istituto Nazionale di Geofisica e Vulcanologia - All rights reserved; DOI:10.6092/INGV.IT-DISS3.1.1.

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Appendix

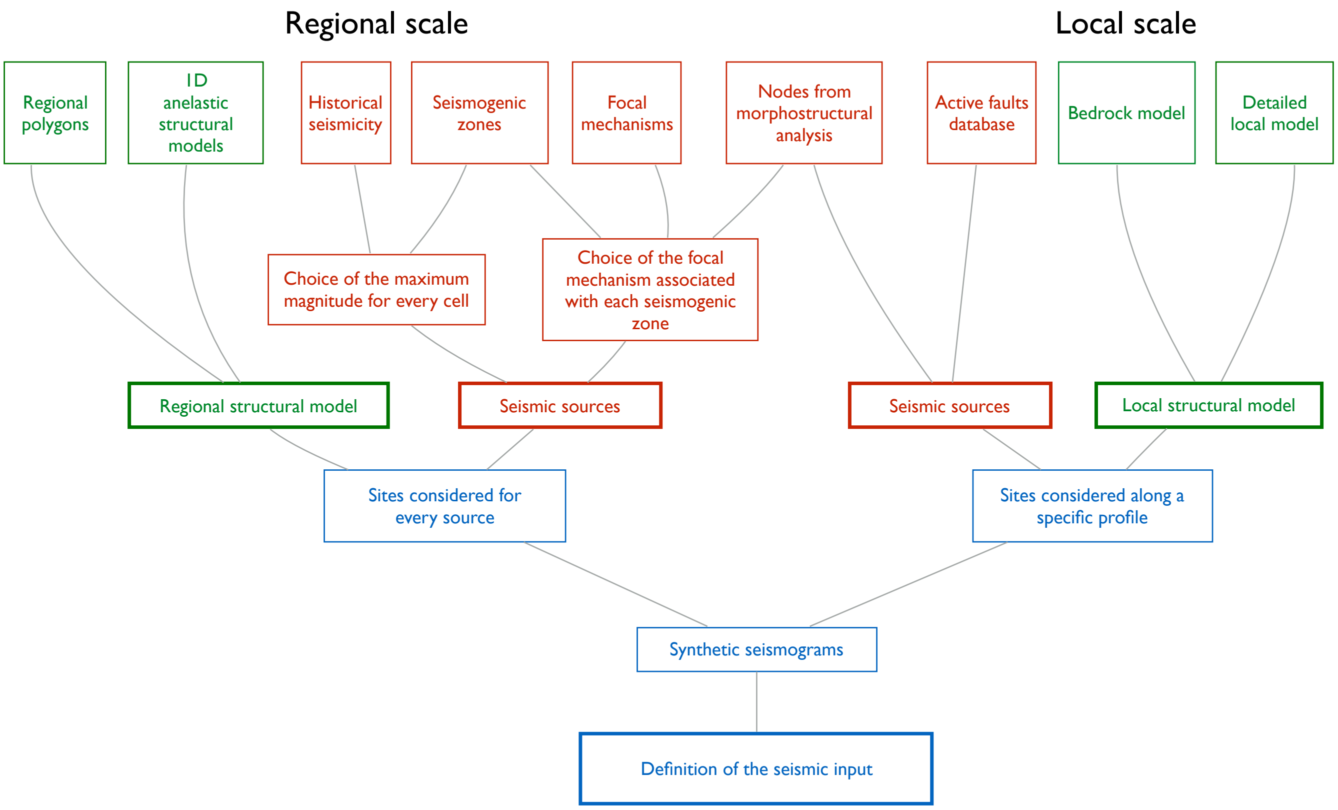
Proposed operational flow: seismological-engineering scheme

Seismic verification of existing buildings

Operational flow

Seismological elaboration

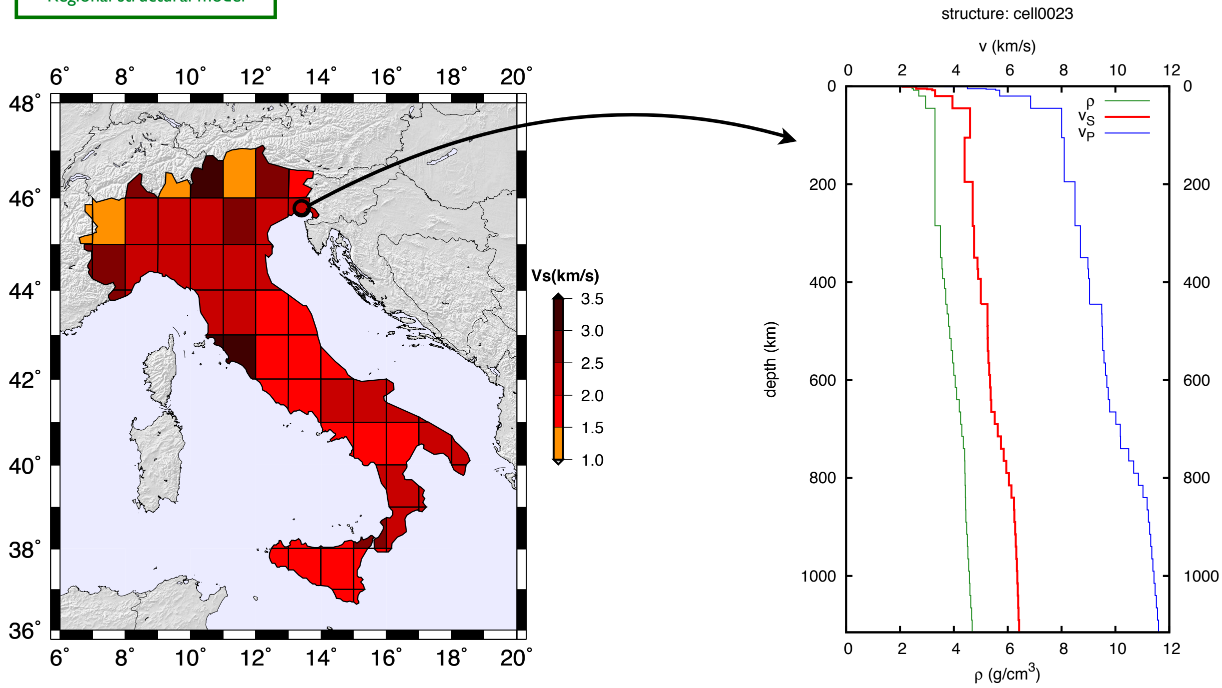
General scheme



Seismological elaboration

Regional scale

Regional structural model

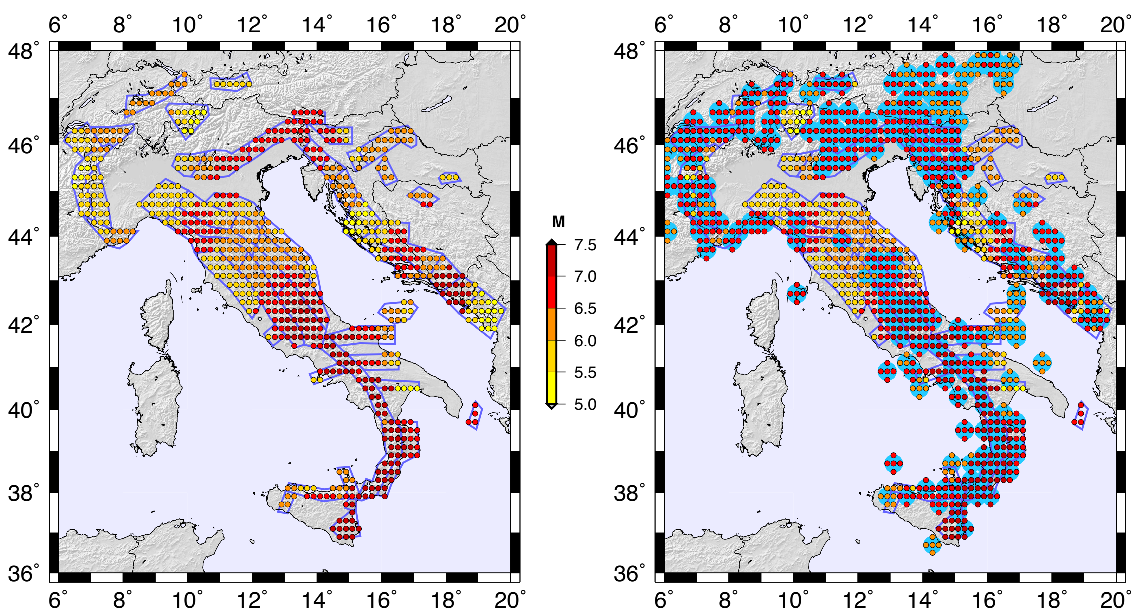


Characterisation of the bedrock model for each cell

Seismological elaboration

Regional scale

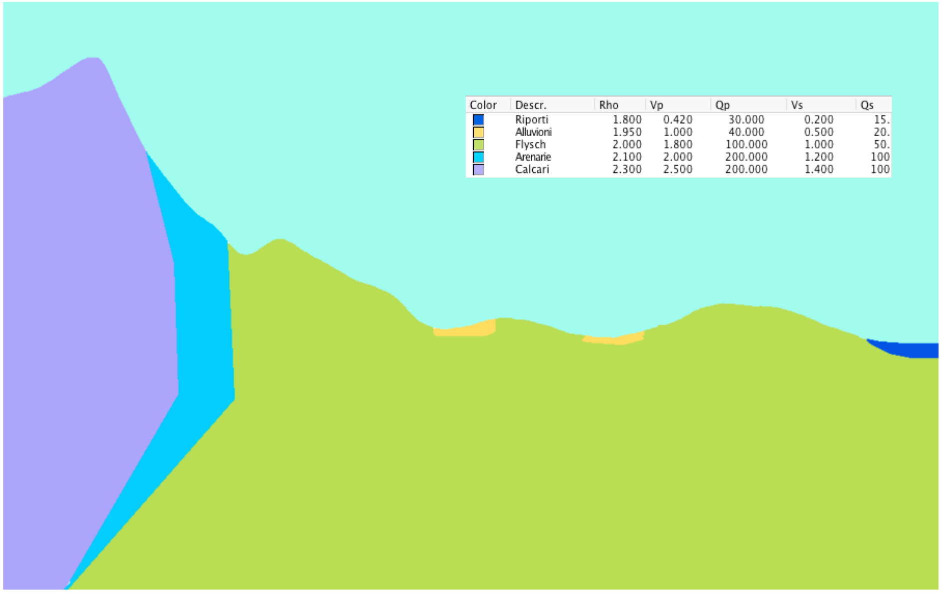
Seismic sources



Definition of the seismic sources with the eventual inclusion of seismogenic nodes

Seismological elaboration
Local scale

Local structural model

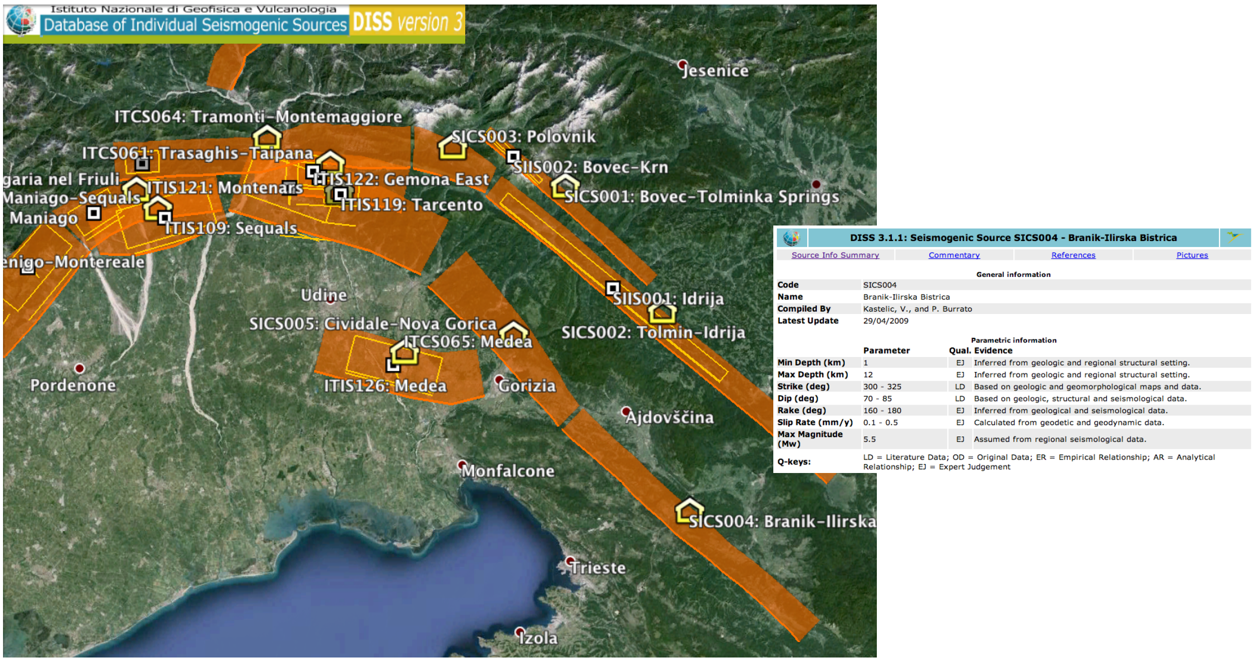


Definition of the geologic section and of the geotechnical parametrisation

Seismological elaboration
Local scale

XeRiS by eXact

Seismic sources



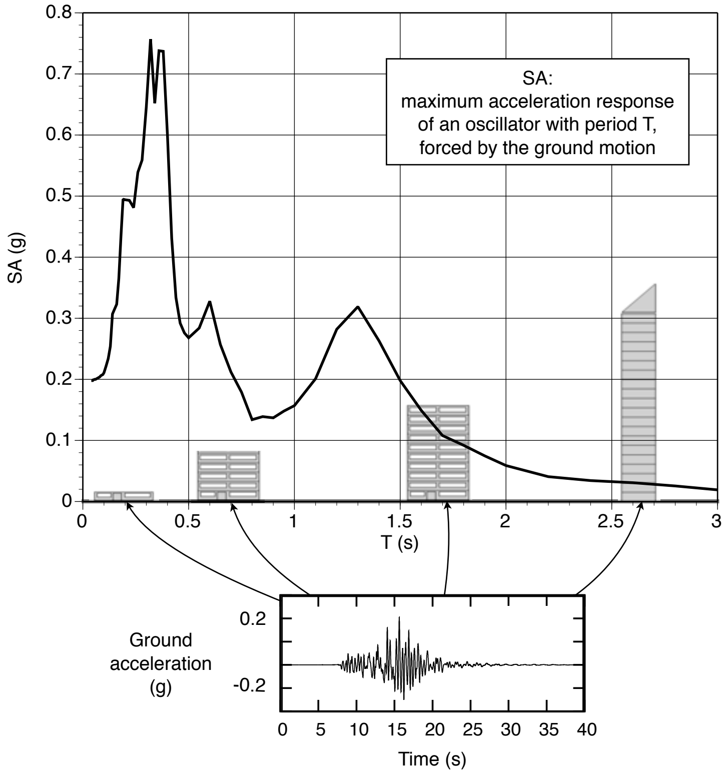
Definition of the sources from the DISS database (INGV)

Seismological elaboration

Seismic input from the local scale modelling

XeRiS by eXact

Input sismico

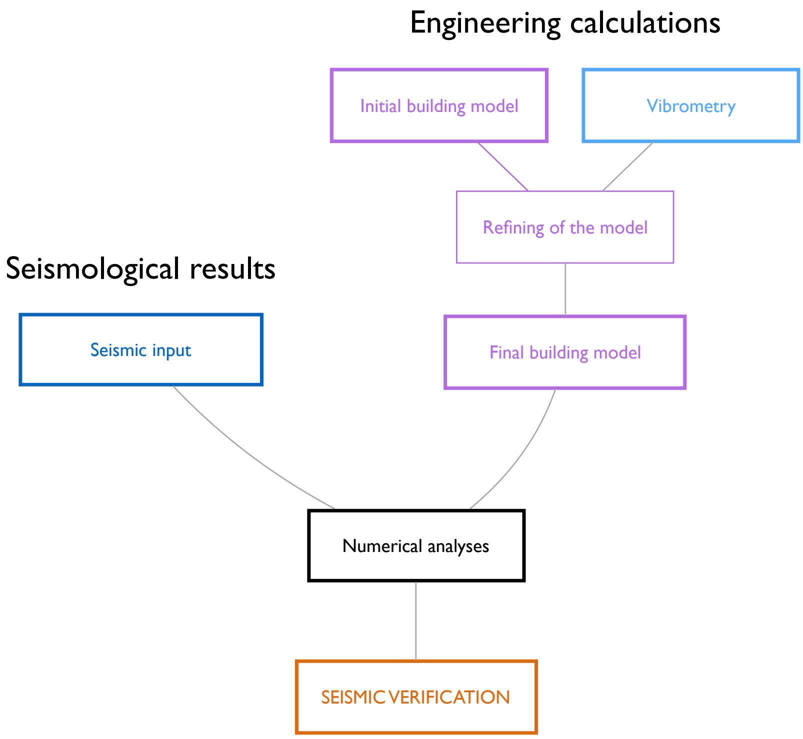


Response spectrum from synthetic accelerogram

XeRiS by eXact

Engineering elaboration

General scheme

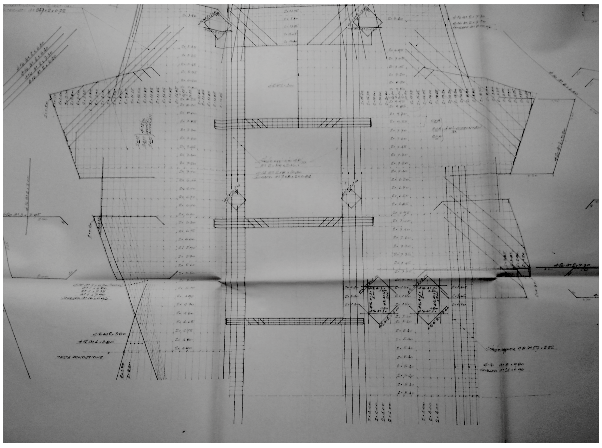


Engineering elaboration

Information acquisition

XeRiS by eXact

Initial model of the building



Acquisition of the design documents

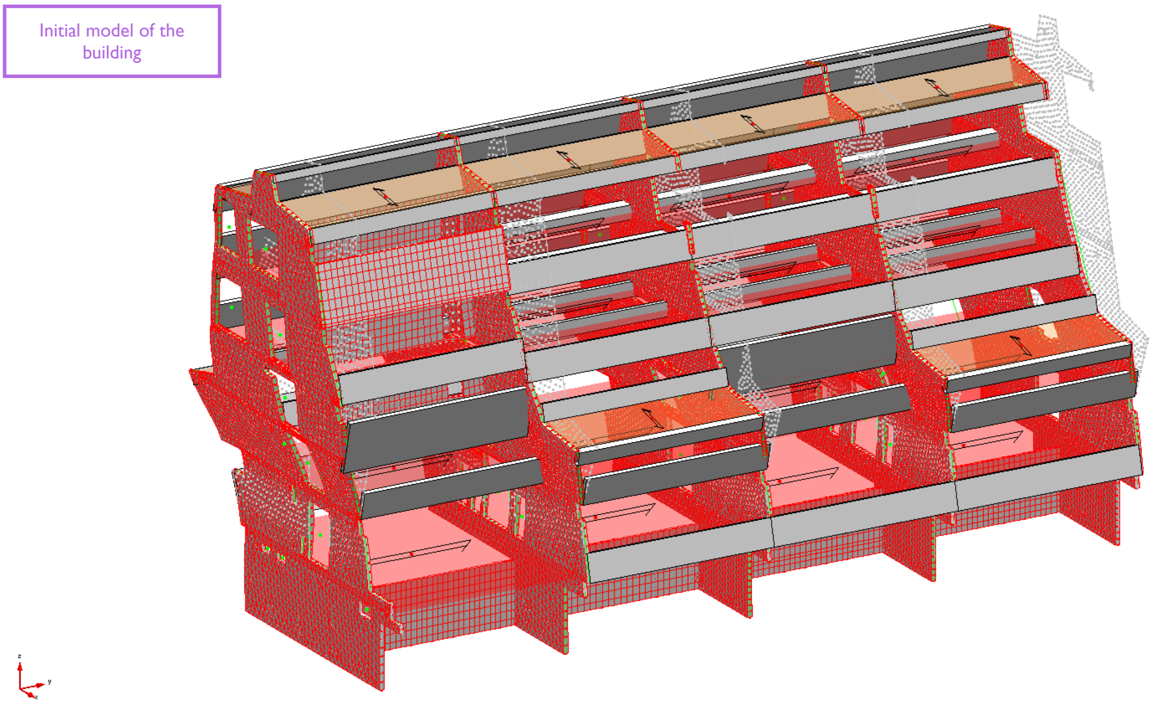
Sampling and analysis of the masonry specimens for the materials characterisation

Engineering elaboration

Initial modelling of the building

XeRiS by eXact

Initial model of the building

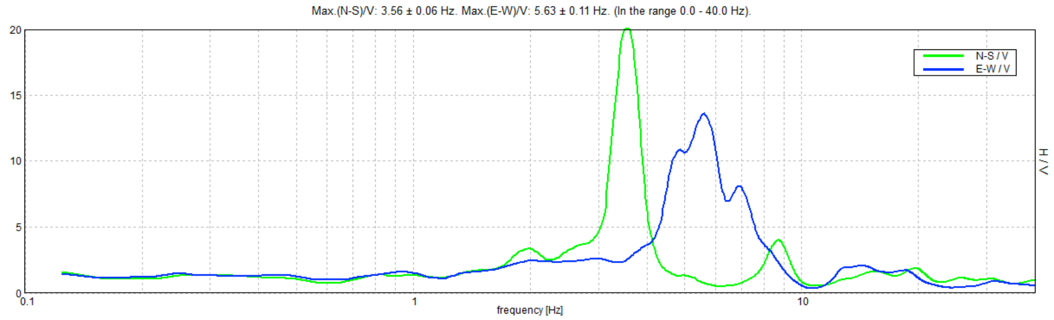


First hypothesis of the model

Engineering elaboration

Acquisition of the vibrometric measurements

Vibrometry

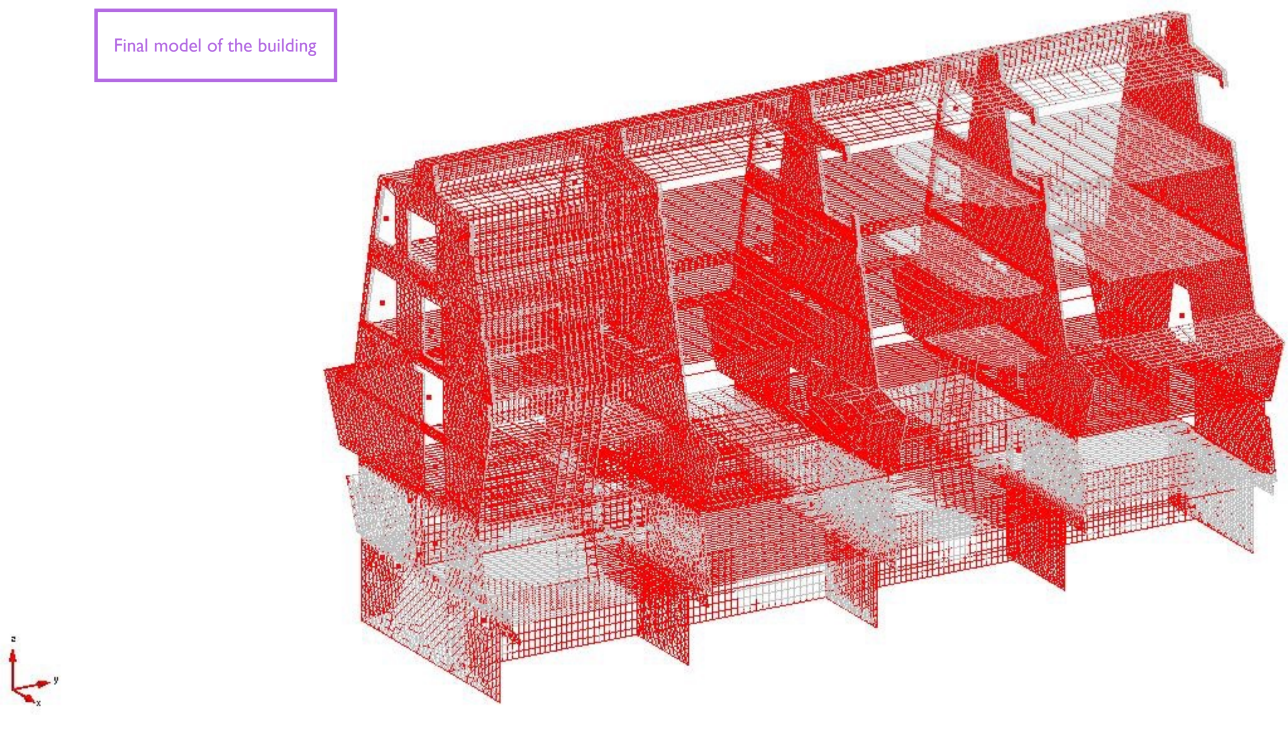


Experimental measure of the resonant frequencies
along the principal axes of the building
to be compared with the theoretical ones

Engineering elaboration

Adjustment of the model

Final model of the building



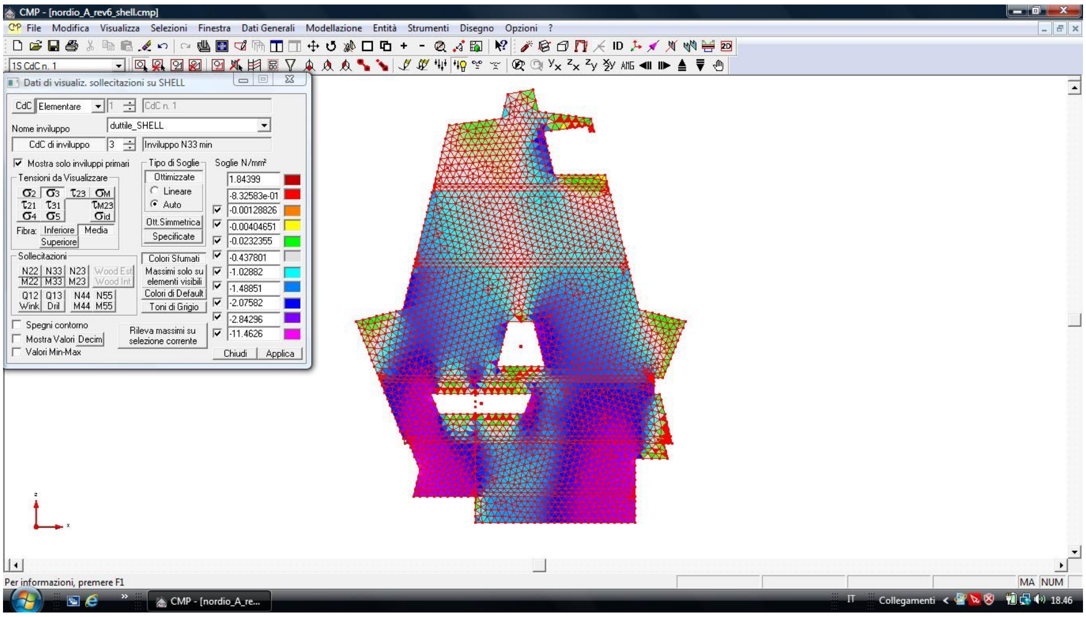
Re-modelling of the building calibrated on the results of the experimental vibrometry

Engineering elaboration

XeRiS by eXact

Calculus of the tensions at the ultimate limit state (SLU)

Numerical analyses



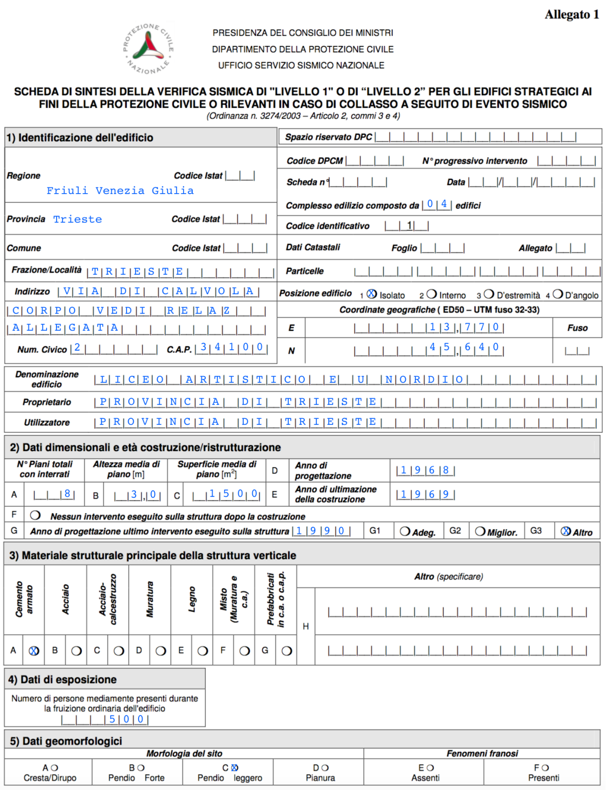
Vertical tensions

Engineering elaboration

XeRiS by eXact

Filling of the seismic verification form

SEISMIC VERIFICATION



Allegato 1

PRESIDENZA DEL CONSIGLIO DEI MINISTRI
DIPARTIMENTO DELLA PROTEZIONE CIVILE
UFFICIO SERVIZIO SISMICO NAZIONALE

SCHEDA DI SINTESI DELLA VERIFICA SISMICA DI "LIVELLO 1" O DI "LIVELLO 2" PER GLI EDIFICI STRATEGICI AI FINI DELLA PROTEZIONE CIVILE O RILEVANTI IN CASO DI COLLASSO A SEGUITO DI EVENTO SISMICO

(Ordinanza n. 3274/2003 – Articolo 2, commi 3 e 4)

1) Identificazione dell'edificio

Spazio riservato DPC

Codice DPCM — N° progressivo intervento

Scheda n° — Data / /

Regione: Friuli Venezia Giulia — Codice Istat

Complesso edilizio composto da 04 edifici

Provincia: Trieste — Codice Istat

Codice identificativo: 1

Comune — Codice Istat

Dati Catastali — Foglio — Allegato

Frazione/Località: TRIESTE

Particelle

Indirizzo: VIA DI CALVOLA CORPO VEDI RELAZ ALLEGATA

Posizione edificio: 1 (X) Isolato 2 ( ) Interno 3 ( ) D'estremità 4 ( ) D'angolo

Coordinate geografiche (ED50 – UTM fuso 32-33)

E: 13,770 — Fuso

N: 45,640

Num. Civico: 2 — C.A.P.: 34100

Denominazione edificio: LICEO ARTISTICO E U NORDIO

Proprietario: PROVINCIA DI TRIESTE

Utilizzatore: PROVINCIA DI TRIESTE

2) Dati dimensionali e età costruzione/ristrutturazione

N° Piani totali con interrati		Altezza media di piano [m]		Superficie media di piano [m^2]				
A	8	B	3,0	C	1500	D	Anno di progettazione	1968
						E	Anno di ultimazione della costruzione	1969

F ( ) Nessun intervento eseguito sulla struttura dopo la costruzione

G Anno di progettazione ultimo intervento eseguito sulla struttura 1990 — G1 ( ) Adeg. — G2 ( ) Miglior. — G3 (X) Altro

3) Materiale strutturale principale della struttura verticale

Cemento armato	Acciaio	Acciaio-calcestruzzo	Muratura	Legno	Misto (Muratura e c.a.)	Prefabbricati in c.a. o c.a.p.	Altro (specificare)
A (X)	B ( )	C ( )	D ( )	E ( )	F ( )	G ( )	H

4) Dati di esposizione

Numero di persone mediamente presenti durante la fruizione ordinaria dell'edificio: 500

5) Dati geomorfologici

Morfologia del sito				Fenomeni franosi	
A ( ) Cresta/Dirupo	B ( ) Pendio Forte	C (X) Pendio leggero	D ( ) Pianura	E ( ) Assenti	F ( ) Presenti