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# Ground shaking at the Vittorio Veneto (N.E. Italy) test site from uniform hazard response spectra

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**Abstract -** The design strong-motion time history for the Vittorio Veneto test site in north-eastern Italy has been computed generating synthetic accelerograms that are compatible with the uniform hazard response spectrum for the site. The response spectrum of this artificial time history has been compared and corrected with those of recorded events considered as suitable design earthquakes for Vittorio Veneto. These last were taken from the European strong-motion databank, selecting the real accelerograms that match a scenario earthquake derived from the disaggregation of the source contribution in the probabilistic seismic hazard assessment. Furthermore, the synthetic design response spectrum for Vittorio Veneto has been compared with that of other records of the European strong-motion databank, considered as a suitable extreme event for the study site. Considering that the actual recordings refer to different soil typologies, the computed design spectrum for Vittorio Veneto is adequate enough to represent also the extreme event for the region.

## 1. Introduction

The seismic hazard of a site can be described through its response spectrum. Sometimes this is not sufficient and a characteristic strong-motion time history is required for seismic design. For this, three approaches can be followed (Bommer et al., 2000): 1) selecting and scaling real accelerograms; 2) generating artificial records that are compatible with a design response spectrum; and 3) generating synthetic records on the basis of a model of an earthquake source. The most popular technique takes a strong-motion record, suitable for the studied site, as characteristic accelerogram; when needed it is scaled in amplitude to reach the desired value, or,

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alternatively, the envelope of several, possible strong-motion records for the site can be taken. This last technique is used, for example, to improve the contents in frequency of the computed accelerogram. An alternative way of generating synthetic records that are compatible with a response spectrum was proposed in the Seventies already (Vanmarke, 1976) and actually has found only a few applications. With this approach, the uniform hazard response spectrum for the site is taken as target spectrum: in such a way, it is not the occurrence of one single earthquake (the design earthquake) that is considered, but the whole seismic hazard at the site. The computed time history, then, models the expected ground shaking caused by the simultaneous occurrence of earthquakes in all the neighbouring seismogenic sources. This approach is particularly useful in the building design phase, when it is important to guarantee the stability and/or functionality of the studied construction, especially if it has a strategic importance, not only if the design earthquake occurs (extreme situation with a low probability of occurrence) but for all possible events. These, in fact, can have frequency contents that are very different to the design earthquake.

The goal of the present work is to compute the design ground motion, in terms of accelerometric time history, for the Vittorio Veneto test site in north-eastern Italy, on the basis of probabilistic hazard estimates and to calibrate this time history on strong-motion records from the European databank at www.isesd.cv.ic.ac.uk (see also Ambraseys and Bommer, 1991; Ambraseys et al., 2004). The methodology used to compute this artificial record is based on the random vibration analysis approach (Vanmarke, 1976) while the choice of the scenario earthquake is made by analysing the conditional distribution of magnitude and distance (Bommer et al., 2000).

The small town of Vittorio Veneto was selected as test site because it is famous for its architecture and located in a critical area from the seismotectonic point of view (western limit of the most seismic Southalpine faults). For these reasons the “Gruppo Nazionale per la Difesa dai Terremoti” (GNDT) is financing a project to define the seismic risk at Vittorio Veneto. Some preliminary results of the GNDT study, from which the present paper benefits, are already available. More precisely, two ground shaking scenarios were computed for the study site, respectively for the design and for extreme earthquakes (Slejko and Rebez, 2002).

## 2. PSHA for Vittorio Veneto

Recent seismic hazard estimates for north-eastern Italy (Rebez et al., 2001) show that seismically the most active area is expected to be central Friuli, and hazard decreases westwards. The Vittorio Veneto area, on the border between the Friuli - Venezia Giulia and the Veneto regions (Fig. 1), is the limit of the most hazardous area. Two large earthquakes occurred there in the last centuries: the 1873 Alpago quake with magnitude 6.3 and the 1936 Cansiglio event with magnitude 5.8 (Gruppo di Lavoro CPTI, 1999).

The probabilistic seismic hazard assessment (PSHA) for Vittorio Veneto has been computed according to the standard approach of Cornell (1968) with the computer formulation of Bender and Perkins (1987). As it is known, this approach needs the following input data: the spatial

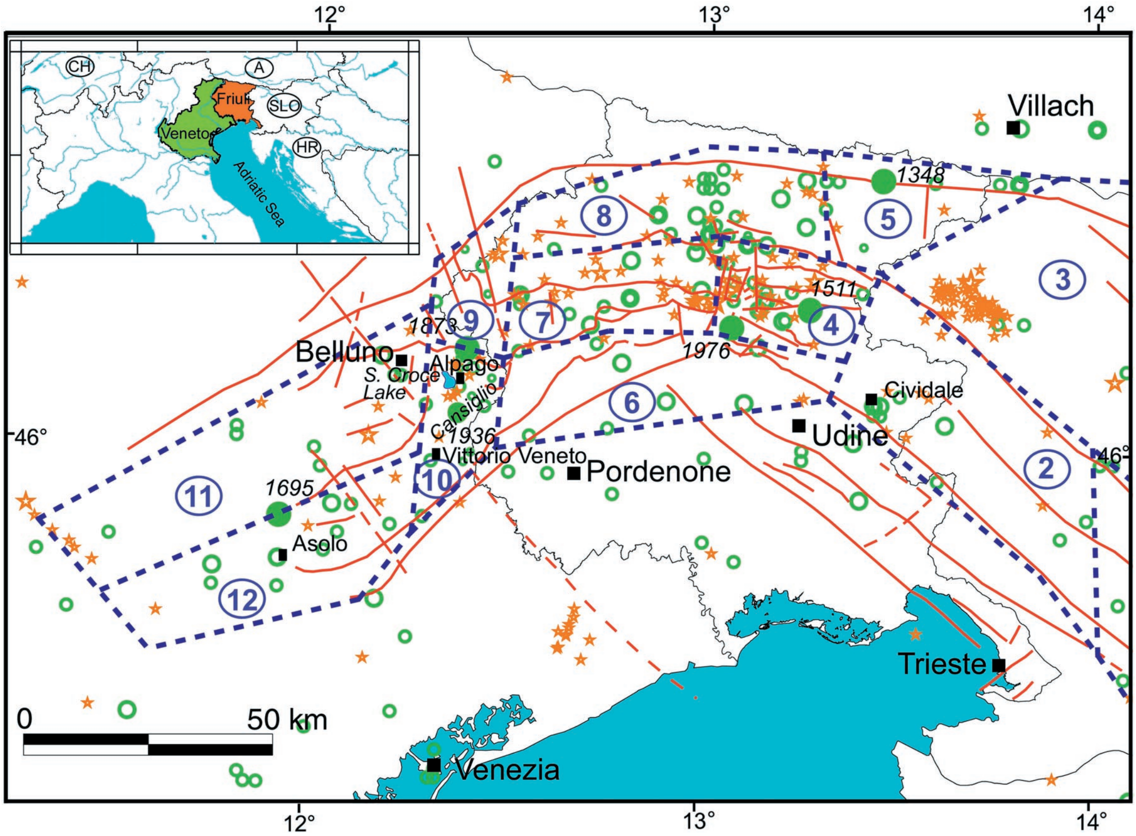


**Fig. 1** - SZs in north-eastern Italy and tectonic setting (from Slejko and Rebez, 2002). Dashed blue boxes indicate the SZs, green (solid if major events, the number indicates the date of the quake) circles show the epicentres of the earthquakes of the GNDT catalogue (Camassi and Stucchi, 1997), yellow stars represent the epicentres of the 1977 - 1999 earthquakes (OGS, 1977-1981, 1982-1990, 1991-1999; Renner, 1995); red lines display the main faults.

delineation of the seismogenic zones (SZs), the seismicity rates (in terms of average number of earthquakes per magnitude interval), and the attenuation relation of the chosen ground motion parameter. A seismogenic zonation (Fig. 1) of regional validity (Slejko and Rebez, 2002), with associated seismicity rates defined according to the methodology used for the definition of the Italian seismic hazard map (Slejko et al., 1998), and the Ambraseys et al. (1996) spectral attenuation relations have been used for the hazard computation (Slejko and Rebez, 2002). These attenuation relations are defined for three soil types to which the hazard estimates refer: values of peak ground acceleration (PGA) with a 475-year return period for Vittorio Veneto are 0.21 g, 0.27 g, and 0.28 g for rock, stiff and soft soil, respectively. These values increase to 0.31 g, 0.40 g, and 0.41 g, for the different soil types respectively, when the standard deviation ($\sigma$) of the attenuation relation is considered. The uniform hazard response spectrum, at a 5% damping, has been computed for the three soil types at 46 spectral ordinates and is reported in Fig. 2: the influence of the soil is evident as well as that of the $\sigma$ of the attenuation relation. The $\sigma$ increases the expected shaking level by about 50%. These spectra have been used as target spectra in the following computations.

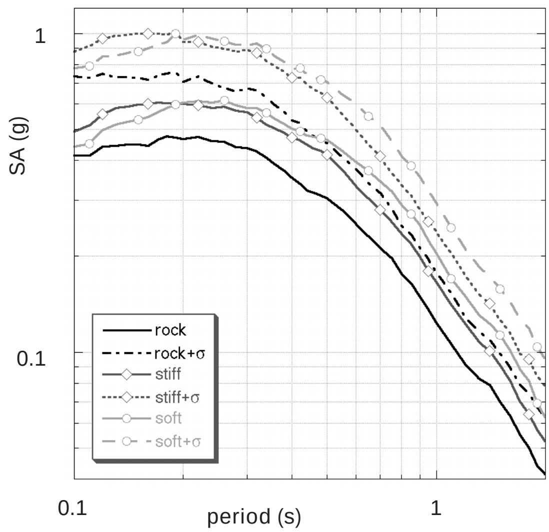


**Fig. 2** - Uniform hazard response spectra (with and without $\sigma$ of the attenuation relation) for the Vittorio Veneto test site: different curves indicate different soil types (rock, stiff, and soft soil).

## 3. Probabilistic design strong-motion time history

It is possible, at this point, to construct a time history with spectral contents very similar to that of the uniform hazard response spectrum (Fig. 2). For the artificial motion generation, the random vibration approach (Vanmarcke, 1976) has been used. According to this method any periodic function can be expanded into a series of sinusoidal waves of variable phase and amplitude. The artificial motion generation is given by superposition of sinusoids having random phase angles and amplitudes derived from a stationary power spectral density function of motion. The final simulated motion is stationary in frequency content with a peak acceleration close to the target peak acceleration. The computer code SIMQKE (Gasperini and Vanmarcke, 1976) is based on this approach and can: 1) compute a power spectral density function from a specified smooth target response spectrum; 2) generate statistically independent artificial acceleration time histories and tries, by iterations, to match the specified target response spectrum. To simulate the transient character of real earthquakes, the steady-state motions are multiplied by a deterministic trapezoidal or exponential envelope function. The input data for SIMQKE are then: the smallest and largest periods of desired response spectrum; the characteristics of the intensity envelope function; the discretisation interval of the desired time history; the desired maximum ground acceleration; the number of cycles that fit the response spectrum of the artificial time history to the target response spectrum; and the number of points describing the target response spectrum. The response spectrum of the artificial time history is computed for several dampings.

The 46 spectral acceleration (SA) values of the uniform hazard response spectrum on rock (Fig. 2) were taken as the target spectrum, taking into account the $\sigma$ of the attenuation relations.The SAs produced by future earthquakes will show, in fact, an aleatory scatter around a predictable mean value: the artificial time history we compute represents, therefore, a conservative result. Several trials were done using different intensity envelope functions and by changing the number of cycles to fit the target spectrum: the final result (Fig. 3) was obtained using an exponential intensity envelope function, with amplitude 5 and decay parameters 0.1 and 0.9, and selecting up to 20 iterations needed to fit the target spectrum. The response spectrum of the artificial time history shows a good agreement with the target spectrum with the exception of some oscillations which are smoothed by definition in the uniform hazard target response spectrum.

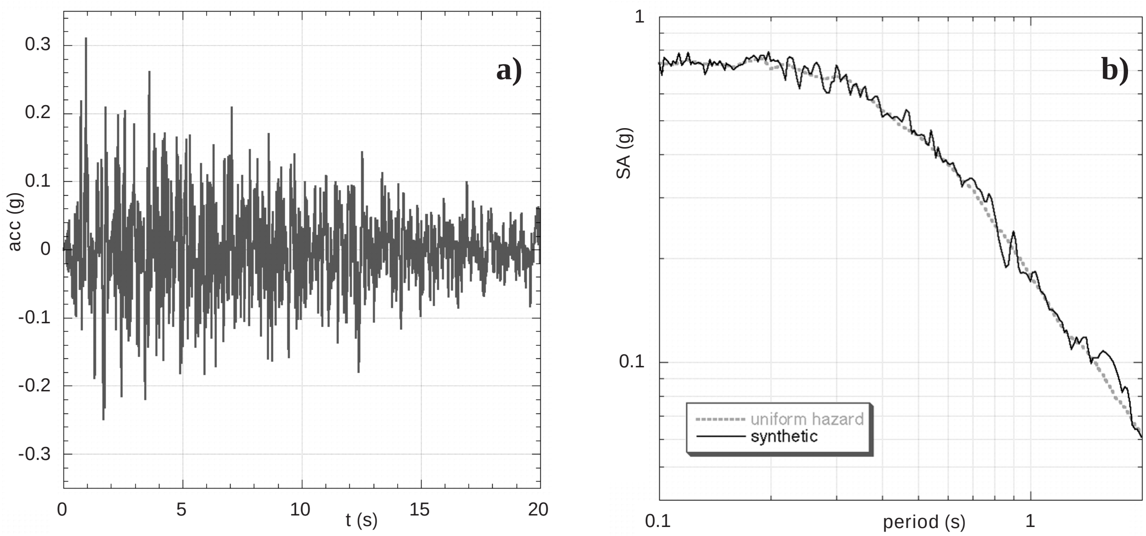


**Fig. 3** - Preliminary design accelerogram for Vittorio Veneto: a) synthetic accelerogram computed in agreement with the uniform hazard response spectrum; b) comparison between the spectrum of the synthetic accelerogram and the uniform hazard response spectrum for rock.

## 4. Comparison with the design earthquake

From the sensitivity analysis of the probabilistic hazard for the Vittorio Veneto broader area the design earthquake for Vittorio Veneto was identified as a 6.0 magnitude event with a 6-km epicentral distance (Slejko and Rebez, 2002).

Three records with similar characteristics were found in the European strong-motion databank (Ambraseys et al., 2000): the Budva (8 km far from the epicenter) record of the $M_s$ 6.3 1979 Montenegro quake, the Colfiorito (5 km from the epicenter) record of the $M_s$ 5.9 1997 Umbria - Marche event, and the Nocera Umbra (11 km from the epicenter) record of the same Umbria - Marche earthquake. Both horizontal records of the three stations are reported in Fig. 4: the PGA value was 0.32 g at Colfiorito, 0.28 g at Budva, and 0.78 g at Nocera Umbra.

Because the Nocera Umbra record has a higher PGA than the expected ground shaking at Vittorio Veneto (PGA between 0.21 and 0.31 g), it cannot be considered suitable as a design earthquake. The recorded time history has been, therefore, scaled to the maximum expected value in Vittorio Veneto. This was done considering the average value of the two recordings and scaling both recordings according to the ratio between the maximum expected value (0.31 g)

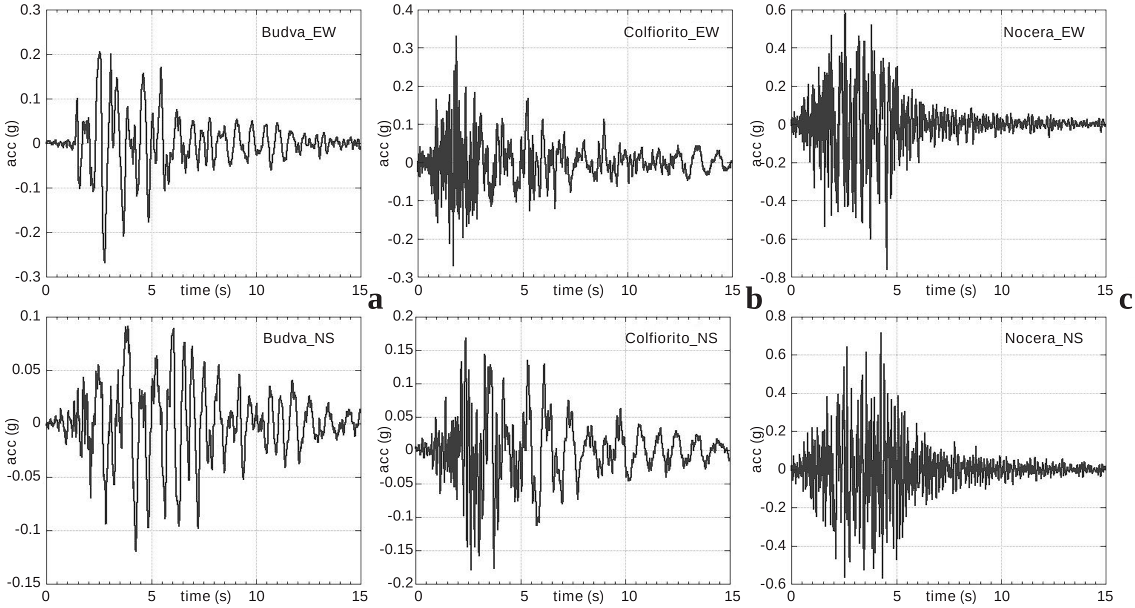


**Fig. 4** - Strong-motion records of possible design earthquakes for Vittorio Veneto: a) Budva horizontal records of the $M_s$ 6.3 1979 Montenegro quake; b) Colfiorito horizontal records of the $M_s$ 5.9 1997 Umbria - Marche quake; c) Nocera Umbra horizontal records of the $M_s$ 5.9 1997 Umbria - Marche quake.

and the mean value (0.74 g) of the two maxima actually recorded. The response spectra of these scaled recordings were computed with the Nigam and Jennings (1969) method, while the spectra of Budva and Colfiorito were taken directly from Ambraseys et al. (2000).

The horizontal spectrum considered for each station is the average value of the two horizontal components; these spectra are reported in Fig. 5 together with the uniform hazard response spectra (with $\sigma$ of the attenuation relations) for the three soil types. It must be pointed out that only the Nocera records refer to rock because the Budva recordings refer to an alluvial soil while those of Colfiorito to a stiff soil. The uniform hazard spectrum for rock represents the spectra of the observed earthquakes for periods lower than 0.4 s rather well; only the spectrum of Nocera shows some higher peaks. The uniform hazard spectrum for soft soil (the highest spectrum) is slightly lower than the Budva spectrum for periods greater than 0.5 s and that of Colfiorito for periods greater than 0.8 s.

To avoid the differences between the uniform hazard design spectrum and those of the recordings suitable for the Vittorio Veneto design earthquake, the target spectrum has been modified in the low-frequency range. More precisely, by taking into account the different soil typologies of the stations that recorded the accelerograms considered, the uniform hazard response spectrum related to rock was modified with the soft soil spectrum for periods greater than, or equal to, 1 s. The two spectra were, then, interpolated between 0.3 s and 1 s. With this new target spectrum, an artificial time history (Fig. 6a) was computed with SIMQKE (Gasperini and Vanmarcke, 1976). The response spectrum of this new artificial time history reproduces those of the observed recordings in the low-frequency range better, although there are still some differences especially with respect to the Budva earthquake (Fig. 6b).

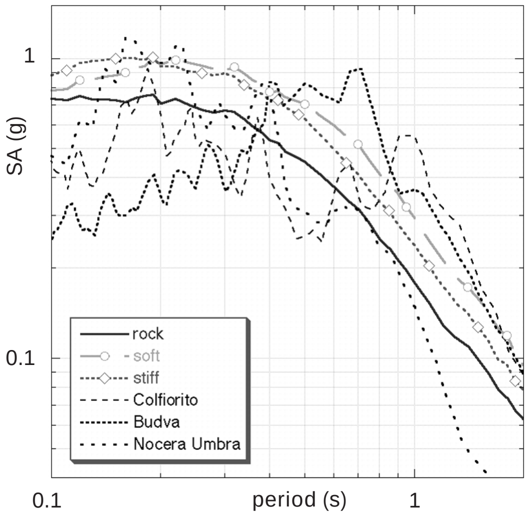


**Fig. 5** - Comparison of the average horizontal response spectra of the 1979 Montenegro earthquake recorded at Budva, of the 1997 Umbria - Marche earthquake recorded at Colfiorito and Nocera Umbra (scaled to 0.31 g, see text), and the uniform hazard response spectra at Vittorio Veneto for three soil types.

## 5. Comparison with the extreme ground shaking

This new computed design accelerogram shows a response spectrum in satisfactory agreement with those of the expected earthquakes at Vittorio Veneto (6-magnitude events at a 6-km distance from the studied site), considering the different soil typologies. It is interesting to check if this response spectrum is in agreement with the extreme earthquake in the region as well.

The extreme event estimated for the seismogenic zone which contributes most to the seismic hazard at Vittorio Veneto (SZ 10 in Fig. 1; see Slejko and Rebez, 2002) is a 6.7-magnitude event with epicenter similar to that of the 1936 earthquake (18 km from Vittorio Veneto). Actually, as Vittorio Veneto is inside SZ 10, one could hypothesize a 6.7 earthquake right under the town but this possibility is not supported by the tectonic information available for the region. Three recordings with the requested characteristics have been found in the Europen strong-motion databank (Ambraseys et al., 2000): the recording in Erzincan (stiff soil, epicentral distance 13 km) of the local earthquake of March 13, 1992 with $M_s$ 6.7, as well as those in Korinthos (soft soil, epicentral distance 20 km) and Xilokastro (alluvial soil, epicentral distance 19 km) of the Alkion earthquake of February 24, 1981 with $M_s$ 6.7 (Fig. 7). The related response spectra are reported in Fig. 8 together with the new design spectrum for Vittorio Veneto. Considering that the actual recordings do not refer to rock, the new design spectrum for Vittorio Veneto is adequate enough to represent also the extreme event for the region with the exception of the spectrum in Erzincan, which does not show any amplitude decay in the considered frequency range. The high level of shaking at periods below 1 s in the Erzincan record can be associated to directivity effects. In fact, the propagation of rupture

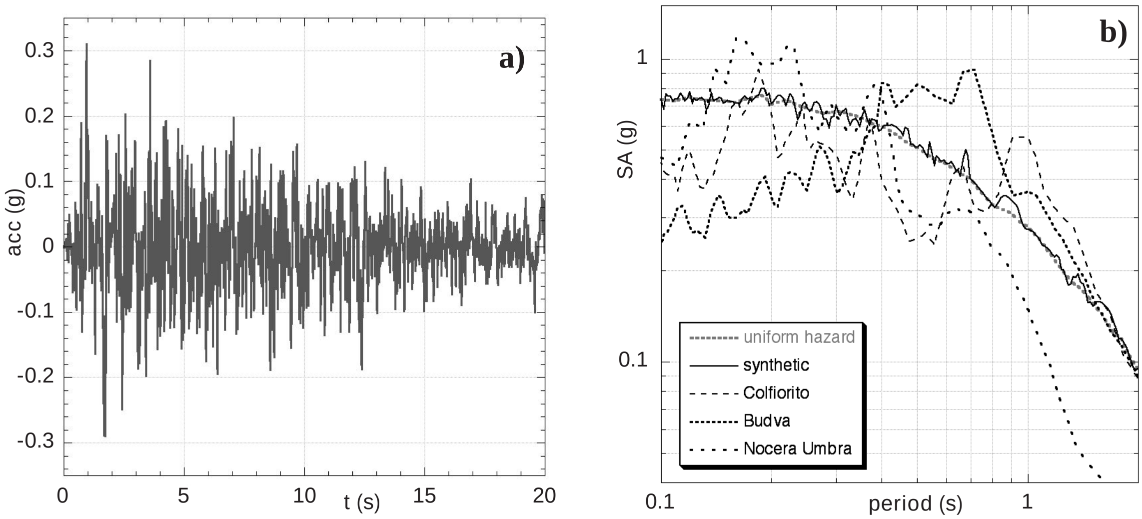


**Fig. 6** - Final design accelerogram for Vittorio Veneto: a) synthetic accelerogram computed in agreement with the uniform hazard response spectrum and the recorded design earthquakes; b) comparison between the spectrum of the synthetic accelerogram and the uniform hazard response spectrum corrected on the basis of the recorded design earthquakes (see text). The average response spectra at Budva, Colfiorito, and Nocera Umbra (scaled to 0.31 g, see text) are reported as well.

towards a site causes larger ground-motion amplitudes at periods longer than 0.6 s (Sommerville et al., 1997). In the case of the 1992 earthquake, the epicenter location and the fault geometry and mechanism (Bernard et al., 1997) favour a forward rupture directivity for the Erzincan station.

## 6. Conclusions

The design strong-motion time history for the Vittorio Veneto test site has been computed generating a synthetic accelerogram that is compatible with the uniform hazard response spectrum on rock for the site (Fig. 3). As its spectrum does not give a good fit to some recorded events considered as suitable design earthquake for the study site (Fig. 5), a new artificial time history has been computed modifying the target spectrum in the low frequency range (Fig. 6). The response spectrum of this new synthetic strong-motion time history seems to represent also those of the extreme earthquakes computed for Vittorio Veneto (Fig. 8) adequatly. It can be taken, then, as a design ground-motion time history in urban planning, especially in the case of special buildings.

In conclusion, the random vibration analysis approach seems adequate to compute a strong-motion time history which, although partly different from those of true events (compare Fig. 6a with Figs. 4 and 7), contains all frequency contents characteristic of the earthquakes important for the study site.

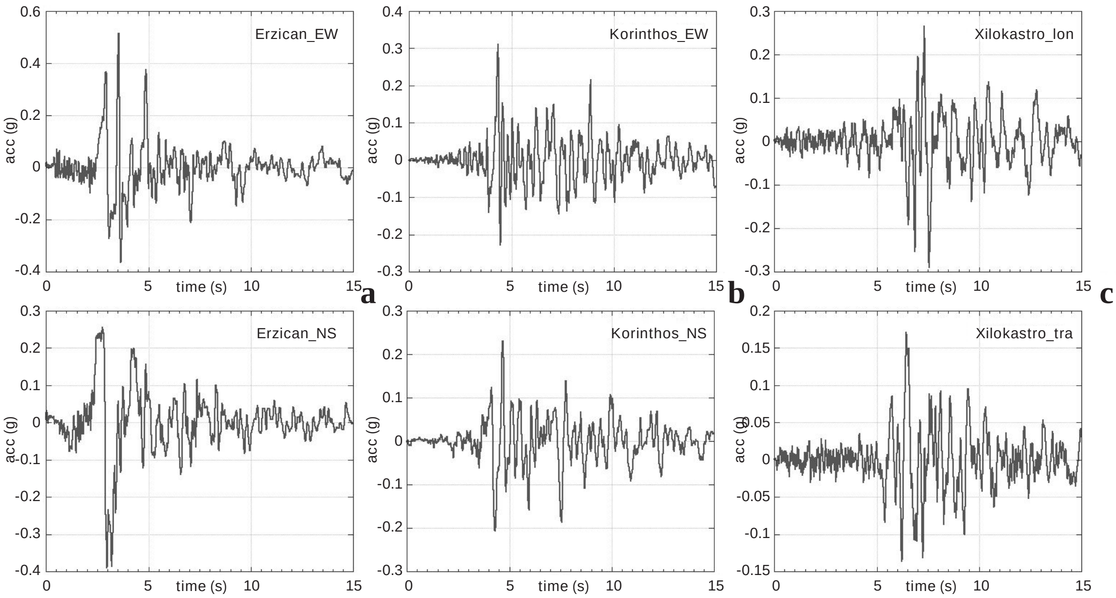


**Fig. 7** - Strong-motion records for possible extreme earthquakes for Vittorio Veneto: a) Erzincan horizontal records of the $M_s$ 6.7 1992 local quake; b) Korinthos horizontal records of the $M_s$ 6.7 1981 Alkion quake; c) Xilokastro horizontal records of the $M_s$ 6.7 1981 Alkion quake.

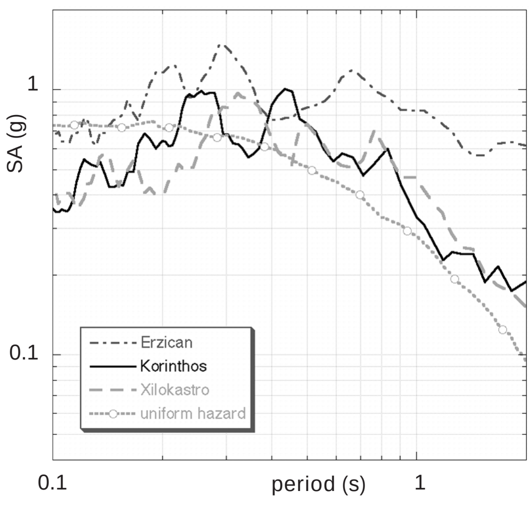


**Fig. 8** - Comparison of the average horizontal response spectra of the 1981 local earthquake recorded at Erzincan, of the 1981 Alkion earthquake recorded at Korinthos and Xilokastro, and the final design uniform hazard response spectrum for Vittorio Veneto.

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