Low-Frequency Seismic Ground Motion At The Pier Positions Of The Planned Messina Straits Bridge For A Realistic Earthquake Scenario

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Abstract. We estimated longer-period (period T>0.5 s) components of the ground motion at the piers of the planned Messina straits bridge. As the shortest fault-to-site distance is only 3-5 km, the kinematic earthquake rupture process has to be described in a realistic way and thus, the causative fault is represented by a dense grid of subfaults. To model the 1908 event, we assume a Mw=7 earthquake, with a 40×20 km rectangular fault, and pure reverse dip-slip. The horizontal upper side of the rectangle is at 3-km depth, and the N corner of the rectangle is just between the piers. For the fault nucleation point, the least favorable place is assumed and a randomized rupture velocity is used in a particular run. In a typical simulation, the fault motion is initially represented by the time history of slip in each of the subfaults and by the distribution of the final seismic moment among the subsources (forming "asperities"), both generated as lognormal random functions. The time histories are then filtered in order to fit a chosen source spectral model. The parameters that are conditioning the random functions can be based on the bulk of published fault inversions, or reproduced from an earlier successful attempt to simulate ground motions in the epicentral zone of the 1994, M=6.7 Northridge, California, earthquake. In the second step of calculations, the Green functions (for each subfault and pier combination) are calculated for a layered halfspace model of the pier foundation stratigraphy, using an advanced Green function calculator, that allows an accurate calculation over the entire relevant frequency band including static terms. Finally, the 3-components of the strong ground motion are obtained at the two piers through convolution and summation over the different subsources. We compare a set of response horizontal velocity spectra (PRV) obtained from our calculations with a reference PRV that is considered as a reasonable upper bound for the possible ground motion near the piers. Our results suggest that the seismic ground motion under Torre Sicilia dominates over this under Torre Calabria and that the median (average log) PRV is generally above the reference one, about 1.1-1.3 times for T>4 s, and up to 2 times for $1<T\leq4$ s. The use of advanced fault and medium models, accounting also for the natural scatter of individual PRV due to events with the same gross source parameters, provides a sound basis for the deterministic engineering estimates of future seismic ground motion.

Keywords: Ground motion; Seismic source; Fault; Response spectra.

GROUND MOTION COMPUTATION

The Messina straits bridge might be an outstanding engineering achievement. The earthquake engineering challenge is the estimate of the seismic load that should be expected at the sites of the piers of the bridge. As the natural period of the construction

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should be longer than 2-3 s, only the longer-period component of the motion is estimated. From the seismological point of view, the largest difficulty in the problem is accounting for the earthquake fault motion with large detail, because the shortest distance from a pier to the nearest point on the fault surface is only about 3-5 km. Thus, a sufficiently dense grid of source nodes, from now on called subfaults is needed for the numerical representation of the earthquake fault slip history. As a general earthquake fault model, we adapted a known model of Valensise and Pantosti [1], assuming a *Mw*=7 earthquake, with a 40×20 km rectangular fault, with pure reverse dip-slip motion, with dip angle 29°, and strike N20°E. The upper side of the rectangle (see Figure 1) is buried at 3 km depth, the inclined NNE fault edge is located near to the bridge, and the N corner of the fault rectangle is located just between the piers. Fault nucleation is assumed to occur at the less favorable place, in the middle of the rectangle side farthest from the bridge, thus producing considerable directivity-related relative amplification of ground motion. In a particular simulation run, a random value of rupture velocity was drawn from the interval 2.38-2.72 km/s, or about 75-85% of the average ambient S-wave velocity [2]. We use 33×15=495-element subfault grid, each subfault represents a 1.33×1.25 km piece of the fault surface. The time step is selected as 0.05 s, resulting in sufficient time resolution for long-period (LP) motion.

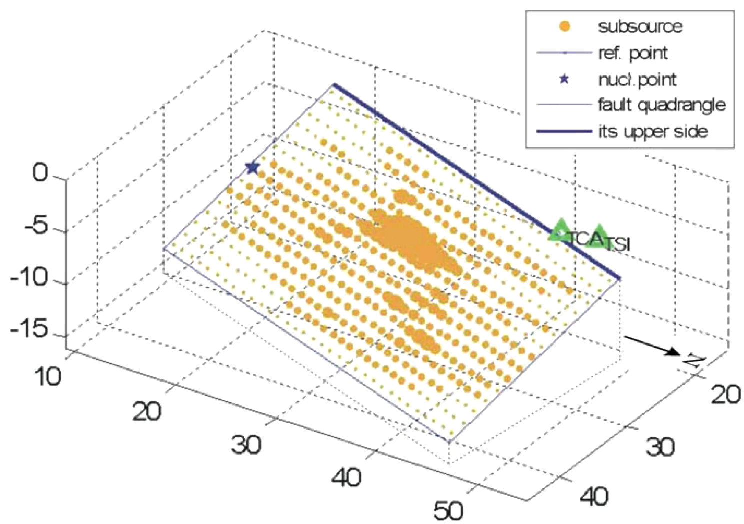

FIGURE 1. 3D view: fault model geographical location together with the position of the two piers: Torre Calabria, TCA and Torre Sicilia, TSI. Star is the rupture nucleation point.

The simulation is performed in three steps (see [3] for a more detailed description of the computational technique). First, fault motion is simulated: it is represented as the time history of the seismic moment rate (or equivalently, of slip) in each of the 495 subfaults. For each subfault, a preliminary version of this time history is first generated as a positive non-stationary random function, called 1D lognormal multifractal, with a duration that is about 10% of the total rupture. The distribution of the final seismic moment among subsources (forming "asperities" of slip function over the fault surface) is also random, and is called 2D lognormal multifractal. I.e., both 2D final slip and any of the 495 subsource time functions are constructed from white Gaussian noise by power-law coloring and exponentiation. As a final step, the preliminary subfault time functions are filtered in order to fit a certain far-field source spectral model: in our case we consider Gusev [4] spectral scaling law. The values of the parameters that conditioned the multifractal random functions are either selected on the basis of published fault inversions, or are reproduced from values used in our earlier study that successfully simulated the ground motion in the epicentral zone of 1994, M=6.7 Northridge, California, earthquake. As the second step we compute 990 Green functions for a layered halfspace, taking each pier, with its stratigraphy [5,6,7,8] as a receiver point, and each subfault as a source. The Green function calculator used employs a novel analytical approach that permits accurate calculation for the entire relevant frequency band including static (near-field) terms. As the final step, the source time functions are convolved with the Green functions and summed, to produce 3-component simulated strong motion at the foundation of each pier (see Figure 2 and 3).

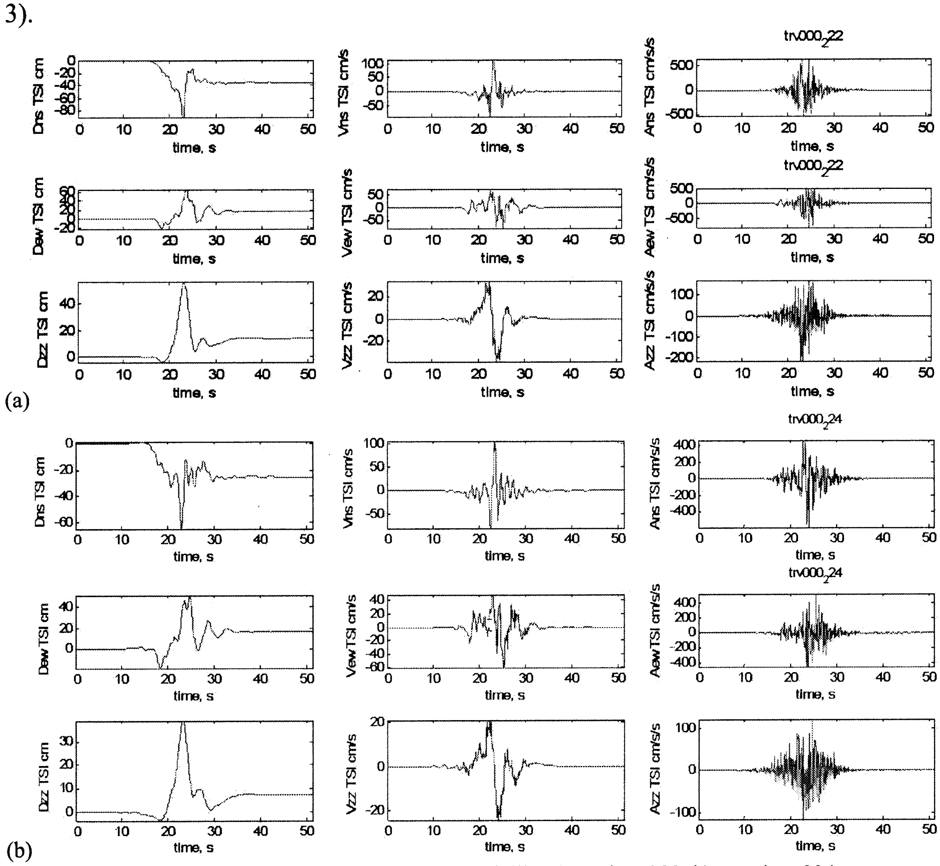

FIGURE 2. Ground motion at pier Torre Sicilia: a): variant 222, b) – variant 224; in each block, from left to right: displacement, velocity and acceleration; from top to bottom: NS, EW and Z component.

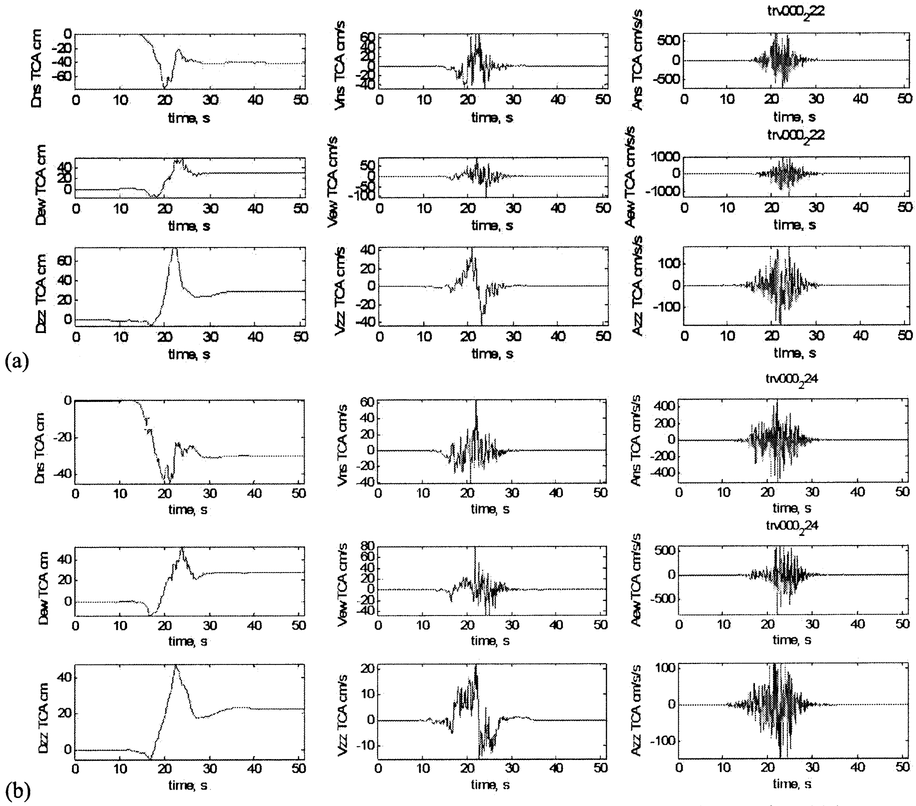

FIGURE 3. Ground motion at pier Torre Calabria: (a): variant 222, (b) – variant 224; in each block, from left to right: displacement, velocity and acceleration; from top to bottom: NS, EW and Z component.

SPECTRAL COMPUTATIONS

As a main engineering output of our simulation we consider the response velocity spectrum, PRV, with a damping coefficient 0.05, and we further discuss only the frequencies below the uppermost accurately simulated frequency of 3 Hz, or periods longer than 0.3 s. As a reference we use the published smooth PRV spectrum proposed by [9] as an upper reasonable limit for ground motion near Messina straits bridge due to a 1908-like event, from now on called SM-PRV.

Our results (see Figure 4, 5 and 6) suggest that ground motions under Torre Sicilia dominate over those under Torre Calabria; thus only the former will be discussed in detail. For any individual sample function of our model ground motion, we see that at some frequencies (periods), there are horizontal spectral ordinates that are above the reference spectrum. If we consider the median (average log or geometric average) spectrum over many sample functions, we observe (see Figure 6) that the median PRV is slightly above the SM-PRV spectrum at all frequencies below 0.25 Hz (periods above 4 s). Between 0.25 and 1 Hz (T=1-4 s), the levels of N and E components of ground motion differ. Whereas the median E component is close to the SM-PRV spectrum, the N component (one oriented roughly along fault slip) is significantly larger, up to 2 times at T=2 s. The r.m.s. deviation of individual spectra corresponds, roughly, to the variation of +65% / -40% with respect to the median. Therefore, if a 84% upper quantile (median+1 r.m.s. dev.) motion is selected as a safe upper limit, it must be positioned at 1.65 times above our median spectrum, or from 1.8 to 2.8 times above the SM-PRV spectrum. The considerable variability of the accelerograms in the individual simulations can be noticed in Figure 7.

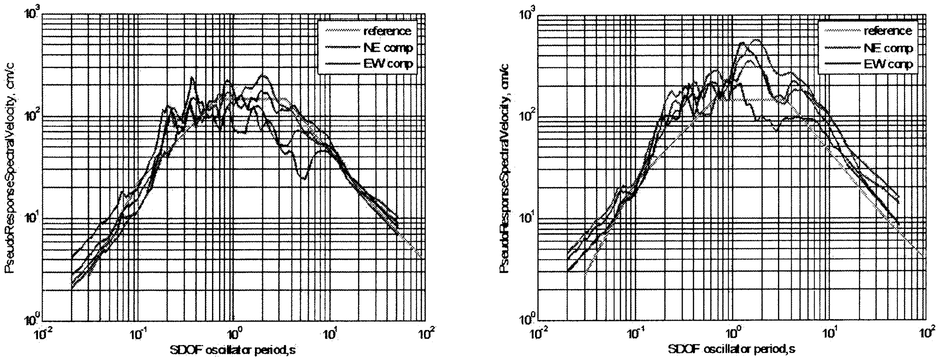

FIGURE 4. PSV Response spectra for horizontal components only, both piers on one plot. variants 222 (left) and 224(right)

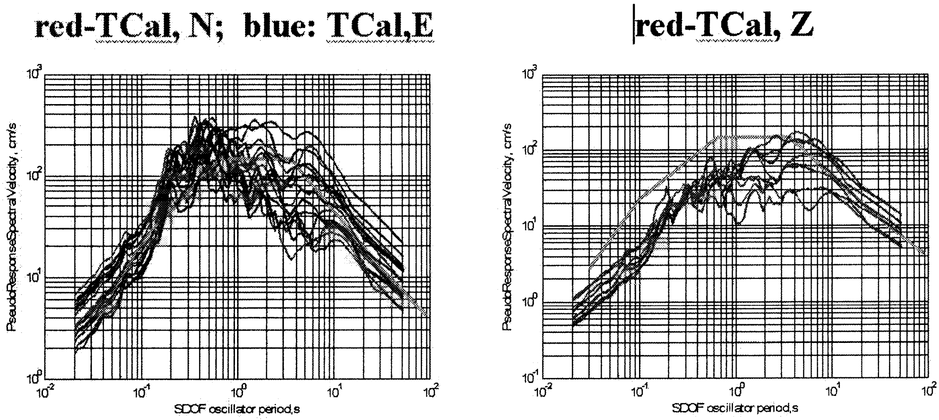

FIGURE 5. PSV Response spectra Torre Calabria only, 8 variants.

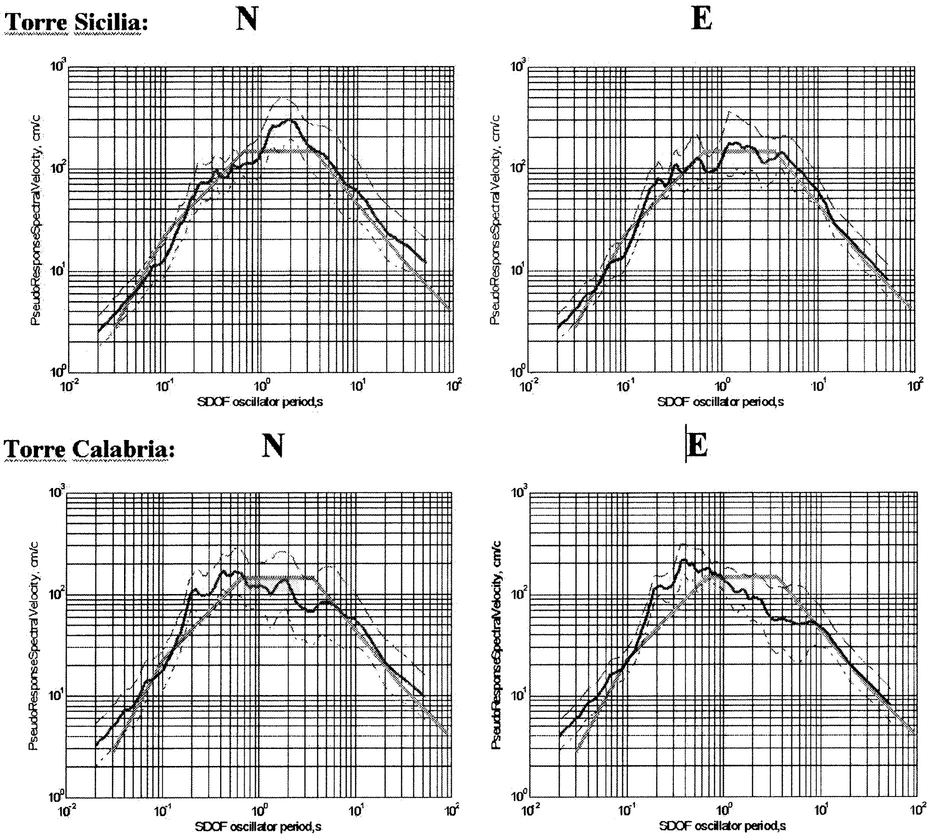

FIGURE 6 . Median, and +/- 1 r.m.s. deviation corridor, for PRV for two horizontal components and the two piers.

We investigate the uniqueness of the results as follows. We test the variant with the use, instead of Gusev [3] spectral model, of the more traditional one of Brune (as modified by [10]), with stress drop of 30 bar. This resulted in increase of about 30% in the amplitudes of LP ground motion, as we could expect, because the Brune's scaling law is known to overestimate the LP spectra. Therefore we consider the lower predictions based on Gusev's model as more realistic. We verified the natural result that the amplitudes of LP motion can be significantly reduced by selecting another nucleation point. The selected mean value of the rupture velocity, of about 80% of ambient S-wave velocity, has been perturbed, resulting in a systematic variation of the strong motion amplitudes. The selected value is however quite representative for several studied earthquakes, and its use in simulation seems reasonable. From Figure 8 one can appreciate the importance of taking into account the realistic stratigraphy.

A well-known cause of uncertainty in the predicted ground motion is the variation of the stress drop. However, with a fixed fault dimensions and moment magnitude, stress drop variations are essentially suppressed. Therefore, we can consider our estimates as relatively reliable.

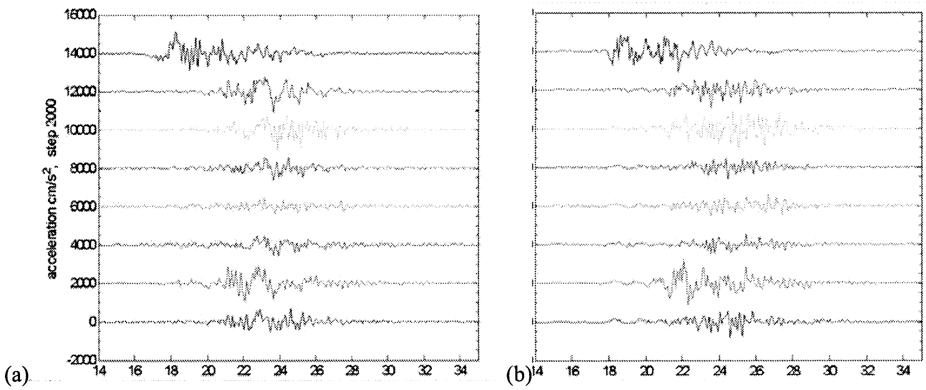

FIGURE 7. Eight sample functions of the ground acceleration at Torre Sicilia for the horizontal components: (a) NS and (b) EW. Vertical interval between zero-lines of traces is 2000 cm/s^2 . The first trace is for the less usual source sample function, when a large asperity happened to coincide with the spot with the highest permitted propagation velocity.

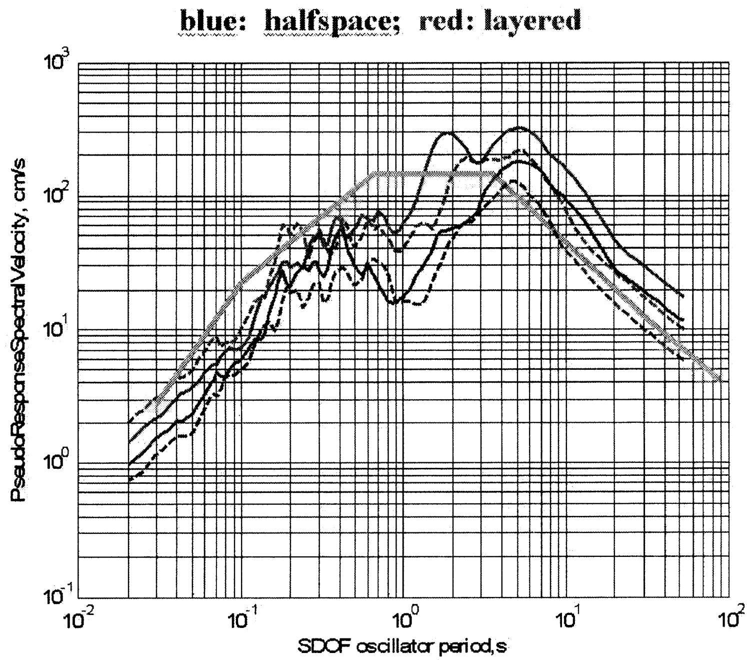

FIGURE 8. Effect of a layered crustal model against the case of a half-space with average-crust properties. Case of Torre Sicilia pier, solid line component NS , dashes - component EW, blue: halfspace; red: layered. The strongest resonance is at 1.5-2 s period, it makes amplification as high as 4-5 times with respect to the average crust. With respect to the "engineering hard rock", such an effect will be significantly reduced.

The reference spectrum SM-PRV in fact has done a quite reasonable job in the determination of the median horizontal PRV spectral shape at T> 3-4 s, and especially in the range T=20-50 s, where accelerogram database provides practically no support.

Our main contribution is the accounting for the statistical variation in individual spectra. In our view, such variations must be taken into account in deterministic engineering estimates of future ground motion. As an example, one can use a 84% upper quantile of the distribution of the spectral ordinates generated from a sufficiently large set of simulated accelerograms.

CONCLUSIONS

We compare a set of response horizontal velocity spectra (PRV) obtained from our calculations with a reference PRV that is considered as a reasonable upper bound for the possible ground motion near the piers. Our results suggest that the seismic ground motion under Torre Sicilia dominates over this under Torre Calabria and that the median (average log) PRV is generally above the reference one, about 1.1-1.3 times for $T>4$ s, and up to 2 times for $1<T\leq 4$ s. The use of advanced fault and medium models, accounting also for the natural scatter of individual PRV due to events with the same gross source parameters, provides a sound basis for the deterministic engineering estimates of future seismic ground motion.

ACKNOWLEDGMENTS

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