COMMENT AND REPLY

Comment on

Assessment of potential strong ground motions in the city of Rome

Antonio Rovelli, Arrigo Caserta, Luca Malagnini and Fabrizio Marra

(Annali di Geofisica, **37** (6), 1745-1769, 1994)

by Donat Fäh, Giuliano F. Panza and Peter Suhadolc

In the paper by Rovelli *et al.* (1994) it is repeatedly stated that Fäh *et al.*'s (1993) results underestimate PGA and similar quantities and therefore the standard method followed by Rovelli *et al.* (1994) should be preferred to the innovative one developed by Fäh *et al.* (1993). Rovelli *et al.*'s (1994) results do not explain the pattern of damage observed in Rome and the same authors ignore the good agreement between observations during the 1913 Fucino earthquake and the numerical results given in Fäh *et al.* (1993).

We cannot discuss opinions (de gustibus non est disputandum) but we may quote page 650 of Fäh *et al.* (1993): «... at a distance of about 85 km from the seismic source, the maximum horizontal acceleration reaches values of the order of 40-60 cm/(s^2). This is in good agreement with the values estimated from an empirical relation between maximum, horizontal peak ground acceleration...».

The empirical relation Fäh *et al.* (1993) refer to is the same used by Rovelli *et al.* (1994) to prove that Fäh *et al*'s (1993) method underestimates the results obtained with the application of the standard procedure used by Rovelli *et al.* (1994). The statement on page 650 of Fäh *et al.* (1993) is clearly supported by figs. 6 and 7 (pp. 654-655).

Rovelli *et al.* (1994), for their comparisons in figs. 11a and 12, used only the transverse component of motion given in Fäh *et al.* (1993), and ignored the dominating *P-SV* results. Due to the fact that «... the transverse component is half the size of the radial component» (page 653 first paragraph in Fäh *et al.* (1993)), the bars in figs. 11a and 12 representing the results of Fäh *et al.* (1993) are wrong, because they are limited to the transverse motion. The correct figures are shown here in fig. 1a,b where the maximum PGA for the radial component of motion is 60 cm/(s^2).

Let us just make a final consideration. The whole situation is particularly strange since the misuse of the results is made to try to prove that the result of Fäh *et al.* (1993) are different from those of Rovelli *et al.* (1994). If, in figs. 11a and 12 of Rovelli *et al.* (1994), the results of fig. 6 and 7 of Fäh *et al.* (1993) were plotted correctly, a very important agreement would exist, between quite different methods.

An important difference between the two methods consists in the fact that Rovelli *et al.*'s (1994) results are limited to *SH*-wave propaga-

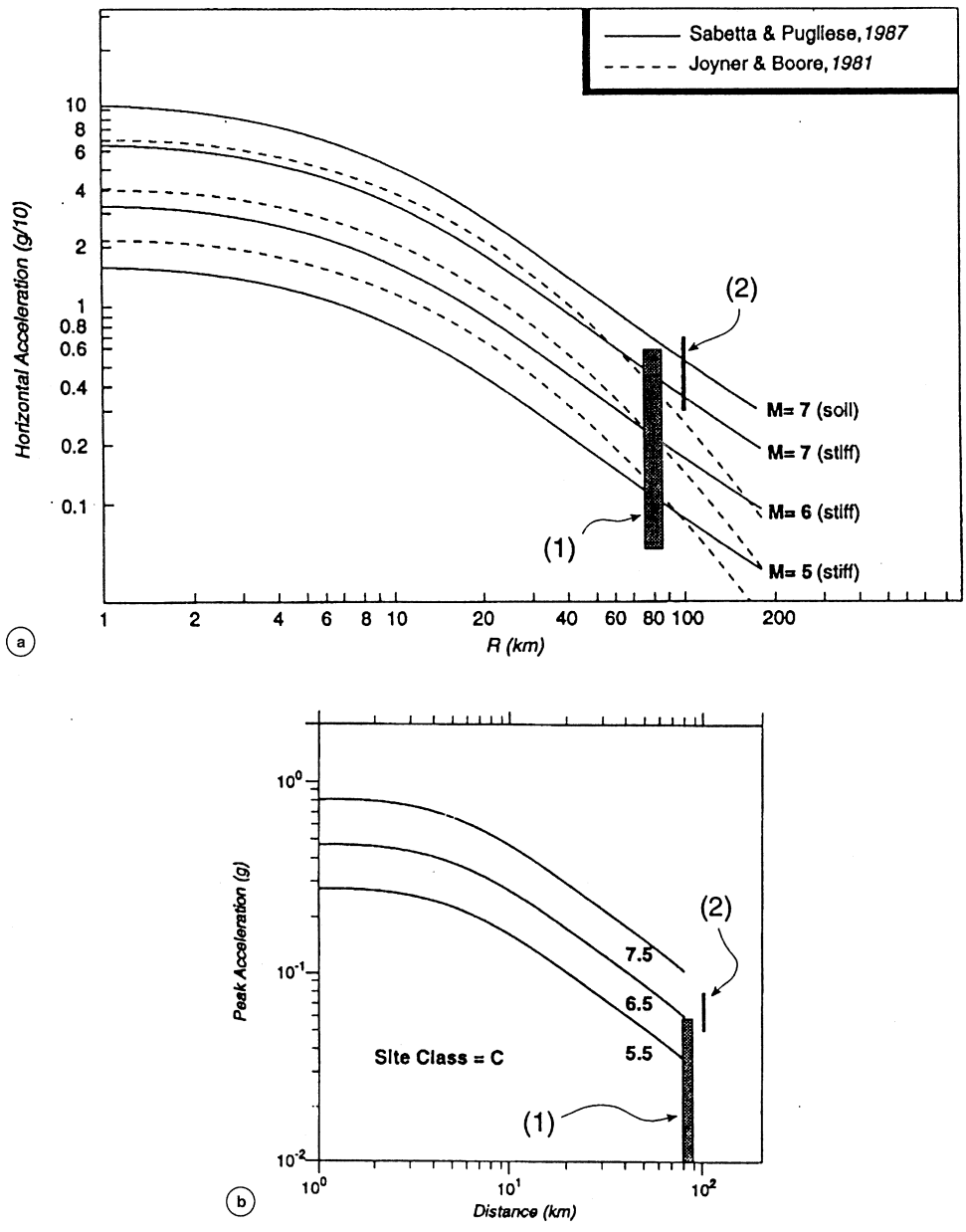

Fig. 1a,b. a) Range of variability of peak ground acceleration (vertical bars) after (1) Fäh *et al.* (1993), (2) Rovelli *et al.* (1994), compared with the regressions by Sabetta and Pugliese (1987) and Joyner and Boore (1981). b) Range of variability of peak ground acceleration (vertical bars) (1) after Fäh *et al.* (1993), (2) predicted by Rovelli *et al.* (1994) for soft sites, compared with the regression resulting for the Western North American data (Boore *et al.*, 1993). In all cases a quite remarkable agreement exists, in spite of the different methodologies used.

tion, and therefore, attribute peak ground acceleration only to transverse motion. As is shown in Fäh *et al.* (1993), this is an oversimplification, and horizontal ground motion can be well dominated by *P-SV* waves.

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Reply to comment on

Assessment of potential strong ground motions in the city of Rome

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A hybrid technique combining mode summation and finite differences (FD) was proposed by Fäh *et al.*, 1993 (hereinafter referred as F93) to generate synthetic seismograms. The technique was innovative: F93 were successful in modelling source, path and local geology effects, simultaneously. On the contrary, standard FD schemes usually adopted to model near-surface 2-D propagation effects assume incident planes wave: the approach proposed by F93 had real merits in trying a more realistic incident input taking into account the source mechanism. Many advantages can derive from this more physical modelling, mainly in the low-frequency band where coherent rupture and absence of crustal heterogeneities are acceptable approximations.

In F93 this approach was used to model high-frequency ground motions in Rome for a magnitude 6.8 earthquake 76 to 88 km east of the city. In the authors' opinion, their procedure allows realistic time histories of ground acceleration to be computed for the urban area of Rome, and general zonation criteria for the city were derived from modelling. In the paper by Rovelli *et al.*, 1994 (hereinafter referred to as R94) we stated that F93 underestimated ground acceleration for the different geological units of the city. We based this statement on fig. 9 of F93 that shows peak ground acceleration (PGA) of the transverse component of motion along the 2-D profile crossing the city of Rome. F93 used this component of motion for engineering considerations, and correlated it

with the aerial variation of damage in Rome after the 1915 Fucino earthquake. In spite of the qualitative agreement with the distribution of damage, that figure showed a maximum PGA lower than 20 gals that does not seem to be consistent with the well documented damage (see Ambrosini *et al.*, 1987). In the same figure a minimum PGA as low as 6 gals at «firm» sites was shown. Both these «soft» and «firm» site predictions were significantly smaller than values resulting from the Sabetta and Pugliese (1987) regressions.

Now Fäh *et al.* (1995) (hereinafter referred to as F95) claim that the radial component in their study attained peak values as large as 40-60 gals, which would be in better agreement with our results. But is this agreement enough to conclude that the two approaches are both realistic? Or are there other assumptions, results and observations in which the two approaches are conflicting? And why did F93 not employ the radial component in their correlations with the trend of damage?

Starting from the last question, in F93 the behaviour of the radial component is not shown along the entire profile as it is for the transverse one, so we do not know where or how many receivers along the profile did attain the largest values. It is hard to evaluate the peak values from a visual inspection of fig. 7 of F93. However, it seems that the amplitude of the radial acceleration monotonically increases with distance within the Tiber Valley. This result is in conflict with the observed concentration of damage at the two edges of that valley. Moreover, the value of 40-60 gals computed for radial acceleration implies a variability of PGA at the surface up to a factor of 10 between «firm» and «soft» sites along the same profile (see fig. 1a in F95). So far such a large PGA variation is not supported by the available literature, since an impedance contrast of 3 to 4 should produce only moderate spectral amplifications restricted to narrow frequency bands. In these conditions, based on the observational experience the PGA variation between «firm» and «soft» sites in expected to be close to 2. This is correctly predicted by R94.

These considerations reinforce our perplexities on the adequacy of the F93's approach in the high-frequency band, where the point-source assumption and the horizontally-layered lithosphere model are not realistic approximations. In R94 we used a stochastic methodology to model the source and the effects of regional propagation; these «bedrock accelerograms» were therefore convolved by upper-layer *SH*-wave transfer functions computed as the 2-D transient response to a delta-like vertically incident seismic input. The bedrock accelerations resulting from the stochastic approach were constructed on the basis of a spectral model estimated from strong-motion accelerograms recorded at rock sites in the region (Rovelli *et al.*, 1988). Consequently, we are confident that these synthetic accelerograms reproduce observed PGA, when an appropriate

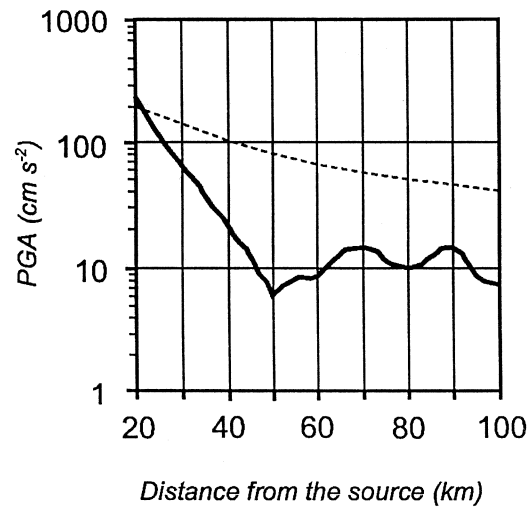

Fig. 1. Attenuation of PGA at the bedrock for a magnitude 6.8 earthquake, as a function of hypocentral distance. The result by Fäh and Panza (1995) (thick solid line) is compared with the empirical regression by Sabetta and Pugliese, 1987 (dashed line). Deterministic predictions underestimate the observations. Moreover, a significant saturation of amplitudes is found using a point-source and horizontally-layered lithosphere model for $50 < R < 100$ km, which does not seem to be required by the data (see also fig. 2).

spectral parameterization is used. On the contrary, in F93 «bedrock» accelerations were computed assuming the validity of a pure mathematical model, *i.e.* a point-source and a horizontally-layered lithosphere. We will show that both these assumptions are not appropriate for ground motion predictions of engineering interest.

A figure which recently appeared in Fäh and Panza (1994) helps us in stressing the limitations of the F93 approach when applied to high-frequency ground motions. Figure 1 shows the trend of PGA at the bedrock as a function of focal distance, for a magnitude 6.8 earthquake. In the same figure their trend is compared with rock site predictions derived from Sabetta and Pugliese's (1987) regression. This comparison demonstrates that the deterministic modelling significantly underestimates the observations, with a theoretical postcritical reflection whose effect on PGA is evident from $R \approx 50$ km. This is due to the simplified 1-D lithosphere and point-source model used by F93. The lithosphere regularity can be excluded for the Latium-Abrutium border on the basis of the abundant literature (see *e.g.* Nicolich, 1989). This issue was extensively discussed in R94 (page 1751). In the real data both in Rome or in the Apennines, no clear «saturation» effect can be recognized (see also fig. 2).

The conclusion is that the most representative figures shown by F93 and Fäh and Panza (1994) demonstrate that their approach underestimates the bedrock input as well as the transverse component of ground accelerations at the city. Figure 1 shows that irregularities of the rupture process over the finite extension of the source and 3-D heterogeneities along the propagation paths cannot be ignored when computing high-frequency ground motion. While we acknowledge that the radial component computed according to the F93 scheme may provide PGA comparable to R94, this cannot be used to conclude that both approaches are realistic (at least for the city of Rome), because of the severe underestimation of the bedrock input and the large amplification of PGA on soft vs. firm ground.

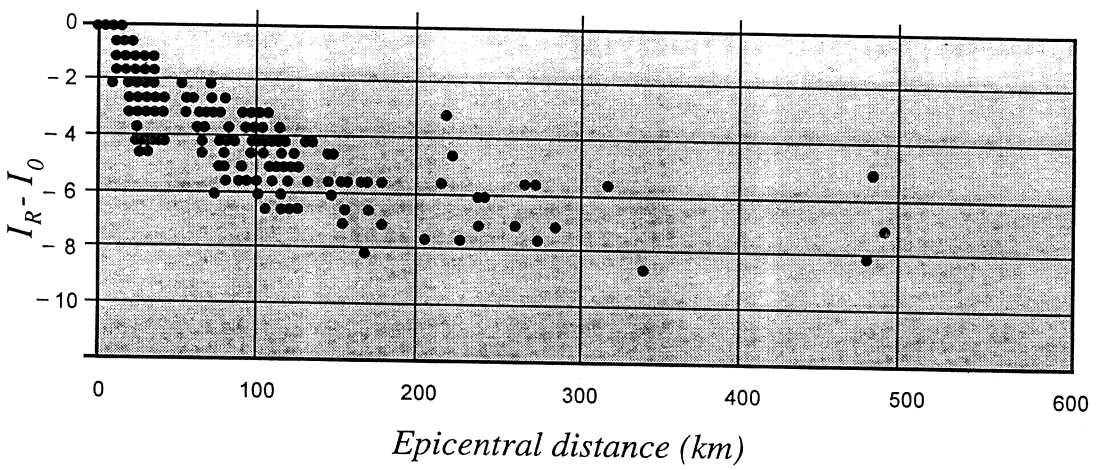

Fig. 2. Attenuation of macroseismic intensity between the epicentre and Rome computed for all the earthquakes felt in the city (redrawn from Molin *et al.*, 1995). I_R is intensity felt at Rome, I_0 the maximum epicentral intensity. No saturation is found between 50 and 100 km, which contradicts the theoretical trend resulting from the Fäh and Panza (1995) modelling. In reality, anomalies begin for $R > 200$ km probably due to 3-D mantle heterogeneities.

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