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Discussion of "Seismic Hazard Assessment in the Southeastern United States" by P. C. Rizzo et al.*

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The authors of the subject paper (which we will call "Rizzo et al.") assert, in the first two paragraphs, that deterministic methods of seismic hazard assessment are superior to probabilistic methods because deterministic methods "are able to use experience and judgment interactively." Regardless of one's view of this assertion, the remainder of Rizzo et al. is not about deterministic vs. probabilistic methods; it is about ground-motion estimation for an earthquake in the southeastern U.S. Our criticisms of Rizzo et al. apply whatever one's particular bias on the probabilistic/deterministic issue, and we point this out so that further debate will be directed to the ground-motion recommendations made by Rizzo et al., not to their initial assertion.

Our real disagreement with Rizzo et al. is in how they develop recommended design spectra on rock and soil for a Charleston, South Carolina, earthquake ($M=7.5$) at a hypocentral distance R of 120 km. The ad-hoc method used by Rizzo et al. involves unfounded assumptions and conservatisms at many stages; we identify a few of these so that potential users of the method can better judge its appropriateness for any particular application. We do agree with one point made by Rizzo et al., that eastern North America (ENA) ground-motion estimates needed reevaluation in light of the Saguenay earthquake. In fact, substantial research has been conducted since publication of the ENA ground-motion papers referenced by Rizzo et al., resulting in more recent ENA ground-motion relations published by EPRI (1993), Atkinson and Boore (1995), and Toro et al. (1995).

Rizzo et al. base the high frequency part of their recommended spectrum on the 1988 Saguenay earthquake, speculating that this was an "ordinary" event in ENA, but this speculation lacks a basis. The Saguenay earthquake was a deep event with a high stress parameter of 500 bars, as pointed out by Boore and Atkinson (1992) and these characteristics are recognized by Rizzo et al. They also appear to agree with the conclusion of Bollinger et al. (1993) that eastern North America (ENA) earthquake

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isoseismals can be fit with a stress parameter of 200 bars. The use of the far-field Saguenay data alone introduces conservatism because of its higher stress parameter. For the Charleston earthquake, the only ground-motion data are intensity observations. These observations allow us to estimate the moment magnitude of the event, under the implicit assumption of an average stress parameter (Hanks and Johnston, 1992). *If* the Charleston event had a stress parameter as high as the Saguenay earthquake, it necessarily follows that the moment magnitude for Charleston was about 0.7 units smaller than that given by empirical relations between intensity and magnitude (see Atkinson and Hanks, 1995), i.e. $M \simeq 6.8$. Use of $M=7.5$ for Charleston in conjunction with an implicit assumption of a 500 bar stress parameter ignores seismological knowledge about ENA earthquakes and is incorrect.

The accuracy of the Rizzo et al. recommended ground motions can be tested by reducing their $M=7.5$ rock spectra to $M=4.7$, and comparing to available data from ENA. This is easy to do, because Rizzo et al. present their frequency-dependent scaling factors in their Table 3 to scale from $M=6.1$ to $M=7.5$. We simply take their recommended far-field spectra for $M=7.5$ and divide by the factors squared (dividing once to reduce the spectra back down to $M=6.1$, and a second time to reduce them to $M=4.7$). Figure 1 compares the Rizzo et al. median and 85% spectra reduced to $M=4.7$ and data from 26 earthquake records with $M=4.3$ to 4.7 and $R=61$ to 154 km (see Table 1). (Rizzo et al. do not report a scaling factor for $f<3$ Hz, so we use their factor for 3 Hz at lower frequencies.) To construct these comparisons, the data were scaled to $M=4.7$ and $R=100$ km using Atkinson and Boore (1995) (this scaling is not large, as shown in the last column of Table 1, compared to the difference between the scaled data and the Rizzo et al. spectra). The only exception was for the Mont Laurier data, which was scaled from vertical to horizontal using Atkinson (1993) and scaled to $R=100$ km by R^{-1}.

Figure 1 shows that the Rizzo et al. spectra generally exceed the data at all frequencies below 15 Hz, and are conservative at all frequencies. At some frequencies the Rizzo et al. median spectrum lies a factor of ten above the center of the data. If the Rizzo et al. spectra scaled down from $M=6.1$ to $M=4.7$ do not match recorded ground motions for $M=4.7$, those spectra scaled up from $M=6.1$ to $M=7.5$ have low credibility, in our view. Introducing a non-linear magnitude scaling would not change this conclusion; the scaled spectra would decrease by 40% or less from those shown in Figure 1.

Further, the Rizzo et al. spectra for $M=6.1$ do not show a good agreement even with the unscaled Saguenay data. This comparison is shown in Figure 2, where the Rizzo et al. $M=6.1$ spectra were obtained by dividing the Rizzo et al. $M=7.5$ spectra by their scaling factors (once, not squared). The median spectrum is near the upper end of the data at most frequencies, and the 85% spectrum exceeds almost all data points.

Our conclusion from these comparisons is that the Rizzo et al. spectra overpredict ENA ground-motion observations. The comparison for $M=6.1$ (Saguenay data, Figure 2) is somewhat better than for $M=4.7$ (Figure 1) but the Rizzo et al. $M=6.1$ spectra still show substantial conservatism, even for the median.

TABLE 1
Data used for comparisons to Rizzo et al. spectra

Event	M	Rock stations	R. km	5Hz Scale Factor*
New Madrid, 3/25/76	4.6	Wappapello dam, Missouri, right toe	151	1.53
Franklin Falls, 1/19/82	4.3	Franklin Falls dam abutment	63	1.46
		White River Junction, VA hospital	61	1.39
		No. Springfield dam, downstream	76	1.76
Saguenay foreshock, 11/23/88	4.5	Charlevoix A61	100	1.34
		Charlevoix A64	107	1.37
		Charlevoix A16	119	1.41
		Charlevoix A21	126	1.44
		Charlevoix All	127	1.45
Mont Laurier, 10/19/90	4.7	TRQ	87	0.87
		OTT	124	1.24
		CKO	154	1.54
New Madrid, 5.4.91	4.4	Old Appleton, Missouri	114	1.65
Saguenay mainshock, 11/25/88	5.9	St. Ferreol, Quebec	118	n.a
		Tadaussac, Quebec (097 comp.)	113	n.a.
		La Malbaie, Quebec	98	n.a.
		Riviere Quelle, Quebec	118	n.a.
		St. Lucie de Beauregard, Quebec	101	n.a.
		Les Eboulements, Quebec	95	n.a.

* - Factor used to scale record to $M=4.7$ and $R=100$ km.

Rizzo et al. make erroneous use of isoseismal data to justify ground motions. Their Figure 4, which has been used elsewhere, serves no quantitative purpose in a scientific or engineering study and should be reserved for lay presentations. It incorrectly implies that much of South Carolina experienced MMI ≥ VII, when in fact about one-half of the state experienced a lower MMI as illustrated in Figure 3. Further, Figure 4 of Rizzo et al. implies equivalencies in sizes of earthquakes that are actually substantially different in size as measured by moment magnitude. In particular, their Figure 4 implies that the 1811 New Madrid earthquake ($M\simeq8$) is equivalent in size to the 1906 San Francisco earthquake ($M\simeq7.7$) and that the 1886 Charleston earthquake ($M\simeq7.5$) is equivalent in size to the 1971 San Fernando earthquake ($M\simeq6.6$). Bollinger et al. (1993) found that damaging ground motions in ENA extend to about twice the distance as for the same magnitude shocks in California, but this conclusion from isoseismals is appropriate only for general comparisons of earthquake characteristics in the two regions. It does not imply that all long-period characteristics of ground motion in ENA are equal to those in California at one-half the distance. There is no physical reason why this one-half distance rule would universally apply, and to adopt this rule based on judgmentally-drawn isoseismals and a few comparisons of arbitrarily derived spectra is specious.

The arbitrariness of the Rizzo et al. spectra is evident from their Table 1, which lists the records they use. For rock sites, 27 of the 31 records are from the northwest quadrant of the 1989 Loma Prieta earthquake, which produced relatively high ground motions (Campbell, 1991). Similarly, 18 of the 26 soil records are from the same quadrant of the same earthquake. An illustration of how variable the spectra are from a small number of records can be seen by comparing the Rizzo et al. spectrum for R=60 to 80 km (their Figure 11) to the spectrum for R=40 to 60 km (their Figure 10). For most frequencies below 2.5 Hz, the more distant spectrum *exceeds* the closer spectrum. With the thousands of ground-motion records available worldwide, selecting just a handful of records instead of a larger number (or in place of an empirical attenuation equation that uses a larger number) cannot be justified except under the guise of unquantified conservatism.

To be sure, there are several important reasons why ground motions in ENA differ from those in California. Among these, ENA earthquakes have more high frequency energy, due to both source and path effects. In particular the higher average ENA stress parameter of 150 to 200 bars, in comparison to an average California stress parameter of 100 bars, increases ground motions by a factor of 1.35 to 1.7, as illustrated on Figure 4. Second, ENA earthquakes occur over a wider range of depths, as deep as 25 km, with deep events having reduced surface motions near the epicenter. Third, anelastic attenuation in the crust is lower in ENA; this is important only at $R > 100$ km. Fourth, older sediments and surficial rock in ENA (as compared to California) modify seismic wave energy differently from in California; this affects high frequency energy, as noted above, but also affects the energy content at lower frequencies. Of these reasons, slower anelastic attenuation, path (wave guide) effects, and surficial rock and sediment effects in ENA are the primary cause of the larger felt and damage areas in that region for large earthquakes, compared to California. Three of the above reasons can significantly affect ground motions for $1 < f < 10$ Hz within 100 km: a deeper source (which will reduce ground motions at the epicenter but leave them virtually unchanged at R=100 km), a higher stress drop, and different surficial soil and rock characteristics. Accurate and defendable predictions of ground motions in ENA require accounting explicitly for the known reasons for differences in ground motions, not ignoring these reasons and adopting a generic rule of thumb.

We make a final comparison on the basis of MMI individual site observations (not isoseismals). Bollinger (1977) published the most complete analysis of 1886 Charleston earthquake MMI data, and derived the following equation for predicting median MMI at a site:

$$MMI = I_0 + 2.87 - 2.88 \log_{10} \Delta - 0.00052 \Delta \qquad (1)$$

where I_0 is the maximum intensity of the earthquake and Δ is epicentral distance in km. For the Charleston earthquake, with I_0 = X, and for a distance of 120 km, this gives

MMI = 6.8, or a value between VI and VII, as the median MMI. This should be taken as the value on soil, since most observations during the Charleston earthquake were at towns and villages located in river valleys or other alluvium. This MMI value is consistent with the band of MMI=VII observations at 120 km, with variations including MMI=VIII at that distance (and farther) and MMI=VI at that distance (and closer). This scatter is typical of MMI data and is best handled by (a) deriving an unbiased estimate of the median MMI as in eq. (1), and (b) treating variations through soil and wave propagation effects, and characterizing the remaining scatter quantitatively. The apparent objective of Rizzo et al. is to estimate ground motion at a "typical" site at R=120 km, so we do not estimate site and wave propagation effects that might increase or decrease the median MMI value, but use the median MMI itself to derive ground motion estimates.

A less desirable alternative to developing a median equation using the distance to each MMI observation is to use the distance to isoseismals. Bollinger (1977) shows that isoseismals lie at about the 80% to 90% fractile of the MMI site data, and his 90% fractile curve is consistent with the isoseismal data for Charleston presented by Rizzo et al. in their Figure 1. Thus using the distance to isoseismals would introduce conservatism.

We do not recommend calculating design ground motions from MMI, for the reasons described in Cornell et al. (1979), but we can get some idea of what peak ground acceleration (PGA) levels correspond to MMI VI and VII from several authors that have published correlations between PGA and MMI. These are shown in Table 2.

TABLE 2
Published correlations between PGA and MMI

		PGA for	
Reference	Application	MMI=VI	MMI=VII
Krinitzky and Chang (1988)	Far-field, all sites	0.08g	0.12g
Murphy and O'Brien (1977)	All sites	0.06g	0.10g
Trifunac and Brady (1975)	All sites	0.06g	0.13g

It is clear that the median PGA level would be in the range 0.06g - 0.13g at 120 km from an I_0=X earthquake, and probably toward the lower end of the range for rock sites (where the MMI level would be lower). The only assumptions in this analysis are that Bollinger's (1977) MMI data and equation (1) are unbiased (they should be, since they are consensus estimates from three interpreters), and that California correladons between MMI and PGA are appropriate in the far field. There are no assumptions about magnitude, stress drop, depth, attenuation, or the accuracy in scaling the Saguenay earthquake up to represent a Charleston-size earthquake. Rizzo et al., in their Figures 25 and 26, indicate a high-frequency limit to their median spectra for rock and soil sites, respecdvely, of about 0.2g (for both rock and soil). This comparison indicates that the Rizzo et al. spectra are conservative by about a factor of two at the high frequency (PGA) limit.

The derivation of appropriate design spectra for large earthquakes in ENA necessarily involves judgment and extrapolation, as we do not yet have a large data base of strong ground-motion records with which to make empirical estimates. In our view that judgment and extrapolation is best made using *all* the earthquake ground-motion data that are available in ENA, of which Saguenay is one part. In the context of these data, the Saguenay ground motions appear high, for the reasons discussed above. They are not, however, incredible, and their occurrence is accounted for in modern ground-motion estimates by including Saguenay in the source scaling model and by including scatter in the attenuation equations. The alternative approach of considering only the Saguenay data set because it is the only one available for $M=6$, and scaling those data to $M=7.5$, is neither required nor defendable, in our judgment. We have learned much about earthquake sources and energy transmission in ENA, and that knowledge should not be disregarded in deriving design ground motions. In this age of tight budgets and competing resources, it is just as unacceptable to promote an overly-conservative seismic design or retrofit of an engineered facility as it is to allow an unconservative design or retrofit. Defendable decisions on seismic issues will be made only when unbiased estimates of median ground motion are developed, accounting for all current seismological knowledge, when uncertainties are accurately represented so that the range of possible ground motions for a given earthquake can be established, and when an appropriate, explicit degree of conservatism is adopted in the choice of design or retrofit ground motion. The degree of conservatism should reflect the importance of the facility, the consequences of failure, and the cost of design or retrofit, among other things. Using the Rizzo et al. spectra, with an unknown level of conservatism, will not allow defendable decisions to be made.

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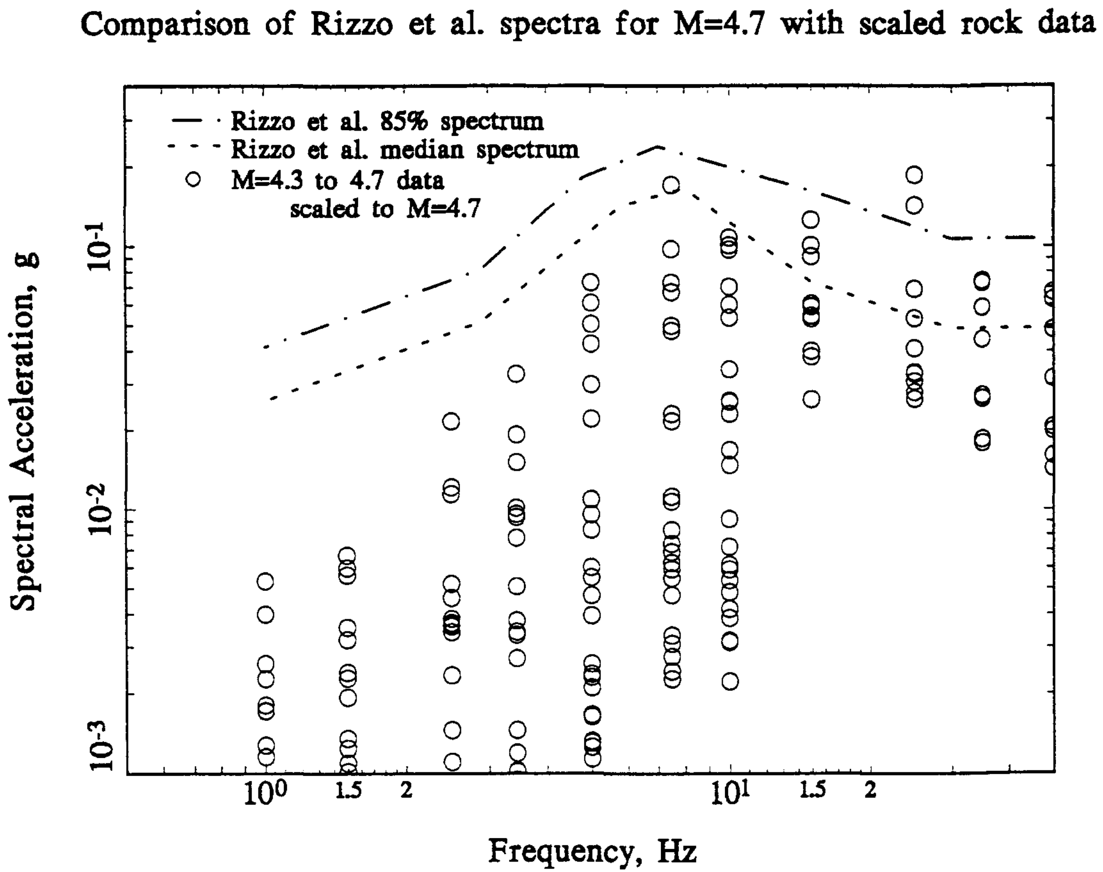

Figure 1. Rizzo et al. spectra scaled down to M=4.7, compared to rock data scaled to M=4.7.

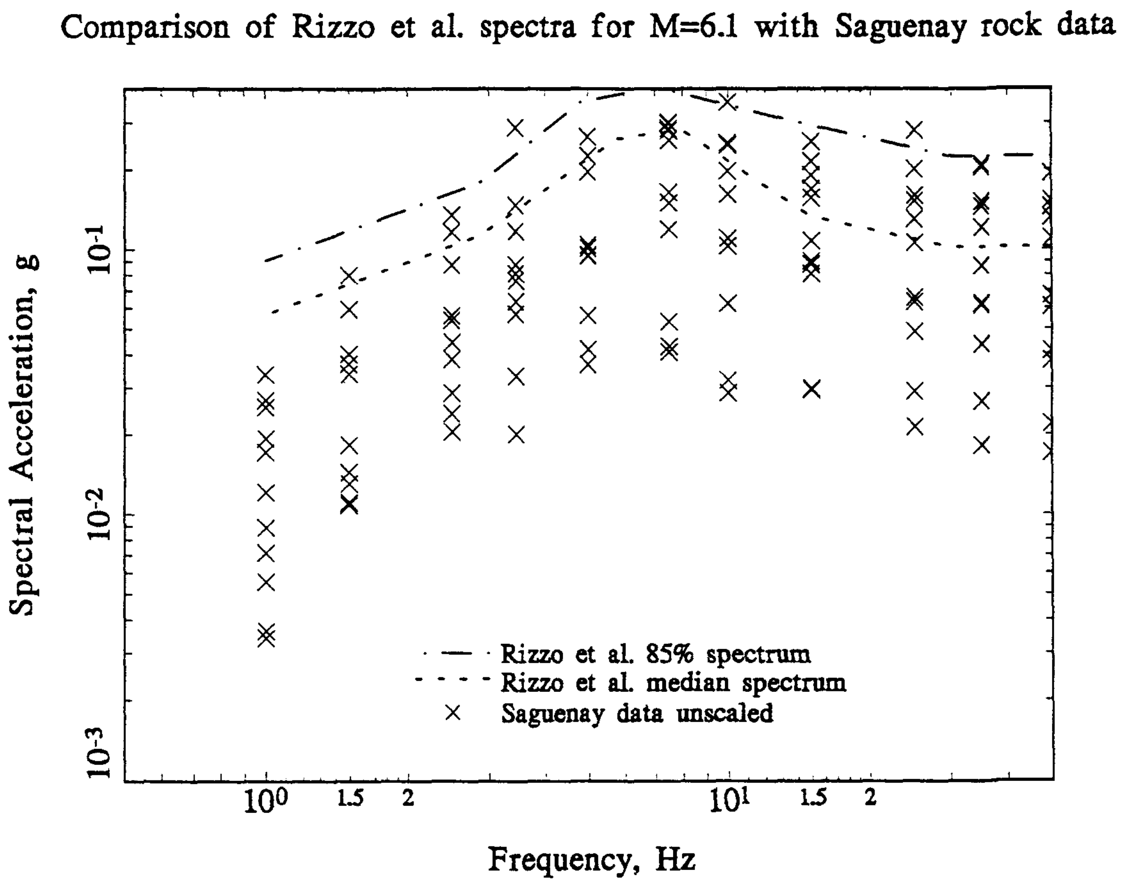

Figure 2: Rizzo et al. spectra scaled down to M=6.1, compared to Saguenay rock data (R=90 to 120 km).

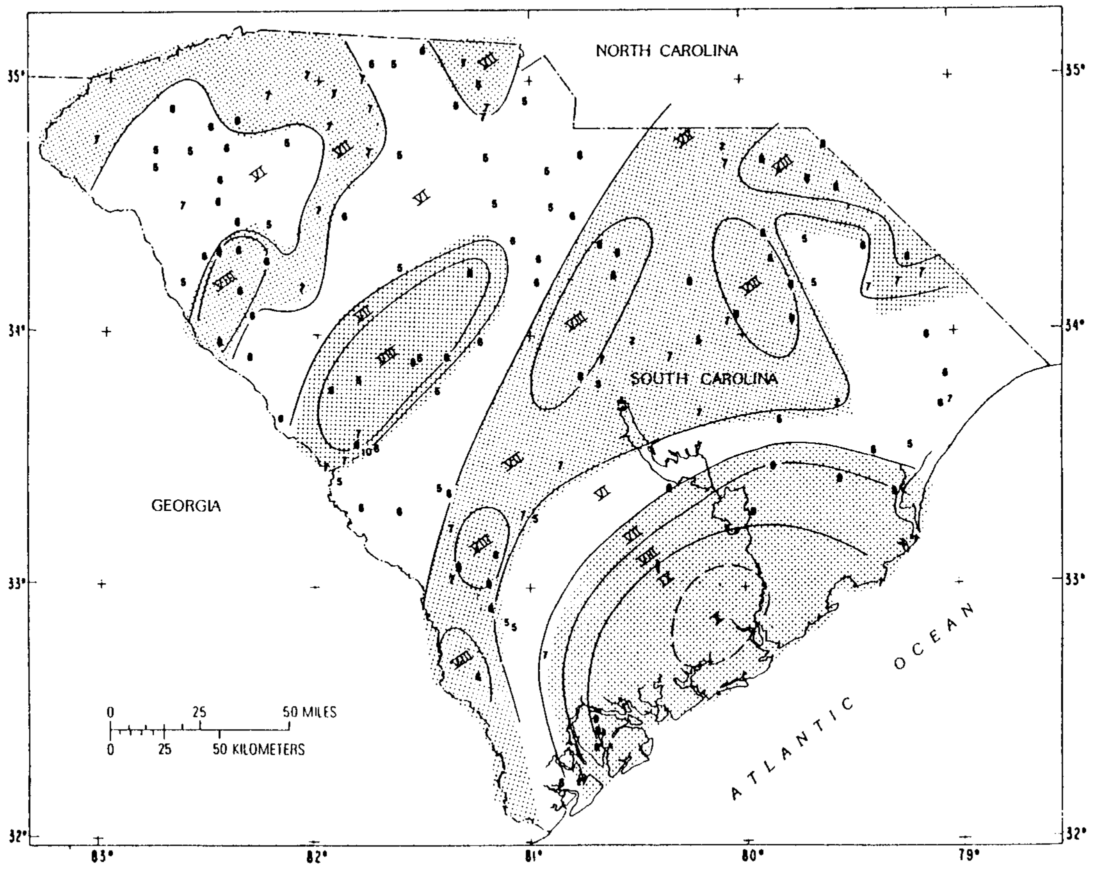

Figure 3: Detailed MM intensities and isoseismals from the 1886 Charleston, South Carolina, earthquake (after Bollinger, 1977). Areas with MMI≥VII are shown hatched.

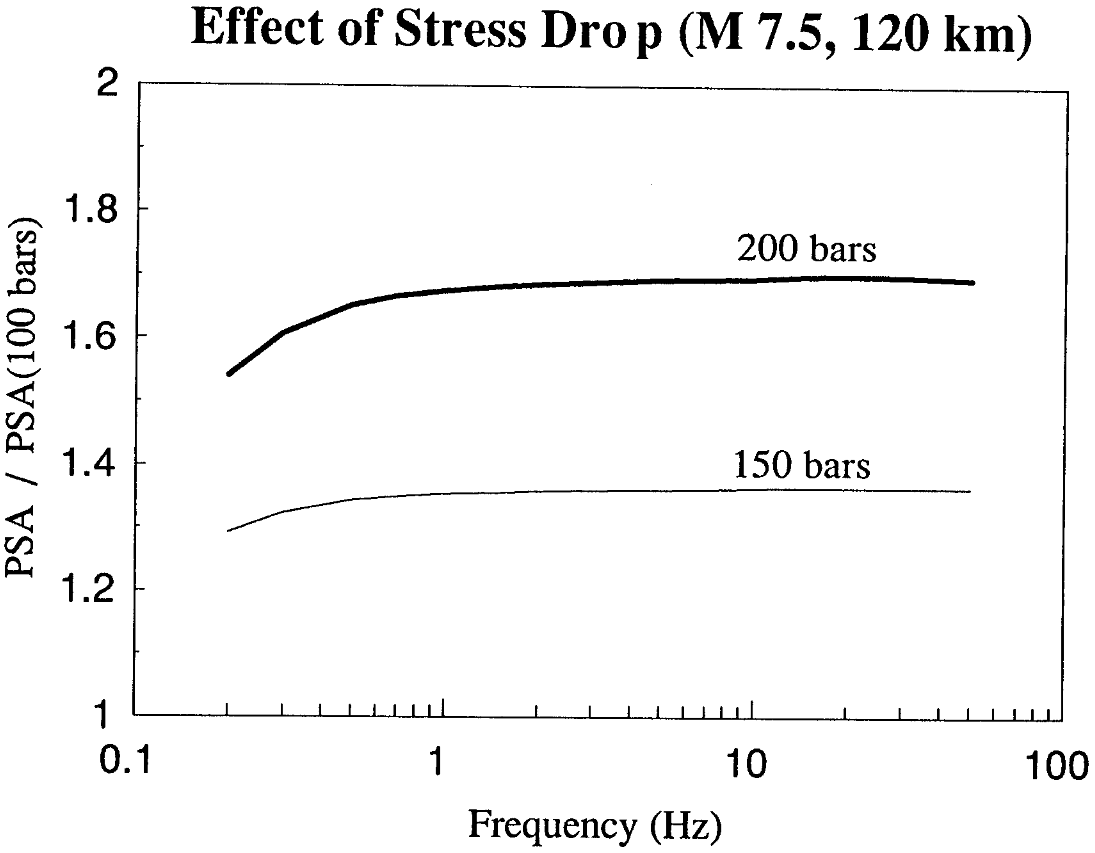

Figure 4: Ratio of spectral acceleration for 150 and 200 bars to 100 bars, for M=7.5 and R=120 km.