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Accelerograms of the 1978 Tabas, Iran, Earthquake

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Three triaxial sets of accelerograms recorded in the near source region (within 50 km epicentral distance) of the September 16, 1978, Tabas earthquake (M_S 7.4 -7.7) are of great engineering importance. The distances of the recording sites from the nearest approach of the rupture surface are approximately 3, 17, and 28 km for Tabas, Dayhook and Boshrooyeh stations, respectively. The measured horizontal peak ground accelerations of 0.94 and 0.88 g at Tabas are higher than previously estimated. The peak vertical ground acceleration recorded at this station is 0.74 g. The normalized response spectra at these three stations are consistent with the Newmark-Hall elastic design spectra, suggesting that the latter adequately represent the spectral amplification factors at frequencies above 1 Hz. The main shock accelerogram at Dayhook exhibits at least three distinct events as indication of a complex source behavior. The widened spacing of these events on the Dayhook records further confirms that the rupture front moved northwestward away from this station and towards Tabas. The measured S minus trigger times at Tabas, Dayhook and Boshrooyeh stations are in conflict with the teleseismically determined epicenter, requiring it to move approximately 30 km to the southwest to about 33° 17'N, 57° 09' E.

INTRODUCTION

The September 16, 1978 earthquake (M_S 7.4-7.7) near Tabas in east-central Iran produced several accelerograms in the near source region. Because of the rarity of close-in observations from major earthquakes, these data are considered important in the characterization of ground motion behavior close to the source. Therefore, despite the unavailability of original seismograms, several preliminary analyses have, thus far, been carried out on poorly reproduced copies of the horizontal accelerograms recorded at Tabas. (Hadley and Mellman, 1982; Hadley et al., 1983, hereafter called Paper I; Niazi, 1984.) The vertical accelerogram could not be recovered from the available copy. Recently, Moinfar and Adibnazari (1982), published a report, hereafter called Paper II, containing copies of the accelerograms produced by this earthquake at Tabas and eight additional sites within epicentral distances of approximately 200 km. The report also contains a listing of the uncorrected digitized time histories at a rate of 50 samples per second.

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In this study, we analyze the mainshock's vertical accelerogram at Tabas for the first time and compare the horizontal accelerograms published in Papers I and II. In addition, accelerograms of the mainshock written at two other sites (Dayhook and Boshrooyeh) within 50 km of the causative fault surface are presented and the limited peak ground acceleration data for this earthquake are compared with empirical predictions for the western U.S.

HORIZONTAL ACCELEROGRAMS

The acceleration polarities of the two sets of accelerograms published in Paper I are reversed for both longitudinal and transverse components as compared to those of Paper II. The polarity reversals were perhaps introduced when the original record was copied and are inconsequential to the integration of time histories and the evaluation of peak velocities and displacements and response spectra of Paper I. Neither are the previous estimates of average rupture velocity and near-source Q (Niazi, 1984) sensitive to correct polarity designation. However, the particle acceleration rose diagrams produced in the latter work have to be revised.

The correct orientation of horizontal particle accelerations are N74°E for the longitudinal and N16°W for the transverse components. They are somewhat different from the misprinted orientations given in Paper II (Shoja-Taheri, 1983 personal communication). The reversed polarities of the traces of Paper I, therefore, correspond to S74° W and S16° E, for the longitudinal and transverse components, respectively. None of the references cited here have yet published correct sensor orientation for the Tabas accelerograms.

The digital ground motion data listed in Paper II were corrected for several obvious mistakes, apparently introduced by typographical errors, by simple interpolation of the two adjacent points. The resulting accelerograms, together with velocity and displacement time histories, are plotted in Figures 1 to 3. Integration was performed by the method suggested by Sunder and Connor (1982). The band-pass filter used in this analysis has the upper and lower frequencies of 20 and 0.125 Hz, respectively. Figure 4 shows a comparison of the two sets of accelerograms given in Papers I and II. For this comparison, the time histories of Paper I have been subjected to polarity reversal. If, as claimed in Paper I, the digitization of the available accelerogram copy was done with sufficient care, the minor drift of the two time histories with increasing duration, approaching as much as 0.2 second over the 24 second record length, may have resulted from inadvertent omissions in the listed values of Paper II. The assertion by Hadley and Mellman (1982) that the time marks were used for correction of these distortions agrees with this explanation. In superposing the time traces, we have matched the beginning of the first long period S arrival 4-6 seconds in the records.

The differences in the uncorrected PGA obtained from the two sets of digitized data are more significant. Here, the information provided by Paper I is less constrained and, therefore, information given in Paper II is considered more reliable because it is based on the original accelerograms rather than a low quality print copy. The base-line adjusted PGA values for Paper II are 0.88g and 0.94g for longitudinal and transverse components, respectively, as compared to 0.81 and 0.72g measured in Paper I. The difference exceeds 30 percent for the transverse component and 8 percent for the longitudinal component. Table 1 compares the peak ground motion parameters obtained by the application of SIVA package

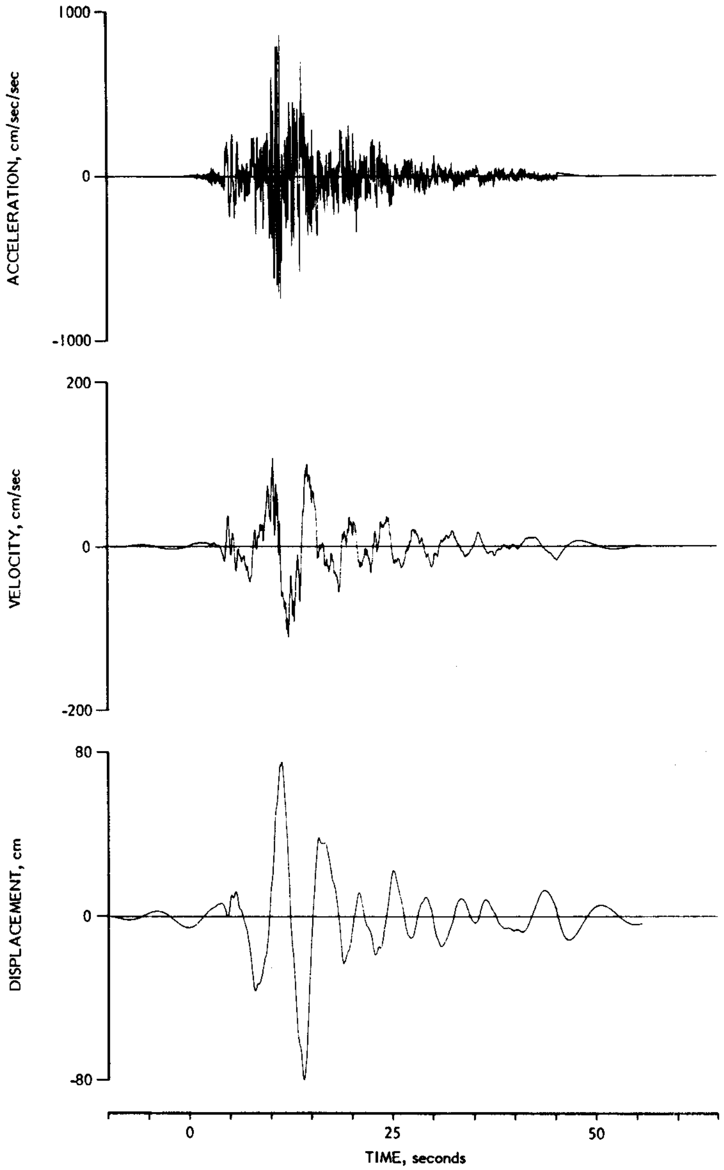

Figure 1 - Corrected acceleration, velocity and displacement time histories recorded by the transverse component (N16°W) of the SMA-1 instrument in Tabas at an epicentral distance of nearly 52 km: The closest station distance from the fault surface is approximately 3km. The brand-pass filter is set between 0.125 and 20Hz. The peak ground motion values are given in Table 1.

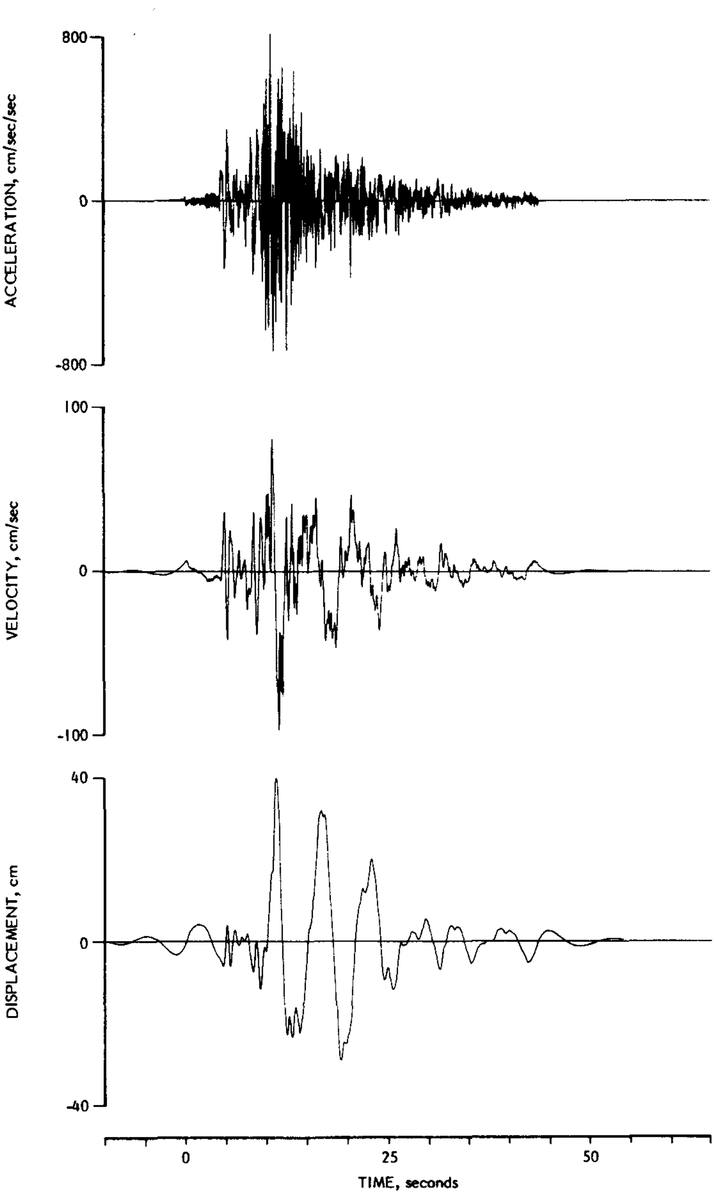

Figure 2 - Corrected acceleration, velocity and displacement time histories recorded by the longitudinal component (N74°E) of the SMA-1 instrument in Tabas. The distance and filter setting are the same as in Figure 1.

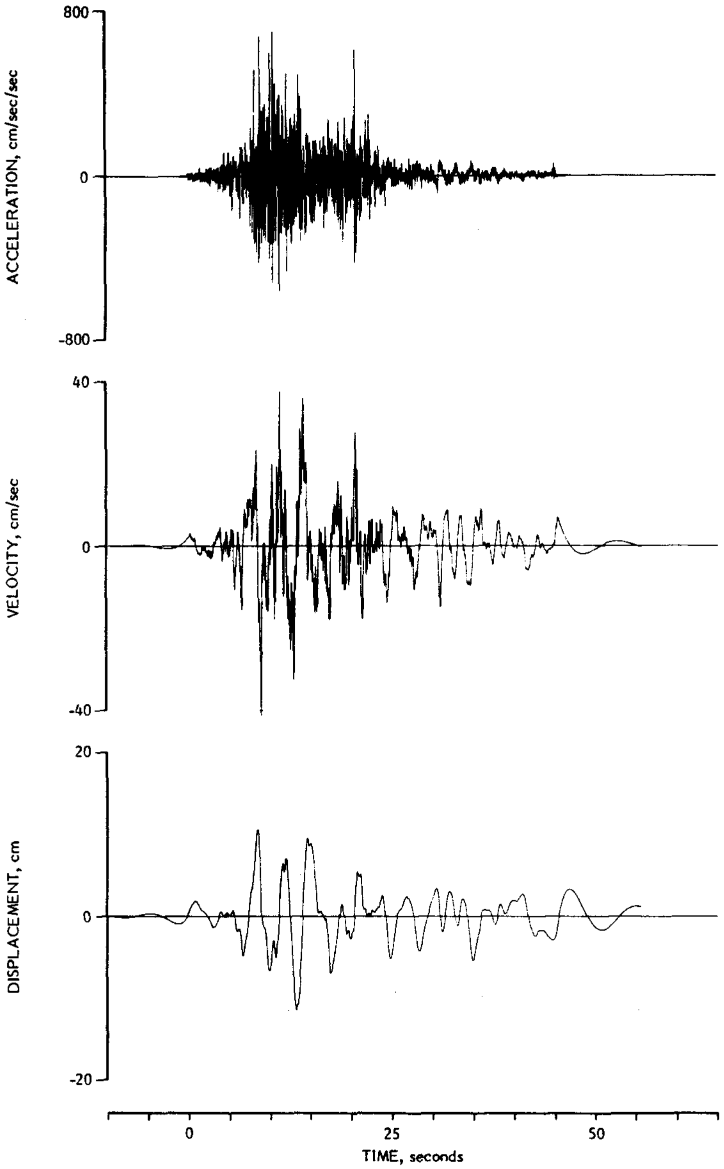

Figure 3 - Corrected acceleration, velocity and displacement time histories recorded by the vertical component of the SMA-1 instrument in Tabas. The distance and filter setting are the same as in Figure 1.

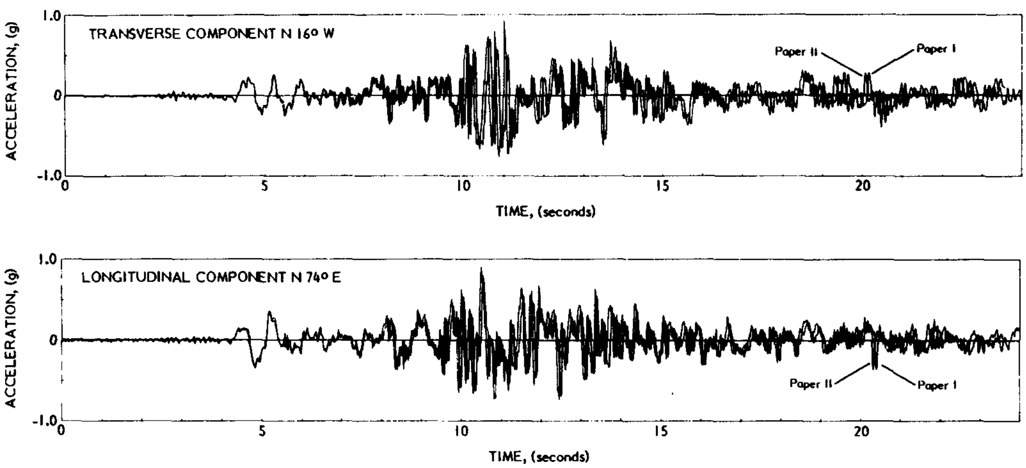

Figure 4 - Comparison of the uncorrected horizontal acceleration of Tabas record as given in Papers I (Hadley et. al. 1983) and Paper II (Moinfar and Adibnazari, 1982).

(Sunder and Connor, 1982) to either data set with those of Paper I. It is noted that the ground motion parameters derived from the data of Paper I in this study are almost identical with the result derived in that paper.

VERTICAL ACCELEROGRAM

The high frequency nature of the vertical accelerogram at Tabas did not permit its digitization from the record copy used in Paper I. However, a value of 0.88g was cited as the minimum estimate of the vertical PGA by the authors. A plot of the first 45 seconds of the digital accelerations listed in Paper II is shown in Figure 3. The base-line adjusted peak value of these data is 0.74g, nearly 19 percent below the lower limit of Paper I. The vertical PGA is recorded 10.7 sec after trigger time. As seen in Figure 3, the high vertical acceleration peaks greater than 0.5g persist for over five seconds and those above 0.1g for over 20 seconds. A single pulse of nearly 0.6g at around 20.5 seconds has a correspondingly high acceleration arrival on the longitudinal component and may have been produced by a second shock. A notable observation on the vertical accelerogram at Tabas is indistinct arrivals corresponding to the first long period S pulse on the horizontal records, which may be indicative of a steeply emerging ray path to the station. These observations will be further discussed below in connection with the source complexity of the mainshock.

ACCELEROGRAMS AT OTHER SITES

In addition to the mainshock accelerations recorded at Tabas, Paper II also provides a listing of one or more acceleration time histories at eight additional sites located within epicentral distances of around 200 km. The location of the

TABLE 1

PEAK GROUND MOTION PARAMETERS OBTAINED FOR THE 1978 TABAS MAINSHOCK AT THREE STATIONS WITHIN 50 km EPICENTRAL DISTANCE

(a = acceleration in cm/sec^2, V = velocity in cm/sec, D = displacement in cm)

		Data of Paper I						Data of Paper II		
		Hadley et al, 1983			This study*			This study**		
Station	Components	a	V	D	a	V	D	a	V	D
Tabas	N16°W (T)	686.7	104.8	76.4	691.6	104.6	78.1	924.9	111.2	79.6
	Vertical	--	--	--	--	--	--	724.2	41.5	11.5
	N74°E (L)	794.6	91.5	43.0	796.0	90.1	43.0	859.7	97.3	39.6
Dayhook	N10°E (T)	--	--	--	--	--	--	383.5	27.5	(10.5)
	Vertical	--	--	--	--	--	--	180.6	12.2	6.1
	N80°W (L)	--	--	--	--	--	--	371.9	(36.7)	--
Boshrooyeh	N11°W (T)	--	--	--	--	--	--	114.3	(29.6)	--
	Vertical	--	--	--	--	--	--	80.2	15.1	6.3
	N79°E (L)	--	--	--	--	--	--	107.6	13.9	7.5

* Record length 29 sec; band pass filter 0.07-35 Hz.

** Record length 45 sec (for Tabas) and 40 sec (for Dayhook and Bashrooyeh); band pass filter 0.125-20 Hz.

three closest sites relative to the mapped surface faulting (Berberian, 1982) is shown in Figure 5. Paper II contains 40 seconds of data for Dayhook and 35 seconds of data for Boshrooyeh. Dayhook and Boshrooyeh are at epicentral distances of about 30 and 70 km, respectively. Dayhook, which is located near the southern tip of the Shotori Horst on the eastern edge of the faulted region, recorded the second highest peak accelerations (0.38g horizontal and 0.18g vertical). Boshrooyeh is located farther north on the eastern flanks of these elevations and recorded relatively modest ground motion (0.11g horizontal and 0.08g vertical). Figures 6 and 7 show the accelerograms written at Dayhook and Boshrooyeh as given in Paper II, after several obvious errors were removed. The calculated peak velocities and displacements at these stations are listed in Table I. The peak displacements for longitudinal component at Dayhook and transverse component at Boshrooyeh could not be evaluated with confidence because of long period baseline oscillation and truncation of time histories when strong energy due to an aftershock was still arriving.

The uncorrected horizontal peak acceleration for the Tabas mainshock at the three sites of Figure 5 and at Ferdows, located beyond the northern edge of this figure at an epicentral distance of about 125 km, are plotted against the closest distance to the fault surface (hereafter, referred to as significant distance, after Campbell, 1981) in Figure 8. The closest distances in an increasing order are 3, 17, 28, and 110 km. For comparison, predicted mean horizontal PGA for magnitude 7.5 earthquake with a reverse fault type plus-and-minus one standard deviation is also given in this figure (TERA, 1982). The assigned distances in Figure 8 agree with the definition of significant distance used by Campbell (1981). While the close-in observations at Tabas and Dayhook (at significant distances of 3 and 17 km) are within one standard deviation bounds of predictions, they both give positive residuals. The mean predictions are exceeded by about 36 and 27 percent at Tabas and Dayhook, respectively. Considering the widely separated locations of these sites on either side of the rupture, directivity is not likely to have produced such high values for the observed peak accelerations. A partial explanation may be the low prediction bias of the model resulting from the underestimation in Paper I of the Tabas data which exerted significant constraints in the prediction at close-in distances. Incorporation of revised accelerations at Tabas by virtue of rarity of close-in observations from major earthquakes may lead to appreciable change in predictions by Joyner and Boore (1981), Campbell, (1981), and Bolt and Abrahamson (1982) among others at zero distance.

COMPLEXITY OF THE SOURCE AND RUPTURE DIRECTION

A set of rose diagrams was previously constructed for the P-coda of the Tabas horizontal accelerograms (Niazi, 1984) under the assumption of 0 and 90 degree sensor orientations for longitudinal and transverse components, respectively. Within the bounds of the presumed uncertainty, thought to be 16 degrees at the time, the rose diagrams agreed with northward propagations of rupture as estimated by an independent phase analysis. But, considering the 180 degree phase shift of the accelerograms of Paper I, and the incorrect instrument orientations assumed for the construction of particle motion rose diagrams, they are not true representations of ground motion. However, the qualitative inferences made from the consideration of their pattern can now be validated by the Dayhook accelerograms. At least three distinct events can be identified on Dayhook accelerograms

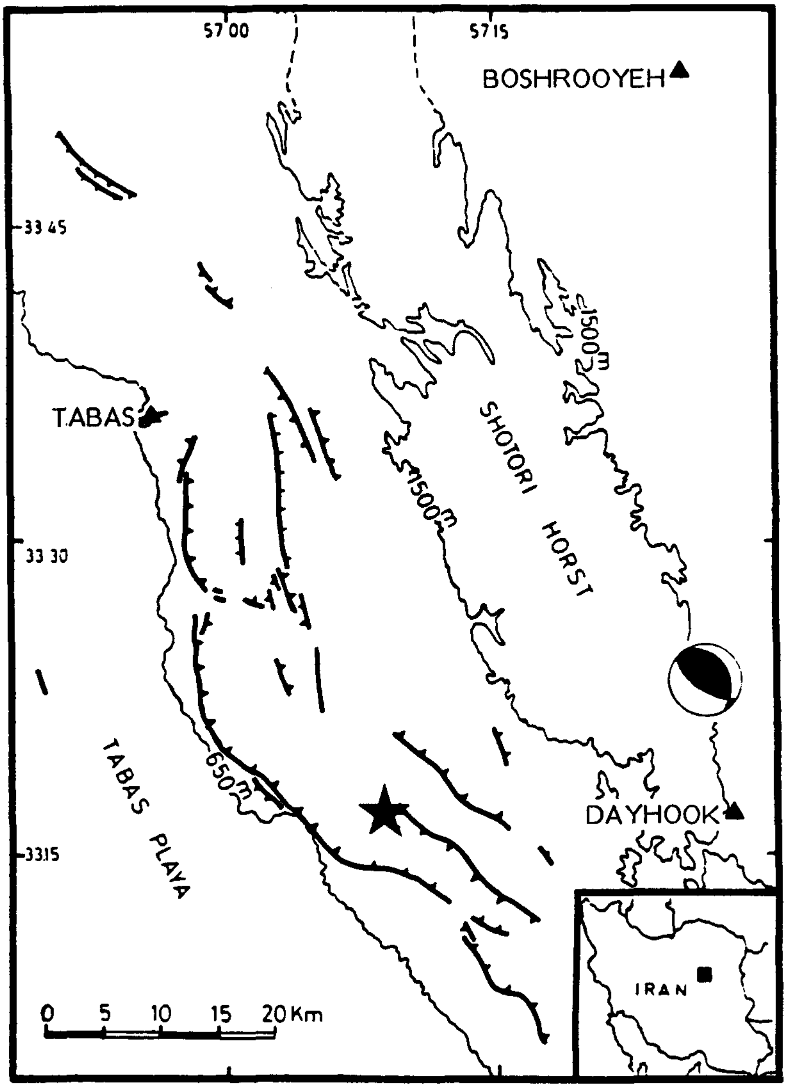

Figure 5 - Map of the epicentral region of Tabas earthquake, showing the topographic features, and the location of the three closest SMA-1 sites (Tabas, Dayhook and Boshrooyeh). The mainshock fault plane solution (Niazi and Kanamori, 1981) is centered at the teleseismic epicenter. The local epicenter (shown by an asterisk near 33° 17' N, 57° 09' E) approximately 30 km to the southwest of it is based on the measured S minus trigger times at the three stations. The base map showing mapped fault traces associated with mainshock is from Berberian, (1982).

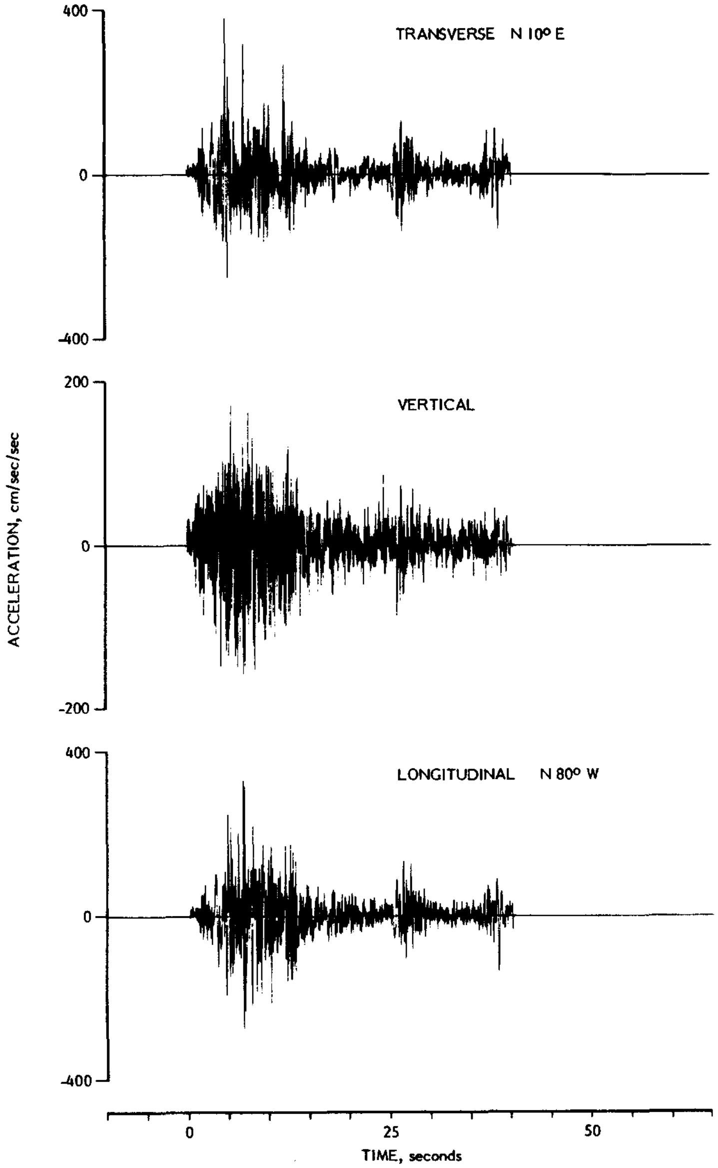

Figure 6 - Corrected acceleration time histories at Dayhook. The orientation of SMA-1 sensor is given for each trace. The epicentral distance is about 30 km and significant distance for this station is approximately 17 km.

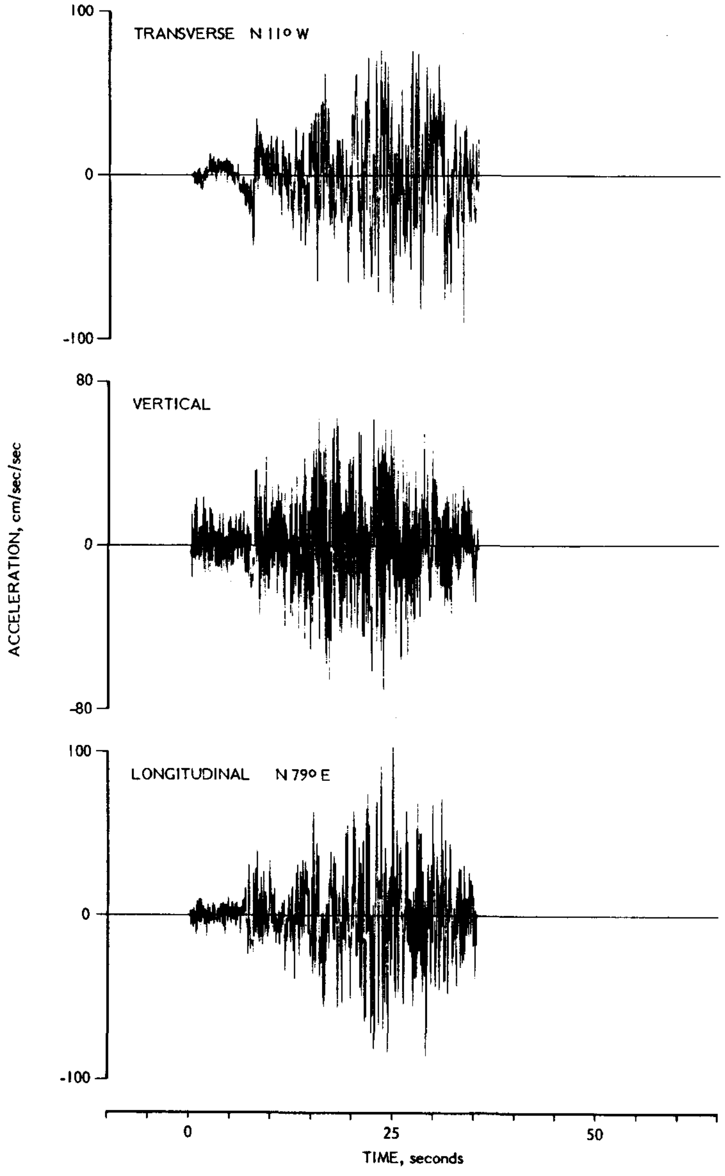

Figure 7 - Corrected acceleration time histories at Boshrooyeh. The sensor orientation of SMA-1 sensor is given for each trace. The epicentral distance is about 70 km and significant distance for this station is approximately 28 km.

(Figure 6), within the 35-second record length of Paper II data which point to the complexity of the source beyond what which was previously assumed in Niazi (1984). The coalescing of the strong signals generated by the distinct events on the Tabas accelerogram itself is a strong evidence for the propagation of the rupture front towards Tabas.

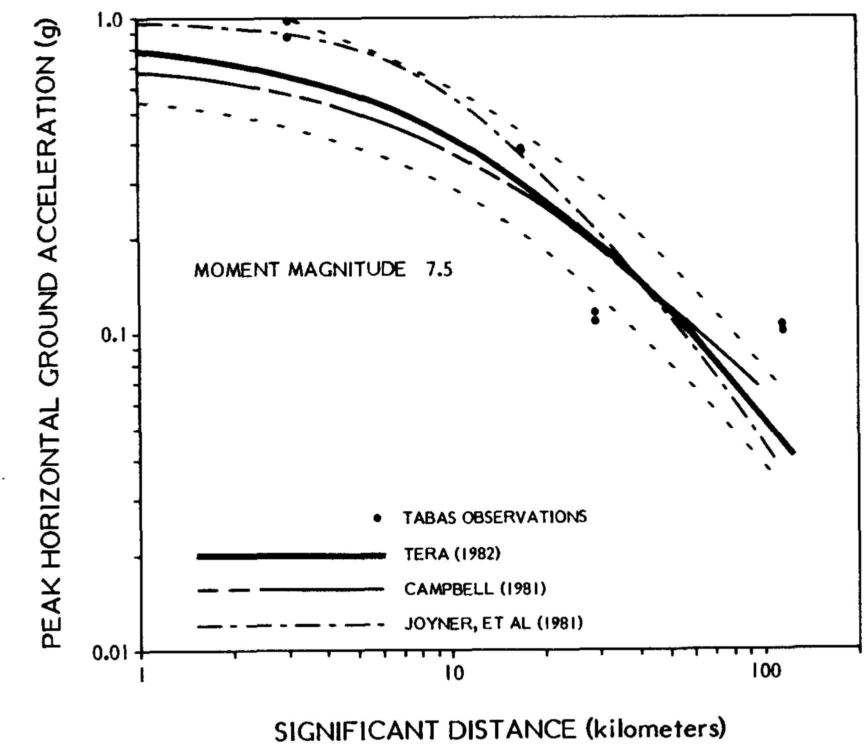

Figure 8 - Attenuation of horizontal peak ground acceleration at nearest four stations (Tabas, Dayhook, Boshrooyeh and Ferdows) as compared with TERA (1982) attenuation model derived for sources with reverse fault type. Both mean prediction and one sigma band are shown for this model. Also shown for comparison are Joyner and Boore (1981) and Campbell (1981) attenuation models for all source types. All models show empirically predicted horizontal PGA for an earthquake with 7.5 moment magnitude. Tabas earthquake has been assigned a moment magnitude 7.4 (Niazi and Kanamori, 1981), and a revised surface wave magnitude 7.4 ± 0.3 (Ambraseys, 1985, personal communication).

The peak horizontal accelerations recorded at Dayhook from the two later events are approximately 1/2 to 1/3 that of PGA which leads them at this station by about 22 and 33 seconds, respectively. For a stationary source, high amplitudes with corresponding lags relative to the PGA signal should be observed at Tabas. Except for the single 0.6g peak on the longitudinal record at 20.5 seconds (about 10 seconds after PGA signal), as discussed in previous sections, no other distinct arrival can be discerned to stand above the coda of the Tabas records. We can, therefore, safely assume that the later events originated closer to the Tabas station relative to the main event with sufficient delay, for the signal to arrive at Tabas within five to fifteen seconds of the mainshock signal.

A likely location for the latter sources is to the west of the epicenter where the surface faulting is deflected northwest and where aftershock activity extends beyond surface expression of faulting (Berberian, 1982; Niazi and Shoja-Taheri, 1984). It should also be noted that the first S signals arrive 3.0, 4.2 and 7.5 seconds after trigger time at Dayhook, Tabas, and Boshrooyeh, respectively. For the teleseismically determined hypocenter, t_s-t_{trig} on the Tabas record is too short to have the instrument triggered by the first P arrival. But, as seen in Figure 5, this can be reconciled by calculating a new epicenter based on three measurements of t_s-t_{trig}, nearly 30 km southwest of the teleseismic epicenter. This epicenter, termed here as local epicenter, in near 33° 17' N, 57° 09' E. The epicentral distances of 30, 40 and 70 km for Dayhook, Tabas and Boshrooyeh referred to in this paper are with respect to this location.

RESPONSE SPECTRA

Figure 9 shows the calculated horizontal and vertical response spectra at 5 percent damping for the unfiltered accelerograms recorded at the three closest stations (Tabas, Dayhook and Boshrooyeh). The six horizontal response spectra are normalized to 1 g ground motion before superposition. For comparison, in the same figure, the Newmark-Hall (1982) elastic design spectrum at 5 percent damping for 50 and 84 percent cumulative probabilities (i.e., median and median plus one sigma normalized to 1 g peak ground acceleration) is shown. A comparison based on the limited data presented here suggests that Newmark-Hall horizontal elastic design spectrum characterizes the high frequency ($f \geq 1$Hz) amplification factors reasonably well.

For completeness, the calculated response spectra for the three unfiltered vertical accelerograms are shown in Figure 10, again adjusted to 1 g peak ground motion acceleration. It is noted that the vertical response spectra of Figure 10 require somewhat higher amplification factors between 10 and 20Hz than those of the horizontal response spectra shown in Figure 9. This excessive amplification of vertical ground motion near 10 Hz is apparently a common feature of vertical response spectra (Hall, 1982). It is of some engineering interest to also note that, contrary to the common assumption, the peak horizontal and vertical accelerations at Tabas were recorded almost concurrently.

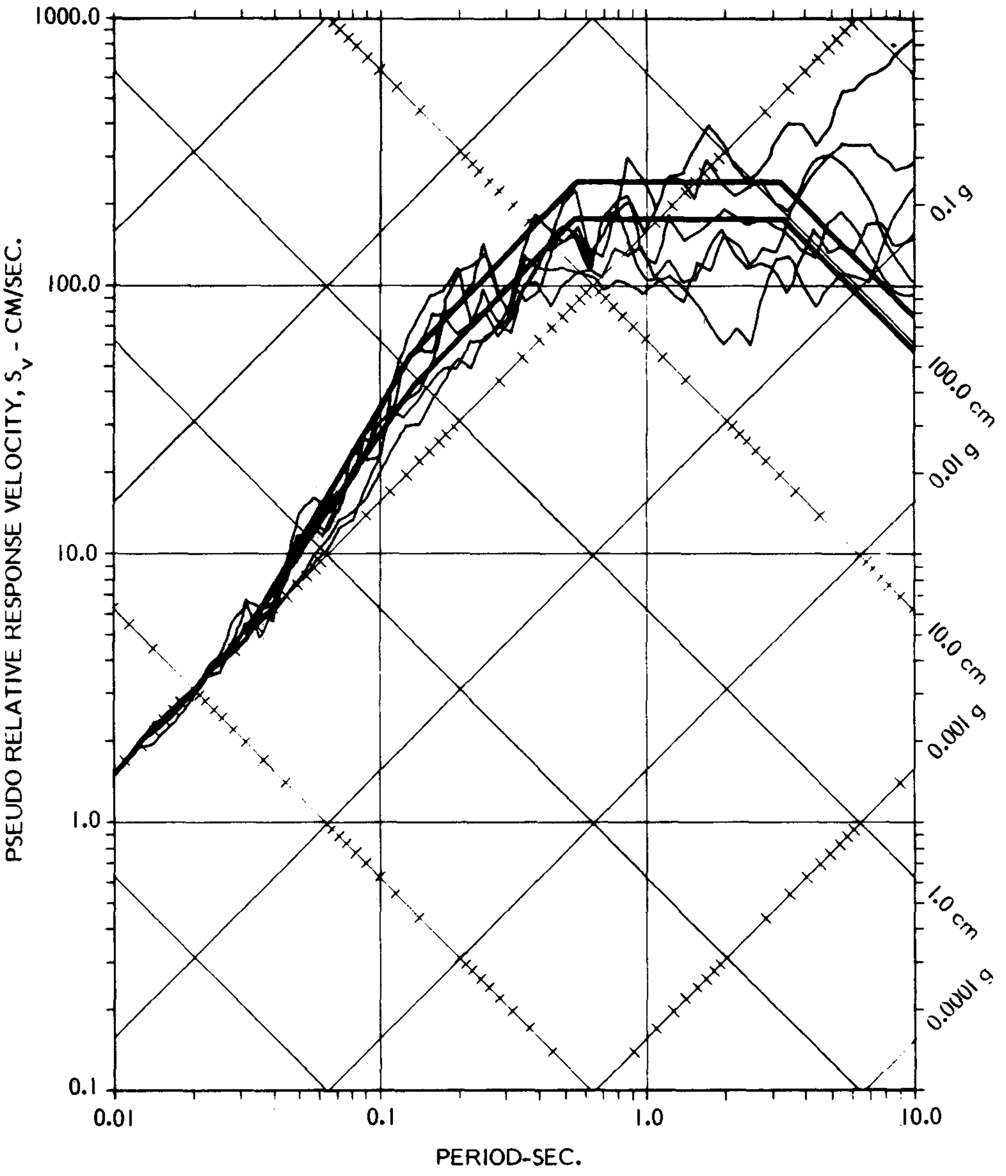

Figure 9 - Horizontal response spectra calculated for 5 percent damping at stations Tabas, Dayhook and Boshrooyeh and adjusted to 1 g PGA. Newmark-Hall (1982) horizontal elastic design spectrum for the same PGA is shown for comparison.

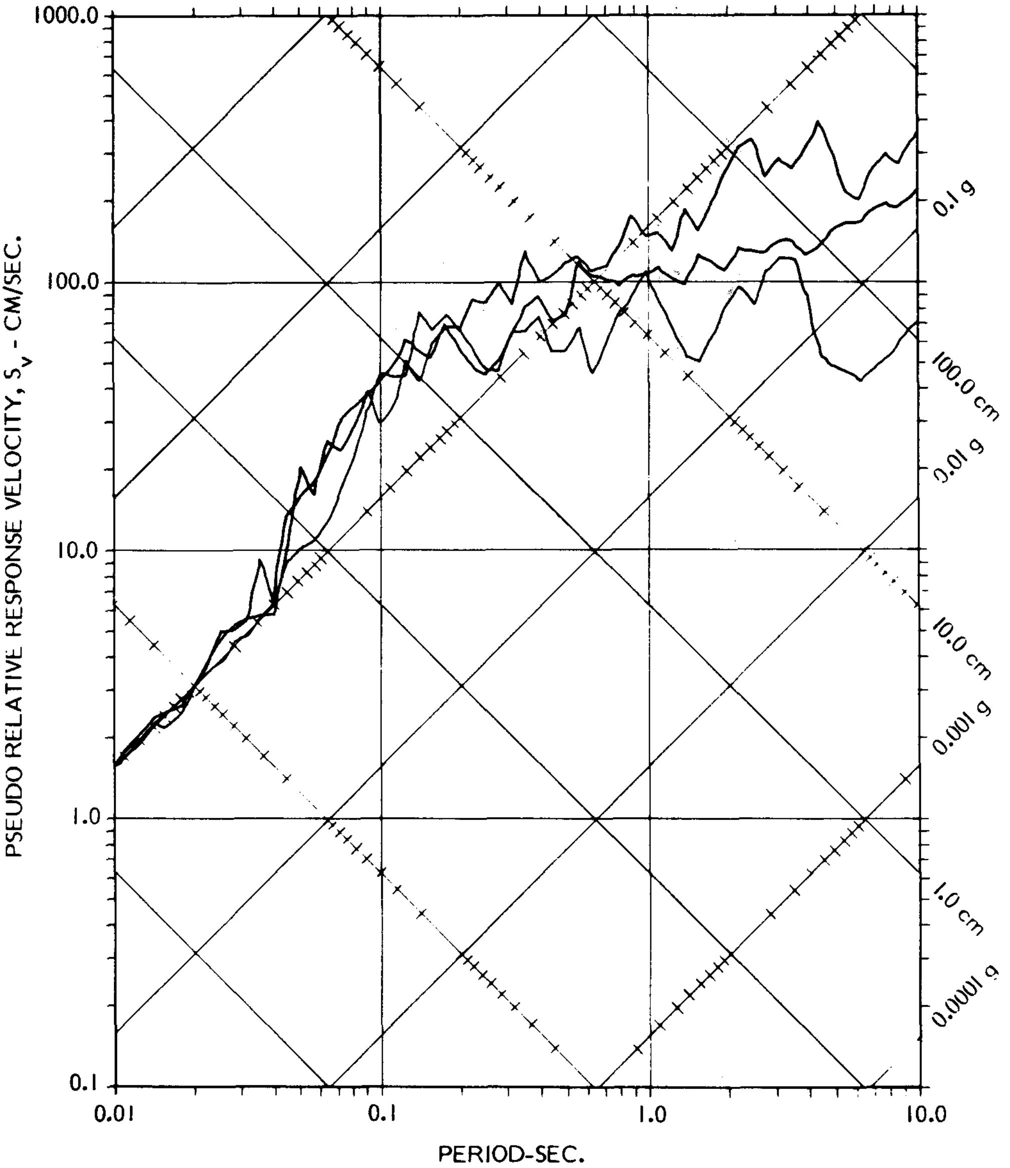

Figure 10 - Vertical response spectra calculated for 5 percent damping at stations Tabas, Dayhook and Boshrooyeh, adjusted to 1 g PGA.

SUMMARY

The 1978 earthquake near Tabas, Iran, provided much needed data for the characterization of the ground motion behavior in the near source region of a major dip slip earthquake. The analyses presented here suggest:

- Record peak ground motion accelerations at Tabas exceeded currently accepted mean empirical predictions.
- The normalized response spectra at three stations closest to the rupture surface compare favorably with Newmark-Hall elastic design spectral shape at high frequencies ($f \geq 1$ Hz).
- The S minus trigger times at these stations suggest that the teleseismically determined epicenter for this earthquake may be in error by as much as 30 km.
- Appearance of several distinct events as parts of the mainshock accelerogram at Dayhook suggest that rupture front moved unilaterally away from this station during the rupture process.

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