LONG-PERIOD SURFACE WAVES

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Earthquake of October 15, 1979

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ABSTRACT

The seismic moment of the 1979 Imperial Valley earthquake is determined to be $6 \times 10^{18} \text{ N} \cdot \text{m}$ (that is, $M_w = 6.5$) from long-period Love and Rayleigh waves. The ratio of local magnitude $M_1$ to $M_w$ for the event is 1.02, significantly larger than the value 0.90 for the 1940 Imperial Valley earthquake.

INTRODUCTION

Long-period surface waves ($R_2$, $G_2$, and $G_3$) generated by the 1979 Imperial Valley earthquake were recorded by the ultra-long-period seismographs at Pasadena and Berkeley, Calif. Here we present these data, determine the seismic moment, and compare this event with the 1940 Imperial Valley earthquake. Table 6 lists the location data for both stations.

Long-period (about 120 s) Rayleigh waves ($R_2$) were recorded with a peak-to-peak amplitude of 0.27 mm by the Pasadena (station PAS) ultra-long-period vertical seismograph (maximum magnification, 28x at $T = 150$ s). Longer period (about 200 s) wave trains corresponding to the Airy phase (group velocity, 3.55 km/s) followed this wave train with a smaller amplitude (fig. 28).

Table 6.—Data on ultra-long-period seismograph stations

<table>
<thead>
<tr>
<th>Station</th>
<th>Epicentral distance</th>
<th>Azimuth</th>
<th>Backazimuth</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAS (Pasadena)</td>
<td>2.82°</td>
<td>303°</td>
<td>122°</td>
</tr>
<tr>
<td>BKS (Berkeley)</td>
<td>7.70°</td>
<td>315°</td>
<td>131°</td>
</tr>
</tbody>
</table>

$G$ waves ($G_2$ and $G_3$) were recorded by an ultra-long-period seismograph (NE-SW component) at Berkeley (station BKS) with peak-to-peak amplitudes of 10.5 and 7 mm, respectively (fig. 29). This seismograph has a peak magnification of 500x at a period of 100 s. Because the backazimuth at station BKS is S. 49° E., this component is almost transverse to the path and represents the $SH$ component.

INTERPRETATION

We compared these seismograms with synthetic seismograms (figs. 28, 29) computed according to the method of Kanamori and Cipar (1974). The fault geometry was assumed to be vertical right-lateral strike-slip with a strike of N. 37° W. that coincides with the overall strike of the Imperial fault. For computing the synthetics, we used fundamental spheroidal and torsional modes with order numbers of from 2 to 100

Figure 28.—Ultra-long-period record of Rayleigh waves ($R_2$) registered by station Pasadena (PAS) seismograph 33; UD denotes vertical component. Synthetic seismogram computed for seismic moment ($M_0$) of $6 \times 10^{18} \text{ N} \cdot \text{m}$ is presented for comparison. Δ, epicentral distance; φ, backazimuth; $U$, group velocity.

Figure 29.—Record of long-period Love waves ($G_2$ and $G_3$) registered by station Berkeley (BKS) ultra-long-period (ULP) seismograph. Synthetic seismogram computed for a seismic moment ($M_0$) of $6 \times 10^{18} \text{ N} \cdot \text{m}$ is presented for comparison. Δ, epicentral distance; φ, backazimuth.
computed for Earth model 5.08 M (Kanamori, 1970; Press, 1970). A point source was placed at a depth of 33 km. For vertical strike-slip, the excitation of long-period (100–300 s) surface waves does not vary significantly for a depth range of 0–50 km.

For the purpose of the present analysis, the choices of the Earth model and the depth are not critical. We obtain a seismic moment of $6 \times 10^{18}$ N·m from comparison of the amplitude of the $G_2$ wave at station BKS. From the amplitude of the Rayleigh wave ($R_2$) at station PAS, we obtain a seismic moment of $5 \times 10^{18}$ N·m. The azimuth of station BKS is in the loop direction (direction of maximum amplitude) of the $G$-wave radiation pattern for the assumed fault geometry (fig. 30), and so a small change in the strike direction of the fault results in an insignificant difference in the amplitude of the synthetic seismogram. On the other hand, station PAS is close to the nodal direction of the Rayleigh-wave radiation pattern, and so a small change in the fault geometry would significantly change our estimate of the seismic moment. For instance, a change in the fault strike of $\pm 3^\circ$ would change the seismic moment by about 30 percent. Thus, we prefer the value of $6 \times 10^{18}$ N·m obtained from the station BKS record to that of $5 \times 10^{18}$ N·m obtained from the station PAS record. The reasonably good agreement between these two estimates, however, suggests that the assumed fault geometry is a good approximation.

The assumed fault geometry (fig. 30) places station BKS almost in the nodal direction of the Rayleigh-wave radiation pattern, as substantiated by the absence of long-period (200 s) Rayleigh waves on the vertical component of the ultra-long-period seismogram from this station (not shown).

**COMPARISON OF 1940 AND 1979 IMPERIAL VALLEY EARTHQUAKES**

The seismic moment of the 1940 Imperial Valley earthquake has not been determined directly from long-period surface waves. On the basis of geodetic data and the amount of surface breaks, Byerly and DeNoyer (1958), Kasahara (1958), and Brune and Allen (1967) estimated the fault length, fault width, and amount of slip on the fault for the 1940 event. Kanamori and Anderson (1975) averaged these results and estimated a seismic moment of $56 \times 10^{18}$ N·m, almost 10 times larger than that for the 1979 event. Converting the seismic moment to moment magnitude ($M_w$) (Kanamori, 1977), we calculate $M_w=6.5$ and 7.1 for the 1979 and 1940 events, respectively. The surface-wave magnitude ($M_s$) of 7.1 for the 1940 event (Gutenberg and Richter, 1949) agrees with this value of $M_w$.

The local magnitude ($M_l$) for the 1940 earthquake ranges from 6.3 to 6.5 (see Kanamori and Jennings, 1978). For the 1979 event, the average value of $M_l$ obtained from the California Institute of Technology network is 6.6. These values can be used to compare the characteristics of the 1940 and 1979 events. Figure 31 plots $M_l$ against $M_s$ (or $M_w$) for major California events and for the 1976 Guatemala earthquake; the data points define a range of $M_l$ at a given $M_s$ for California earthquakes. Two important features are (1) the $M_l$ scale appears to saturate at 7½, and (2) for a given $M_s$ the range of $M_l$ is about 0.5. Because $M_l$ represents the size of an earthquake at high frequencies, events that plot near the upper edge of the band are more likely to cause stronger ground shaking than events with the same $M_s$ that plot near the lower edge of the band. We note that the 1940 and 1979 Imperial Valley earthquakes seem to represent the two extremes of California events. Because practically all $M_l$ values have been determined from the data obtained at stations to the north of the epicenter, this contrast may be due to rupture propagation rather than to any intrinsic difference in the two events. Nevertheless, it is significant that two earthquakes originating from approximately the same source region could have such different spectral characteristics.
DISCUSSION AND CONCLUSIONS

The seismic moment \( (M_0) \) of \( 6 \times 10^{18} \, \text{N} \cdot \text{m} \) obtained for the 1979 event indicates that the average slip (offset) at depth was approximately 57 cm. This estimate assumes a fault length of 35 km, a fault width of 10 km, and rigidity of 30 GPa. The average surface displacement observed over a 35-km section of the Imperial fault was about 20 cm about 1 day after the earthquake; although this displacement nearly doubled during the subsequent 10-day period (K. E. Sieh, oral commun., 1979), it is still considerably smaller than the amount of slip inferred from the seismic data. The surface break probably represents a delayed anelastic response of the sedimentary and soil layers to slip at depth. If this interpretation is correct, we expect that the surface break will eventually equal the slip at depth (57 cm).

The nearly tenfold difference in the magnitude of the seismic moment between the 1940 and 1979 events suggests that the overall fault displacement of the 1979 event is only a small perturbation in comparison with that of the 1940 event. Nevertheless, in terms of the ratio of \( M_s \) to \( M_w \) (or \( M_0 \)), the 1979 event appears to be unusually significant because it contained so much high-frequency energy (at least for paths to the north) for its relatively small overall size, as measured by \( M_w \).

ACKNOWLEDGMENTS

The ultra-long-period seismograms from station BKS used in this report were made available to us through the courtesy of the director of the Seismographic Stations at the University of California, Berkeley. We thank Donald Michniuk for useful information on the instrumental constants, and Kerry E. Sieh for information on and discussion of the surface break. This research was supported by the Earth Sciences Section, National Science Foundation, under Grant EAR 78-0001-18321.

Note added.—After our data were finalized, long-period seismograms from International Deployment of Accelerometers (IDA) stations (Agnew and others, 1976) became available to us by the courtesy of the IDA project team at the University of California, San Diego. To check the result reported in this chapter, we analyzed 14 Rayleigh-wave phases from 7 IDA stations and obtained the source parameters, according to the method of Kanamori and Given (1981). We constrained the mechanism to be either pure vertical strike-slip or 45° pure dip-slip, and obtained the following solution:

Fault type ____________ Strike-slip
Fault strike ____________ N. 34° W. (right lateral)
Seismic moment ______ 7x\( 10^{18} \, \text{N} \cdot \text{m} \) at a period of 200 to 250 s, with a slight indication of increasing moment at longer periods (assuming a point source at a depth of 9.75 km).

This result agrees well with that reported in this chapter.

REFERENCES CITED


Kasahara, Keichi, 1958, Physical conditions of earthquake faults as deduced from geodetic data: University of Tokyo, Earthquake Research Institute Bulletin, v. 36, no. 4, p. 455–465.