LONG-PERIOD SURFACE WAVES

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The Imperial Valley, California,
Earthquake of October 15, 1979

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CONTENTS

ABSTRACT

The seismic moment of the 1979 Imperial Valley earthquake is determined to be 6×10^{18} N · m (that is, $M_w = 6.5$) from long-period Love and Rayleigh waves. The ratio of local magnitude M_L 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, 28× 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*

Station	Epicentral distance Δ	Azimuth ϕ_E	Backazimuth ϕ_s
PAS (Pasadena)	2.82°	303°	122°
BKS (Berkeley)	7.70°	315°	131°

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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 500× 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

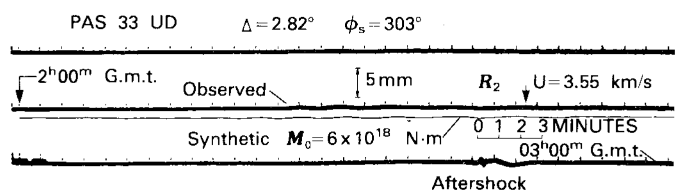

FIGURE 28.—Ultra-long-period record of Rayleigh waves (R_2) registered by station Pasadena (PAS) seismograph 33; UD denotes vertical component. Synthetic seismogram computed for seismic moment (M_0) of 6×10^{18} N · m is presented for comparison. Δ, epicentral distance; ϕ_s, backazimuth; U, group velocity.

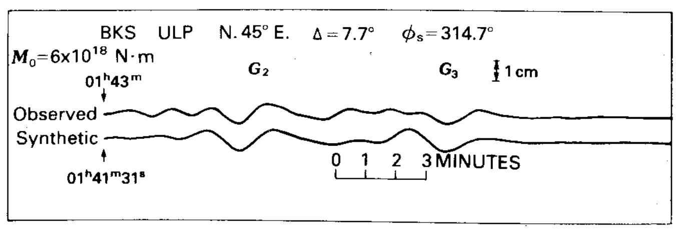

FIGURE 29.—Record of long-period Loves waves (G_2 and G_3) registered by station Berkeley (BKS) ultra-long-period (ULP) seismograph. Synthetic seismogram computed for a seismic moment (M_0) of 6×10^{18} N · m is presented for comparison. Δ, epicentral distance; ϕ_s, backazimuth.

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 6×10^{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 5×10^{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 $\pm3°$ would change the seismic moment by about 30 percent. Thus, we prefer the value of 6×10^{18} N·m obtained from the station BKS record to that of 5×10^{18} N·m obtained from the station PAS record. The reasonably good agreement between these two estimates,

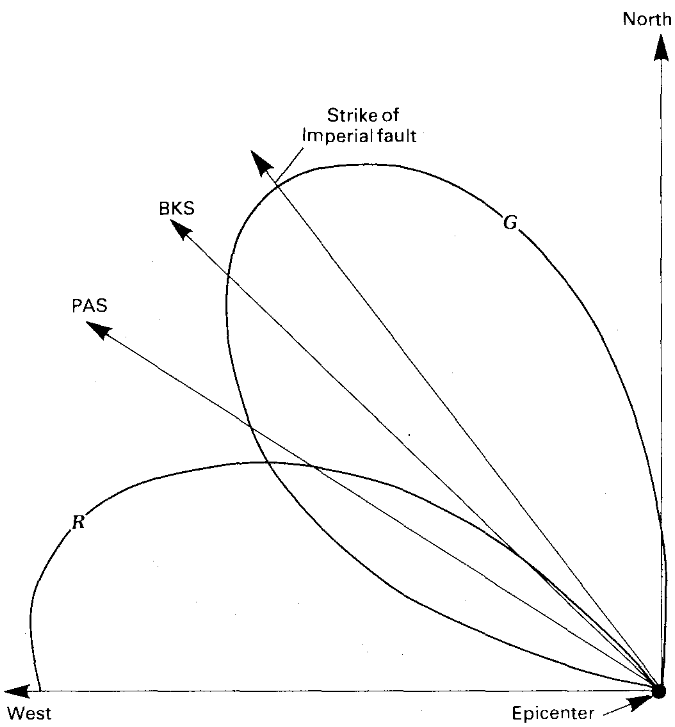

FIGURE 30.—Amplitude-radiation patterns of long-period Love (G) and Rayleigh (R) waves for a vertical strike-slip fault whose strike coincides with that of Imperial fault. Arrows indicate azimuths of seismograph stations PAS and BKS.

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 56×10^{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 7¼, 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 6×10^{18} N·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_L to M_S (or M_W), 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.

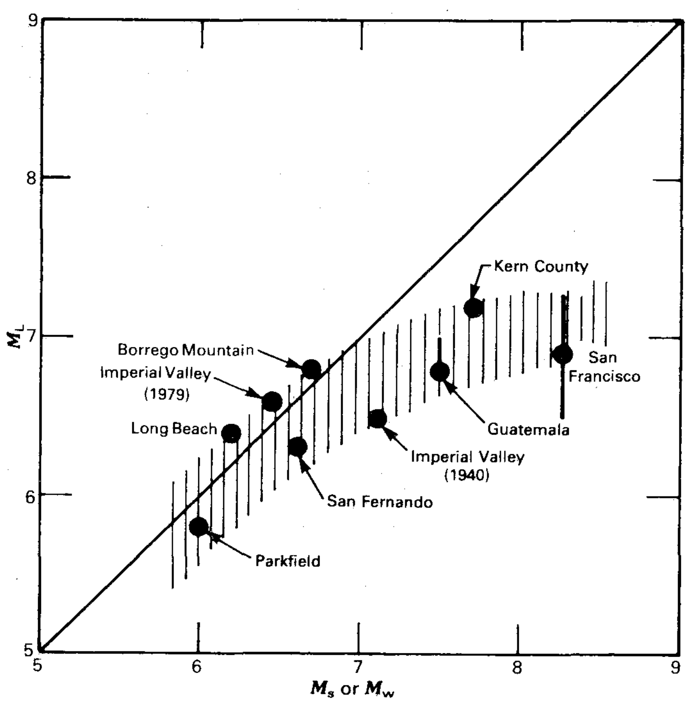

FIGURE 31.—Local magnitude (M_L) as a function of surface-wave magnitude (M_s) or moment magnitude (M_w) for California earthquakes and 1976 Guatemala earthquake (modified from Kanamori, 1979). Diagonal line represents M_L equivalent to M_s; band of vertical lines defines range of M_L at a given M_s for California earthquakes.

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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	7×10^{18} N·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.

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