Bulletin of the Seismological Society of America, Vol. 68, No. 2, pp. 517–521, April, 1978

LARGE CREEP EVENTS ON THE IMPERIAL FAULT, CALIFORNIA

BY N. R. GOULTY, R. O. BURFORD, C. R. ALLEN, R. GILMAN, C. E. JOHNSON, AND R. P. KELLER

During September 1975, three creepmeters were installed across the Imperial fault and one across the southern end of the Brawley fault, two members of the San Andreas fault system in the Imperial Valley of southeastern California. These supplement earlier installations in the Imperial Valley of one dial-gauge creepmeter and six alignment arrays (Figure 1 and Table 1). Each creepmeter uses either an invar or a stainless steel wire suspended in a horizontally buried pipe, and crosses the fault at an angle of about 45°. Those at Heber Road and Tuttle Ranch are of the design described by Yamashita and Burford (1973), using a linear variable differential transformer as the displacement transducer, and are 20 m long. The three more northerly creepmeters are similar in design to that described by Smith and Wyss (1968), and are between 12 and 15 m in length. Those at Harris Road and Ross Road use a potentiometer in a bridge circuit as the displacement transducer for continuous recording. The Superstition Hills creepmeter is equipped with a dial-gauge micrometer, which is read periodically.

Although only insignificant amounts of slip were recorded by the three creepmeters spanning the Imperial fault during the first 18 months of operation (Figure 2a), creep events of about 15 and 24 mm were recorded at Ross Road and Heber Road in April 1977 (Figure 2b). These creepmeters are 7 km apart. An inspection of road surfaces along the trace of the Imperial fault during June 1977 by Robert V. Sharp revealed offsets in the white lines on both Ross and Heber Roads, but no new cracking across roads and concrete-lined canals could be discerned between these two localities. Nevertheless, the coincidence in time between the creep episodes at Ross Road and Heber Road is very striking. These creepmeter sites were chosen largely because well defined en echelon crack patterns already existed in the asphalt at both localities. It is possible that the failure characteristics of the material at intermediate road crossings and canal crossings are different. The material may fail sufficiently slowly, or over a sufficiently broad zone, so that clear cracks are not produced. However, cracks were observed at intermediate crossings, as well as at Ross and Heber Roads, following the 1966 event (Brune and Allen, 1967), when surface breakage was associated with a magnitude 3.6 earthquake.

A southerly bound on the April 1977 creep episodes is provided by the Tuttle Ranch creepmeter, 5 km southeast of the Heber Road site (Figures 1 and 2). Unfortunately, the invar wire in this creepmeter broke on 20 June 1977 due to corrosion, and has since been replaced with a stainless steel one. A similar disaster befell the Harris Road creepmeter on 29 September 1976. The apparent accumulation of 2 to 3 mm of right-lateral slip at Harris Road since then may be due to an annual temperature effect on the replacement stainless steel wire.

A theodolite alignment array traverses the Imperial fault at Highway 80, 4 km northwest of Ross Road (Figure 1). The span of this array is about 75 m perpendicular to the fault. Twenty-five resurveys of this alignment array have been made since installation in 1967, the most recent being on 26 May 1977 (Figure 2c). No detectable motion took place in association with the creep episode to the south, although past results suggest that slip is due. There have been three episodes of slip in the past: between 5 January and 19 April 1968, when slip was associated with the

Borrego Mountain earthquake on 9 April (Allen *et al.*, 1972), between 8 June and 13 October 1971, when slip may have been triggered by the Kane Spring earthquake on 30 September (ibid.; Hileman *et al.*, 1973), and between 14 September 1973 and 21 May 1974. Errors due to "geodetic noise" are hard to quantify, so no error bars are included in Figure 2c. However, the good agreement between the four surveys in April 1968, following the Borrego Mountain earthquake, shows that errors in theodolite technique are negligible. Surveys of the mekometer network of Imperial College, London in early 1971 and early 1975 showed a total right-lateral slip of 32 mm between those times (Mason, 1976). Our alignment array observations are in good agreement with this result (about 35 ± 4 mm).

If the Imperial fault did break at some depth all the way from Ross Road to

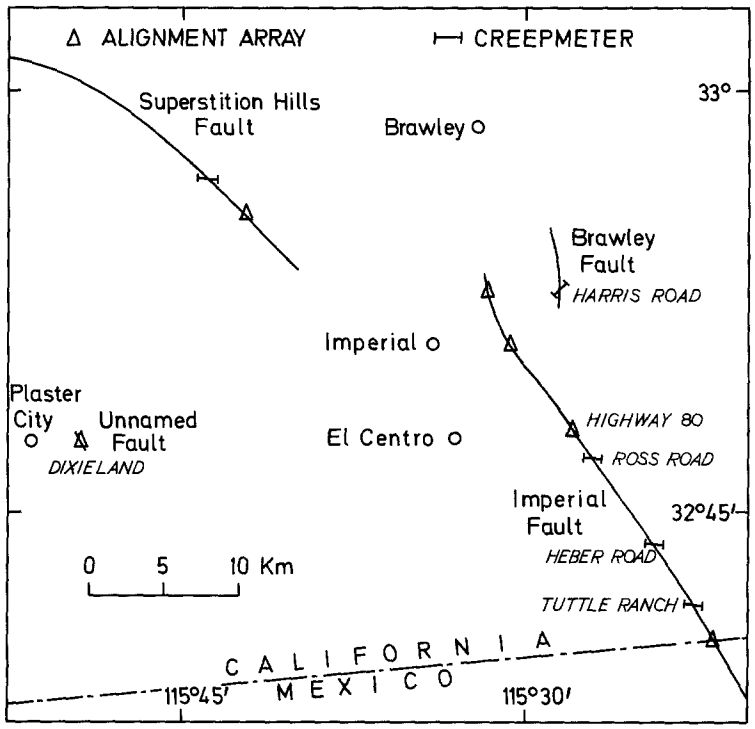


FIG. 1. Locations of alignment arrays and creepmeters in the Imperial Valley.

Heber Road in April 1977, the amount and extent of surface faulting were very comparable with those observed in 1966, following a magnitude 3.6 earthquake (Brune and Allen, 1967). We tentatively conclude that over the past decade creep on the northern segment of the Imperial fault has taken place episodically, with 1.5 to 2.5 cm of slip every 3 years or so. The slip may be triggered by the dynamic shaking from local earthquakes, but apparently this is not required.

There was little seismic activity on the Imperial and Brawley faults during the first half of 1977. A swarm did occur on the Imperial fault covering the region from Ross Road to Heber Road from 13 June to 22 June 1975. Other swarms took place further north on the Imperial fault and on the Brawley fault between June 1973 and October 1977. Thus, the whole Imperial fault/Brawley fault system from Heber Road to the Salton Sea has been seismically active in recent years. The only surface breakage known to be associated with these earthquakes was that at the southern

end of the Brawley fault associated with the January 1975 swarm. (Johnson and Hadley, 1976; Sharp, 1976). Similar periods of swarm activity occurred in the mid-1950's and mid-1960's.

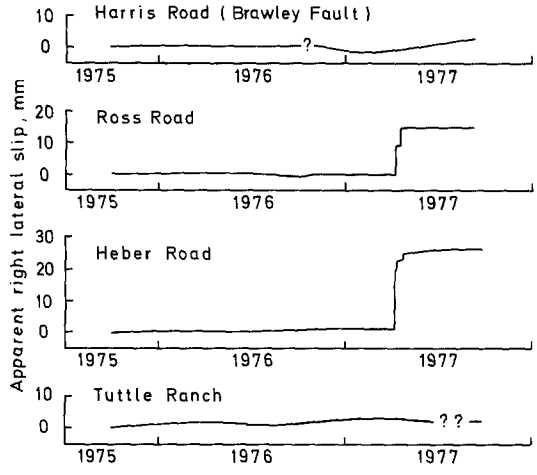
Our data show that episodic fault creep is occurring on the northern segment of the Imperial fault at an average rate of 1 cm/yr or less. In central California, fault creep occurs on the San Andreas fault at rates of about 3 cm/yr (Savage and

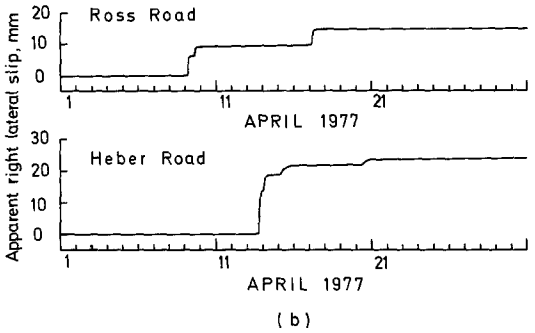
TABLE 1

CREEPMETERS AND ALIGNMENT ARRAYS IN IMPERIAL VALLEY, CALIFORNIA

Installation Name	Fault	Lat.N.	Long.W.	Initial Reading Date	Summary of Observations of Apparent Right-Lateral Slip to September 1977
Creepmeters					
Superstition Hills	Superstition Hills	32°56.8′	115°43.3′	8 May 1968	Less than 2 mm
Harris Road	Brawley	32°53.0′	115°28.5′	26 Sept. 1975	Possibly 2 to 3 mm (see text)
Ross Road	Imperial	32°46.9′	115°26.9′	25 Sept. 1975	15 mm, all in April 1977
Heber Road, XHB1	Imperial	32°43.8′	115°24.3′	3 Oct. 1975	26 mm, nearly all in April 1977
Tuttle Ranch, XTR1	Imperial	32°41.6′	115°22.5′	2 Oct. 1975	About 2 mm
Alignment arrays					
Superstition Hills	Superstition Hills	32°55.6′	115°41.8′	7 May 1967	No detectable motion
Harris Road	Imperial	32°53.0′	115°32.3′	5 Jan. 1968	About 8 mm between 5 January and 19 April 1968. No further motion until October 1972. Array subsequently destroyed.
Worthington Road	Imperial	32°50.9′	115°30.7′	10 May 1967	About 10 mm between 10 May and 29 December 1967. No detectable motion since, but data very noisy.
Highway 80	Imperial	32°48.2′	115°28.0′	10 May 1967	About 55 mm in 10 years, mainly in three episodes.
All American Canal	Imperial	32°40.6′	115°21.5′	10 May 1967	Readings indicate 14 mm from 1970 to 1977, but data very noisy.
Dixieland	Unnamed	32°47.4′	115°47.2′	8 Aug. 1970	About 47 mm from 1970 to 1976. Then apparent reversal of 11 mm from 1976 to 1977.

Burford, 1973), and this is less than the value expected from the widths of magnetic lineations on the sea floor in the Gulf of California. It may be that fault creep is occurring on other faults in the Imperial Valley region. One possible example is at Dixieland, two miles east of Plaster City, where a zone of cracking crosses Highway 80 and extends into the desert on both sides of the highway for over 1 km. An alignment array established on 8 August 1970 has been resurveyed eight times (Figure 2c). It showed 47 mm of apparent right-lateral slip along the strike of the





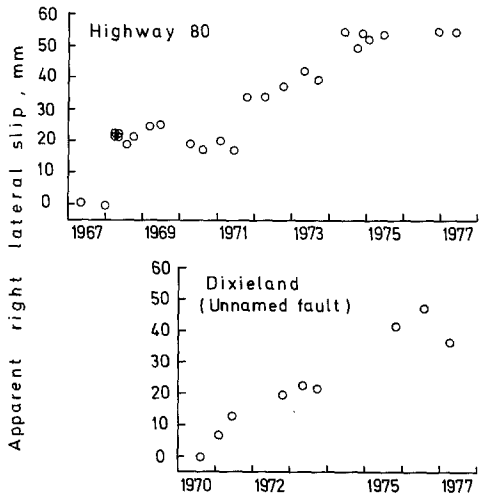


FIG. 2. (a) Records from creepmeters in the Imperial Valley. (b) Records from the Ross Road and Heber Road creepmeters during April 1977. (c) Results of repeated surveys of Highway 80 and Dixieland theodolite alignment arrays.

cracked zone, N26°W, until 28 July 1976, although at the time of the latest survey on 8 April 1977 there had been a reversal of this trend by 11 mm.

ACKNOWLEDGMENTS

This research was supported by the U.S. Geological Survey under contract 14-08-0001-15860. NRG held a research fellowship at CIT in 1975/6, and has since been supported by NERC. Robert V. Sharp searched along the Imperial fault in June 1977 for signs of recent activity at localities other than Ross Road and Heber Road, and reported his negative findings to us.

REFERENCES

Allen, C. R., M. Wyss, J. N. Brune, A. Grantz, and R. E. Wallace (1972). Displacements on the Imperial, Superstition Hills, and San Andreas faults triggered by the Borrego Mountain earthquake, *U.S. Geol. Survey, Prof. Paper 787,* 87–104.

Brune, J. N. and C. R. Allen (1967). A low-stress-drop, low-magnitude earthquake with surface faulting: The Imperial, California, earthquake of March 4, 1966, *Bull. Seism. Soc. Am.* **57,** 501–514.

Hileman, J. A., C. R. Allen, and J. M. Nordquist (1973). Seismicity of the Southern California region 1 January 1932 to 31 December 1972, Seismological Laboratory, California Institute of Technology, Division of Geological and Planetary Sciences, Contribution 2385.

Johnson, C. E. and D. M. Hadley (1976). Tectonic implications of the Brawley earthquake swarm, Imperial Valley, California, January 1975, *Bull. Seism. Soc. Am.* **66,** 1133–1144.

Mason, R. G. (1976). Mekometer measurements in the Imperial Valley, California, 1975, USGS contract 14-08-0001-14800, final report.

Savage, J. C. and R. O. Burford (1973). Geodetic determination of relative plate motion in central California, *J. Geophys. Res.* **78,** 832–845.

Sharp, R. V. (1976). Surface faulting in Imperial Valley during the earthquake swarm of January–February, 1975, *Bull. Seism. Soc. Am.* **66,** 1145–1154.

Smith, S. W. and M. Wyss (1968). Displacement on the San Andreas fault subsequent to the 1966 Parkfield earthquake, *Bull. Seism. Soc. Am.* **58,** 1955–1973.

Yamashita, P. A. and R. O. Burford (1973). Catalog of preliminary results from an 18-station creepmeter network along the San Andreas fault system in central California for the time interval June 1969 to June 1973, *USGS Open File Rept.*

DEPARTMENT OF GEOPHYSICS AND PLANETARY PHYSICS
SCHOOL OF PHYSICS
THE UNIVERSITY
NEWCASTLE UPON TYNE, NE1 7RU
ENGLAND (N.R.G.)

U.S. GEOLOGICAL SURVEY
MENLO PARK, California 94025 (R.O.B.)

SEISMOLOGICAL LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
DIVISION OF GEOLOGICAL AND PLANETARY SCIENCES
PASADENA, California 91125 (C.R.A., R.G., C.E.J., R.P.K.)
CONTRIBUTION NO. 2977

Manuscript received November 18, 1977