SUPERSTITION HILLS EARTHQUAKES—NOVEMBER 23 AND 24, 1987
IMPERIAL COUNTY, CALIFORNIA

Two strong earthquakes occurred in the area some 20 km west of Westmorland, California. The first, Ms 6.2, occurred in the evening of November 23, 1987 at 5:54 PM PST. The second larger event, Ms 6.6, occurred on the following morning, November 24, 1987, at 5:15 AM.

The following report has been provided by Jack Meehan (EERI, 1966), Earl Hart (1980) and Anshel Schiff (1974). Editing by Gerald Brady has removed some of the duplication. Acknowledgements are owed J. E. Kahle (CDMG), A. F. Shakal (CSMIP), C. Chaffin (SSS/OSA), R. M. Burnett (OSHPD), R. J. Rister (Imp. Cty. Bld. Dept.), Ken Hudnut (Lamont), Bob Sharp (USGS), and H. Legaspi (Imp. Valley Irr. Dist.).

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FAULT RUPTURE

Significant surface faulting occurred in association with the Superstition Hills earthquakes of November 23 and 24, 1987, in Imperial County, California. Most of the ruptures occurred along the Superstition Hills fault, which had previously recorded triggered slip (creep) from the Borrego Mountain M6.4 earthquake of 1968 and the Imperial M6.6 earthquake of 1979 (see figure). These earthquakes and their effects are detailed in USGS Professional Papers 787 and 1254. Minor faulting also occurred along a number of northeast-trending faults in the epicentral area (incompletely shown on figure).
As in other earthquakes on strike-slip faults, it is important to make a prompt field response in order to distinguish between coseismic rupture and afterslip, as well as to map ruptures before they are obscured. Of the many geoscientists from the U.S. Geological Survey, California Division of Mines and Geology, and universities and other organizations that made field investigations, Jim Kahle (CDMG) probably made the first critical observations of the Superstition Hills fault. At 0230 hours on 11/24, he noted that the fault had not ruptured Imler Road (Locality A of figure) after the first event (M6.2 at 1754 hours, 11/23). Following the M6.6 shock (0515 hours, 11/24), Kahle reobserved Imler Road about 0545 hours and found 10 to 15 cm of right-lateral slip. This clearly indicated that the second event was caused by the Superstition Hills fault. Subsequent observations at that locality revealed afterslip of 9.5 cm after 12 hours and 23.5 cm after six days.

Similarly, observations at Locality B (see figure) showed about 40 cm of right-lateral displacement on November 24 and 60 cm on December 7. Detailed mapping by CDMG revealed that continuous surface rupture had occurred for a distance of 23 km along the Superstition Hills fault. These ruptures coincided with previous ruptures triggered by the 1968 and 1979 events. By December 7, the maximum displacement measured by CDMG was 65 cm. A vertical component of slip also was measured along several segments of the fault, the maximum being about 10 cm. Minor rupture also occurred on several previously unmapped subsidiary faults as much as 400 m from the main trace.

Surface faulting also occurred along a zone of north to northeast-trending faults in the vicinity of the M6.2 earthquake. The most significant of these had at least 5 km of rupture length and maximum of 12 cm of

Recently active surface faults and principal fault ruptures (heavy lines) associated with the Superstition Hills earthquakes of November 23 and 24, 1987. Localities A, B, C are discussed in text; TC identifies triggered creep. Superstition Hills epicenters shown by solid stars; previous earthquakes associated with surface faulting shown by open stars.

<table>
<thead>
<tr>
<th>A Sampling of Peak Accelerations from CDMG and USGS Networks</th>
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<tbody>
<tr>
<td>CDMG:</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Westmorland</td>
</tr>
<tr>
<td>Niland</td>
</tr>
<tr>
<td>El Centro, Imperial Co. Bldg FF</td>
</tr>
<tr>
<td>El Centro Hlway 8, Meloland Overpass</td>
</tr>
<tr>
<td>Ground</td>
</tr>
<tr>
<td>Structure</td>
</tr>
<tr>
<td>USGS:</td>
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<tr>
<td>Superstition Mtn.</td>
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<tr>
<td>Parachute Test Site</td>
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</tbody>
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left-lateral displacement (locality C in Figure). As much as 3 to 4 cm of slip (mostly left-lateral) were reported on other nearby faults. The orientations and sense of displacements on these faults, which were incompletely mapped prior to the earthquakes, seems to fit the reported first motion data of the M6.2 event and its northeast-trending aftershock zone.

Fault creep also was reported on segments of the Imperial and Coyote Creek faults (TC in figure). Each fault showed as much as 1.5 cm of right-lateral slip over lengths of several kilometers. It is not known if creep was triggered on the south segment of the San Andreas fault, but this would not be surprising as creep had been previously noted after the 1968, 1979 and other earthquakes in the region.

More details of surface faulting will be presented in a preliminary report by CDMG, which will be printed in the March 1988 issue of California Geology. A more extensive report on the Superstition Hills earthquakes probably will be published by the USGS, which was still conducting field investigations in mid-December.

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**STRONG MOTION**

The report of the CSMIP Strong Motion Records of the two earthquakes, distributed on November 25, 1987, provided the data in the accompanying table.

The USGS reports that an instrument located at Superstition Mountain recorded a peak of 0.91 g accompanied by strong shaking for a duration of 16 seconds. A sample of USGS data for the two events appears in the accompanying table.

<table>
<thead>
<tr>
<th>Ms</th>
<th>6.2</th>
<th>6.6</th>
</tr>
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<tbody>
<tr>
<td>PST</td>
<td>23 Nov 1987 1754</td>
<td>24 Nov 1987 0515</td>
</tr>
<tr>
<td>GMT</td>
<td>24 Nov 1987 0154</td>
<td>24 Nov 1987 1315</td>
</tr>
<tr>
<td>Lat.</td>
<td>33.07 N</td>
<td>33.01 N</td>
</tr>
<tr>
<td>Long.</td>
<td>115.79 W</td>
<td>115.86 W</td>
</tr>
</tbody>
</table>
LOSSES

General
On November 27, 1987 Governor Deukmejian proclaimed a state of emergency in Imperial County due to the earthquakes. This establishes mutual aid between counties and some relief from property taxes and state income taxes. It was reported that there was over $1 million in public property loss and just less than $2 million in private property loss in Imperial County.

Public Schools
There was no structural damage to any public school building in the area; however, there were a few hair-line cracks in plaster and other light superficial non-structural damage in the Imperial, El Centro and Calexico school buildings. Also, a few ceiling tiles fell along the perimeter of several rooms in Central High School in Imperial.

Hospitals
The acute care hospitals in the area also performed very well. No structural damage was observed. A few ceiling tiles were dislodged and a few hair-line cracks in plaster were observed in several hospitals. There was some piping leakage in the Calexico Community Hospital boiler room. The in-house telephone system at the El Centro Community Hospital was out of service for about 6 hours.

Where power outages occurred, the emergency generators came on line as appropriate. However, one emergency generator developed a problem in its operation because debris in the day tank was shaken loose and clogged the filters. This condition has been observed in past earthquakes. Prudent maintenance requires that the day tank should be drained periodically and the main tank should be checked for debris and moisture condensate.

Brick veneer damage at Port of Entry Building in Calexico.

Port of Entry Building in Calexico was closed to the public due to asbestos contamination.

Imperial County Buildings
The replaced Imperial County Services Building, a two-story steel frame building suffered no structural damage — only the usual, non-structural damage. This building replaced the original 5-story reinforced concrete shear wall/moment frame building which was damaged in the 1979 earthquake to such an extent that it was later removed.

All county-owned buildings in El Centro were closed to the public on November 24 for clean-up purposes. There was no structural damage in the buildings. There was however the usual non-structural damage consisting of spilled shelves and cabinets, and light fixtures and ceiling damage. Several pieces of marble wainscoting in the court house were displaced.
Bridge Damage
The Imperial County bridge on Worthington Road across the New River was closed due to liquefaction damage of the approach fills on both sides of the bridge and to the bridge itself. The bridge and fill are scheduled for removal and replacement.

Port of Entry Building
The Port of Entry Building at Calexico was closed to the public due to the exposure of asbestos. The building suffered some non-structural damage such as spilled cabinets and shelves, and veneer displacement.

Trailers
Many trailers throughout the area were knocked off their jacks or displaced.

Unreinforced Masonry Buildings
Several unreinforced masonry buildings in Imperial, El Centro and Calexico suffered structural damage when portions of the parapets fell and cracks were formed in the walls. Automobiles parked next to the walls suffered considerable damage.

The Calexico City Library building constructed of hollow clay tile was damaged to the extent that it is scheduled for demolition.

Non-Structural Damage
Department stores in Calexico suffered plate glass and T-bar ceiling damage. The stores also had considerable merchandise loss due to cabinet and shelf spilling. The damage to the perimeter tiles of T-bar ceilings is typical of many older T-bar ceiling installations. Currently the building code requires a hanger within 8" of the wall and a member to prevent spreading of the ends of the T-bars and thus dropping the tile. The codes have further requirements for T-bar installations such as bracing within the field of the ceiling, and competent member splices and intersection joints.

Baled Hay Stacks
It was interesting to note the many stacks of baled hay which were spilled over along Worthington Road and other roads in the vicinity. Not surprisingly, the outer bales of hay in the stacks fell outward. There was some rotation of the bales to offer some resistance to spilling.

RESPONSE OF LIFELINES
Summary: Of the two earthquakes, the second caused most of the damage and disruption. The most costly damage was to concrete facing on irrigation channels with estimated repair cost of about $500,000. The
seismic stops on a steam generating unit were severely damaged and internal roof supports on an oil storage tank were damaged. There were numerous blown fuses and feeder line burn down. Total estimated damage to the power system is $100,000. There was extensive power disruption but most power was restored within an hour. Soil instability affected some bridge abutments and roadways.

**POWER SYSTEM**

**System Description**

The area has ties at 230 KV and 161 KV with transmission at 92 KV and subtransmission at 34.5 KV. Steam generating facilities consist of four units of 22, 30, 48, and 80 mega watts (MW). There are small hydro units to recover power associated with the drop of water in the major irrigation canals. There are several drops with one or more units per drop. Total firm capacity is 47 MW. The district also has a 1/3 interest in a 75 MW steam unit. There is about 180 MW of gas turbine or diesel peaking units distributed about the system.

**System Performance**

The El Centro Steam Plant had only Unit No. 3 operating at the time of the earthquake and it was taken off line by a misunderstanding of instructions. All power to the system was thus lost except for the 161 KV and 230 KV lines. Numerous 92 KV and 34.5 KV lines opened. As a result most customers from the Calipatria to El Centro were without power. At 5:23 the 92 KV to 33 KV lines were reenergized and most customers' power was restored. Power to most distribution substations was restored by 5:40.

**Damage**

The estimated total cost of repairs to power facilities was about $100,000.

**Generating Facilities**

At El Centro power station, Unit 3's seismic stops, which restrict the horizontal motion of the suspended boiler, were severely damaged. Repair should be simple and are estimated at $1000.

There was structural damage at the Number 4 fuel storage tank. Internal structural members that support the roof of a 45,000-bbl tank were damaged.

Two tanks, 15,000 bbls and 100,000 bbls, had similar damage in the 1979 earthquake. They were strengthened at that time and were not damaged in the recent earthquake. An elevator counterweight came out of its guide rails and put the unit out of service. There were minor signs of distress in the structure, primarily at construction joints.
Hydro

Hydro power is obtained at several locations along the canal as it drops. After relaying most units were restarted and inspection indicated that there was no significant damage. A float well that is used to measure water level fell in to the All-American Canal and had to be replaced or repaired before the unit could be put back into service.

Peaking Plant

Anchorage of a reverse osmosis water tank at the Rockwood peaking plant pulled out and must be replaced and an outlet connection on the tank has developed a leak. Estimated repair costs are $300.

Distribution System Damage

Service units at Calexico, Brawley, El Centro, and Holtville reported wrapped lines (1), blown line fuse (over 31), blown transformer fuses (over 30), and downed lines (11). There were at least 9 downed lines on feeder circuits. One transformer was rehung and two were damaged. One pole was downed and one crossarm was broken.

There was burn down of about 12 distribution lines and some wrapping. All burned down lines were copper.

IRRIGATION SYSTEM

System Description

The Imperial Irrigation District imports about 2.6 million acre feet of water a year which is distributed for agricultural purposes and sold to municipalities that have their own distribution systems.

System Performance

There was no disruption of service and no loss of water as occurred in the 1979 earthquake.

Damage

The Westmorland Div. of the Imperial Irrigation District experienced moderately heavy damage. Other divisions had little or no damage. Typical damage was to concrete lined channels and associated structures from soil settlement and berms slipping. Damage occurred to reinforced concrete pipe siphons by the pipe separating at joints or from structures. Light damage in other divisions were, for example, longitudinal cracks occurring along the banks of the Westside Main Canal and the All-American Canal from slipping berms. This slippage did not result in loss of water as occurred in the 1979 earthquake. Within the system there were 54 sites of damage. Historically, additional earthquake damage to siphons and road crossings, for example, comes to light some time after the earthquake. There was extensive cracking of concrete lined irrigation channels. Damage to the irrigation system is estimated at $500,000.
Strong Motion Accelerogram from the Superstition Hills Earthquake of November 24, 1987, Magnitude 6.6 at USGS and CDMG Stations (USGS OFR 87-672 and CDMG OSMS 87-06).