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GEOLOGICAL SURVEY

Distribution of Intensity for the Westmorland, California Earthquake of April 26, 1981

by

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Abstract

The maximum Modified Mercalli intensity of the April 26, 1981 earthquake located 5 km northwest of Westmorland, California is VII. Twelve buildings in Westmorland were severely damaged with an additional 30 sustaining minor damage. Two brick parapets fell in Calipatria, 14 km northeast of Westmorland and 10 km from the earthquake epicenter. Significant damage in rural areas was restricted to unreinforced, concrete-lined irrigation canals. Liquefaction effects and ground slumping were widespread in rural areas and were the primary causes of road cracking. Preliminary local government estimates of property loss range from one to three million dollars (Imperial Valley Press, 1981). The earthquake was felt over an area of approximately 160,000 km^2; about the same felt area of the October 15, 1979 (Reagor and others, 1980), and May 18, 1940 (Ulrich, 1941) Imperial Valley earthquakes.

Introduction

The Westmorland, California earthquake of April 26, 1981 was located in the seismically active Imperial Valley of southern California. Instrumental data for the earthquake obtained from Preliminary Determination of Epicenters (National Earthquake Information Service, 1981) is as follows:

Origin Time:	12:09:28.4 (April 26, 1981)
Latitude:	33.133 North
Longitude:	115.650 West
Depth:	6 km
Magnitude:	5.6 M_L (Pas); 6.0 M_S (USGS)

The Imperial Valley has repeatedly experienced earthquakes of significantly high intensity. Fifteen earthquakes of Modified Mercalli Intensity VII or higher have been recorded since 1906. These earthquakes are listed in Table 1 (Coffman and Von Hake, 1973; Coffman, 1979). Prior to 1906 the historical earthquake catalogue for the area is very incomplete, and the extremely sparse population and questionable accounts of time and location of shaking have made the historical record rather uncertain. Settlement of the valley was promoted in the early 1900's by the construction of the Imperial Canal. The diversion of water from the Colorado River into the Valley created more than 1,068,290 acres of arable land in what has formerly been a desert (Imperial Valley Irrigation District, 1977).

Following the April 26 earthquake a field investigation was undertaken to determine actual observed intensity, type of structural damage and geological effects in the epicentral area. Extensive canvassing by means of questionnaires mailed to post offices in a 500 km radius of the epicenter was used to

Table 1.--Historical earthquakes of intensity VII or greater in the Imperial Valley, California (from Coffman and Von Hake, 1973; Coffman, 1979).

Date	Location	Latitude (North)	Longitude (West)	Maximum Modified Mercalli Intensity
April 18 1906	Brawley	33.0	115.0	VIII
June 22 1915	El Centro Calexico, & Mexicalli, Mexico	32.8	115.5	VIII
November 05 1923	Calexico	32.5	115.5	VII
January 01 1927	Imperial Valley near Mexican border	32.5	115.5	VIII
February 25 1930	Imperial Valley	33.0	115.5	VIII
March 01 1930	Imperial Valley	33.0	115.5	VIII
May 18 1940	Southeast of El Centro	32.7	115.5	IX
July 29 1950	Imperial Valley	33.1	115.6	VIII
January 23 1951	Imperial Valley	33.1	115.6	VII
June 13 1953	Imperial Valley	32.8	115.7	VII
December 16 1955	Near Brawley	33.0	115.5	VII
April 25 1957	Southwest end of Salton Sea	33.2	115.9	VII
January 23 1975	Imperial Valley	33.0	115.5	VII

Table 1. (cont.)--Historical earthquakes of intensity VII or greater in the Imperial Valley, California

Date	Location	Latitude (North)	Longitude (West)	Maximum Modified Mercalli Intensity
October 15[1] 1979	Imperial Valley	32.6	115.3	VII (IX damage to one building)
April 26[2] 1981	Westmorland	33.1	115.7	VII

[1]Reagor and others, 1980.

[2]This report.

assign intensities and assess the distribution and nature of the earthquake effects in areas not included in the field investigation.

Shaking Effects and Distribution of Damage

The intensity values in this report refer to evaluations appearing in the Modified Mercalli Intensity Scale of 1931 (Wood and Neumann, 1931). Table 2 lists intensity assignments at cities throughout southern California and southwestern Arizona. These data are the basis of the generalized isoseismals shown in figure 1.

Within such an earthquake-prone area as the Imperial Valley, particular care is needed in assigning intensity values. The long history of frequent, high-level shaking has the effect of progressively weakening some structures that remain standing through one or more of the earthquakes. Indeed, buildings condemned as a result of shaking in the Westmorland earthquake showed evidence of repairs of previous earthquake damage. Some incidents of structural failure or severe damage are misleading as criteria in the assignment of intensity if the structure has been weakened by previous earthquakes.

A maximum intensity of VII was assigned at Westmorland and Calipatria, in the epicentral area. This evaluation is based on a large number of intensity VII damage effects.

Damage in Westmorland

Westmorland is a city with a population of approximately 1,470. Many of the heavily damaged downtown buildings consist of stuccoed, wood-framed, two-story structures. Typically these structures have porticos extending over the sidewalks. The porticos are supported by unreinforced concrete colonnades. This is a characteristic architectural style throughout the cities of the Imperial Valley. In Westmorland the buildings are relatively old, dating from the 1930's or earlier. Many old residences in the area are wood-frame stuccoed houses on wooden or cinder block foundations. Another common construction type for residences is stucco over adobe brick, and in at least one case, a residence of this construction had severe damage. Westmorland has a number of mobile home residences, five of which fell off their supports. The mobile homes were generally resting on supports of wood, hollow cinder blocks, or metal jacks. No securing bolts or other tie down provisions were apparent.

Westmorland's water treatment plant was temporarily inoperational as a result of damage to the filtering system. Residents were without city water for 10 hours, necessitating trucked-in water from the city of Brawley. The water storage tower tilted slightly to the south as a result of the earthquake. Damage to the city's sewer treatment plant required the city to run sewage through an old plant which had been unused for years. The sewage plant sustained an estimated $40,000 damage (Imperial Valley Press, 1981). Damage repair costs to the water treatment plant had not been estimated at the time of the field survey. Traffic on State Highway 86, which is Westmorland's Main Street, was rerouted for a short time after the earthquake because of fallen debris in the street and danger from sagging facades on Main Street buildings. The most heavily damaged buildings were those located in the center of

Table 2.--Modified Mercalli intensities assigned for the Westmorland, California earthquake of April 26, 1981. Asterisk entries indicate intensities assigned on the basis of the field investigation of the earthquake. The intensities assigned to each city are, in every case, the highest intensity known to have occurred in that city as a result of the earthquake.

Location	Coordinates (deg) Lat. (N)	Long. (W)	MM Intensity
	Arizona		
Bouse	33.93	113.00	III
Ehrenberg	33.63	114.50	II
Gila Bend	32.93	112.70	II
Martinez Lake	32.98	114.47	III
Parker	34.15	114.30	IV
Poston	33.98	114.40	IV
Quartzsite	33.68	114.23	IV
Roll	32.75	113.98	IV
Riviera	34.87	114.15	IV
Stanfield	32.83	111.97	II
Tacna	32.67	114.00	V
Wellton	32.65	114.15	IV
Wikieup	34.70	113.60	IV
Yuma	32.66	114.65	IV
	California		
Alamorio			V
Alpine	32.83	116.75	IV
Anza	33.56	116.68	IV
Azuza	34.12	117.91	III
Bard	32.78	114.56	IV
Beaumont	33.91	116.98	III
Blythe	33.60	114.61	III
Boulevard	32.66	116.26	IV
Brawley*	32.98	115.51	VI
Cabazon	33.91	116.78	V
Calexico*	32.67	115.50	V
Calipatria*	33.13	115.50	VII
Campo	32.60	116.47	IV
Cathedral City	33.76	116.46	IV
Cedar Glen	34.24	117.23	III
Chino	34.00	117.70	V
Coachella	33.66	116.16	IV
Corona	33.88	117.56	III
Coronado	32.68	117.18	IV
Dana Point	33.45	117.71	III
Descanso	32.85	116.61	V
Desert Center	33.71	116.50	III
Desert Hot Springs	33.95	116.50	V
Dulzura	32.64	116.78	IV

Table 2.--Modified Mercalli intensities assigned for the Westmorland, California earthquake of April 26, 1981

Location	Coordinates (deg) Lat. (N)	Long. (N)	MM Intensity
Eagle Mountain	33.85	115.48	V
El Centro*	32.79	115.56	V
El Cajon	32.78	116.95	IV
Encino	34.16	118.49	III
Forest Falls	34.11	116.90	IV
Glamis	32.99	115.07	V
Guatay	32.82	116.56	IV
Havasu Lake	34.48	114.40	IV
Heber	32.73	115.53	V
Holtville*	32.80	115.40	IV
Idyllwild	33.74	116.71	IV
Imperial*	32.85	115.55	V
Imperial Beach	33.73	116.32	IV
Indian Wells	33.73	116.32	IV
Indio	33.71	116.21	IV
Jacumba	32.61	116.18	IV
Joshua Tree	34.13	116.31	III
Julian	33.07	116.60	V
La Mesa	32.78	117.03	IV
Laguna Niguel	33.50	117.73	IV
Laguna Beach	33.53	117.75	III
Lakeside	32.82	116.89	IV
Lemon Grove	32.73	117.03	IV
Los Angeles	34.05	118.25	IV
Mecca	33.57	116.08	IV
Mount Laguna	32.87	116.41	V
Murrieta	33.55	117.23	IV
National City	32.66	117.11	IV
Needles	32.83	114.60	III
Niland*	33.24	115.51	V
Nuevo	33.80	117.15	II
Oceanside	33.20	117.38	IV
Ocotillo*	33.14	116.13	V
Onyx	35.68	118.23	III
Pala	33.36	117.08	IV
Palm Desert	33.72	116.37	V
Palm Springs	33.81	116.56	IV
Palo Verde	33.43	114.73	V
Parker Dam	34.28	114.14	IV
Pine Valley	32.82	116.53	IV
Plaster City*	32.79	115.85	V
Potrero	32.61	116.61	IV
Ramona	33.03	116.86	IV
Ranchita	33.20	116.55	IV
Ripley	33.52	114.65	V
Salton City	33.31	117.65	V
San Bernardino	32.10	117.31	V

Table 2.--Modified Mercalli intensities assigned for the Westmorland, California earthquake of April 26, 1981

Location	Coordinates (deg) Lat. (N)	Long. (W)	MM Intensity
San Diego*	32.73	117.16	IV
San Juan Capistrano	33.50	117.65	IV
San Jacinto	33.78	116.96	V
San Marcos	33.14	117.19	IV
San Luis Rey	33.22	117.34	IV
Santee	32.81	116.93	IV
Seeley*	32.79	115.68	V
Spring Valley	32.75	117.0	IV
Thermal	33.64	116.14	V
Thousand Palms	33.81	116.39	IV
Vista	33.20	117.25	IV
Westmorland*	33.00	115.61	VII
Winterhaven	32.72	114.60	IV

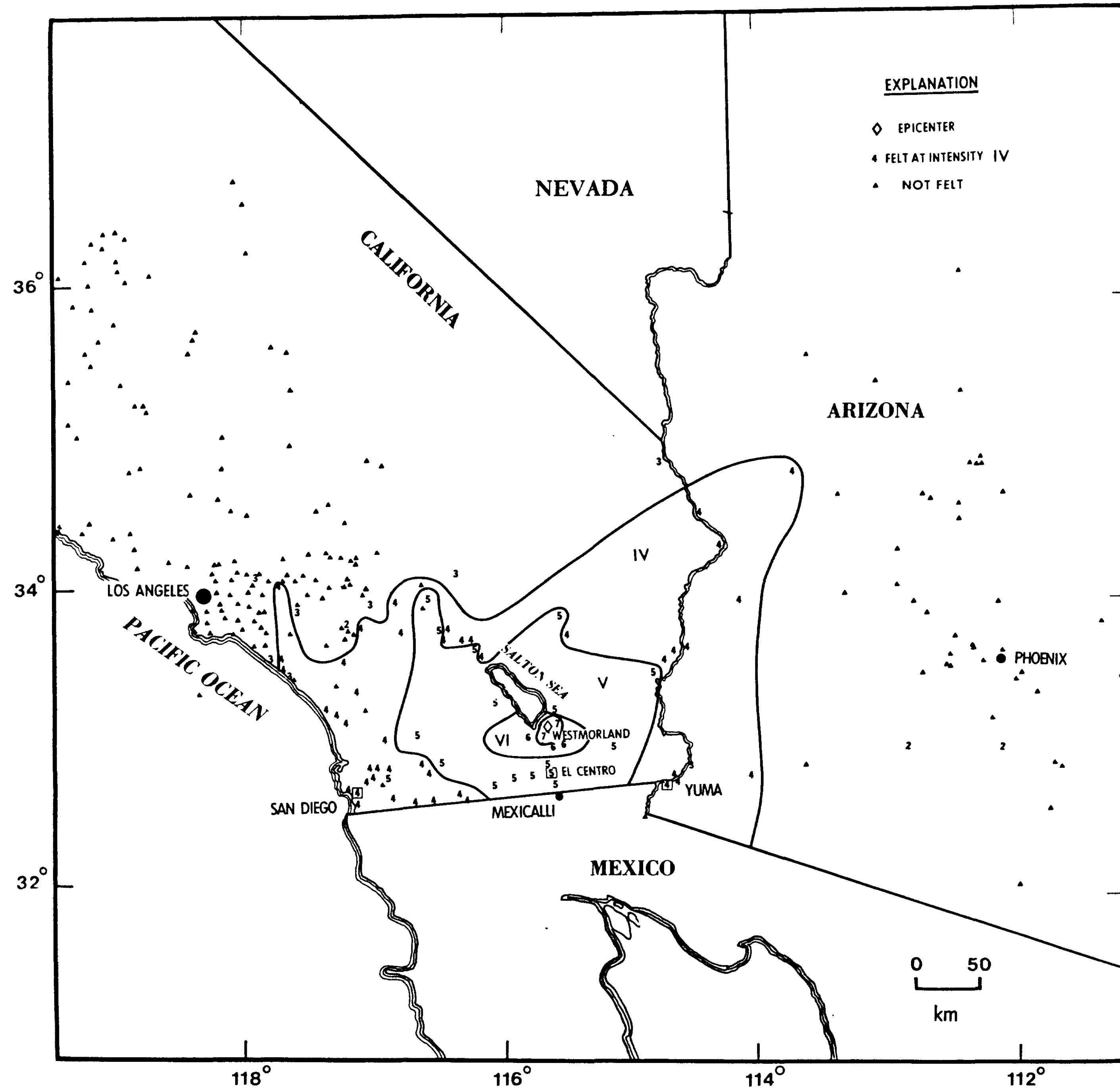

Figure 1.--Preliminary isoseismal map of the Westmorland, California earthquake of April 26, 1981. Intensity evaluations are assigned in accordance with the Modified Mercalli Intensity Scale of 1931 (Wood and Neumann, 1931). Note: Roman numerals are used to delineate isoseismals and, for clarity, arabic numerals are used to indicate intensities assigned at discrete locations.

town along Main Street (fig. 2). Six of these buildings were condemned by the Brawley Building Inspector, and the remainder were recommended for repair. The descriptions of damage that follow have been summarized from field notes and from a damage report prepared by the Brawley Building Inspector (written communication, 1981[1]). The numbers of the damage descriptions correspond to the numbered sites of figure 2.

1. The adobe building located at 231, 239, and 241 West Main Street was damaged beyond repair. The adobe wall along the west side of 241 West Main Street fell westward on the roof of the adjoining small building. The east wall of 231 West Main Street collapsed entirely allowing the roof to fall in. The pillars at curbside have deteriorated at their base, and the Brawley Building Inspector recommended that this building be demolished in its entirety.
2. This building has no apparent structural damage. A crack has opened throughout the vertical extent of the front wall where the building adjoins the fire station. The building is constructed of cinder blocks.
3. The Westmorland fire station had a crack open about one-half inch in the brick veneer at the northwest corner of the building.
4. This building had damage to the arcade only. The balance of the building appeared to have escaped major damage.
5. Porter's Fountain (fig. 3a and 3b). Porter's Fountain was badly damaged. The concrete columns at the corner of the building tilted out towards the street. Apparently these columns were not tied to the overhead portion of the building. The rebar in the columns simply extended into the framework and were not secured by any means. The building has been torn down by demolition crews. This building was constructed in a style typical of the area—two-story, wood frame, covered by stucco with a front portico extending the length of the building.
6. At 176 Main Street there was a separation between the arcade and the rest of the building.
7. The rear portion of this three-story wood frame, stucco hotel had major damage. A column tilted outwards allowing at least a six-inch separation between the wall and the building. Removal of this building has been recommended by the Brawley Building Inspector.
8. 170 West Main Street. Construction is of hollow tile masonry. A good portion of the masonry broke loose at the foundation line. The tile has apparently deteriorated due to water damage and is in very poor condition. Removal of this building has been recommended by the Brawley Building Inspector.
9. The building located at the southeast corner of Center Street and Main Street sustained damage to the parapet wall at the arcade (fig. 4). The building is primarily of frame and plaster construction with metal "ornamentation" along the Center Street side. Some weakness was apparently caused by a leaking roof that allowed water to rot the wooden members. The balance of the building appeared undamaged.

[1] Letter from Mr. Robert L. Lane, Brawley Dept. of Planning and Building to Mr. Ron Rodriguez, Mayor of Westmorland describing results of Mr. Lane's and Mr. Francisco Soto's inspection of Westmorland after the April 26, Westmorland earthquake. The letter is dated April 27, 1981.

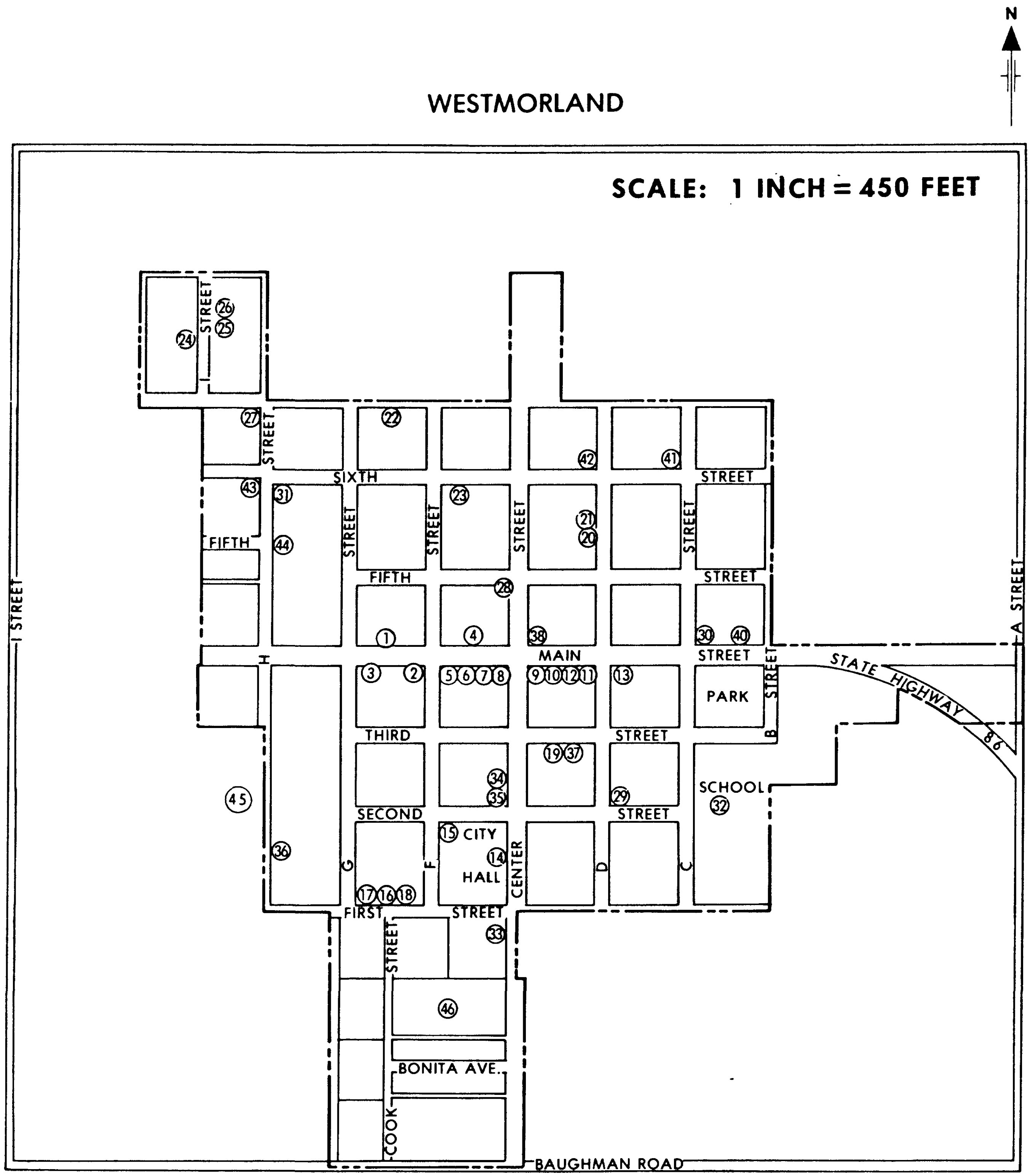

Figure 2.--Plat of the city of Westmorland, California. Circles indicate damage to a structure at that site and the numbers refer to the corresponding damage description in the text. (Redrawn from a plat of the city provided by the Westmorland City Government.)

Figure 3A--Porter's Fountain. (This Westmorland building is located at site number five in Figure 2. See text for damage description). Minutes after this photo was taken, a portion of the front of the building was torn down by demolition crews. (Photo courtesy of Paul Noden, Imperial Valley Press).

Figure 3B--Porter's Fountain (rear view). Photo shows major structural damage at junction of the portico and the building. This photo was taken after demolition crews had torn down the front section of the building. (Photo by S. T. Algermissen, U.S. Geological Survey).

Figure 4.--Westmorland, southeast corner of Center and Main Streets. This building is located at site number 9 in Figure 2. See text for damage description. (Photo by S. T. Algermissen, U.S. Geological Survey).

10. Roofing tin was shaken loose during the earthquake. The roofing tin was extending some distance over the sidewalk in front of the building at the time of the field inspection.

11. This building had no major apparent damage. A 6-foot high concrete block wall that extends along the rear portion of the property adjacent to the alley tilted approximately 10 feet to the south. There appears to be no steel reinforcing in this block wall. The Brawley Building Inspector recommended that this wall be removed.

12. In this building, cracks and spalls occurred in the bottom corners of concrete pillars supporting the building's arcade. Cracks in the front wall of the structure occurred where the portico joins the building.

13. Damage to the tiled roof was apparent in the building at this site. Some tiles slid off of the roof entirely. A cracked stucco eve, extending the length of the building on the west side, was cracked in many places. A large vertical crack was found at the southwest corner of the structure.

14. Built in 1934 as a WPA project, Westmorland City Hall is a one-story adobe brick structure with massive 24-inch thick walls. The structure sustained relativley minor exterior damage in the form of tile loss on the roof and a cracked chimney (fig. 5a). Interior damage was restricted to minor cracks opening diagonally above the corner of a door lintel in the south chambers entrance and along the bottom of the east-facing wall of the chambers (fig. 5b).

15. A swimming pool house on city hall property sustained minor loss of roof tile.

16. 263 West First Street. Moderate damage to a wood frame dwelling. An east-west trending crack opened in the living room floor along with extensive cracking of plaster walls. The west wall of the kitchen has a crack from ceiling to floor along vertical joints. The quake apparently enlarged existing cracks.

17. 294 West First Street. A house trailer had minor shifting on its support piers. The doors of the trailer no longer close.

18. 231 West First Street. This is a wood-frame dwelling. Along the south wall, a one-half-inch gap opened where the wall joins the ceiling. Along the east wall, the roof was sagging. The sagging may have existed prior to the earthquake. Stucco and plaster showed moderate cracking damage but the framing beneath the cracks appeared sound.

19. 146 East Third Street. This concrete dwelling sustained moderate damage to the north wall. Existing cracks apparently widened.

20. 215 North Center Street. This is a two-story wood-frame dwelling. Extensive cracking occurred in the front pillars but framing appeared sound. On the interior there was a moderate amount of cracked plaster. A non-bearing wall in the living room had buckled.

21. 271 North Center Street. The walls of this adobe dwelling shifted horizontally about 2 inches causing severe cracking. The building has been condemned.

22. 230 Seventh Street. This house trailer shifted about 18 inches and fell off of its metal jack supports (fig. 6).

23. 152 West Sixth Street. The west wall and wood-frame roof of this adobe storage shed collapsed. The structure has been condemned (fig. 7).

24. 423 North I Street. This wood-framed storage building fell off supporting concrete piers, but no structural damage to the wooden frame was apparent.

Figure 5A--Westmorland City Hall. Damage occurred in the form of cracking of interior walls (Figure 5B) and tiles shaken from the roof. This building is located at site number 14 in Figure 2. See text for further damage description). (Photo by S. T. Algermissen, U.S. Geological Survey).

Figure 5B.--Interior wall damage in Westmorland City Hall. (Photo by S. T. Algermissen, U.S. Geological Survey).

Figure 6.--House trailer shaken off of supports. This structure in Westmorland is located at site number 22 in Figure 2. See text for damage description. (Photo courtesy of Paul Noden, Imperial Valley Press).

Figure 7.--The west wall and wood frame roof of this adobe storage shed collapsed. This structure in Westmorland is located at site number 23 in Figure 2. See text for damage description. (Photo courtesy of Paul Noden, Imperial Valley Press).

25. 454 North I Street. A house trailer fell off metal supports, breaking the sewer line.
26. 462 North I Street. A house trailer fell off metal supports, breaking the drain line at the washing machine.
27. Seventh and H Streets, southwest corner. The rear walls and roof, in the rear portion, collapsed on this adobe structure. The front wall is cracked and windows are broken. The structure has been condemned.
28. Center and Fifth Streets, southwest corner. This commercial building of adobe construction has a severely cracked front parapet. Removal of the parapet was recommended by the Brawley Building Inspector.
29. 201 East Second Street. A 6-foot high unreinforced concrete block fence collapsed. The structure was condemned.
30. 301 Main Street. The front porch of this house collapsed. Some cracking occurred in the front portion but the rear portion appeared sound.
31. 292 H. Street. Immediately following the earthquake a gas smell was noted at this residence. The gas to the residence was shut off pending further inspection.
32. 200 South C. Street. This is the Westmorland Elementary School which is constructed of concrete block. The boy's bathroom in the north wing had a crack at the roofline. The north wall at joint to roof and west wall has a gap where separation has occurred.

Room number 12 in the south wing had small cracks in the east wall but no apparent structural damage.

Room E had small cracks in the east and west walls near the ceiling and a crack in the west wall about six inches above the floor had loose mortar.

The cafeteria had minor bending of accoustical ceiling frame. As a gas smell was noted after the earthquake the gas in the kitchen had been shut off.

33. 401 South Center. This wood-frame building shifted on its wooden foundation. Interior cracks were restricted to the finish only.
34. 223 South Center Street. This wood-frame dwelling sustained cracked plaster in child's bedroom, living and dining room.
35. 225 South Center Street. The house trailer at this location shifted about 1 inch on its supports.
36. 5232 H Street. A wood-frame building shifted about 1 inch on its foundation.
37. 162 East Third Street. The rear part of the foundation of this adobe dwelling collapsed (figs. 8a and 8b). The east wall also collapsed. Severe cracking occurred in all of the walls, and the dwelling was condemned by the Brawley Building Inspector.
38. 100 North Center Street. The front wall of this laundromat appeared to be adobe. This wall separated 2 inches from the south wall and the north wall was cracked. Windows were jarred loose from their framing. The building was condemned.
39. Wood-framed Catholic church. No damage was noted.
40. 363 East Main Street. This dwelling is wood-framed and situated on a wood foundation. The masonary front steps have separated about 3 inches from the dwelling and are badly cracked. The bath floor is slanting to the northeast. The west wall has horizontally shifted to the west and wood members of the foundation have been displaced to the north. The structure incurred severe damage to the foundation.

Figure 8A.--Collapsed foundation of stucco-over-adobe-brick residence. This dwelling was condemned by the Brawley Building Inspector. This Westmorland home is located at site number 37 in Figure 2. See text for further damage description. (photo courtesy of Paul Noden, Imperial Valley Press).

Figure 8B.--Side view of residence described in Figure 8A. (Photo courtesy of Paul Noden, Imperial Valley Press).

41. The dwelling at this location had an inflection in the foundation.
42. The front porch of this dwelling separated from the remainder of the house. Supporting columns buckled, tilting the porch roof towards the structure (fig. 9).
43. A small amount of stucco had fallen from the exterior walls of this dwelling.
44. Cracking was apparent in the adobe walls. Large pieces of plaster fell.
45. The house trailer at this location shifted off of its supports. The floor of the trailer broke loose from the frame and was hanging out of the trailer.
46. Westmorland Water Treatment Plant. The water filtering system was damaged, rendering the plant inoperable. The water tower at the plant now tilts south.

Damage in Calipatria

Calipatria, a city of approximately 2,200 people, located 14 km to the northeast of Westmorland sustained damage of Modified Mercalli intensity VII. The following documentation of damage is from field notes only. The numbered accounts correspond to the numbered sites in figure 10.

47. The Herald Newspaper Office. Moderate cracking of plaster walls was apparent with old cracks being widened in some cases. Some plaster fell. Heavy furniture and shelves moved and trays of steel type-set were thrown down.
48. Bricks were thrown down from the parapet of this two-story unreinforced brick drugstore. Interior plaster walls cracked.
49. Bricks from the parapet of this one-story unreinforced concrete building fell onto the neighboring roof causing it to collapse.
50. At this grocery store, groceries fell from shelves causing loss of merchandise. A small amount of plaster fell from an interior wall. Fall of merchandise off shelves occurred mainly in Westmorland and Calipatria, in the epicentral area and was not observed elsewhere (fig. 11).
51. Damaged fuel tanks spilled 2,000 to 3,000 gallons of fuel. (B. Sorensen, oral communication, May 5, 1981).

Rural Damage

Primary damage in rural areas consisted of broken unreinforced, concrete-lined irrigation canals. Total estimated cost of repair to canals was placed at approximately $100,000.00 according to the Imperial Valley Irrigation District. Vail Canal, a principal canal in the northern part of the valley, and located in the epicentral region, sustained heavy damage along a 1-mile section as a result of slumping (fig. 12). Slumping was frequently observed along earthen canals that had no concrete lining (fig. 13). Unfortunately, the canal damage could only be observed second hand through newspaper photos taken shortly after the earthquake occurred. Repair of damaged canals is made as quickly as possible so as to return the flow of vital irrigation water.

Damage to sub-surface drainage tiles, which commonly occurs as a result of large earthquakes in the Imperial Valley, could not be immediately assessed. Salt buildup in the soil is commonly associated with broken drainage

Figure 9.--Westmorland residence--the front portch separated from the rest of the house. The house is located at site number 42 in Figure 2. See text for damage description. (Photo by S. T. Algermissen, U.S. Geological Survey).

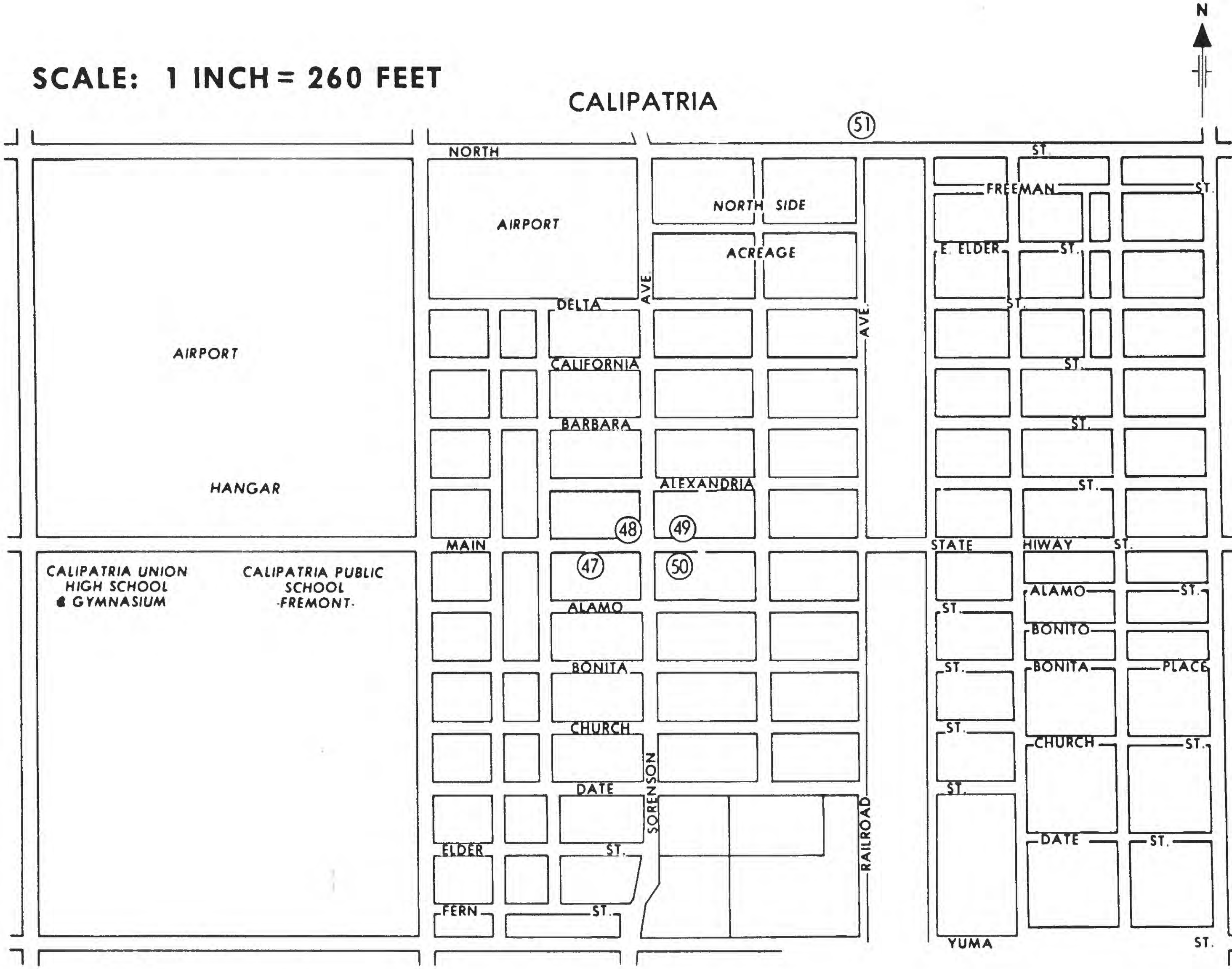

Figure 10.--Plat of the city of Calipatria, California. Circles indicate damage to a structure at that site and the numbers refer to the corresponding damage description in the text. (Redrawn from a plat of the city, provided by the Calipatria City Government.)

Figure 11.--Merchandise off of shelves in Westmorland grocery store. This type of damage also occurred at grocery stores in Calipatria. (Photo courtesy of Paul Noden, Imperial Valley Press).

Figure 12.--Damage to the Vail Canal in the epicentral area. The damage is thought to be due to ground slumping. (Photo by Ronnie Valles, Imperial Valley Press).

Figure 13.--Slumping which occurred in many earthen canals. Canal has been dammed to stop water flow for repairs. (Photo by S. T. Algmermissen, U.S. Geological Survey).

tiles but several months are usually required to confirm the buildup. None had been reported at the time of the field investigation. The Imperial Valley Irrigation District estimates that 80 percent of the agricultural area within the valley is tiled for drainage and that 100 percent of the area around Westmorland is tiled.

Highway and Bridge Damage

Several bridges in the epicentral area sustained cracking and chipping of concrete. This was most noticeable on a bridge just west of Brawley which crosses the New River. At this site, the bridge deck shifted noticeably at each end, causing the highway pavement to become cracked and uneven (fig. 14). This bridge experienced damage in the 1979 El Centro earthquake, principally to the abutments at each end of the bridge which were cracked and chipped to the extent that the reinforcement bars were exposed at bridge level. Also, many of the support pillars were cracked at the bridge deck connection, and the asphalt road had settled about 13 cm relative to the bridge (Reagor and others, 1980). A bridge on State Highway 111 over the Alamo River, closer to the epicenter, had hairline cracks around the supporting piers, about 20 cm below the road deck. In cases of minor damage such as this, in such a seismically active region, it is often difficult to determine unequivocally that the damage occurred during the latest episode of shaking. Lacking any prior record of damage to the structures, such judgements are made according to the fresh appearance of the damage. Small, loose flakes of concrete were apparent in an anastomosing network of fine hairline cracks on one of the piers. There was much slumping around the bridge abutments and sand boils were found in close proximity to the bridge.

Ground and road pavement cracks were widespread in the epicentral region, especially near major canals and rivers where one would expect a somewhat higher water table. Figures 15a and 15b show pavement cracking on an area of Lack Road about 2 1/2 km northwest of Westmorland. No building damage resulting from liquefaction was observed.

Intensity VI effects

For this earthquake, the assignments for Modified Mercalli intensity VI were characterized by the following list of reported effects:

1. Bottles and canned goods thrown from grocery shelves.
2. Doors knocked out of alinement.
3. Many pictures shaken off walls.
4. Knick-knacks knocked off shelves.
5. Cracks in weak plaster.
6. Everyone awakened.
7. Discernable east-west rocking motion and "heavy" shaking.
8. Television sets knocked over in homes.
9. Tiles shaken off roofs.

At Brawley, located 14 km southeast of the epicenter, the four-story Planter's Hotel sustained damage in the form of cracking and falling of exterior stucco. This damage occurred mainly around windows and at the junctions of the Hotel's story levels. Figures 16a and 16b show character-

Figure 14.--New River Bridge located on Highway 86 just outside the western city limits of Brawley. This bridge sustained major damage in the 1979 El Centro earthquake. (Photo courtesy of Paul Noden, Imperial Valley Press).

Figure 15A.--Road pavement cracking occurred throughout the epicentral area. This photograph was taken on Lack Road, west of Westmorland. (Photo by S. T. Algermissen, U.S. Geological Survey).

Figure 15B.--Closer view of road cracking. (Photo by S. T. Algermissen, U.S. Geological Survey).

Figure 16A.--West side of Planter's Hotel in Brawley. Cracking is noticeable in mid-area of picture. (Photo by S. T. Algermissen, U.S. Geological Survey).

Figure 16B.--Angular view of west side of Planter's Hotel showing extent of cracking. (Photo by S. T. Algermissen, U.S. Geological Survey).

istic cracking and fall of plaster at this site. The Planter's Hotel has experienced exterior cracking in prior earthquakes and shows evidence of much patching and repair. As indicated in figure 1, Brawley was assigned Intensity VI.

As shown in Table 2, intensity assignments range from a maximum Modified Mercalli intensity of VII to that of II. "Not Felts" are not listed in Table 2 but are shown on the isoseismal map in figure 1.

Discussion

Both the total area and the shape of each of the intensity isoseismals for this earthquake are affected by several variables. Social factors and physical geographic factors interact in controlling the distribution of population and the type and degree of economic development.

Large tracts of land in southern California, being extremely arid and/or mountainous, remain sparsely populated. Felt areas of many earthquakes thus consist of points which are clumped in settled areas, leaving much unpopulated desert area which is impossible to evaluate. Also, to the west, the Pacific ocean precludes complete intensity evaluations of long-period effects. The Salton Sea also has an effect on isoseismal shape because of its size and because population is distributed only intermittently around its shores. Traditionally, people tend to settle areas very near rivers--location and direction of flow of major rivers (such as the Colorado River to the east of the Imperial Valley) affect the distribution of population and thus, intensity isoseismals.

No intensity study was undertaken in Mexico resulting in lack of tenable evaluations to the south. This lack of data from Mexico has been the norm for evaluations of recent earthquakes occurring in the Imperial Valley even though a number of earthquakes in the Imperial Valley are known to have caused damage in Mexico. Earthquake effects in Mexico have been successfully investigated for several Imperial Valley/Mexico earthquakes which occurred in the early 20th Century. Perhaps a means for observing future intensity effects in Mexico should be investigated, although logistical problems in gaining access to areas of Mexico may be somewhat more complicated at present.

The Imperial Valley proper, by comparison, is relatively densely populated. Variation in population concentration however, occur within the Imperial Valley, most notably in the size of and type of development of its cities and their conterminous areas. Cities such as El Centro and Calexico, both located at the southern end of the valley, have combined populations of approximately 35,800. The northern part of the Imperial Valley, by contrast, has two major towns, Westmorland and Calipatria, that have combined populations of approximately 3,670 (Imperial Irrigation District, 1977). The southern portion of the valley is much more urban in nature than the northern part which is still characteristically rural. In the southern portion, the cities of El Centro, Brawley, and Calexico have many recently built, modern commercial structures dispersed around large downtown sections. The older downtown areas are typically comprised of many (pre-1940) wood-frame and stucco buildings described previously on page 5 of this report. A number of older structures in Westmorland are apparently being gradually weakened by successive Imperial Valley earthquakes and many will undoubtedly be torn down as they become damaged. As new buildings are constructed in Westmorland using the current building codes, there will be a gradual increase in the number of earthquake resistant buildings. From the point of view of interpreting degrees of shaking using the Modified Mercalli Intensity scale criteria, buildings that relate well to the intensity scale criteria (developed prior to 1930) will eventually cease to exist. This indicates the need for revision of the Modified Mercalli scale to include criteria that reflect changes in the earthquake resistance of structures resulting from the adoption of modern building codes.

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