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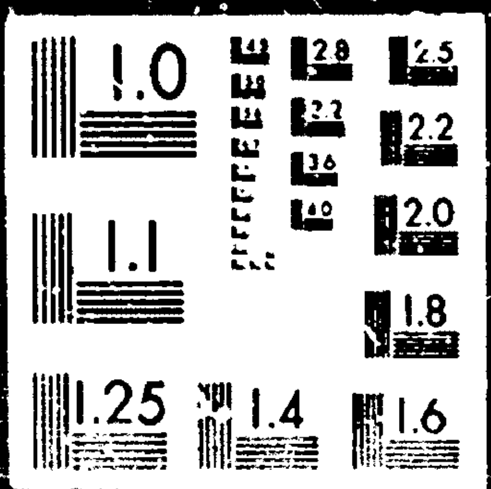

NATIONAL TRANSPORTATION SAFETY BOARD

PB 210 270

Special Study

PROTECTION OF TRANSPORTATION FACILITIES AGAINST EARTHQUAKES

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NATIONAL TRANSPORTATION SAFETY BOARD
Washington, D. C. 20591
Report Number: NTSB-STS-72-1

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Special Study

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Adopted : February 8, 1972

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16. Abstract

This study is an examination of Federal involvement in the earthquake field, specifically in the transportation field. The study discusses the need for reexamination of the criteria used in the design of transportation structures, stepped-up earthquake-related programs, and better coordination between Federal agencies. It also discusses earthquake history in the United States, existing standards for earthquake-resistant design and construction of transportation systems, and possible modifications to existing transportation structures.

Recommendations are made for coordination of Federal activities in earthquake-related matters, and increases in Federal programs by the Department of Transportation, the Department of Commerce, and by the Office of Science and Technology.

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TABLE OF CONTENTS

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PROTECTION OF TRANSPORTATION FACILITIES AGAINST EARTHQUAKES

I. INTRODUCTION

The San Fernando, California, earthquake which occurred at 6 a.m. on February 9, 1971, caused catastrophic damage to transportation facilities. The National Transportation Safety Board, under its statutory authority to conduct special studies of safety in transportation and the prevention of accidents, instituted an investigation of this event.

The Board found that several agencies – Federal, State and private – were concerned by the earthquake and its effects. However, there was little coordination between the many interested parties. The Board decided to examine the activities of these agencies and evolve recommendations intended to reduce the earthquake hazard to transportation in future earthquakes.

This report is an examination of Federal involvement in the earthquake problem, especially as it relates to transportation. Major elements of programs and existing design practices are discussed and recommendations are made which should reduce the earthquake hazard to transportation facilities and the people who use them.

The National Transportation Safety Board received a copy of the draft report to Congress by the Office of Emergency Preparedness of the Executive Office of the President, on the subject of "Disaster Preparedness." It was received on February 9, 1972, the day after the Safety Board had considered and adopted its report. It is noted that there are coincidental similarities in portions of the subject matter in both reports, but that the Safety Board's report is directed to improvements in resistance of transportation structures to damages resulting from earthquakes. The report of the Office of Emergency Preparedness is recommended as a reference because of its coverage of the factors involved in preventing or minimizing the loss of life and damage to property as the result of earthquakes, as well as other natural disasters.

II. EARTHQUAKE HISTORY

The famous earthquake of San Francisco occurred on April 18, 1906. With a Richter rating of 8.3, its magnitude was almost 100 times as great as the San Fernando quake, which registered 6.6.[1] Its intensity, as measured by the modified Mercalli scale, was XI; that of the San Fernando quake was XIII.[2]

The losses of the San Francisco earthquake totaled 700 dead and one billion dollars in

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[1] The "Richter Scale," named after the famed seismologist, Dr. Charles F. Richter, describes in a quantitative way the size (magnitude) of an earthquake. The scale is exponential in character so that an increase of 1 unit in magnitude signifies a 10-fold increase in ground motion.

[2] The "modified Mercalli scale" grades earthquakes into 12 classes describing what an earthquake has done to a given area. A "I" rating indicates that the quake is felt only under especially favorable circumstances, and a "XII" rating indicates total damage.

damage (present-day value).[3] The San Fernando quake cost 64 lives and between 500 million and one billion dollars.[4] The cost of the San Fernando quake would have been much greater had it occurred a few hours later.

Between the period 1903 and 1936, there were 55 earthquakes in California and Nevada of magnitudes of 6 or greater on the Richter scale.[5] An earthquake is definitely not a once-in-a-lifetime occurrence, and although California has had more than any other State, the danger is not unique to it. In 1968, six earthquake epicenters of intensity of VII on the modified Mercalli scale or greater occurred four in California, and one each in Alaska and Illinois.[6] Yearly, about 700 shocks from earthquakes around the world are capable of causing considerable damage.[7]

The history of earthquakes and their locations in the United States leave no room for contentedness. Major earthquakes of intensity XII occurred near New Madrid, Missouri, on December 16, 1811, January 23 and February 7, 1812.[8] They caused little damage in that sparsely populated area. Should an earthquake of equal intensity occur today, a major catastrophe would result.[9]

Besides the New Madrid area, in the eastern United States, there are zone 3 areas around Boston, Massachusetts, and the Saint Lawrence Seaway. A major earthquake, intensity about VII, occurred north of Boston on November 18, 1775; the latest major earthquake in the Saint Lawrence River region occurred on February 28, 1925, with an intensity of about VIII.

One of the greatest earthquakes on the North American continent occurred on March 27, 1964, in Alaska.[10] Its epicenter was about 80 miles east of Anchorage. With a Richter reading of 8.4, it damaged an area of 50,000 square miles. The quake struck after businesses were closed (5:36 p.m.) and hence the loss of life was relatively small (115).

The highway system was severely crippled in the south-central part of the State.[11] Most of the secondary roads and all of the major highways were damaged. About $25 million in damage to bridges and $21 million to roadways were incurred. Ninety-two bridges were severely damaged or destroyed and 83 miles of roads had to be replaced or relocated.

The seismic record for this earthquake was incomplete. There was a lack of strong-motion seismographs; existing instruments within several hundred miles of the epicenter were thrown off scale by the violence of the shock. The lack of seismic records makes it difficult to determine the physical mechanism of the earthquake or the causes of structural damage.

A major recommendation of the National Academy of Sciences, which undertook a comprehensive study at the request of the President, is to increase the strong-motion net-

[3] U. S. Department of Commerce, *Earthquake Investigation in the United States*, Coast and Geodetic Survey Special Publication No. 282, Revised (1969) Edition (Washington, D. C.: Government Printing Office, 1969), p. 13.

[4] National Academy of Sciences, *The San Fernando Earthquake of February 9, 1971*, (Washington, D. C.: The Academy, 1971), p. 1.

[5] Karl V. Steinbrugge, *et. al.*, *The Santa Rosa, California, Earthquakes dated October 1, 1969*, (Washington, D. C.: Government Printing Office, 1970), p. 47.

[6] *Earthquake Investigation in the United States*, p. 8

[7] *Ibid.*, p.5.

[8] *Ibid.*, p. 17.

[9] The area surrounding New Madrid is zoned "3," the number assigned by the U. S. Department of Commerce to areas of the highest seismic risk. Portions of six states are included in the area. A seismic risk map of the United States is included in the Appendix, p. 32.

[10] For a full report of the earthquake damage to the highway system, see: Reuben Kachadoorian, *The Effects of the Earthquake of March 27, 1964, on the Alaska Highway System*, Geological Survey Professional Paper 545-C, (Washington, D. C.: Government Printing Office, 1968).

[11] Edwin B. Eckel, *The Alaska Earthquake, March 27, 1964: Lessons and Conclusions*, Geological Survey Professional Paper 546, (Washington, D. C.: Government Printing Office, 1970).

work in Alaska.[12] The National Oceanic and Atmospheric Administration (NOAA) has since installed a network in Alaska. The need for extension of such networks, not only in Alaska but throughout the United States and the world, is apparent. NOAA is constantly working to increase this network.[13]

The Alaska earthquake had repercussions on other surface transportation systems. The Federally owned Alaska Railroad sustained damage of more than $35 million.[14] Bridges and culverts sustained damage in the amount of $2.5 million; and roadway and tracks, $8.8 million.

Damage to bridges resulted from (1) permanent vertical and horizontal displacements of foundation materials; (2) temporary horizontal movement of the ground; and (3) high acceleration in the bridge structures. The displacement of the ground or liquefaction of the soil were the major causes of damage, although it was estimated that horizontal gravity forces (g-forces) in the structures of up to 1.7 probably occurred.[15] Such high g-forces could result from amplification of the ground motion by the bridge structure.

There was a direct relationship between the type and severity of the damage to the railroad and the surficial geology and underlying physiography. This was so apparent that a geologic map could be used as a damage-distribution map. No doubt it was because of this close relationship that the National Academy of Sciences recommended that a detailed geologic mapping be made of all earthquake-prone areas of this country, with special emphasis given to populated areas and areas likely to be developed in the future.[16] A correlative recommendation would be to prepare earthquake-hazard maps. A seismic risk map has been published by the U. S. Department of Commerce, but it does not take into consideration the probable frequency of occurrence of earthquakes.

Air transport is more vital to Alaska than to any other State.[17] Of the 64 airports throughout the stricken area, 13 sustained damage to taxiways and runways. Some airplanes were damaged by flooding or seismic vibration.

Airport facilities were damaged by vibration, by sea waves, and by tectonic subsidence and compaction. The most notable loss by vibration was the control tower at Anchorage International Airport. At the Kodiak Naval Station, parts of the runway were flooded by seismic sea waves, and a few smaller airstrips were either destroyed by the waves or subjected to flooding by high tides due to regional subsidence. Total damage to Alaska's air facilities amounted to a few million dollars.[18]

The airport dollar loss was small, as compared to the more than $100 million loss to the water, rail, and highway systems. More significant, however, is that the air facilities were operational within a few hours after the earthquake. It was several months before all damaged highway routes were passable.

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[12] National Academy of Sciences, *Toward Reduction of Losses from Earthquakes*, (Washington, D. C.: The Academy, 1969), p. 16.

[13] As of September 14, 1971, there were 112 strong-motion stations in Alaska. Throughout California there were approximately 420 stations, while the rest of the United States had 60 stations. NOAA also had 8 stations in South and Central America. (Phone interview with Charles F. Knudson, Acting Chief, Seismological Field Survey, San Francisco.)

[14] David S. McCulloch and Manuel G. Bonilla, *Effects of the Earthquake of March 27, 1964, on the Alaska Railroad*, Geological Survey Professional Paper 545-D, (Washington, D. C.: Government Printing Office, 1970), p. D1.

[15] *Ibid.*, p. 91.

[16] *Toward Reduction of Losses . . .*, p. 14.

[17] For the effects of the earthquake on air, water, and utilities, see: Edwin B. Eckel, *Effects of the Earthquake of March 27, 1964, on Air and Water Transport, Communications, and Utilities Systems in South-Central Alaska*, Geological Survey Professional Paper 545-B, (Washington, D. C.: Government Printing Office, 1967).

[18] *Ibid.*, p. B3.

The damage to the water transportation industry was very heavy. In all south-central Alaska, only the port of Anchorage remained operational, and even it operated under restricted conditions for a while. In Alaska, 90 percent of all civilian and military material is imported, mostly by water. The devastation interrupted the normal flow of materials.

New port facilities were rapidly rebuilt. In most cases, they were built to reduce their susceptibility to future earthquakes.

Three pipelines in the area played a significant part in the transmission of petroleum and gas products; none was damaged appreciably. A single leak developed in a natural gas line, and none occurred in oil pipelines, or in a multi-product military pipeline. Some terminal oil storage tanks were damaged and some small leaks developed at a refinery.

The gas distribution system in Anchorage was damaged (about $1 million). Most of the breaks occurred at landslide grabens. Some of the 200 breaks were caused by ground cracks which had little or no visible displacement. Tension, compression, and shear failures were common. There were also some fatigue failures.

Since the earthquake in Alaska, many others have occurred on the West Coast. One of the better documented earthquakes occurred in the Parkfield-Cholame area of California (about 200 miles northeast of Los Angeles.)[19] The earthquake had a magnitude of 5.5 on the Richter scale and occurred on June 27, 1966. For its magnitude, this quake had fairly high ground accelerations (up to 0.5g) and high modified Mercalli intensities (up to VIII or IX). Such high ground accelerations, intensities, and tectonic fracturing are usually associated with earthquakes having a magnitude of 7 or more.

There was some bridge damage. The main cause was fault movement; the secondary cause was seismic shaking. Since there were few structures in the area, overall damage was relatively minor.

One buried oil pipeline was ruptured, resulting in considerable oil loss, and a 2-inch buried private water line was broken. An irrigation pipe also broke.

On October 1, 1969, Santa Rosa, California was damaged by two earthquake shocks occurring within a 2-hour span. The first of the shocks occurred at 9:57 p.m., and the second at 11:20 p.m.[20] The damage resulting from these two shocks can be considered as happening from one earthquake. The intensity at the most damaged area was VII to VIII on the modified Mercalli scale.

The Coast and Geodetic Survey report mentioned only slight damage to the highway system, with some settlement of fill at one highway overpass. About 50 instances of water pipe damage included breakage of 15 water mains, some fire protection lines, and 30 service laterals to houses and buildings. Gas pipe leaks developed in many homes and pilot lights were extinguished from shifting appliances. One leak was detected in a distribution system.

The greatest amount of damage occurred in areas on young alluvium soil where the ground water levels are quite high. Amplification of ground motion might have been reinforced by reflections from harder, adjacent formations. Because of a general lack of geologic mapping, geophysical exploration, and seismographic records of the area, it was difficult to arrive at a precise description of the damage sustained in the earthquake. An interesting comment was that the damage to earthquake-resistive structures was greater than expected.

The San Fernando earthquake of February 9, 1971, was moderate, registering 6.6 on the Richter scale, but it was accompanied by record ground accelerations. Some measurements showed peak horizontal and vertical accelera-

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[19] Robert D. Brown, *et al., The Parkfield-Cholame California, Earthquakes of June-August 1966*, Geological Survey Professional Paper 579, (Washington, D. C. Government Printing Office, 1967).

[20] *The Santa Rosa, California, Earthquakes of October 1, 1969*. Karl V. Steinbrugge; Government Printing Office, 1970.

tions of 1 g.[21] Because of these large accelerations and the closeness of the epicenter to housing and public works, the damage wrought was high (estimated at nearly $1 billion).

Sixty-four persons lost their lives in the quake, two of them in the collapse of an incompleted interstate freeway ramp onto an existing interstate route.[22] Many more fatalities and injuries would probably have occurred had the epicenter been closer to the Los Angeles City center, or had the earthquake occurred a few hours later than 6 a.m.

Whereas the loss of life was limited, bridges collapsed which need not have, and damage to the freeway system was over $20 million. An additional $20 million damage occurred to other highways on the Federal-aid system.

Could the bridges which failed have been designed to better resist earthquake forces? Could total collapse have been avoided? All published articles since the quake indicate that the answer is yes.[23] The California Highway Department has halted bridge construction to allow for redesign. How bridges behave under earthquake stresses will be greatly influenced by the standards to which they are constructed.

Historical experience shows clearly that there is every reason to expect that earthquakes will continue to impinge upon transportation structures and will produce human fatalities and injuries, property damages and secondary losses resulting from denial of use of transportation facilities. The large scope of the potential losses and their widespread location imply a need for a national approach to minimize the losses to transportation caused by earthquake damage.

III. EXISTING STANDARDS FOR EARTHQUAKE-RESISTANT DESIGN AND CONSTRUCTION OF TRANSPORTATION SYSTEMS

In the Federal-aid highway program, the states select and design the projects to be built, award the contracts, and supervise the construction subject to Federal Highway Administration review, approval, and control. Design specifications for roads and bridges have been developed by the American Association of State Highway Officials (AASHO),[24] through the participation of the state highway departments in conjunction with the Federal Highway Administration (FHWA). The specifications are intended to serve as a standard or guide for the preparation of state specifications and as a reference for engineers. Their use is generally accepted on Federal-aid projects.

The specifications require that in regions where earthquakes may be anticipated, a bridge structure must withstand an equivalent lateral force applied horizontally in any direction at the center of gravity of the weight of the structure.[25] This force is equal to the dead load of the structure multiplied by a coefficient which depends on the type of foundation or the bearing pressure of the soil. The maximum coefficient is 6 percent for pile foundations. This means that the structure must withstand a lateral shake force of .06g, a low value.

The State of California has refined the AASHO formula for its use with two coef-

[21] R. P. Maley and W. K. Cloud, "Preliminary Strong-Motion Results from the San Fernando Earthquake of February 9, 1971," The San Fernando, California, Earthquake of February 9, 1971, Geological Survey Professional Paper 733, (Washington, D. C.: Government Printing Office, 1971), p. 163.

B. J. Morrill, "Evidence of Record Vertical Accelerations at Kagel Canyon during the Earthquake," *ibid.*, p. 177.

[22] For photographs of some of the collapsed structures, see pp. 10, 11, & 12.

[23] For example, the National Academy of Sciences, in its report on the earthquake, states that "...earthquake design of highway bridges...(is) grossly inadequate...," *The San Fernando Earthquake...*, p. 13.

[24] American Association of State Highway Officials, *Standard Specifications for Highway Bridges*, (Washington, D. C.: The Association, 1969).

[25] *Ibid.*, p. 26

ficients to multiply the dead load.[26] One coefficient represents the energy absorption of the structure, and the other the stiffness of the structure. The highest obtainable value of the combined coefficient is 13.3 percent, although the California code further states that special consideration should be given to structures founded on soft materials capable of large earthquake movements and to large structures having massive piers.

Seven western states (including California) were surveyed by AASHO as to their design policy regarding earthquake forces.[27] The information received was as follows: Utah does not consider earthquake forces. Nevada follows AASHO specifications. Hawaii is using AASHO specifications but is considering reducing the earthquake load requirements. Alaska essentially follows AASHO specifications. Oregon follows AASHO specifications except that their minimum coefficient is two times the minimum recommended by AASHO. Washington uses a coefficient based on deflection. Whereas most of the western states consider seismic forces, they use the low 6 percent AASHO specifications.

Other states generally do not even consider earthquake forces. For example, New York State contains the Saint Lawrence Seaway area which has been assigned the highest seismic risk rating of 3, but it does not use earthquake-resistant bridge design.[28] [29]

Most of the work in seismic design of structures has been in the building field. The Uniform Building Code (UBC) uses a basic linear equation similar to AASHO specifications, but the coefficient used in multiplying the dead weight of the structure considers more parameters.[30] The UBC coefficient includes a dynamic factor which depends on the vibratory period of the building. Torsion, which is not considered in AASHO, is treated lightly in the Uniform Building Code. Since torsion may have significant effects where the center of gravity and the center of rigidity of the structure do not coincide, it should be considered in design.

The building codes of several other nations were surveyed by the authors of *Seismic Design of Building Structures* and they found that several countries had more appropriate earthquake building codes than the United States.

It would appear that transportation structures, such as control towers for airports, airport passenger terminals, railroad dispatch offices, railroad stations, etc., should be designed using more sophisticated codes. (A 50-foot reinforced-concrete control tower collapsed at the Anchorage Airport during the Alaska earthquake, which nessitated the use of a plane on the ground to provide emergency air traffic control.[31] Needless to say, the collapse of a control tower at a much larger airport would create a more critical situation). Portions of the San Francisco Bay Area Rapid Transit system are being designed in compliance with the

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[26] State of California, Highway Transportation Agency, *Manual of Bridge Design Practice*, (Sacramento, California: State of California, 1963), pp. 3-9.

[27] American Association of State Highway Officials, *Design Procedures for Earthquake Loads*, A Report Prepared by the Subcommittee on Loads to the AASHO Bridge Committee's Region IV meeting, San Diego, California, April 5 and April 6, 1971. (Mimeographed).

[28] Phone interview with Domenic Massimilian, Principal Design Engineer, New York State Department of Transportation, Albany, New York.

[29] It should be noted that vertical accelerations (and hence forces) are also caused by earthquakes and no consideration of these forces is taken into account by AASHO or any state specifications.

[30] J. T. P. Yao, *et al.*, *Seismic Design of Building Structures*, A Report Prepared by the Construction Engineering Laboratory, University of New Mexico (Champaign, Illinois: Department of the Army, 1971), p. 6. (in process of publication).

[31] Edwin B. Eckel, *Effects of the Earthquake of March 27, 1964, on Air and Water Transport, Communications, and Utilities Systems in South-Central Alaska*, Geological Survey Professional Paper 545-B, (Washington, D. C.: Government Printing Office, 1967), p. B4.

UBC.[32] It is not clear why the lower UBC design criteria were selected.

Information concerning the design of bridge structures to resist earthquake forces may be available in other nations which have highway, railroad, and maritime structures in high-risk earthquake zones. Such literature would be of value in this country.[33]

The configurations of bridges are unique and many schemes to make buildings earthquake resistant cannot be applied readily to bridges. After determination has been made of the forces acting on bridge structures, the members and their connections may be designed to resist those forces or to allow gross movements of piers or abutments to occur without causing the bridge to fall. Present-day bridge design assumes elastic behavior of the structure. However, earthquake forces often produce stresses beyond the elastic limit. Further research into the behavior of structures in the plastic range is needed to understand all factors involved. While AASHO deals only lightly with earthquake forces, nothing is said about detail design for earthquake-induced stresses. In the report "Damage to Transportation Systems," the California Office of Architecture and Construction makes seven recommendations for improving detailing of bridge structures.[34] The California Institute of Technology makes similar recommendations.[35]

An on-the-scene examination of the structural damage in the San Fernando earthquake disclosed major failures of bridge seats and column ties.[36] Bridge hinges and seats were installed without anchoring systems, with the result that sections of the bridge roadway were displaced from the supporting structures by vibration and simply slipped off the seats and fell to the ground.

The practice of installing highway bridge sections without provision for retention against earthquake forces is widespread. Many bridges now in place in known earthquake-sensitive areas could fall with relatively small movement of bridge seats. These small movements are, in many cases, unresisted or unprotected by secondary structures.

There are serious questions whether the practice of supporting highway access bridges on a single column is adequate. When a span supported by a single centered column was shaken laterally during the San Fernando earthquake, the column was subjected to bending stresses, and failed at both top and bottom. The single column support appears to be one of the least efficient support methods where resistance to lateral shake is important (see Figure 4).

The foundation materials that support bridges are integral parts of the highway and railroad systems. Settlement of fills, slope instability, and liquefaction of soils may cause extensive damage, and the behavior of foundation materials is taken into account in design. Present methods of analysis of dynamic soil behavior do not seem to provide a full understanding of soil behavior under earthquake loads.

Transportation structures also include the pipelines that move gas and liquids throughout the United States. There are a few exceptions, but for the most part, little consideration has

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[32] Phone interview with Al... Hynes, Regional Director, Region 7, Federal Railroad Administration, San Francisco, California.

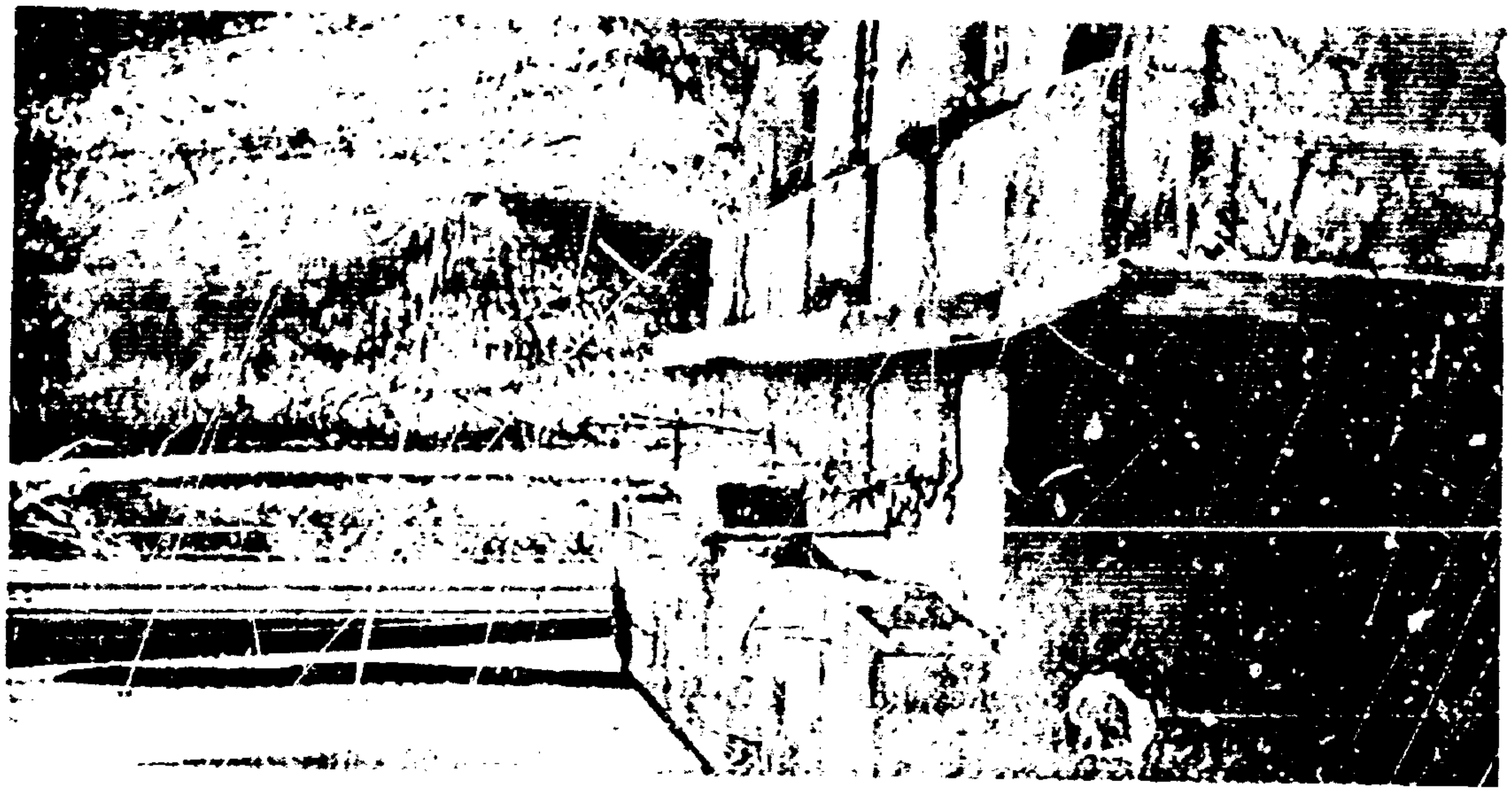
[33] The FHWA now has a contract with the University of California at Berkeley for a search of Japanese literature.

[34] J. F. Meehan, "Damage to Transportation Systems," *The San Fernando, California, Earthquake of February 9, 1971*, Geological Survey Professional Paper 733, (Washington, D. C.: Government Printing Office, 1971), p. 241.

[35] Paul C. Jennings (ed.), *Engineering Features of the San Fernando Earthquake of February 9, 1971* Report EERL 71-02, (Pasadena, California Institute of Technology: 1971).

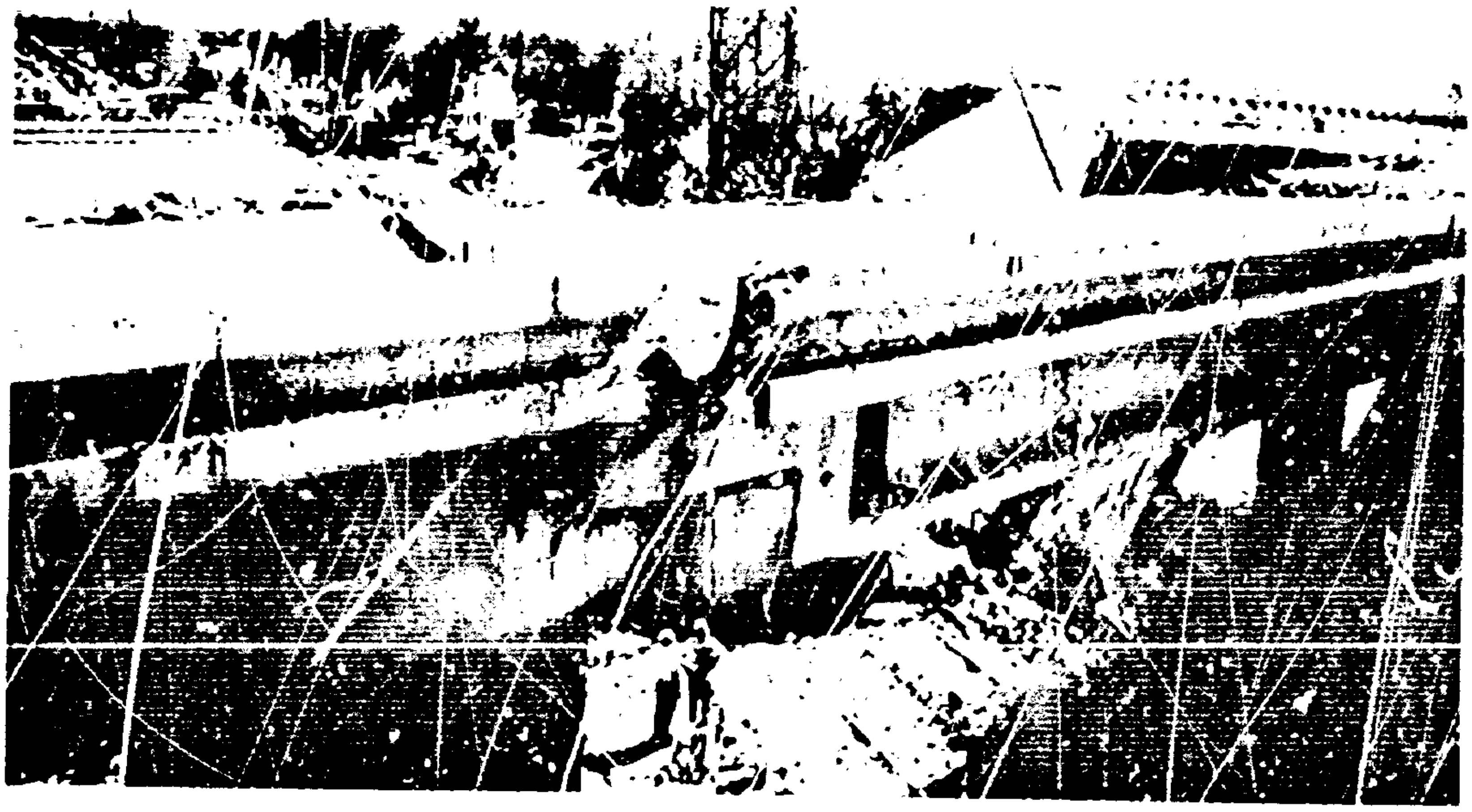
[36] See Figures 1,6. These photographs of bridges at Interstate 5 and 210 vividly portray beam to column and seat failure.

[37] *Engineering Features of the San Fernando Earthquake of February 9, 1971*, California Institute of Technology, 1971.



I-5 Bridge Hinge Showing Design Details.

Connecting span had not been completed prior to San Fernando earthquake.



I-5 Bridge Over Southern Pacific Railroad

Note partial separation, but deep hinge retained brid span. However, adjacent roadway span seperated fr hinge and fell.

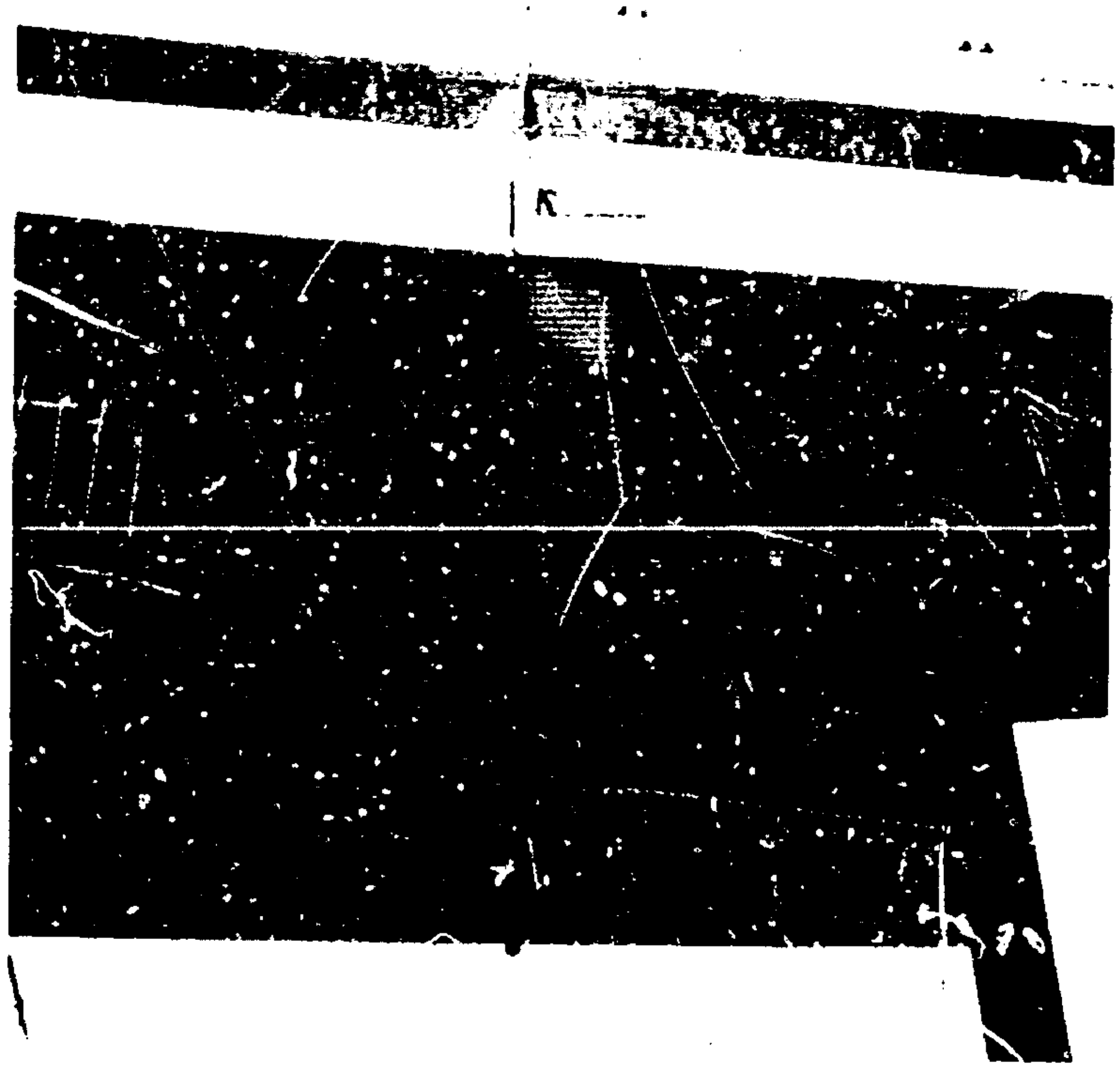


FIGURE 2 Highway Bridge San Francisco Area Note Narrow Hinge (Arrow) Between Spans of Roadway

FIGURE 3 Freeway Bridge San Francisco Area Narrow Column Seat For Support of Bridge Spans

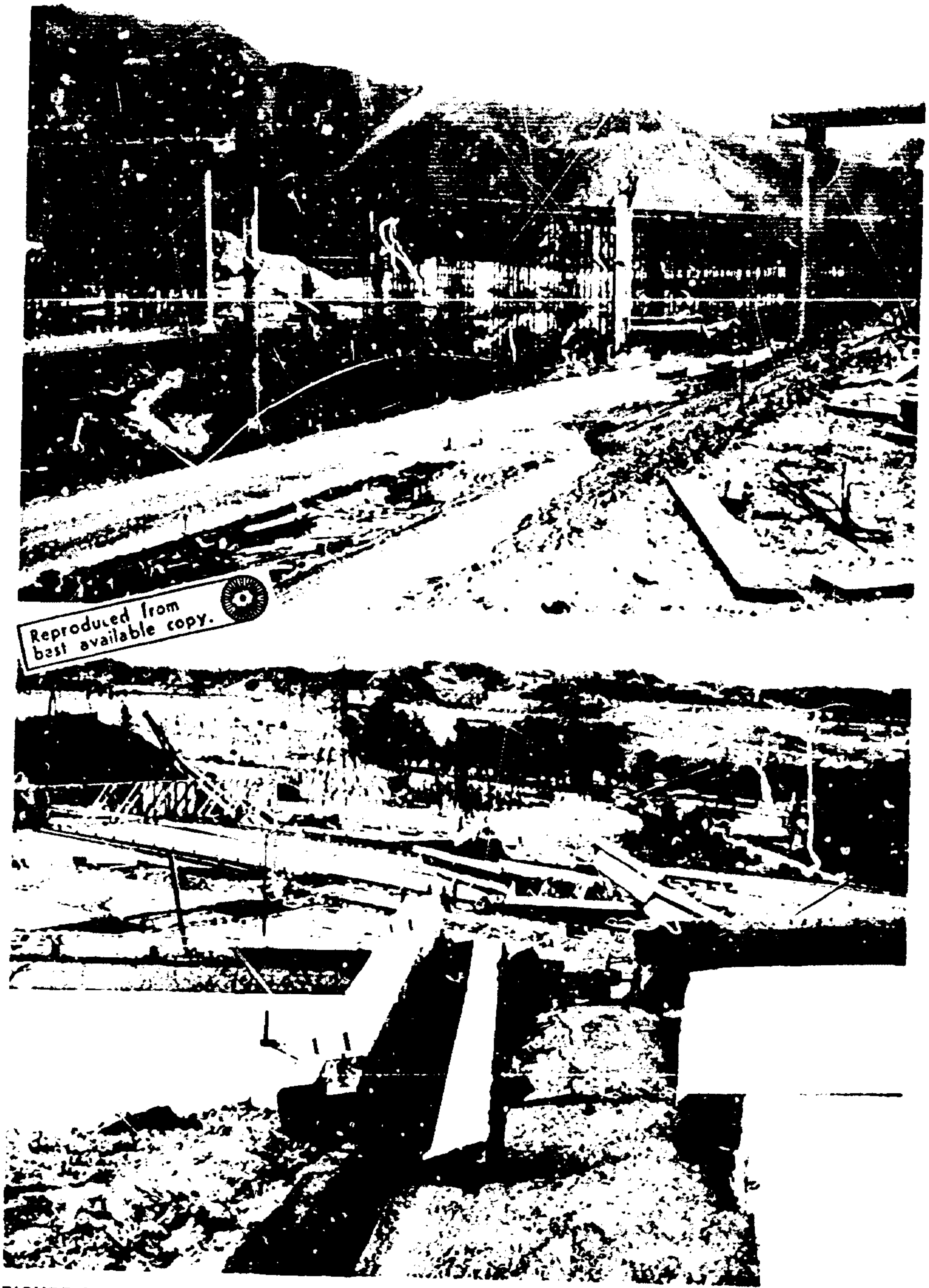


FIGURE 4 San Fernando, California Earthquake, February 9, 1971, Top: Ramp Collapse, Interstate 5 & California 14. Bottom: Ramp Collapse, Interstate 5 & 20.

FIGURE 5 San Fernando, California Earthquake, February 9, 1971, Beam to Column Failure, Interstate 5 & 210

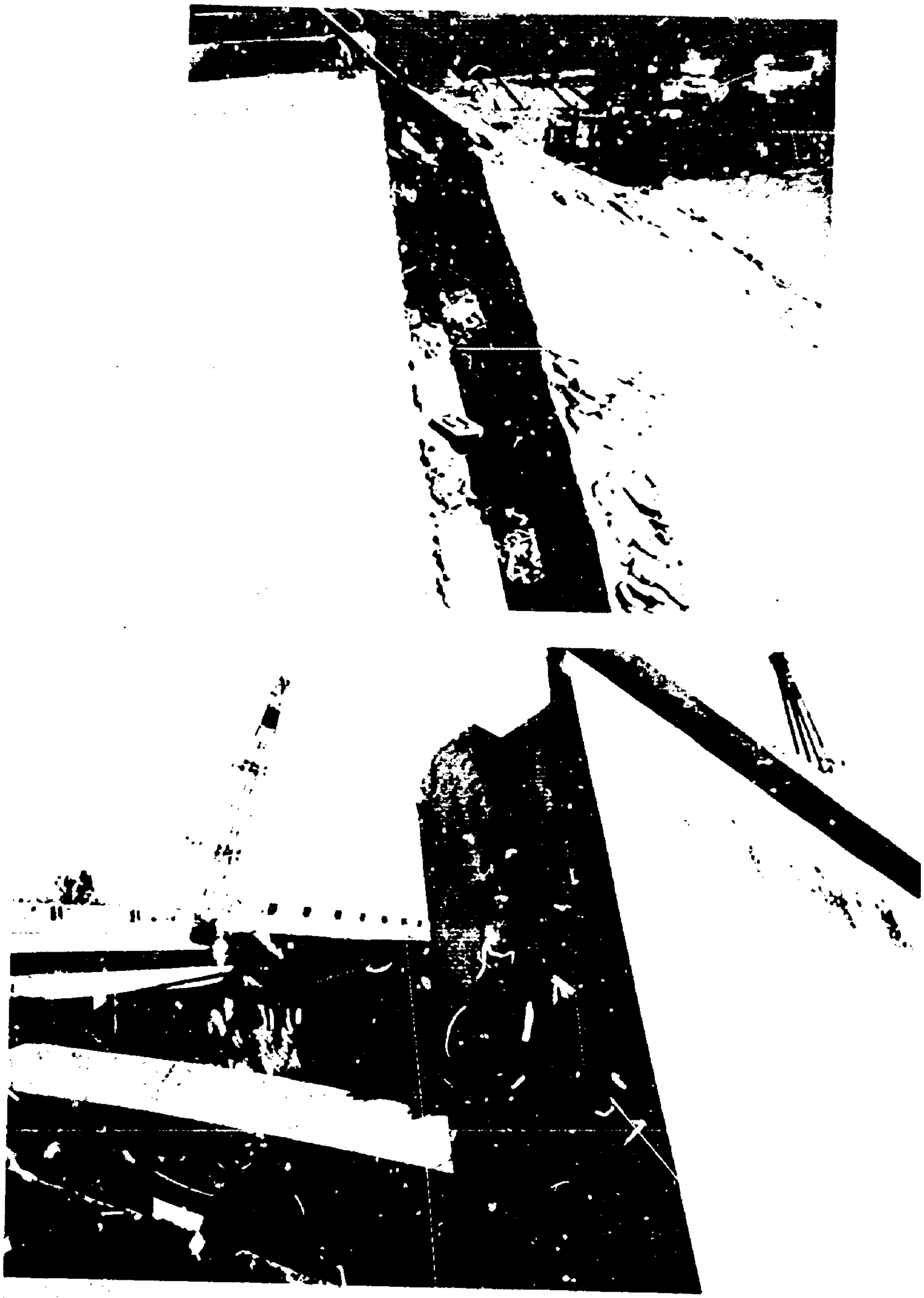


FIGURE 6 San Fernando, California Earthquake, February 9, 1971, Top: Bridge Seat Separation
Bottom: Ramp Deck Seat Separation (Hinge-Expansion Joint)

been given to the design of these systems against earthquakes.

In the San Fernando earthquake, four primary gas feeder lines in the 12-inch to 26-inch diameter class were damaged.[37] Approximately 450 breaks were reported in the local distribution system, interrupting service to 17,000 consumers. Few fires were attributed to leaking gas lines, but some spectacular failures happened. Escaping gas from ruptured 16-inch lines caused craters in streets, some as large as 10 feet in diameter and 8 feet deep. Breaks resulted from axial compression and tension. In the vicinity of the gas leaks, water line breaks also occurred. These breaks might have been from either the gas line eruptions or earth movements. In one case, a ruptured gas line blew a hole in a freeway bridge. No catastrophic failures resulted, but the potential was there.

Whereas the development of improved standards is dependent upon research and investigations, both of which are time consuming, goals are needed if the earthquake hazard to transportation structures is to be minimized.

IV. MODIFICATION OF EXISTING TRANSPORTATION STRUCTURES

Most of the existing transportation facilities were designed under codes which recent earthquakes have shown to be inadequate. A major quake in an urban area would cause considerable damage and loss of life in transportation systems. A crash program for retrofit of bridges to make them earthquake worthy is necessary. Likewise, other transportation structures, such as airport control towers and railroad dispatch buildings, require inspection to determine the need for retrofit to provide resistance against collapse by earthquakes.

The scope of this program is large and important. Priority should be given to highways and railroads carrying high traffic volumes and those most necessary for emergency routes; generally, this would include major portions of the primary and interstate systems. Decisions about the selection of specific transportation facilities for redesign and retrofit would be based upon cost/benefit analysis techniques which explicitly considered earthquake risk.

Correction of Hinged Joint Hazard

An outstandingly evident hazard of many highway bridges located in high earthquake-risk areas is a design weakness of bridge hinges which can allow spans of the bridge to fall under relatively small earthquake movement. Because corrective design of existing bridges at relatively low cost appears possible, this problem deserves a detailed consideration.

Fatalities in bridge collapses in the San Fernando earthquake would have been much higher had the roads been occupied by commuter traffic at the time. At the early hour, however, only one bridge span fell while a vehicle was beneath or on it. That vehicle was crushed, resulting in the death of all occupants.

Many of the highway bridges are constructed of separate spans connected by open hinge joints. The breakup of a multi-span bridge ramp connected in this way is shown in the center portion of the lower part of Figure 4. The several sections of the bridge ramp have separated cleanly.

Expansion and contraction of the bridge spans are accommodated by the design of the hinges. However, narrow seats permit the bridge to be disassembled by small movements during earthquakes. A typical example of this design is shown in Figure 6. This photograph shows an end section of a span which has moved sufficiently to allow it to slip off the narrow ledge which is its seat. In addition, the span had been keyed laterally by a block at the center. This block was placed in a corresponding hole in the adjacent portion of the bridge to resist lateral movement. As can be seen, the key was disengaged in the lateral direction by the same small amount of longitudinal movement which allowed the hinge seat to disengage. A hinge is necessary in such bridges to allow for the effects of thermal expansion, which causes the dimensions of the structure to change by fractions of an inch. The hinge used is not like an ordinary door hinge in that it contains no pin. The hinge is usually a simple open pivot upon which the parts can move laterally and rotate sufficiently to accommodate thermal expansion. Such hinges, however, also interrupt the structural continuity of the bridge, so that the bridge as a whole has little lateral or longitudinal strength to resist earthquake stresses.

Several of the bridges which had such hinges and which fell in the San Fernando earthquake were restrained only by the friction between the engaging parts of the hinges. This friction is completely unable to resist earth movement. In other bridges, a few steel bars are employed (see upper part of Figure 1) but their strength also appears far short of that necessary to resist the movement of the earth. The collapse of such a bridge hinge is shown in the upper right-hand corner of the upper part of Figure 4, where the slipped-off span has left an overhanging end.

The lower part of Figure 1 shows how the much deeper overlapping seat of a highway bridge on Route I-5 near San Fernando proved adequate in dimension to accommodate the earthquake movement. The bridge has moved, but not sufficiently to allow the span to drop off its ledge. The span to the rear, however, was moved sufficiently to allow the span to slip off its hinge and seat.

Many bridges in high earthquake-risk areas of California appear to exhibit the hinged joint hazard. Figure 2 shows a highway bridge in the San Francisco area which has a narrower overlap than those in either of the bridges shown in Figure 1. This highway bridge appears capable of falling under a movement of as little as 6 to 8 inches. Figure 3 shows a steel-framed freeway bridge in the San Francisco area. This bridge has steel hinges and seats and also appears to require about 8 inches of movement before falling. Some bridges of this type include a socket arrangement which does not appear capable of resisting earth movement. These bridges, of course, carry heavy automobile traffic during most of the hours of the day. Collapse of such bridges under small earthquake movements would not only cause heavy casualties, but also seriously disrupt important highway communications.

It appears that future bridge construction could easily remedy this slipping-off of spans from their seats by the use of deeper seats or by the provision of restraining devices to prevent a short drop from becoming complete collapse. It does not appear that the cost of providing a broad overlap between bridge spans would be a significant part of the cost of the bridge, if it were done in original design. However, that does not solve the problem for the many standing bridges in high earthquake-risk areas, which exhibit this problem. The problems seen in Figures 2 and 3 are found in varying degrees in dozens of spans in the San Francisco area.

It is not difficult to envision broader column seats of steel which might be welded to the freeway bridge type shown in Figure 3. Another possible form of modification for the bridge type in Figure 3 would employ steel links through the webs of girders which engage only under earthquake movement to limit the drop. It appears possible to add such corrections to existing steel bridges.

Modifications to increase the amount of accommodation to earthquake movement by concrete bridges, such as those in Figure 6 and the upper part of Figure 1, would apparently require considerable design effort and additional structure. This problem was also found in a number of railroad bridges. Considerable analysis may be required merely to learn the scope of this problem. For example, the bridge shown in Figure 2, although it appears similar to the bridge-hinge arrangement of the upper part of Figure 1, could conceivably include a greater overlap in the interior portions, which is not visible externally. However, it should be possible, by a systematic review of every highway and railroad bridge in high earthquake-risk areas, to develop a rating for each standing bridge in terms of the amount of lateral and longitudinal separation movement which could be sustained before the bridge collapsed. Such a survey would form part of the basis for plans to correct bridges which would be included in a priorities plan.

The widespread existence of this bridge hinge problem in high earthquake-risk areas can probably be regarded as indicative of the degree to which earthquake-resistance planning has been employed in transportation structure design generally. The present scope of this problem, so easily remedied at the design stage, but now involving hundreds of highway bridges in high earthquake-risk areas, illustrates the importance of realistic analysis and authoritative direction in establishing highway design standards.

Planning, inspection, and design for a retrofit program could logically be handled in a fashion similar to the bridge inspection program of the 1968 Federal Highway Act. Perhaps it could even be incorporated into the same program. The safety of railroad bridges is now under the jurisdiction of the Federal Railroad Administration of the Department of Transportation, but standards have not yet been issued. No design provisions for earthquake forces exist under the American Railway Engineering Association code.[38] It is not known what earthquake forces can be resisted by existing railroad bridges.[39]

V. COST/BENEFIT STUDIES IN TERMS OF RISK TO TRANSPORTATION STRUCTURES

The necessity for protection against earthquakes can be evaluated in terms of probability of occurrence and the consequences of the occurrence. Determining the probability of occurrence is essentially a form of earthquake prediction. This type of prediction is not available at the present time. However, the historical record of seismicity in the United States does provide very long-term guidelines to the relative seismicity of various areas of the country.

In 1948, the United States Coast and Geodetic Survey issued a "Seismic Probability Map" which was based primarily on past damaging earthquakes. It was later withdrawn because it was too general and subject to misinterpretation. It has been used by the Uniform Building Code as part of the criteria in the establishment of lateral force requirements.

S. T. Algermissen, in his paper *Seismic Risk Studies in the United States* presents a "Seismic Risk Map" which is based on the old map but considers somewhat different factors.[40]

The Seismic Risk Map (Appendix, p. 32) is based upon the following factors:

1. The distribution of modified Mercalli intensities associated with known seismic history of the United States;
2. Strain released in the United States since 1900; and
3. The association of strain release patterns with large-scale geologic features believed to be related to recent seismic activity.[41]

The Seismic Risk Map is an interim one, and like its predecessor, does not consider frequency of occurrence of seismic events. Elsewhere in his paper, Algermissen estimates the relative rates of occurrence of earthquakes of various modified Mercalli intensities in each zone using strain release and recurrence data.

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[38] Railroad structures are designed for braking of trains and "nosing" of locomotives. Design consideration of these factors may provide a sufficient safety factor against earthquake forces. However, designs should include a check for earthquake loading. The design of details should receive special attention.

[39] Since the San Fernando earthquake, the Southern Pacific Railroad has braced some of their bridges with cable to provide extra protection against quakes. (Telephone interview with Albert Hynes.)

[40] S. T. Algermissen, *Seismic Risk Studies in the United States*, reprint of paper presented at the Fourth World Conference on Earthquake Engineering, Santiago, Chile, January 13-18, 1969, (U. S. Dept. of Commerce, 1969).

[41] Jerry L. Coffman and William K. Cloud, *United States Earthquakes 1968*, Environmental Science Services Administration, (Washington, D. C.: Government Printing Office, 1970), p. 9.

Algermissen suggests that it eventually may be possible to estimate seismic risk by the use of three separate maps. One map would be geological in nature, a second would estimate frequency of occurrence, and a third would show the distribution of maximum intensities throughout the United States.[42] Development of this data for large areas will take a long time. It should be possible, however, to obtain such data during route planning for new highway corridors and other transportation facilities. Seismic risk will vary along different routes for the transportation system. However, by knowing location and degree of risk, corrective measures can be designed to mitigate the hazards. Costs for land and construction of alternate routes and designs can then be obtained for analysis.

The loss, or the consequence of an earthquake occurrence, will vary with the magnitude, geologic conditions, design of structures, and location of an earthquake. Considerations of the losses must include populations at risk, properties at risk, and systems at risk.

The toll in lives from United States earthquakes has been small compared with other areas of the world. The two strongest United States earthquakes in this century, San Francisco in 1906, and Alaska in 1964, took 700 and 130 lives respectively.[43] The San Fernando earthquake took 64 lives, two of which were related to transportation failures.[44] In contrast, a single earthquake in Nan-shan, China, in 1927, resulted in 200,000 deaths.[45] The total United States loss has been small (about 1,600 persons since 1800). We cannot, however, be complacent. Had the San Fernando earthquake occurred at a different time than the early morning hour and had the street interchanges been complete, the ramps would have been filled with cars and the loss of life in transportation would have been much larger. Had the epicenter occurred 25 miles southwest in downtown Los Angeles, the losses would have been overwhelmingly greater.

The billion dollar (present-day value) property loss of the San Francisco earthquake, the 500 million dollar loss of the Alaska earthquake, and the up to one billion dollar loss of the San Fernando earthquake should always be warnings that the earthquake menace cannot be ignored.[46] (The loss to Federal-aid highways was in excess of $40,000,000 in the San Fernando earthquake.)[47]

The losses in an earthquake also include those due to system failures. Fuel cutoff to a plant, or lack of transportation to move people and goods, affects normal economic activity and productivity. Other indirect costs such as emergency services should also be considered. For example, in San Fernando, detours were built to circumvent the fallen bridges. Admittedly, the cost of such services is difficult, if not impossible, to predict. Inclusion of such cost considerations, however, helps to place the cost of providing earthquake-resistant design in better perspective.

In a 1966 research needs statement, the Bureau of Public Roads (now the Federal Highway Administration) suggested that investigations be made to find "...the incremental costs involved in providing various degrees of seismic damage protection for each zone of potential seismic intensity, and what

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[42] Algermissen, p. 9.

[43] *Earthquake Investigation in the United States*, p. 51.

[44] *The San Fernando Earthquake of February 9, 1971*, p.1.

[45] *International Dictionary of Geophysics* quoted in National Academy of Sciences *Earthquake Engineering Research* (Washington, D. C.: The Academy, 1969), p. 2.

[46] *Earthquake Investigation in the United States*, p. 3, p. 51. *The San Fernando Earthquake of February 9, 1971*, p. 1.

[47] U. S. House of Representatives, *Department of Transportation and Related Agencies Appropriations for 1972*, Part 1 (92nd Cong., 1st. Session, April 1, 1971), p. 456.

level of protection can be justified."[48] Studies of past earthquakes can provide a data base.

Earthquake-resistant design will also produce a stronger structure, better able to withstand other natural disasters. For this reason, part of the incremental cost for earthquake-resistant design should be attributed to the cost of providing supplementary protection against other natural disasters.

Independent of cost/benefit analysis, the disruption or collapse of the transportation system may be militarily, socially, or politically unacceptable.

All answers cannot be obtained by cost/benefit studies and risk analyses. Analysis does, however, give decisionmakers a valuable input for determining a viable system design.[49]

VI. STRONG-MOTION SEISMIC EQUIPMENT

An earthquake should be regarded as a full-scale laboratory experiment the study of which can produce scientific and engineering data unobtainable by any other means. Without actual information from the quake, all protection efforts are based on assumption. This is not to say that simulation or model building of earthquakes is unimportant, but no information is as important in planning economical protection measures as that obtained from actual earthquakes.

In the Alaska earthquake of March 27, 1964, there were no strong-motion instruments to record the ground motion. Because of this, studies of structural response as a guide to improved design are of limited value.

The San Fernando earthquake of February 9, 1971, on the other hand, was the best monitored earthquake in the history of the United States. As a result of the Los Angeles building code, strong-motion recorders were positioned in the basement, middle, and top floors of all newly constructed buildings more than six stories high. Those recorders plus instruments located at dam sites and on different geologic formations, provided data for a variety of structural responses and geologic conditions. Yet there were no instruments in any highway bridges or embankments. While it is gratifying that there was an excellent record from non-highway structures, it is important that future installations include highway and railroad structures, for these structures have different configurations and responses than buildings. Without records of the responses of structures, it will be very difficult to optimize future designs.

Priority of installation should be given to areas of high earthquake frequency, to different foundation materials, and to different bridge designs. Instruments should be placed within the structure and adjacent to the foundations.

Present instruments have not fully exploited modern technology. For example, information is mechanically recorded and requires considerable data reduction effort. Cost has been high because of small production volume. With an expanded demand, both reduced unit costs and better instrumentation should result. For example, real-time instrumentation and data transmission might permit very accurate warnings and pinpoints of location, and obviate the off-scale problem of some current instruments.

Since most of the important highways and highway bridges are built with Federal con-

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[48] U. S. Dept. of Commerce, *Task and Study Statements of the National Program for Research and Development in Highway Transportation*, a report prepared by the Bureau of Public Roads, (Washington, D. C.: Dept. of Commerce, 1967), pp. 6, 27.

[49] For an interesting beginning at an attempt to estimate benefits from earthquake-resistant design, see: U. S. Department of Commerce, *A Preliminary Study of EngineeringSeismology Benefits*, Environmental Science Services Administration, (Washington, D. C.: Government Printing Office, 1967).

Current research into risk analysis is being done under NSF sponsorship. The research is being done at the Massachusetts Institute of Technology and the title of the contract is "Optimum Seismic Protection for New Building Construction in Eastern Metropolitan Areas."

tributory funds, the requirement for such instrumentation on new construction can be Federally initiated. The Federal Highway Administration, the distributor of these funds, would be the logical administrative agency to control such projects for new construction. There is at present no Federal authority to require retrofit of bridges.

In interstate railroad projects, not connected with highway projects, the Federal Railroad Administration (FRA) could serve as the agency to require railroad bridges and embankments to be instrumented.

The Federal Railroad Safety Act of 1970 extended FRA's authority to regulate all areas of railroad safety.[50] The Urban Mass Transportation Administration (UMTA) provides funds to local transit systems for feasibility studies, construction, and improvements, and it appears that they could insist on certain long-term safety design requirements such as the inclusion of seismic instrumentation in earthquake-sensitive areas.[51]

The networks should be designed in cooperation with the National Oceanic and Atmospheric Administration. Their National Ocean Survey's Seismological Field Survey unit maintains most of the existing networks in the United States and would be the logical agency to maintain the installations.

VII. GEODETIC MAPPING

The earth's crust moves in response to strains, and movement indicates developing strain. Accurate measurements can find these strains, and this information is critical in understanding the rates of earthquake recurrences and establishment of areas susceptible to future quakes. Such measurements are especially desirable along faults.

A precise geodetic network will enable a study of ground displacements resulting from earthquakes. In the 1964 Alaska earthquake, the geodetic network was minimal and hence the records of cause and magnitude of the earth movements that occurred are lacking. Other areas in the United States also lack precision elevations and distances, and should a quake occur, tectonic movement information would be lost forever.

Research is being conducted by the National Oceanic and Atmospheric Administration of the United States Department of Commerce to improve the accuracy and efficiency of instruments, methods, data development, and analysis of photographic data.

Long baseline laser interferometry allows distances of thousands of kilometers to be measured within a few centimeters, and could thus permit measurement of small changes in vertical and horizontal movements due to seismic activity. Supersensitive tiltmeters can show changes in elevation of the earth. Rotational irregularities of the earth for short periods of time can also be determined; correlation of rotational irregularities to seismic activity might be useful in earthquake forecasting and research.

The magnitude of this program is great, but costs could be reduced if priority were assigned to the known highest seismic risk areas. Yet large area geodetic mapping must be done if we wish to be able to predict earthquakes, since the development of strain is one of the basic predictors.

VIII. GEOLOGICAL AND SEISMICITY MAPPING

Geological mapping provides the essential base for appraisal of resources and land-use potential. The maps and surveys provide the

[50]U. S. House of Representatives, *Report of the Committee on Interstate and Foreign Commerce on S. 1933 to Provide for Federal Safety, Hazardous Materials Control and for Other Purposes*. Report No. 91-1194, 91st. Cong., 2nd Session, June 15, 1970, p. 16.

[51]The UMTA has an investment in the San Francisco Bay Area Rapid Transit System, the Los Angeles Rapid Transit System, and the Seattle Rapid Transit System; all are located in the highest earthquake-risk zones.

basic knowledge for appraisal of problems such as landslide hazards, fault zones, and foundation conditions. At the Federal level, the Geological Survey of the Department of Interior is the agency responsible for the mapping.

In the United States, only a little more than 22 percent of the land has been geologically mapped, and this is primarily on large-scale maps. This mapping is taking place at a slow pace, less than 1 percent a year, and the information obtainable from these maps provides little more than the most rudimentary information on foundation conditions and the nature of geologic hazards.[52] Small-scale mapping is taking place in California and Colorado in areas where serious foundation problems and geologic hazards exist. Fault zone mapping, with initial emphasis on the San Andreas fault, is also taking place. (Many faults remain unmapped. For example, while scores of faults were mapped in the Los Angeles area, the fault on which the San Fernando earthquake occurred was not.)

In the past, subdivisions have been built over faults; a classic example is shown in the Appendix, p. 34, where housing tracts are shown in relation to the San Andreas Fault area. In Alaska, the town of Valdez was originally built on unstable ground; after the 1964 quake, it was rebuilt on a more stable site as indicated by geological maps.

Damage from quakes is influenced by the location of the epicenter, but the effects can be greatly magnified by the ground on which structures are built. The increasing sprawl of our cities has resulted in the residential development of areas considered to be more susceptible to damage from earthquakes. This trend gives urgency to rapid geologic mapping of our land.

Transportation facilities, atomic energy plants, dams, and other structures all have to be built somewhere. The geologic map is a needed input to assure a safer location.

Our knowledge of seismicity, the study of the locations, sizes and frequency or occurrence of earthquakes, is based on short historical records. This knowledge must be supplemented with the hows and whys of earthquakes if we are to provide our engineers with better criteria upon which to base their designs.

Some of the questions which must be investigated are the relationships between earthquake frequency, magnitude, and geologic characteristics, the relationship between small shocks and large earthquakes, and the relationship between strain rates and the onset and magnitude of earthquakes. Perhaps there are still undiscovered indicators of seismicity.

The development of maps and descriptions of seismicity is an important goal. Together with a better understanding of structural foundation characteristics and their susceptibility to earthquake shocks, better location and construction of transportation structures should result.

IX. EARTHQUAKE ENGINEERING RESEARCH

Earthquake engineering is a relatively recent development. The first appearance of earthquake design requirements was in the 1927 edition of the Uniform Building Code. The impetus for the seismic design requirements was the Santa Barbara earthquake of June 29, 1925.[53]

This first code was rudimentary in nature and has been changed over the years as knowledge has been gained through research and the study of damage from other earthquakes. Some improvements have been made, but codes still do not consider the varieties of factors which can

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[52] Office of Science and Technology, *Proposal for a Ten-Year National Earthquake Hazards Program*, Ad Hoc Interagency Working Group for Earthquake Research of the Federal Council for Science and Technology. (Washington, D.C.: 1968), p. 18.

U. S. House of Representatives, *Department of the Interior and Related Agencies Appropriations for 1972*, Part 3. 92nd Cong., 1st Session, March 1971, p. 484.

[53] Charles H. Norris, *et al.*, *Structural Design for Dynamic Loads*, (New York: McGraw Hill Book Co., 1959), p. 358.

magnify earthquakes or the varieties of structural responses to earthquake ground movement or vibration. The solutions will require increased earthquake engineering research.

The objectives of earthquake engineering research are to provide information on the nature and effect of destructive ground motion, to develop practical methods of analysis and design, and to develop safe and economical countermeasures. It is concerned with the effect of earthquakes on the works of man.

Pure research in the earthquake field involves seismology, geology, theoretical mechanics, and oceanography. The need for improved pure research has been covered elsewhere in this report. In applied research, as related to bridge and highway design, there is a need to know the accelerations produced by the earthquakes, the soil mechanics, and the response of the structure.

Accelerations and wave movements are measured through strong-motion instrumentation. Accelerations will vary with the soil conditions; development of a mathematical model of the excitation suitable for use in a design code is difficult because the effects of dynamic loads have received relatively less attention in codes. However, present development work in building structures is encouraging and the continuance of this work with a technology transfer to bridge design should be encouraged.

Soil instability resulting from earthquakes is of many types. Settlement of cohesionless soils and liquefaction of saturated sands are two of the many types of soil problems facing the structural designer, which are only partially understood. More research into these problems would provide the civil engineer the data needed for better earthquake-resistant designs and better codes, for transportation structures as well as general structures.

The response spectra of various bridge designs and structures are also largely unknown when compared with other structures, such as aircraft structures. Both linear and nonlinear dynamic analysis is needed. Full-scale testing of structures would be warranted because model testing is inadequate to show all the large-scale effects. Vibration testing of buildings and structures is in its infancy due to the large-scale shaking equipment necessary.

Most of the research in this country is performed by the universities funded through National Science Foundation (NSF) grants. Seventy-one grants, budgeted at $6,314,600, have been made in earthquake engineering since 1965. Significant experimental facilities have resulted and continued support is warranted.[54] However, the total funds expended by NSF grants from 1965 to 1971 are minor when compared with the $25,000,000 damage to highway bridges alone in the 1964 Alaskan earthquake, and the $20,000,000 damage to highway bridge structures in the San Fernando earthquake. Much of the loss in both earthquakes was due to weaknesses in structural design of highway structures. It would appear that considerable damage reduction is possible with relatively little additional expense or added weight through the application of earthquake-resistant design for new structures and retrofit for existing inadequate design details.

Earthquake Engineering Research, a report prepared by the Committee on Earthquake Engineering Research, Division of Engineering, National Research Council, National Academy of Sciences, and funded by NSF, is an excellent work emphasizing the need for increased earthquake research in practical problems caused by earthquakes.[55]

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[54] Michael P. Gaus, Charles A. Babendeur, and George K. Lea, "Current Research in Wind and Seismic Effects Carried on Through NSF," Unpublished Talk to the Third Annual Meeting of the Panel on Design of Structures to Resist Wind and Seismic Effects of the U. S. - Japan Joint Commission on Natural Resources (Program originated and guided by the Department of Commerce), Tokyo, Japan, May 10-12, 1971. (Typewritten).

[55] The Committee was chaired by George W. Housner of the California Institute of Technology.

X. EARTHQUAKE STUDY TEAMS

Since destructive earthquakes in the United States occur relatively infrequently, foreign earthquakes should be exploited to determine valuable information relative to seismology, geology and engineering. Investigation of the 1967 Caracas, Venezuela, earthquake, for example, provided information which was useful in design of structures.[56]

Often the emergency procedures, after an earthquake, destroy much of the evidence, so it is important that teams are ready to go to the site as fast as possible.[57] The National Academy of Sciences has even recommended rapid air reconnaissance studies.[58]

In the recent San Fernando earthquake, personnel were sent from many different Federal departments, state agencies, industry, universities, and professional organizations. Coordination was not apparent, but because of the large number of experts, and the best instrumented earthquake in history, meaningful data should result. In investigating future earthquakes, both here and abroad, multi-disciplinary teams should be formed beforehand so that ready coordination will result.

A proper organization to coordinate such activities could be the Federal Office of Science and Technology or the Office of Emergency Preparedness. A closer look at these agencies' functions is provided later in this report.

XI. EMERGENCY RELIEF

After a major earthquake in a metropolitan area, there is a need for both immediate emergency relief and restoration of services. The quickness of response is dependent upon prepared plans and the ability of agencies to adapt to the situation. In a metropolitan area, where there often is a multiplicity of governments, the coordination of the units of government becomes especially critical.

It is the general opinion that emergency measures worked well in the San Fernando earthquake relief operation. The California Division of Highways had surveillance teams at the scene both on the ground and in the sky within 15 minutes after the first shock.[59] Less than 3 hours later, crews were removing debris and within 14 hours, a bypass was open for north-south traffic. Crews from the Southern Pacific Railroad also were on the scene in rapid fashion and they had a damaged rail link opened within a few days.

The utility company serving San Fernando and surrounding areas had several ruptured gas lines which were not shut off for several hours.[60] Explosion and fire hazards existed during this period, but fortunately neither occurred. Reference is made to the National Transportation Safety Board's "Special Study of Effects of Delay in Shutting Down Failed Pipeline Systems and Methods of Providing Rapid Shutdown," released in February 1971. The Safety Board recommended that the Office of Pipeline Safety of the Department of Transportation conduct [illegible] study to develop standards for the rapid shutdown of failed natural gas pipelines and work in conjunction with the Federal Railroad Administration to develop similar standards for liquid pipelines.

Radio communication played [illegible] role in the speed with which the highw[illegible] utility people responded to the havoc c[illegible] the earthquake. (Many telephone [illegible] in-operative.) Likewise, medical assistance was rapid because of the interconnection of 110

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[56] See: Robert D. Hanson and Henry J. Degenkolb, *The Venezuela Earthquake, July 29, 1967* (New York: American Iron and Steel Institute, 1969).

[57] The National Science Foundation has proposed a grant for supporting the dispatch of a team of experts to locations of damaging earthquakes to modern structures. "Current Research in Wind and Seismic [illegible]fects . . .".

[58] *The San Fernando Earthquake of February 9, 1971*, p. 10.

[59] Mike Van Cott, "Earthquake!", *Highway User* (May 1971), pp. 22-24.

[60] "After the Quake", *American Gas Association Monthly*, [illegible]III (May 1971), pp. 4-6.

county hospitals with a short-wave radio network.[61] Police emergency operations were also well planned.

The Federal Government, through the Corps of Engineers (COE) and through the Office of Emergency Preparedness (OEP), also played a major role in emergency relief.[62] COE's Disaster Operation Center was opened within an hour of the quake; rescue operations were begun shortly thereafter.

Many sewer, water, and road systems were damaged in the quake area and demolition, debris removal, and restoration became a major project for COE. Advice was received from the Geological Survey to avoid, for 6 months, permanent pavement repairs in the fault area because of possible additional ground movement and settlement.

Emergency transportation services are provided at the Federal level by the Office of Emergency Transportation in the Office of the Secretary of Transportation. This Department's Regional Emergency Transportation Coordinators (RETCOS) receive input from agencies connected with transportation and suggest actions which will deal with disaster-connected transportation emergencies. The field representatives of the agencies can take immediate action when the situation warrants it. Input and coordination are provided to OEP.

In Washington, a similar cooperating and coordinating effort takes place among the various transportation agencies. Each administrative head can order action in the field or, if necessary, the Secretary of Transportation can take direct action.

[61] *Los Angeles Times*, February 10, 1971, p. 2, p. 29.

[62] For the COE role in the San Fernando earthquake, see: Col. Robert J. Malley, "Earthquake Disaster Engineering," *The Military Engineer*, CDXIII (May-June 1971), pp. 153-156. For an interim report on the Federal role to the San Fernando earthquake, see: Office of Emergency Preparedness "Q-Day + 100, The Federal Response to the California Earthquake of Feb. 9, 1971: An Interim Report as of May 20, 1971" (Washington, D. C.: The Office, 1971).

One important lesson from previous disasters is that preparedness is the best guard against unnecessary losses. Federal, State, local, and private agencies must plan ahead and coordinate their efforts to provide the disaster relief necessitated by catastrophic failures. The Disaster Relief Act of 1970 is designed to expand Federal relief programs. One of its main purposes is to achieve greater coordination of Federal major disaster relief programs.

After the San Fernando earthquake, the previous planning of local authorities permitted rapid emergency measures by police and firefighting authorities. An outstanding example was the highly successful evacuation of residents from the area below a weakened and overflowing dam. This operation was facilitated by the fact that the road net in the area remained open. It is obvious that detailed surveys and actions to strengthen selected highway systems against earthquake damage will result in assurance that most selected escape and emergency services routes will be available in disaster situations.

XII. AGENCIES INVOLVED IN THE EARTHQUAKE PROBLEM

National Science Foundation (NSF)

The Foundation was created by the National Science Foundation Act of 1950.[63] The basic purpose of the Foundation is to strengthen research and education in the sciences in the United States. One of its programs is ". . .aimed at improving the coordination of the various scientific information activities within the Federal Government; developing new or improved methods of making scientific information available; fostering the interchange of scientific information among scientists of the United States and foreign countries; and

[63] General Services Administration, Office of the Federal Register, *United States Government Manual-1970/71* (Washington, D. C.: Government Printing Office, 1970) p. 475.

providing support for the translation of foreign scientific information."[64]

The Foundation is the main supplier of funds for earthquake engineering research through contracts with universities. It correlates this research through the Universities Council on Earthquake Engineering. There is, however, no mechanism for correlating research done by the various governmental agencies or private organizations.

For fiscal year 1971, the National Science Foundation organized most of its coordinated and problem-focused research into a single set of program activities called Research Applied to National Needs (RANN). Earthquake engineering research is a major effort in this program. RANN will take the results of various fundamental research efforts and integrate them into research projects designed to bridge the gap with applications.

The National Science Foundation has had close liaison with the President's Science Adviser and the Office of Science and Technology in establishing research needs into RANN. Other Government agencies which have been consulted by NSF include the Departments of Interior and Commerce, which are the two primary Government agencies dealing directly with the earthquake problem. In accomplishing its objectives, NSF expects to use the resources of the academic institutions, industrial and commercial laboratories, and nonprofit research organizations. Although it is expected that most of the objectives can be accomplished with existing organizations, new groupings will be established if needed.

To assure that arrangements are well coordinated, interagency agreements will be utilized to involve personnel of other agencies at various research steps. Where the need arises, coordination will also be accomplished by the use of working task groups of other agency personnel, joint funding, formal program reviews for other agencies, and multi-agency site visits and panels. In addition to obtaining Federal cooperation, action has been taken through its Intergovernmental Science Program to provide coordination with interested State and local government agencies and officials.

The research that will be done by RANN in structures is not specific with regard to transportation structures, although one proposal is for the study of the effects of earthquakes on gas and water systems.[65] Specific work with regard to bridge structures is being done by the University of California at Berkeley under a United States Department of Transportation contract.

NSF funds some seismological observations operated by the National Oceanic and Atmospheric Administration. Other NSF programs, such as improvement in the seismic warning system, will benefit transportation as a by-product.

National Oceanic and Atmospheric Administration (NOAA).

NOAA, an agency in the Department of Commerce, was created October 3, 1970, to bring together in one Administration many of the Nation's major civil programs involving the oceans and the atmosphere. The Environmental Science Services Administration (ESSA), formerly the major agency involved in seismology, was absorbed in the new agency.

The major earthquake and earthquake-related activities of NOAA are seismological observations, seismological analyses, engineering seismology, seismological data services, and geodesy.

NOAA operates and maintains a network of 17 seismological observatories in the United States and its territories, and assists in the operation and maintenance of a network of 15 cooperative seismic stations.[66] The seismological

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[64] *Ibid.*, p. 476

[65] Phone interview with Dr. Charles Thiel, Asst. Director, Research Applications, National Science Foundation.

[66] From material (unpublished) of the Department of Commerce for the 1972 Congressional Appropriation Hearings, p. NOAA-15.

data obtained from the observatories are analyzed and processed to establish the location and description of earthquake and tsunamis (seismic sea waves) and to provide for mapping of earthquake risk zones.

Engineering seismology is directed toward the reduction of hazards and damage losses due to earthquakes and their secondary effects. Benefits include better designed earthquake-resistant structures and reduction of monetary loss or improved provisions for recovery of loss in the event of disaster. The strong-motion network is the primary means of gathering information for establishing design criteria.

At present, there are 592 strong-motion seismographs maintained by NOAA in the United States and eight in South and Central American countries.[67] In addition, 380 seismoscopes are maintained by NOAA.[68] Under a 5-year program, this network is being expanded.

Under the geodesy program, improved techniques are being developed for obtaining geodetic control for mapping and engineering surveys. This should allow for better knowledge of earth movements resulting from earthquakes. The possible correlation of rotational irregularities to seismic activity might indicate its use in earthquake forecasting.

National Bureau of Standards

The Bureau of Standards, also part of the Department of Commerce, does earthquake-related research in design techniques, building codes, and engineering. It has been working with the Department of Housing and Urban Development in developing earthquake-resistant building standards for the "Operation Breakthrough" program. Its investigation of structural damage caused by earthquakes supplies valuable input to its mandated functions.

[67] *Supra*, footnote 13.

[68] *Ibid.* 1972 Congressional Appropriation Hearings, p. NOAA-107.

Geological Survey

The Geological Survey is part of the Department of the Interior and was established in 1879.[69] One of its functions is to examine the geological structure of the national domain through surveys, investigations, and research. The Survey requested an increase of $200,000 or a total of $1,665,000 in fiscal year 1971 for seismological and geological studies to reduce potential losses from earthquakes.[70] This increase will be used to include ". . .geologic surveys of high-risk areas, seismological and soils engineering investigations of ground motion and failure, assistance in land-use planning and pre-disaster emergency planning, and geophysical monitoring and geologic analysis of earthquake faults."[71]

The geologic mapping function has been mentioned in the chapter on Geological and Seismicity Mapping. Such mapping should proceed at a more rapid pace, for geologic data is a necessary input in the design of earthquake-resistant structures.

The Survey is also working on earthquake prediction. While the prediction does not yet tell when the earthquake will happen, encouraging headway has been made to locate the area and the approximate magnitude of earthquakes. This knowledge is valuable in determining the location of structures to minimize the earthquake risk.

The Survey is the source of additional information for the seismic risk maps mentioned earlier. In view of the potential savings of millions of dollars in loss to property, including transportation systems, in earthquake risk areas, the work of the Survey should be facilitated by increased funding, for the

[69] *United States Government Organization Manual - 1970/71*, p. 237.

[70] *Department of the Interior and Related Agencies Appropriations for 1972*, p. 483.

[71] *Ibid.*

examination of the geological structure of the nation is basic to all measures for protection against earthquakes.

Atomic Energy Commission

The Atomic Energy Commission, in its quest for peaceful uses of atomic energy, must build some of its nuclear reactors in seismic areas where there are little data on the area's geology or the seismic behavior of the soil. The absence of such knowledge has led the Commission to support an extensive earthquake research program. In many cases, they have arranged for cooperative programs with the Geological Survey and the Coast and Geodetic Survey.

The Commission also needs seismological, geological, and geophysical data for their programs in weapons testing and the peaceful use of nuclear explosives.

Departments of the Army, Navy, Air Force, and Defense

The Departments of the Army, Navy, and Air Force, and the Advanced Research Projects Agency of the Department of Defense all support earthquake programs. Primarily their support results as a contribution to underground detection and identification of nuclear explosions. Knowledge has been gained in wave propagation, structure of the earth's crust, system development and instrumentation.

The Corps of Engineers of the Department of the Army is involved in earthquake engineering because of its large military and civilian construction program. For example, the construction of large hydroelectric projects in the high seismic-risk area of the Pacific Northwest requires earthquake-resistant design. As was mentioned in the previous chapter, the Corps is also involved in emergency relief work. In the San Fernando earthquake, the Corps' help in drawing down water from the partly demolished Van Norman Dam, restoring the water and sewer systems, and repairing the roads was vital in preventing further disaster and returning the area to normalcy. Under Public Law 91-606, passed in 1970, the Federal involvement has been increased in disaster relief and recovery; it can be expected that the Corps of Engineers will play an even larger emergency role in the future.

National Aeronautics and Space Administration (NASA)

The National Aeronautics and Space Administration has space technology which can contribute to earthquake research programs. NASA has rapid reporting facilities, accurate measuring instruments, and aerial photographic capabilities for disaster surveys and photogrammetry.

Department of Housing and Urban Development (HUD)

The Department of Housing and Urban Development has a project with NOAA for seismic risk mapping which will be included in its report to Congress on the feasibility of earthquake insurance. To develop such a report, HUD will also require the expertise of other Federal agencies which have long dealt with the earthquake problem.

Department of State

The Department of State requires seismology information in reference to the nuclear test ban treaties. It also cooperates with foreign lands when major earthquakes occur in their nations.

Department of Transportation

The Department of Transportation, because its facilities and those over which it has regulatory jurisdiction are often built in earthquake zones of high risk, has an intrinsic interest in the earthquake problem. In fiscal year 1971, the Federal Highway Administration (FHWA) issued a contract to the University of California for research into bridge design methodology for seismic effects. FHWA has planned $76,500 in FY 71, $71,500 in FY 72, and $101,507 for FY 73 for this kind of research. Its control of moneys for transportation projects gives it an enviable position in requiring the construction of structures which will better resist earthquake-induced forces.

Office of Emergency Preparedness

The Office of Emergency Preparedness was created in 1968 to assist and advise the President in the coordination and determination of policy for all emergency preparedness activities. The Office played a major role in the disaster relief of the San Fernando earthquake. It was the Federal agency responsible for contracting and funding much of the necessary repairs to public property.

Office of Science and Technology

Another Executive office involved in the earthquake problem is the Office of Science and Technology, established in the Executive Office of the President, in 1962. The Director "...provides advice and assistance to the President with respect to *developing policies* and evaluating and *coordinating programs* to assure that science and technology are used most effectively in the interests of national security and general welfare." (Emphasis added.)[72]

Federal Council for Science and Technology

The Federal Council was established in 1959. A primary mission is: "...to promote closer cooperation among Federal agencies, to facilitate resolution of common problems and to improve planning and management in science and technology, and to advise and assist the President regarding Federal programs affecting more than one agency."[73] The Director of the Office of Science and Technology serves as Chairman to the Council; the Office also supplies the Council its secretariat.

The Office and Council have sponsored important reports dealing with the earthquake problem. Their report, *Proposal for a Ten-Year National Earthquake Hazards Program*, published in 1968, is an often-quoted work. This report was prepared by a special group made up of representatives from the Federal agencies involved in the earthquake problem.

Their report recommends a 10-year National Earthquake Hazards Research Program, the creation of a permanent coordination and guidance group, and cooperation and coordination with foreign research programs, especially the Japanese who are leaders in the field.

This program has been recommended in part or total by other research, yet little has been done to implement it. The National Academy of Sciences said it this way, "A Federal task force should be established to recommend a comprehensive Government program directed toward reduction of losses from hazards such as earthquakes..."[74]

It is apparent from the above discussion that there is urgent need for a permanent interagency committee to exchange information and coordinate activities of the Federal agencies. This committee or group must also have strong liaisons with state and local governments, universities, private concerns, and foreign groups involved in the earthquake problem. The problem is too vast and serious to expect a complete solution from uncoordinated separate efforts.

XIII. CONCLUSIONS

1. The history of earthquakes indicates that continuing impacts against transportation systems can be expected, that past losses in high-risk zones have been relatively minimal because of fortunate location or timing, and that much more severe damage can be expected if earth-

[72] *United States Government Organization Manual - 1970/71*, p. 71.

[73] *Ibid.*, p. 543.

[74] *Toward Reduction of Losses from Earthquakes*, p. 11.

quakes occur in areas of concentrated population, or under conditions of severe, repeated shocks to structures.

2. The current funding for earthquake engineering research is not only far smaller than the losses sustained by transportation modes in recent earthquakes, but is apparently much less than potentially preventable losses.

3. Existing building, highway bridge, railroad bridge, and pipeline design codes in use in the United States have been shown to be inadequate against earthquake forces. Consideration of lateral forces is minimal and little notice has been taken of vertical accelerations.

4. Existing transportation structures in high-risk earthquake areas are susceptible to great damage because of inadequate design provisions against earthquake shocks. Cost/benefit analyses should be made to permit selection of structures to be retrofitted to insure high probability of usable escape and emergency routes in high risk areas.

5. A program for placement of strong-motion instruments in transportation structures is needed to obtain basic data on the parameters of earthquake effects to these structures. Such data are mostly not available due to lack of instrumentation of transportation structures. With sufficient data, it should be possible to make appropriate revisions to design details for new construction as well as existing structures.

6. There is a pressing need to obtain basic earthquake hazard information for all high risk areas in the United States. Such information can be gathered only through greatly expanded geodetic, geological, and seismicity mapping. The information is needed for decisions as to placement of structures, design of structures, and assessment of risk.

7. The existing fragmented Federal and state programs for earthquake research require formal coordination by a single Federal agency to insure the most efficient use of available funds.

8. Rapid reconnaisance of earthquake-hit areas throughout the world would furnish invaluable information. Emergency inspection teams are needed in standby status, ready to proceed upon notice, in order to be able to obtain data firsthand to increase available knowledge of the results of earthquakes.

9. Exchange of earthquake information of all types on an international basis should be increased to permit all nations with earthquake problems to benefit from the experiences of other nations.

10. It is apparent from the San Fernando, California, earthquake damage that relatively minor, inexpensive modifications to highway bridges will provide much greater protection against the collapse of bridge structures. The provision of wider seats with retention devices should act to prevent bridge sections from slipping from their supporting structures. Single column designs should be reevaluated as to adequacy against earthquake shocks.

XIV. RECOMMENDATIONS

The Safety Board recommends that:

1. Consideration be given by the President's Office of Science and Technology to the need for coordination of all Federal agencies now involved in earthquake-related activities to increase the availability of knowledge, to make the most efficient use of available funds, and to present a coordinated request to the Congress for a greatly expanded program to increase protection against earthquakes.

2. The Secretary of Transportation consider undertaking the following programs to increase the resistance of transportation structures to earthquakes in risk areas:

   a. Revision of highway bridge design standards.
   b. Revision of railroad bridge design standards.
   c. Revision of pipeline design standards.
   d. Improved design criteria for airport control towers and other vital structures.
   e. Conduct of cost/benefit analyses in high-risk areas, in coordination with the States involved, to arrive at decisions for retrofit programs for existing structures on the interstate highway system to reduce

potential loss of life and provide emergency routes.

f. Increased funding for research into earthquake-resistant design of highway structures.

g. Examination of structures in the Saint Lawrence Seaway to ascertain resistance to earthquakes in that high-risk area.

h. Analysis of methods by which the Federal Government can assist the states and railroads in retrofitting selected transportation structures.

i. Installation of strong-motion seismic equipment on bridges and other transportation structures, in coordination with the National Oceanic and Atmospheric Administration of the Department of Commerce.

j. Examination of contingency emergency relief transportation planning, looking toward improvements for earthquake risk areas.

3. The National Oceanic and Atmospheric Administration of the Department of Commerce and the Geological Survey of the Department of the Interior undertake a coordinated program of expanded and improved geodetic mapping, geological mapping, and seismographic networks, with special emphasis on high-risk zones, in order to permit better planning for the installation and improvement of transportation systems.

4. The Office of Science and Technology establish coordinated 5- and 10-year plans for all Federal agencies involved in the earthquake problem, including a sound cooperative program to be established with other nations having problems with damage from earthquakes. In this connection, emergency funds and trained professional personnel should be available for the inspection and analysis of earthquake damage throughout the world.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD:

/s/ JOHN H. REED
Chairman

/s/ LOUIS M. THAYER
Member

/s/ ISABEL A. BURGESS
Member

Oscar M. Laurel and Francis H. McAdams, members, filed the attached dissent.

February 8, 1972

McADAMS and LAUREL, Members, Dissenting:

We do not agree that there is a clear and present need for Federal involvement in the earthquake problem as related to transportation safety to the extent that is recommended by the majority.

The loss of life and damage to property that can be directly attributed to earthquakes which affect transportation facilities is rather small. There are other far more pressing safety problems directly related to transportation which should be given higher priority if Federal funds and manpower are to be utilized. The exposure rate of major earthquakes is measured in decades and the high-risk area is mostly centered in the West Coast area of the United States; whereas, the exposure rate of other major transportation problems can be measured on a daily and continuing basis, and involve the national interest.

For the foregoing reasons we cannot subscribe to broad, costly, and in some instances, vague recommendations of the majority.

/s/Francis H. McAdams
Francis H. McAdams, Member

/s/Oscar M. Laurel
Oscar M. Laurel, Member

February 23, 1972

APPENDIX

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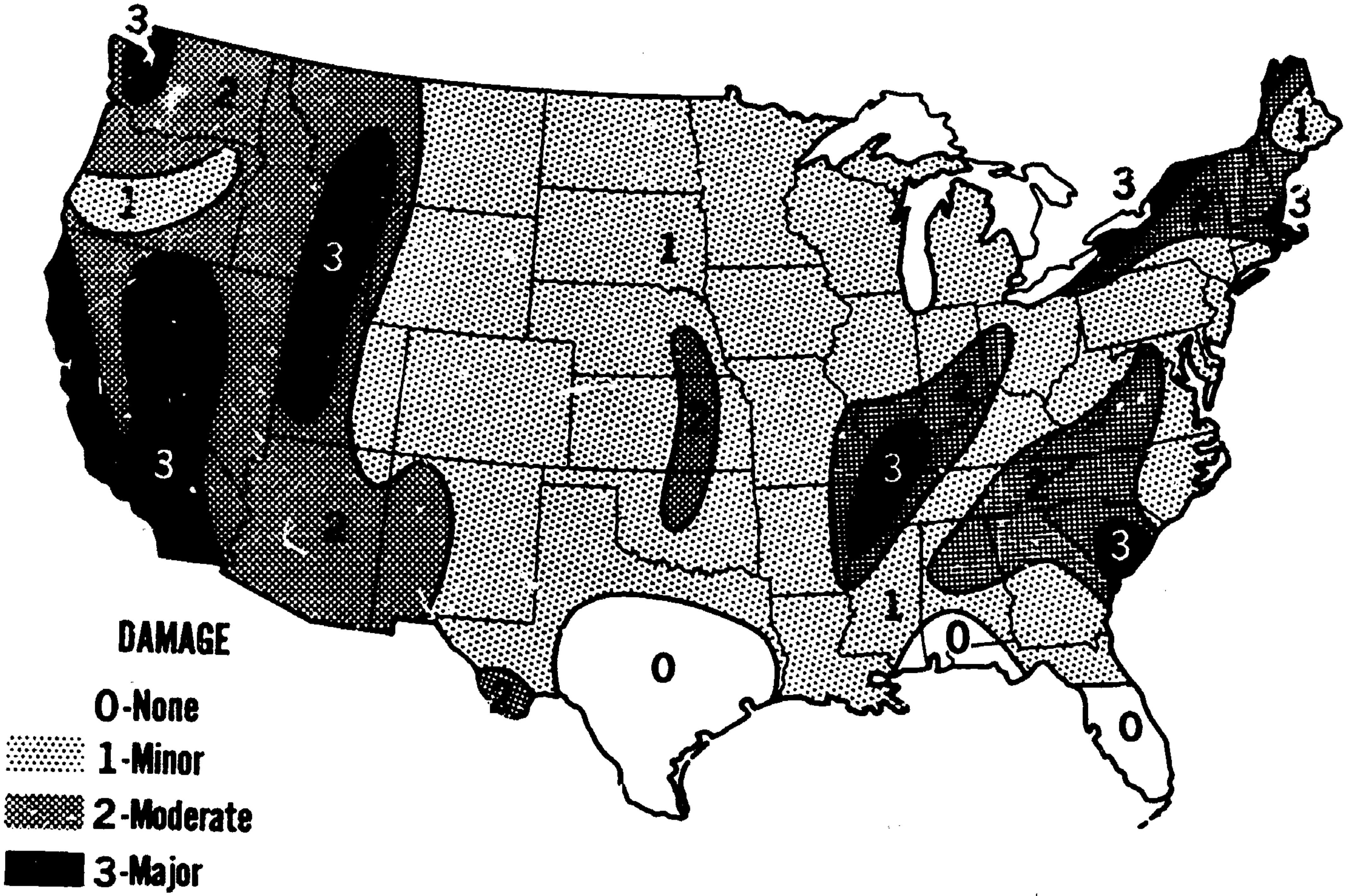

FIGURE 7 Seismic risk map for conterminous U.S., developed by ESSA/Coast and Geodetic Survey and issued in January 1969. Subject to revision as continuing research warrants, it is an updated edition of the map first published in 1948 and revised in 1951. The map divides the U. S. into four zones: Zone 0, areas with no reasonable expectancy of earthquake damage; Zone 1, expected minor damage; Zone 2, expected moderate damage; and Zone 3, where major destructive earthquakes may occur.

FIGURE 8 Earthquake Fault Zones Vicinity of Los Angeles, Calif. Los Angeles Times Map by Donald Clement

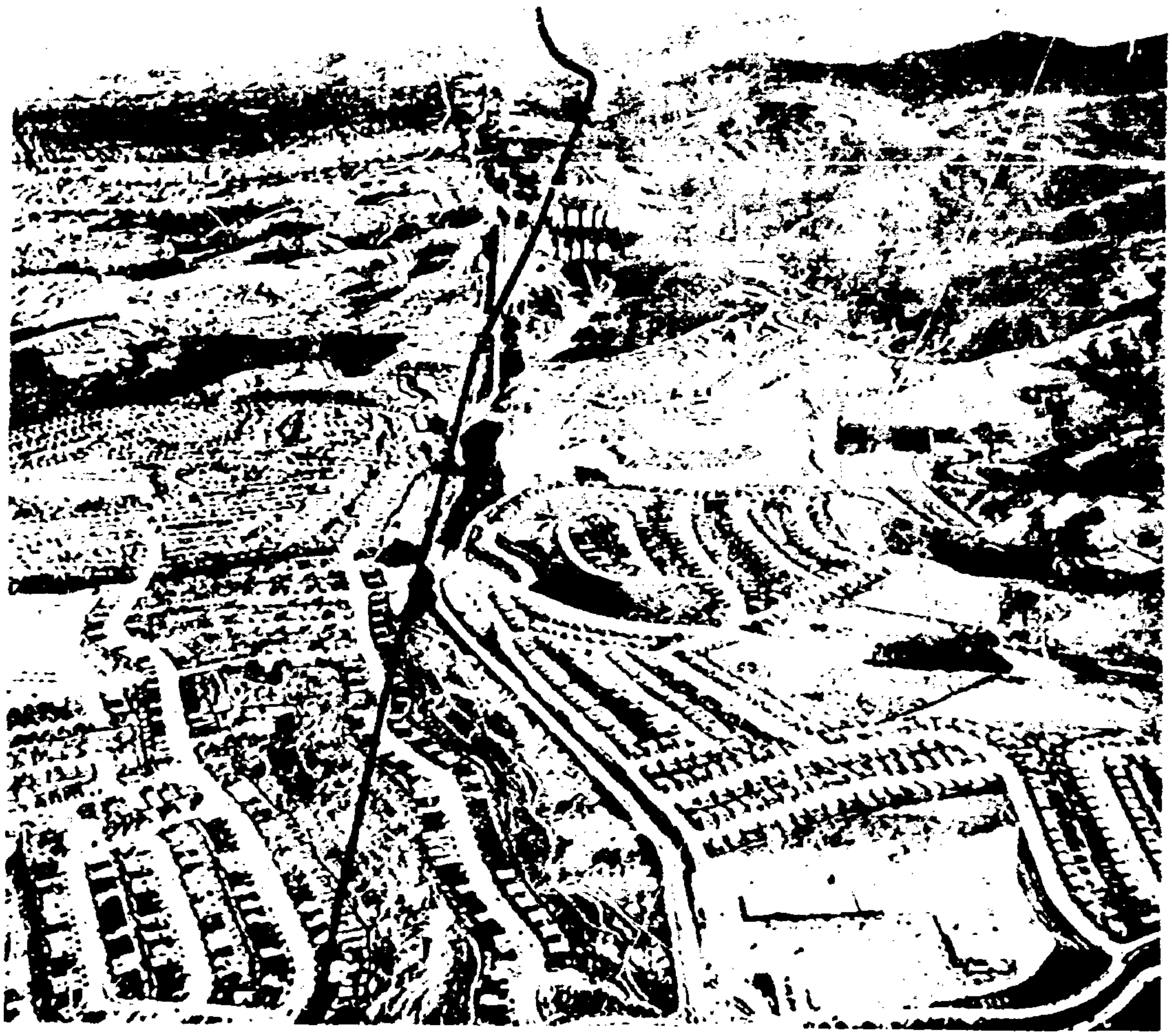

FIGURE 9 Housing tracts are being built within the San Andreas fault zone. Solid line indicates approximate location where the ground was ruptured and shifted more than 5 feet in the 1906 earthquake. Photograph by Robert E. Wallace, U. S. Geological Survey

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