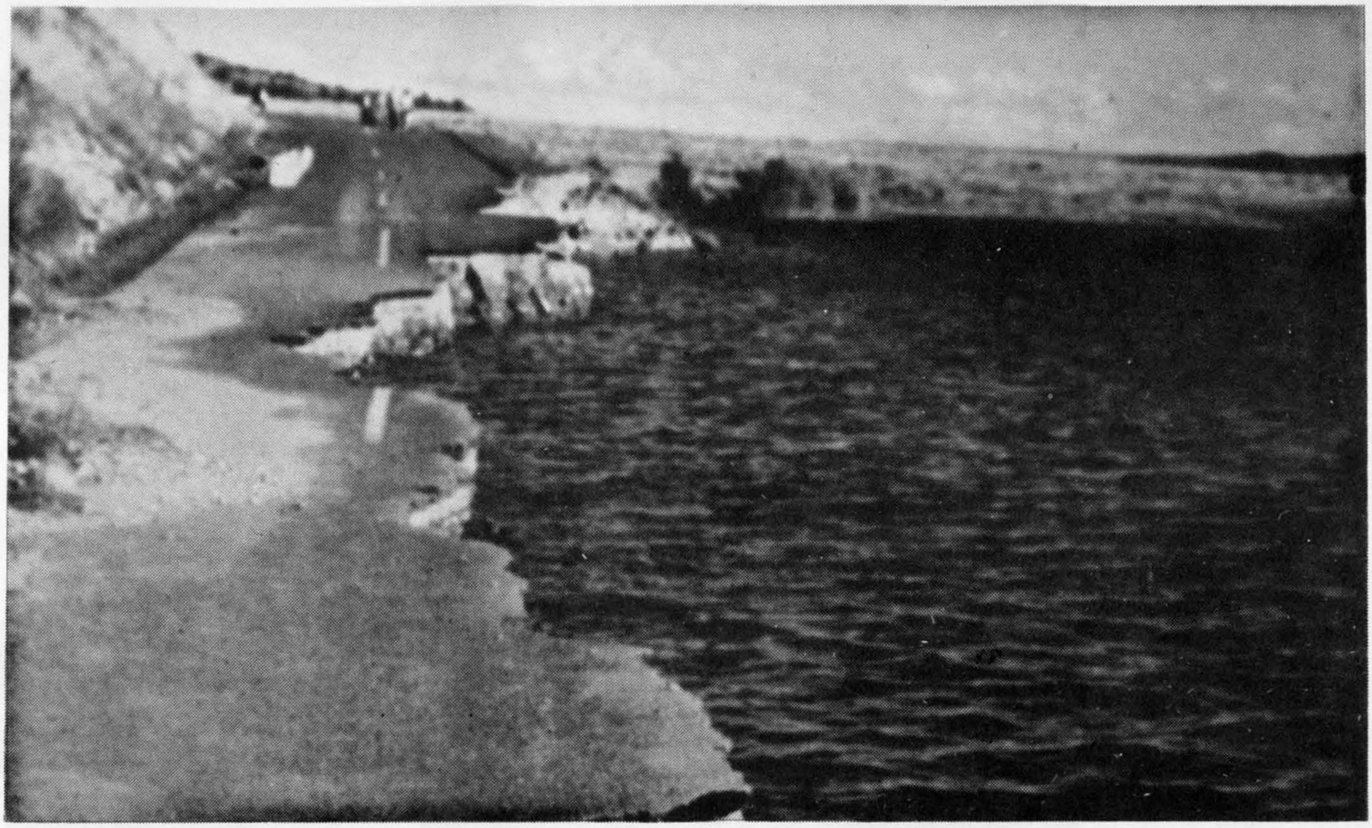
EARTHQUAKE DAMAGE TO TRANSPORTATION SYSTEMS



U.S. Department of Commerce

National Oceanic and Atmospheric Administration

National Geophysical Data Center

Boulder, Colorado 80303, USA

Earthquake Damage to Transportation Systems

Earthquakes represent one of the most destructive natural hazards known to man. A large magnitude earthquake near a populated area can affect residents over thousands of square kilometers and cause billions of dollars in property damage. Such an event can kill or injure thousands of residents and disrupt the socioeconomic environment for months, sometimes years. A serious result of a large-magnitude earthquake is the disruption of transportation systems, which limits post-disaster emergency response. Movement of emergency vehicles, such as police cars, fire trucks and ambulances, is often severely restricted. Damage to transportation systems is categorized below by cause including: ground failure, faulting, vibration damage, and tsunamis.

Ground Failure

A principal cause of earthquake damage to transportation systems is seismically generated ground failures in the form of **landslides, lateral spreads, differential settlements,** and **ground cracks**. During strong ground shaking, areas of clay-free sands and silts (where groundwater is near the surface) can temporarily lose strength and behave as viscous fluids. Consequently, highways and railways may settle or tilt in the **liquefied soil**, or are ripped apart as the ground flows or spreads laterally.

Ground failure can cause movement of large blocks of soil on top of a liquefied subsurface. There lateral spreads, which break up into many fissures and scarps, usually develop on gentle slopes. In the 1964 Alaska earthquake, lateral spread failures damaged streets and highways, and restricted the use of railway grades and bridges.

Ground failure also can dislodge rock and debris on steep slopes, triggering rockfalls, avalanches, and earth slides. The dislodged material is deposited on highways and railways, blocking traffic for hours or days.

Faulting

Earthquake surface faults sometimes cross highways and railroads. Where this occurs, the roadbed may shift in the horizontal or vertical plane, or both. Roadway buckling sometimes results from ground shortening where thrust faulting occurs, and distortion can result from drag rebound or from concealed, closely spaced fractures. The length of surface fault ruptures in major earthquakes is highly variable ranging from a few hundred meters to about 400 km. Fault displacements have varied from less than a centimeter of differential offset to more than 10 meters.

Vibration

One of the most common disruptions to traffic in city streets occurs where debris from earthquake-damaged buildings blocks roadways. Highway structures sometimes fail where built on earth fills that settle during strong shaking, or where columns and supports are unable to withstand lateral or vertical movement. Several failures of raised highways occurred during the destructive 1971 and 1989 California earthquakes. Heavy earthquake damage occurred to some highway structures in spite of the fact that they were constructed of reinforced concrete or of pre-stressed reinforced concrete; span construction was generally superior.

Tsunamis

Another less common hazard to highways and railroads results from tsunamis (incorrectly called tidal waves) generated by offshore earthquakes. A large tsunami can wash out bridges, docks, and wharfs, and also may destroy railroads and highways near the ocean shore.

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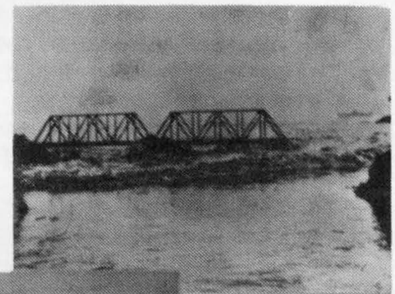
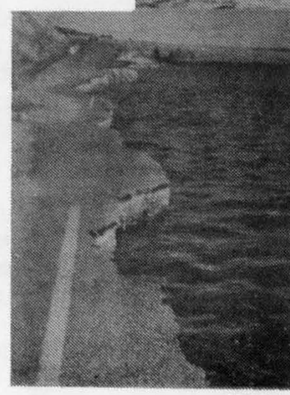
Earthquake of April 1, 1946, Aleutian Islands, Alaska. (Slide 1) Catastrophic waves (tsunamis) generated by the 7.4 magnitude earthquake in the Aleutian Islands engulfed the Hawaiian Islands. The maximum rise of water was as much as 17 m on the Island of Hawaii. The tsunami cost the islands 159 lives and $26 million in property damage (1946 dollars).



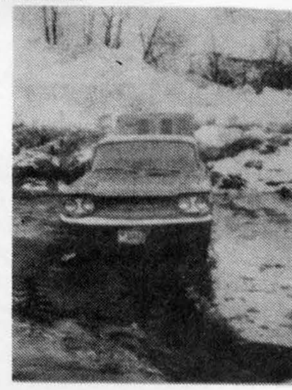
1-[TSUNAMI DAMAGE]
This picture taken near Hilo, Hawaii, shows a bore advancing up the Wailuku River past the railroad bridge. The water rose about 5.1 m at the mouth of the Wailuku River. A steel span of the railroad bridge was torn from its foundation and tossed 273 m upstream by an earlier wave. Photograph credit: Univ. of California at Berkeley.

Earthquake of August 18, 1959, Hebgen Lake, Montana. (Slide 2) The magnitude 7.1 earthquake killed 28 and caused $11 million in property damage. The shock was felt over 1,560,000 km^2.

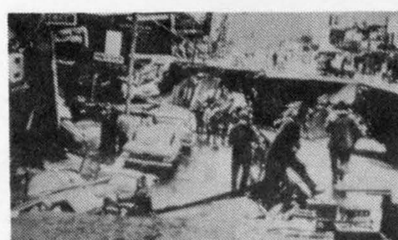


2-[DAMAGE CAUSED BY GROUND FAILURE]
In this photograph a section of Highway 287 has slumped into Hebgen Lake. Highway 1 was made impassable for a distance of nearly 56 km from its intersection with U.S. Highway 191. Over 200 vacationers were trapped in Madison Canyon when the earthquake destroyed sections of the highway. Timber and road damage from this shock were estimated at $11 million. Photograph credit: Univ. of California, Berkeley.

Earthquake of March 27, 1964, Gulf of Alaska. (Slides 3-8) This 8.5 magnitude earthquake, one of the largest earthquakes in our century, caused between $350-500 million in property damage in Alaska and directly resulted in the deaths of nine people. An area consisting of 120,700 km^2 was shaken with damaging intensity.



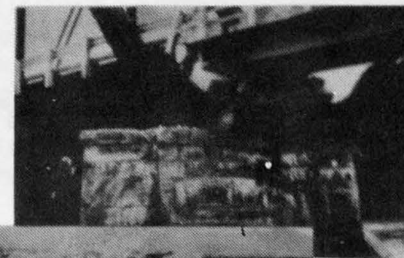
3-[DAMAGE CAUSED BY GROUND FAILURE]
In this photo a car straddles a crack in the pavement caused by lateral spreading in the 1964 earthquake. The Alaska highway system in the region of strong shaking was severely damaged. Roads in soft ground or on embankments sustained extensive cracking, settlement, and sloughing. More than $13 million was needed to repair the damage. Photograph credit: NOAA/NGDC.



4-[DAMAGE CAUSED BY GROUND FAILURE]
This view of Fourth Avenue in downtown Anchorage shows the damage to the street and buildings resulting from the landslide. There was 3.3 m of subsidence and 4.2 m of horizontal movement. Two and one-half blocks of shops, bars, and stores slowly settled until their entrances were below street level. The landslide was induced by a combination of loss of strength in sensitive (quick) clay layers and liquefaction of sand and silt lenses. Photograph credit: Earthquake Engineering Research Institute.

5-[DAMAGE CAUSED BY GROUND FAILURE]
This aerial view shows the effects of compression by movement of unconsolidated stream bank material on the railroad. Longitudinal compression dislodged the wooded railroad bridge superstructure from the substructure. Two and one-half years and $22 million were required to repair the damage to the railway system. Photograph Credit: University of Colorado.

6-[VIBRATION DAMAGE]
The steel trusses of the Copper River and Northwestern Railroad bridge near Round Island were shifted from one-third to two-thirds meter. This view shows one of the displaced trusses, which pounded against an adjacent steel girder span. The girder span was moved to the right, its concrete pedestal was rotated, and the girder span almost fell into the river. Note the shortening indicated by buckling of the guard rail. Photograph credit: U.S. Geological Survey, Menlo Park, CA.

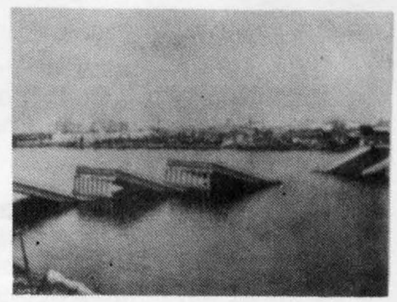


7-[TSUNAMI DAMAGE]
The tsunami caused much damage to the railroad facilities at Seward Port. Rails were stripped from the railroad ties by the tsunami. Most of the Alaska Railroad dock was washed away by the waves. The railroad also lost two cranes and its waterfront trackage. Note also the fire-damaged oil storage tanks. Damage at Resurrection Bay totaled $14.6 million dollars. Photograph credit: NOAA/NGDC.

8-[TSUNAMI DAMAGE]
This photo shows a beached fishing boat in the Seward area. The tsunami waves severely damaged many boats and washed them into the lagoon north of Seward and onto the tidal flats at the head of Resurrection Bay. Dock and harbor facilities were destroyed. A section of the waterfront about 1,060 m long, including the docks and the small boat harbor, slid into Resurrection Bay. Photograph credit: University of Colorado.

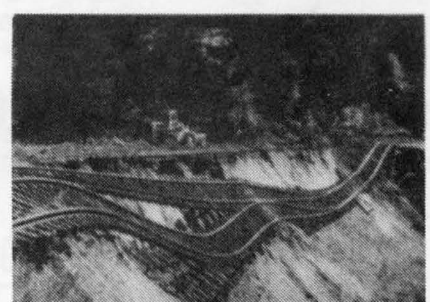
Earthquake of June 16, 1964, Niigata, Japan. (Slide 9)
The magnitude 7.4 earthquake killed 26 people, injured 447, and destroyed 3,018 houses and moderately or severely damaged 9,750 structures in Niigata prefecture.

9-[VIBRATION DAMAGE]
The Showa bridge pictured at left had only recently been opened to traffic. The bridge had seven spans across the river, each supported by piers consisting of structural steel girders carrying a reinforced concrete deck. Two of the piers collapsed. The corresponding spans of the bridge collapsed and dropped into the river. The successive spans toward the west bank also dropped while one end of each span remained connected at the top of successive piers. The construction was such that one end of the girders was locked and the other end was free to slide longitudinally off the pier after about 30 cm of movement. Photograph credit: NOAA/NGDC.



Earthquake of April 29, 1965, Seattle, Washington. (Slide 10)
The magnitude 6.5 earthquake killed 7 and caused $12.5 million property damage. The shock was felt over an area of approximately 336,700 km^2 of the United States and British Columbia, Canada.

10-[DAMAGE CAUSED BY GROUND FAILURE]
Damage to the Union Pacific Railway occurred when hillside fill slid away from beneath a 121-m section of the branch line just outside Olympia more than 60 km from the epicenter. Photograph credit: University of California, Berkeley.



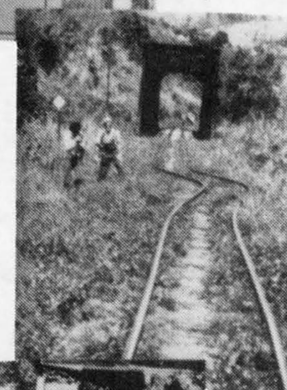
Earthquake of February 9, 1971, San Fernando, CA. (Slides 11,12)
The magnitude 6.7 earthquake killed 66 and caused $0.5-1.0 billion in property damage in the San Fernando Valley, California. Seventy highway structures were damaged. Numerous roads and city streets in the Sylmar-San Fernando area were made dangerous or impassable by ruptures. Railroad rails were distorted.

11-[DAMAGE CAUSED BY FAULTING]
This photograph shows freeway compression of about 67.5 cm that occurred south of the Interchanges of Routes 5 and 210. Structural damage to highways and bridges centered in an area north of San Fernando. This area included the Route 5/210 Interchange and the Route 5/14 Interchange which are about 1.7 km apart along Route 5 and about 10 km from the earthquake epicenter. Photograph credit: NOAA/NGDC.

12-[DAMAGE CAUSED BY VIBRATION]
Among the most spectacular damage was the collapse of freeway overpasses such as the one shown here that was under construction at the time of the earthquake. At the Route 5/210 interchange (Foothill Boulevard and Golden State Freeway,) three highway overpasses totally collapsed and two required rebuilding. Two men were killed at this location when one of the overpasses collapsed smashing their truck. Photograph credit: J.R. Evans.

Earthquake of February 4, 1976, Guatemala. (Slides 13, 14)
The magnitude 7.5 earthquake killed 23,000, injured 76,000, and caused $1.1 billion in property damage. The earthquake was felt over 100,000 km^2 and was accompanied by the most extensive surface faulting in the Western Hemisphere since the 1906 San Francisco earthquake.

13-[DAMAGE CAUSED BY FAULTING]
The picture is looking north along railroad tracks that were twisted and offset 107 cm by the Motagua fault, which is perpendicular to the tracks. This is one of numerous localities along the main railroad line between the coastal port of Puerto Barrios and Guatemala City disrupted by the faulting. Photograph credit: U.S. Geological Survey.



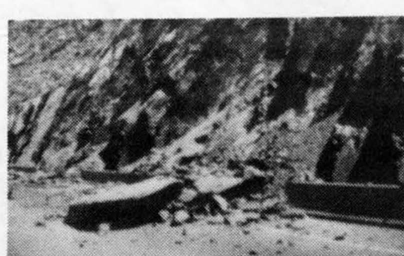
14-[VIBRATION DAMAGE]
Collapse of three central spans of the Agua Caliente Bridge on the road to the Atlantic Ocean. Both ground shaking and ground failure contributed to this collapse. Photograph credit: Earthquake Engineering Research Institute.

Earthquake of April 24, 1984, Morgan Hill, California. (Slide 15)
This magnitude 6.2 earthquake caused $30 million in property damage in northern California. The earthquake was felt over an area of 120,000 km^2 in California and western Nevada.

15-[DAMAGE CAUSED BY GROUND FAILURE]
A landslide blocked the highway and bridge on Dunne Avenue at the east side of Cochrane Bridge. The bridge on East Dunne Avenue over Anderson Reservoir (about 7.2 km east of Morgan Hill) was closed to traffic due to a rock slide and major structural damage. Photograph credit: U.S. Geological Survey.

Earthquake of July 8, 1986, Palm Springs, California. (Slide 16)
The magnitude 6.0 earthquake caused $4.5 million in property damage and injured at least 29 people. Landslides occurred in the area. The shock was felt throughout much of southern California and in Las Vegas, Nevada, Lake Havasu City, Arizona and in the northern Baja California area of the United States and Mexico.

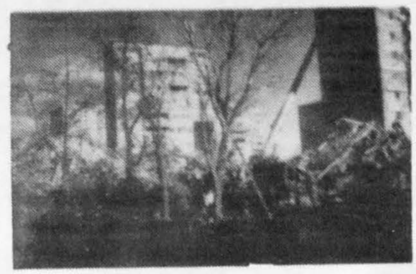
16-[DAMAGE CAUSED BY GROUND FAILURE]
A rockfall and debris slide has partially blocked the highway. Photograph credit: Bay Area Regional Earthquake Preparedness Project.



Earthquake of September 19, 1985, Mexico City. (Slide 17)
The magnitude 8.1 earthquake struck Mexico City at 7:17 A.M. on September 19, 1985. An estimated 10,000 people were killed, 20,000 were injured, and $5 billion in property damage was sustained.

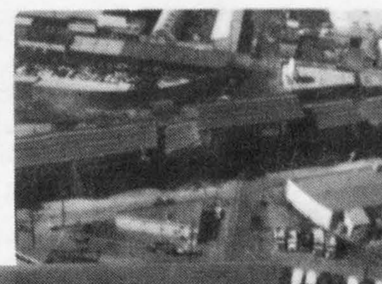
17-[DAMAGE CAUSED BY GROUND FAILURE]
Vibration caused failure of the subsoils and subsidence which resulted in the collapse of streets. This type of damage was particularly prevalent in Mexico City since much of the city is located on unconsolidated lake-bed sediments. These soft sedimentary clay deposits amplified the seismic waves and resulted in ground failure. Photograph credit: Munchener Ruck, Munich Re.

Earthquake of December 7, 1988, Armenia. (Slide 18)
The magnitude 6.9 earthquake shook northwestern Armenia and was followed four minutes later by a magnitude 5.8 aftershock. The earthquakes hit an area 80 km in diameter comprising the towns of Leninakan, Spitak, Stepanovan, and Kirovakan in Armenian SSR. Twenty-five thousand were killed, 15,000 were injured, and direct economic losses were put at $14.2 billion (U.S.).

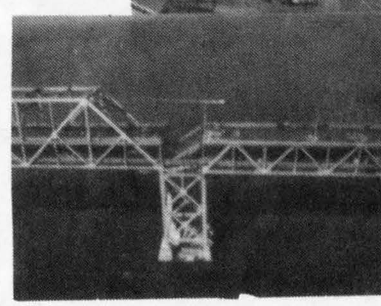


18-[DAMAGE CAUSED BY VIBRATION]
The ground shaking resulted in the partial or total collapse of buildings in Leninakan and filled the streets with debris making them impassible. The heavy equipment needed to lift off heavy sections of buildings to free survivors had difficulty getting to the sites. Photograph credit: U.S. Geological Survey (C.J. Langer).

Earthquake of October 17, 1989, Loma Prieta, CA. (Slides 19, 20)
The magnitude 7.1 earthquake was located 96 km south-southeast of San Francisco. It killed 67 people, injured 3,757, and caused an estimated $7 billion dollars in property damage. Although the earthquake occurred in the remote Santa Cruz Mountains, it was one of the costliest natural disasters in United States history.



19-[DAMAGE CAUSED BY GROUND FAILURE AND VIBRATION]
Close-up view looking west of Cypress Section of I-880 in Oakland in which fifty-one spans collapsed. A truck is visible on the lower roadway under the one span that did not collapse. Photograph credit: U.S. Geological Survey (E.V. Leyendecker).



20-[DAMAGE CAUSED BY VIBRATION]
View of the double-deck San Francisco-Oakland Bay Bridge looking towards the north. San Francisco is to the west and Oakland is to the east, support Pier E-9 is located in the center of the photo. The 15-m long deck sections in both the upper and lower decks were pulled from their support bearings when the 88-m long truss on the right of Pier E-9 moved about 25.4 cm east. Photograph credit: U.S. Geological Survey (E.V. Leyendecker).

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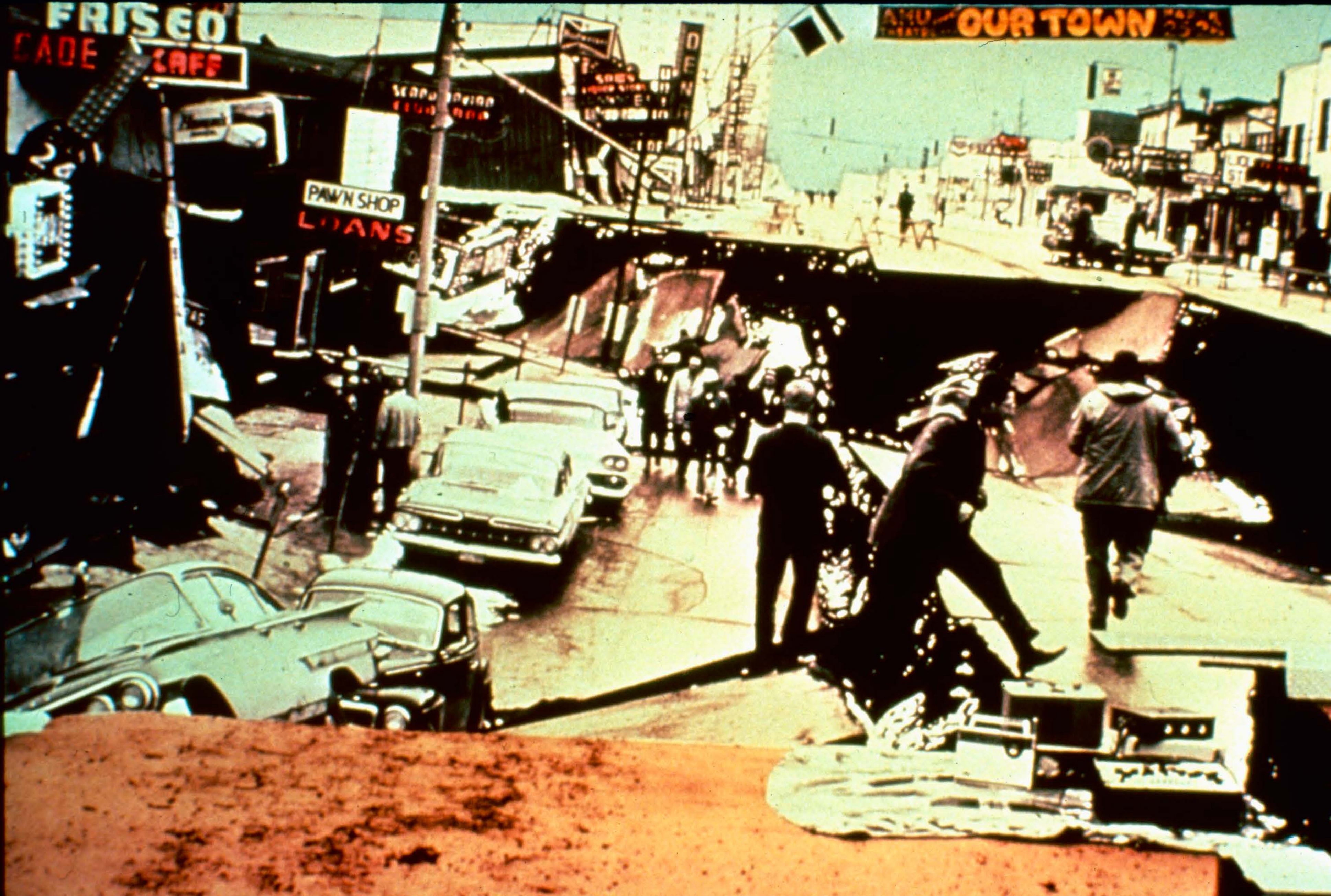
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