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PERFORMANCE OF LIFELINES DURING RECENT EARTQUAKES

BY

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ABSTRACT

Lifeline systems provide the only effective way to overcome potential inefficiencies of human activities in time and space caused by urban growth in size and improved quality of life. Damage to these systems in recent earthquakes has highlighted their significance and impact on the social fabric of a society. This article describes the components, risks and remedies associated with each lifeline system alongwith its performance in recent earthquakes. In the last section observations and recommendations are made for conditions in Pakistan.

1. INTRODUCTION

The functioning of daily life in the urban areas heavily upon the operation of society's lifelines which can be grouped into five categories : transportation facilities, water supplies and sewerage, gas and oil lines, power lines, and communication links. These are called "Lifelines" as these are systems with wide spatial distribution, passing through various regions and often forming a continuous link between various cities and towns. Another characteristic of lifeline facilities is their highly hierarchical configuration owing to which any disruption at one location can severely hamper the smooth flow of everyday life in other parts. Their failures (and proper documentation) in recent earthquakes have drawn attention to their importance and much research on how to safeguard these facilities is now in progress. Their importance can be judged from the fact that lifelines are dealt as a separate entity while evaluating the effects of any earthquake as damage to these facilities constitutes a major chunk of the cost of whole disaster both in terms of direct structural damage and indirect damages incurred due to loss of functionality and closure of business.

In this article a brief overview is provided for each type of lifeline along with a historic note on its performance in the past earthquakes in different regions of the

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World. The vulnerable links in each system and possible remedial measures are also discussed. Finally observations are made with regard to conditions in Pakistan.

2. TRANSPORTATION LIFELINES

These include roads, highways, railways, highways and rail road structures (bridges, tunnels, culverts, flyovers etc.), airport and harbours. Due to the devastating effects of their failures in terms of both financial loss and social disruption, the components of transportation lifelines are receiving the maximum attention from both transportation authorities and researchers.

2.1 Performance of Bridges

Bridges seems to be the most vulnerable component. Several spectacular failures are well documented (Figures 1 to 5) caused by either structural or soil failure. Inadequate bearing seat length, lack of continuity and shear-susceptible sub-structure design has traditionally been blamed for most of the damage. Some or all of these short-comings can be found in bridges built in Pakistan which are mostly supported on squat sub-structure with non-ductile detailings, have simply supported discontinuous superstructure and span rivers susceptible to both scour and liquefaction.

Collapse of Cypress Viaduct and Oakland Bay bridges in the 1989 Loma Prieta earthquake, near San Francisco, and damage to other freeways accounted for nearly one third of the $7 billion damage [1] . How soil failure can devastate a robust looking and supposedly, earthquake proof transportation network of elevated highways and bullet trains is evident after the 1995 Kobe earthquake in Japan. Severance of these vital communication links and collapsed bridges delayed emergency relief efforts by hours thus compounding the miseries unleashed by this $100 billion rumbler [2]. Structures designed to old (1960's and 70's) code suffered most of the damage as retrofit measures were not envisioned necessary in this part of relatively earthquake free western Japan [3]. Exactly a year earlier, failure of nine elevated highways during the 1994 Northridge earthquake near Los Angeles not only disrupted the transportation system but also severely hampered the rescue operations. Cost of the whole disaster was estimated to be $ 30 billion [4].

2.11 Current Trends in Aseismic Design of Bridges

Current state-of-the-art in bridge engineering is the use of super structure isolation using various devices like Spherical Sliding bearings (or FPS bearings), Rubber Springs, Wire Rope Springs and Fluid Spring dampers [5]. Isolation using uplift or rocking which involves a discontinuity of contact between part of the foundation and the soil, or between a column and its base has also been employed. One such example is the 320m long South Rangitikei railway bridge in New Zealand [6]. It was constructed in 1971 and has performed satisfactorily todate. Non isolation techniques stress the need of ductility based capacity design of the substructure elements along with proper attention to detailing in reinforced concrete structures [7,8].

2.2 Highways and Railway Tracks

Highways and railway tracks are susceptible to damage due to soil liquefaction and/or landsliding (Figure-6). Answer to this problem lies in proper soil investigations to asses the liquefaction potential of the area through which it is planned to pass. The same is true for airport runways. Airport terminals and control buildings should be engineered to withstand the earthquake without losing functionality. Tunnels and subways have his historically performed satisfactorily due to their buried and confined nature with the exception of the recent Kobe quake in Japan which severely damaged a 100m long section of the Kobe underground rapid transit tunnel [3]. This failure is highly significant because it is the first instance of severe earthquake damage to a modern tunnel for reasons other than fault displacement.

2.3 Harbours and Ports

Damage to ports and harbours have been either due to ground failure or tsunami. Tsunami resulting after the 1964 Alaska earthquake not only destroyed the port of Kodiak in Alaska but also played havoc with Californian port of Crescent City nearly 2,600 Km away. The 1993 earthquake of Guam [9] caused liquefaction induced soil failure beneath the container handling area of the commercial port resulting in serious economic consequences for the island nation..

2.4 New Tools for Assessment of Damage

Emergency relief to the effected area can be delayed, with dire consequences of course, due to disruption in this lifeline. Geographical Information System (GIS) is currently being used to study the effect of earthquake on the emergency response due to some failure in the transportation system (say a collapsed bridge [10].

3.0 WATER SUPPLY AND SEWERAGE SYSTEM

3.1 Performance of Water and Sewer Pipes

Water is not only required for everyday use but in the case of any catastrophe like earthquake, it is also needed for fire fighting. The components which constitute this system are: pipelines, elevated and ground reservoirs, pumps, pump houses and their accessories. As pipelines are buried in soil, so these are well confined on all sides. These get damaged only due to excessive soil movement (Fig.7). Other component at risk is the joints (Fig.8). In seismically active regions, flexible joints are now in common use (Fig.9). Water supply system has suffered damage in almost every moderate and strong earthquake[4,9,11,12,13]. The great fire after the 1906 San Francisco earthquake, which reduced the city to ashes, was mainly due to broken water mains which left the city without water for fire fighting. These breaks were mostly caused by lateral spreading of liquefied soil[14].

Pipelines of sewerage system are also vulnerable to the same degree but their failure is not mentioned in most of the post earthquake reconnaissance reports as it is very difficult to detect leaks in this gravity flow system, except in the case of a choked system. Whereas a drop of pressure can easily identify leaks in the water supply system. Self-activated isolation valves which start functioning after a threshold ground acceleration, are currently being used[15] to reduce the loss of water, through broken mains, from storage tanks. This type of solution is required as the cost of repair to older system is prohibitive. For example cost of replacement for Seattle water system is $100 million[16].

3.2 Performance of Water Retaining Structures

Chilean earthquake of 1960 severely damaged the water reservoirs and prompted

detailed study of their seismic response[17]. Elevated water tanks are at great risk of damage due to their inverted pendulum configuration in which a great mass is concentrated at the far end from ground which not only generates horizontal inertia forces but also overturning moment due to P-Δ effect. This is the reason that most building codes are ultra-conservative while dealing with these structures and it is recommended to design them ensuring elastic behavior even when subjected to earthquake forces. Because of the hydrodynamic effects, sloshing of the contained liquid can cause spillage or damage to the roof. Excessive bracing and rigidity of the supporting frame is the only economical solution. Sophisticated solution include base isolation and active control. Underground tanks may be subjected to excessive buoyancy because of increase in the pore water pressure associated with soil liquefaction as was observed during the 1964 Nigata, Japan earthquake.

4. GAS AND OIL LINES

4.1 Performance in Past Earthquakes

In the modern industrialized society, gas and oil not only constitute the main energy source for running power plants, factories and assembly lines, house hold use and for most of the transportation modes but also a major source of revenue for oil rich countries. Their supply from the source to the different parts of a country is effective and economical through large dia, high pressure pipelines. These pipelines constitutes a very linear system passing through different kind of soils and terrain.

During an earthquake, damage to pipelines, along with other buried structures, may be caused by either traveling ground waves or permanent ground deformation. Although traveling seismic waves cover a larger area than that in which permanent ground deformation occur; their damaging effects are far lesser than that caused by the rather localized ground movement associated with liquefaction and landsliding. Seismic waves develop strains in buried pipelines, but because there are little or no inertial effects from dynamic excitation, the strains usually remain below yield level. There is only one documented case, during the 1985 Mexico City earthquake, that damage to modern girth welded steel pipeline was caused by traveling waves[18]. In contrast, the greatest earthquake damage to such pipelines has been caused by large ground deformations. During the 1964 Alaska earthquake, soil liquefaction, landslides and tectonic subsidence caused over 200 breaks in Anchorage gas distribution system

and ruptured a fuel tank flooding the area with 1,200,000 liters of diesel fuel[19]. Eight of the 12 pipelines and conduits connecting the dock and the Puerto Cortes Refinery in Honduras were ruptured during the 1976 Guatemala earthquake[20]. The largest single pipeline loss in history resulted from a massive landslide and flooding during the 1987 Ecuador earthquake which washed away nearly 40 km of the 660mm dia. Trans-Ecuadorian petroleum pipeline. Most of the damaged portion was supported above ground, either on 'H' pile support frames or concrete pedestal foundation saddles. Cost of reconstruction plus lost revenues for six months totaled $1.2 billion[21]. Any rupture in these lines can instantly cause fire as was observed during the 1994 Northridge earthquake where one oil main and 250 gas lines ruptured igniting untold number of fires[4,22].

4.2 Remedial Measures

Because the fate of buried pipelines is the fate of the ground, engineering measures to mitigate damage should focus on the hazards of ground failures. The most likely location of liquefaction induced ground deformation occurs at river crossings as shown in Fig.10. Other potential weak spots exists at locations of restraints like connection with bridge abutment, tanks or buildings and equipment anchorages at pump and compressor stations. Severance of these pipelines can easily cause an environmental disaster by contaminating the surface/sub-surface water and/or fouling the wildlife habitat.

5. POWER LINES

5.1 Performance of Power Station Components

The vulnerability of electrical transmission equipment was highlighted during the 1971 San Fernando earthquake. Severe damage to central switchyards and sub-stations caused long power outages and direct and indirect financial loss. It was estimated that about 10% of the total cost of damage was attributed to damage to mechanical and electrical equipment in this earthquake[23]. Toppled equipment (Fig.11) was a common scene at many power/distribution stations. Unanchored equipment, like transformers, switch gears, control panels etc., at these facilities, remains todate the most vulnerable component (Fig.12) alongwith piping and ducting at thermal/nuclear power plants. Base isolation for critical components has been successfully employed using lead-rubber bearing pads and hydraulic or friction dampers[24,25]. Local outages can also be caused by transformer fires, wires

slapping together and wire burning down. Nearly 3 million people were without power after the 1994 Northridge earthquake[4].

5.2 Performance of Transmission System

Performance of high tension power transmission system can be put to test due to ground movement or landslides. In such cases the tower can give way causing snapping of HT cables and subsequent power failure down the line. However, highly redundant configuration of the transmission towers help to minimize this type of failure. In the Landers earthquake of 1992[13], the two legs of a transmission tower moved 9 ft. apart but there was no damage to the power lines and the ceramic insulators, although some braces got twisted and buckled (Fig.13). After the 1991 Garhwal, India earthquake, the area was without power for a fortnight due to collapsed transmission system as a result of earthquake triggered landslides[9].

6. COMMUNICATION LINKS

The importance of communication links can not be overemphasized during and after an earthquake or other calamity in particular and in everyday life in general. Modern communication facilities include telephone, radio, television, microwave links etc. The hardware which constitutes this system is similar to the one discussed under Power lines, therefore it is subjected to the same hazards. But the important difference is that severance of communication links can severely hinder the timely rescue operations. Functioning of telephone system has not suffered widespread damage in recent earthquakes[4,9,11,12,13] except for some tensile breaks in the underground telephone lines.

7. CONCLUDING REMARKS

In established communities, lifelines are already installed and the cost of improving them is formidable. In the meantime, however, engineering knowledge of the behavior of lifeline structures is improving and new installations are made secure by using the current state-of-the-art techniques and ways are sought to improve the performance of older ones in certain viable cases.

The current state of affairs in Pakistan is such that earthquake engineering is still in its infancy and lifeline earthquake engineering can be best described as being in an embryonic stage. Though nobody seems to care about providing the "lifelines" to the people of Pakistan, where daily load-shedding tests the nerves of millions, where only 20% of the population has access to potable water and sanitation facilities, where primary source of energy for 60% of the people is primitive wood and bio-waste, where telecommunication facilities are available mostly to the urban populace; this article may seem to be bit ahead of time. But it should be borne in mind that Pakistan lies in a region where seismicity is moderate but the associated risks to lifelines and other structures are great due to non existent seismic design practices. As the population is growing at a rate of 5% per annum, the land-use patterns are undergoing a visible change at an alarming rate. This is forcing the people to inhibit areas where seismic risk is pronounced on the one hand and on the other improved technology, industrialization and better living standards are helping to expand the existing infrastructure. All these parameters point toward the need to properly cater for the seismic 'demands' of structures and lifelines in various regions of the country. In the past earthquakes in Pakistan, moderate loss of infrastructure was not due to the lesser intensity of the quakes but due to the non-existence of these components. Scenario will be quite different and more miserable in the future if proper planning is not done today. It is hoped that this article will certainly provide some food for thought to those who are concerned with the reduction of social and economical hazards associated with earthquakes.

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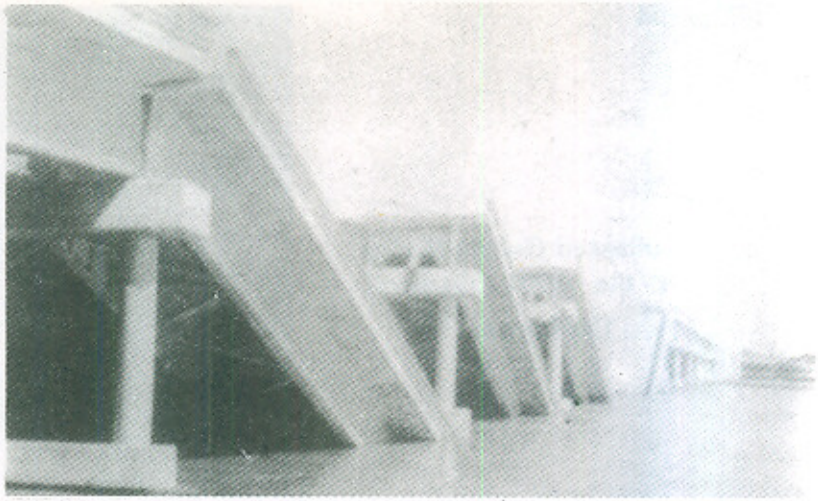


Fig. 1: Showa Bridge damaged in the 1964 Nigata, Japan Earthquake[1]

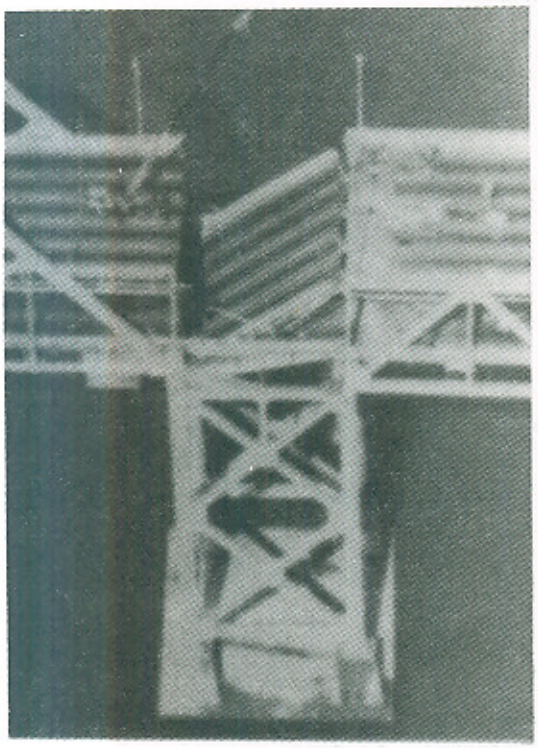


Fig. 2: Collapsed Upper and Lower decks of Oakland Bay Bridge in the 1989 Loma Prieta, California Earthquake[1]



Fig. 3: Punching of severed pile extensions through the deck of the Struve Slough Bridge in the 1989 Loma Prieta Earthquake[1]

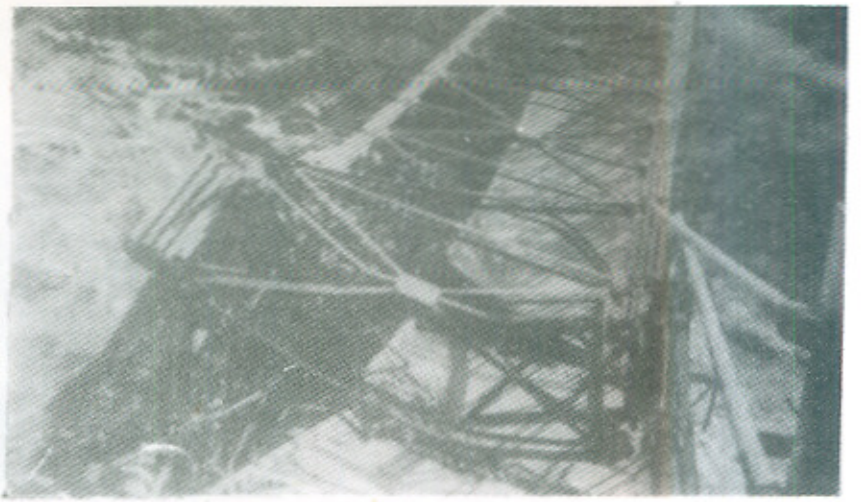


Fig. 4: Collapsed Gwana Bridge in the 1991 Garhwal, India Earthquake[12]



Fig. 5: Shear Failure of one of the Cypress Viaduct's Column during the Loma Prieta Earthquake[1]

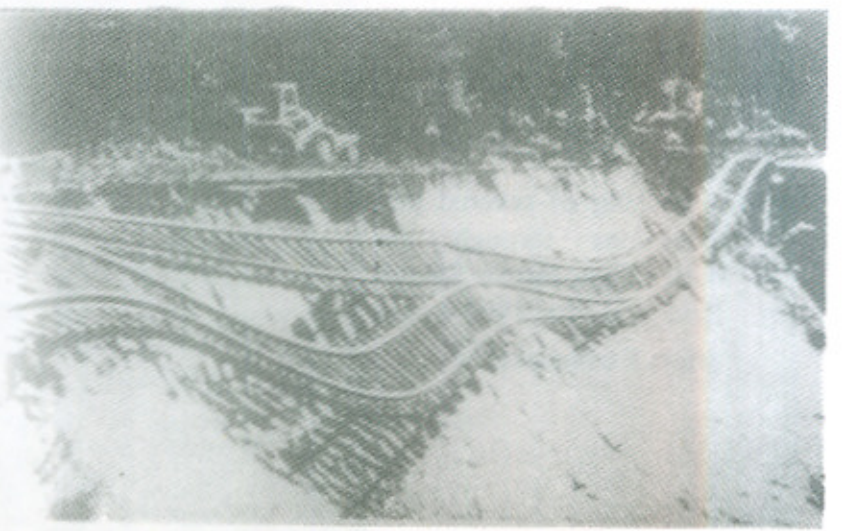


Fig. 6: Railroad tracks hanging in air when the fill beneath them slid away during the 1965 Olympia, Washington Earthquake[26]

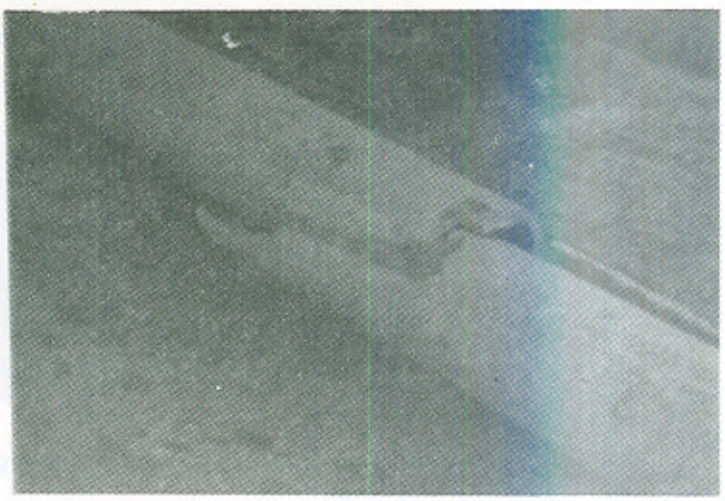


Fig. 7: Telescoping Failure at a joint in 200mm dia. AC water line during the 1992 Landers, California Earthquake[11]

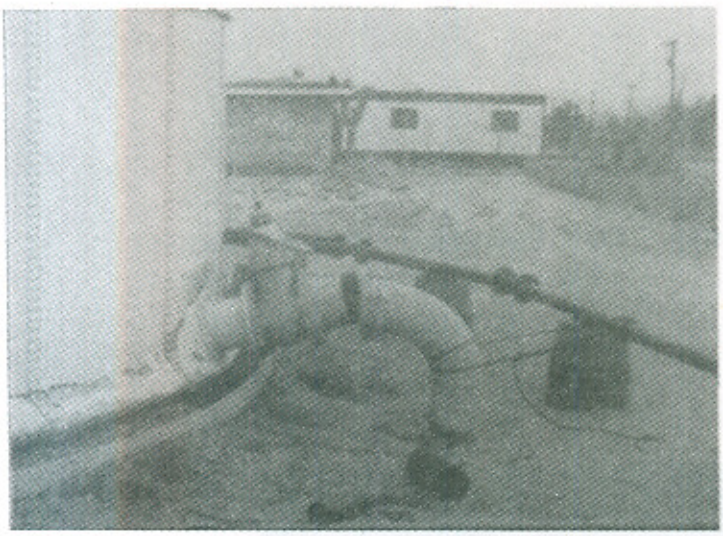


Fig. 8: Elephant Foot Buckling during the 1992 Landers Earthquake[11]

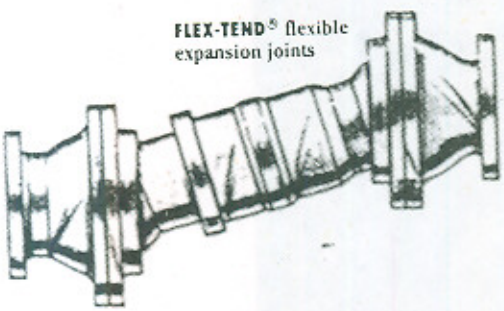


Fig. 9: A Patented Flexible Joint

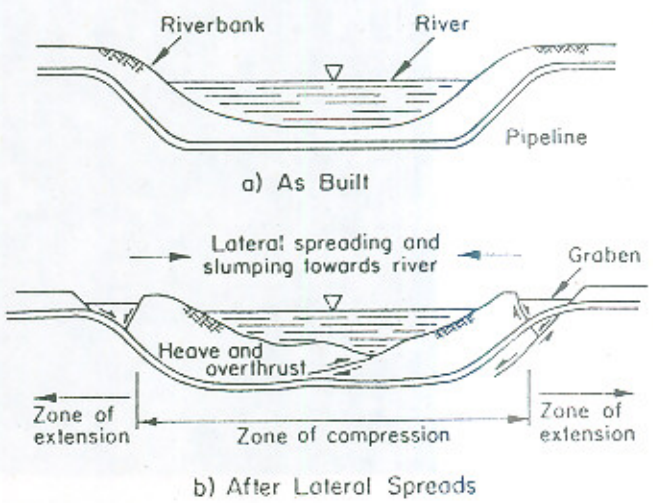


Fig. 10: Profile of pipeline river crossing before and after Liquefaction induced Lateral Spreading.



Fig. 11: Toppled Equipment at the Sylmar Convertor Station: 1971 San Fernando Earthquake[26]



Fig. 12: Overturned Power Supply Equipment at the Navy's Piti Steam Plant: 1993 Guam Earthquake[9]

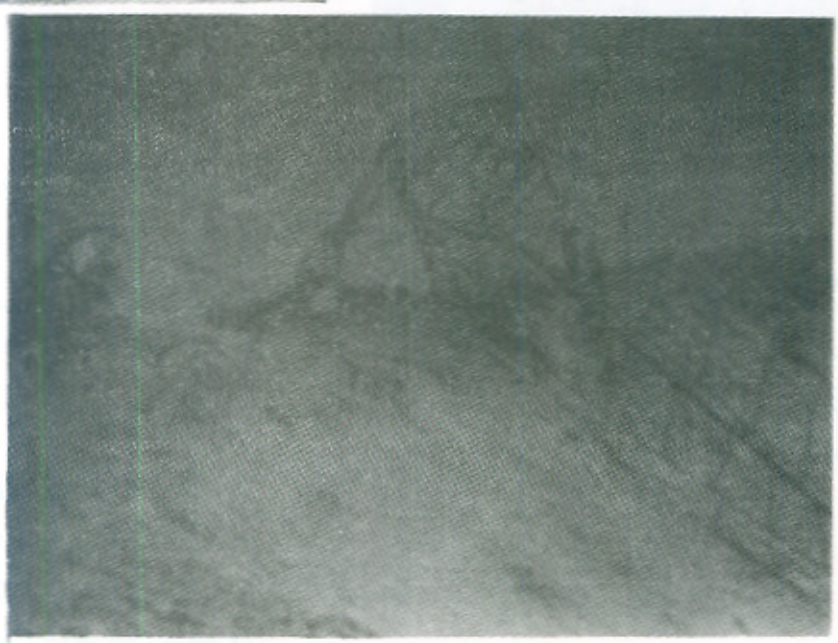


Fig. 13: Footing of a High Voltage Transmission Tower Displaced by Emerson Fault Surface Rupture in the 1992 Landers Earthquake[13]