

Behavior of lifeline systems during Manjil-Iran earthquake of June 20, 1990

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ABSTRACT: The devastating earthquake of magnitude 7.3 struck northern central region of Iran on June 20, 1990. Many major failures occurred in lifeline systems comprising transportation, electric power, telecommunication, and water supply facilities. The damages to lifelines were associated with the ground failure, which not only interrupted the distribution of essential services to the public, but also interfered with the rescue efforts during and after the event. The failure mechanism and lost services of the lifeline systems during the 1990 Manjil-Iran earthquake and their restoration process are summarized in this paper.

1 INTRODUCTION

On June 21, 1990 at 30 minutes past midnight local time (21:00, June 20, 1990 GMT), a catastrophic earthquake occurred in North central Iran. The M 7.3 quake caused widespread damages to two provinces of Iran resulting in, 37,000 life losses and 137,000 building failures (Cuborn,1990).

A number of geotechnical failures contributed to the destruction in this earthquake such as landslides and rock falls, and liquefaction. Local site effects also played a major role in amplifying strong motion and contributed to the structural failures (Eshghi, 1991).

The damages to lifeline systems were directly associated with the resulted failures in ground. Utilities suffered severe damage due to permanent ground movements and surface faulting. Rescue operations were seriously interrupted by debris resulted from rock falls large land slides. Liquefied soil damaged foundations and resulted in disposition of irrigation canals, broken pipelines, cracked pavements, and filled water wells with boiled sand (Eshghi, 1990). After the earthquake, the affected area experienced closures of the roads, suspension of electric power, water and gas supply, down of telephone lines and many other failures in the lifeline systems. The impact of disrupted services on the affected communities has been one of the major characteristics of this earthquake, Figure 1 illustrates locations of the most important components of lifeline systems in the imprinted area (Eshghi, 1990).

This paper presents behavior of lifeline systems comprising transportation, electric power and water supply and telecommunication systems during Manjil-Iran earthquake and draws conclusions regarding their design and reevaluation.

Twenty stations of Iranian national strong motion accelerograph network were triggered

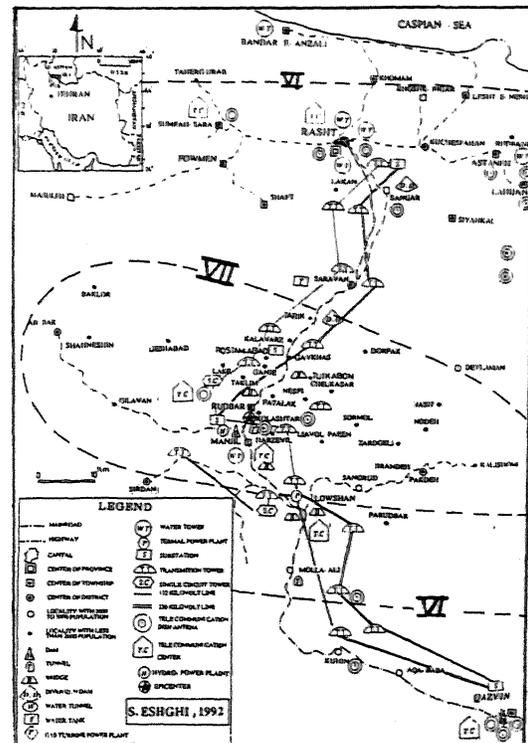


Fig. 1 Map of the imprinted area of Manjil earthquake showing locations of the most important components of lifeline systems.

by this earthquake (Table 1, BHRC, 1991). The accelerogram recorded at Ab-bar, 40 km from the epicentral zone recorded a peak ground acceleration of 0.56g and 0.47g in the horizontal and vertical directions, respectively (Figure 2).

Table 1. Peak values of accelerograms.

St. (km)	Accel. (cm/sec ²)	Vel. (cm/sec)	Dis. (cm)
Ab-bar (40km)	554.2	-26.8	-4.8
Ab-har (65km)	-193.8	-15.89	-2.07
Qazvin (70km)	-183.73	-15.06	-4.00

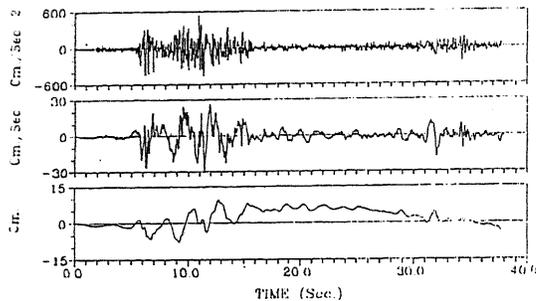


Fig.2 Acceleration, velocity and displacement time histories of the Manjil earthquake of 20 June, 1990, recorded at Ab-bar station.

2 TRANSPORTATION SYSTEM

Transportation lifelines of the area comprising roads, bridges and tunnels suffered severe damage in this earthquake. Landslides, rock falls, and other seismically induced ground failures were the primary causes for the interruptions in the highway system. During the earthquake, steel bridges and tunnels performed fairly satisfactory while reinforced concrete bridges sustained some damages. The damaged structures and debris caused interruption in rescue operations right after the quake, but was cleared within the next couple of days of the event.

2.1 Roads

The extent and types of damages of roads due to the main shock and aftershocks of Manjil earthquake were primarily different and dependent on the position of the road section. Namely, road sections passing through wide and flat areas mainly damaged due to the ground settlements as a result of liquefaction or other types of seismically induced ground failures (Fig.3). Contrary, the road sections passing through steep hilly and mountainous regions were much severely damaged due to the local and global soil and rock slope instabilities. In total, more than 1200 km rural roads were needed improvement or reconstruction (Eshghi, 1991a).

2.2 Bridges

Bridges are usually vulnerable to many earthquake hazards, and represent the most vital links in transportation and other lifelines. There were three types of bridges, built more than 20 years ago, in the affected area: steel truss bridges, concrete girder bridges, concrete slab and old brick masonry arch bridges. Two of the old arch bridges sustained severe damage. Total of 10 bridges, total length ranged from 30 to 800 m, were investigated after the earthquake (Eshghi, 1990). In general steel and R/C bridge structures, performed satisfactory. Damage to bridges due to the earthquake, resulted mainly from:

- (1) Severe disruption and settlement of the bridge approach embankment and abutment fills due to seismic shaking (e.g. most of bridges).
- (2) Liquefaction and lateral spreading of foundation soil (e.g. Bala-Bala bridge).
- (3) High acceleration in the bridge structures (e.g. slab bridges).

Damage to super-structures, those to bearings supports e.g. failures of shoes, breakage of pins, protrusion of rollers, expansion devices and also pounding of longitudinal girders against each other or against abutments, were most prominent. Some shear cracks occurred at the edges of the bridge seats near the shoes. Differential movements damaged sidewalks, service conduits and guard/hand rails (Fig. 4) (Eshghi, 1991b).

2.3 Tunnels

Along Ghazvin-Rasht highway, there were seven tunnels with a total length of about 2 km which effectively resisted damage even in the most devastated areas. In Manjil, an unlined tunnel withstood very heavy shaking and only sustained a large permanent displacement along an inclined plane, due to the movement of the causative fault.

In most cases, damage to the tunnels was limited to partial collapse of the stone masonry portal due to rockfalls, minor exterior spalling and cracking of the linings. (Eshghi, 1990)

3 ELECTRIC POWER SYSTEM

Electricity for approximately half a million houses was cut off as soon as the earthquake hit the areas. So the affected area was plunged into complete darkness. During the Manjil earthquake, many structural and non-structural failures occurred in electric power facilities causing power outages throughout the region for months.

3.1 Electrical power plants

Power plants in the region comprised a 360 MW Lowshan power station and a 87.5 MW Manjil

hydroelectric power plant containing a total of 9 units. Power generating facilities suffered severe damage as a result of the earthquake.

Lowshan power plant (built 1971), was forced to go off the line immediately because of internal station damage. It was located 7 km from Lowshan, equipped with 2x120 MW steam units and 2x60 MW gas turbine units and provided with a 230 kv transformer station. Based on the Ab-bar record which had a peak horizontal acceleration of 0.56g, the resulting PGA for the station was estimated about 0.2g in horizontal direction (Tavakoli, 1991). The bus-duct destroyed due to falling of the non-structural elements (Fig. 5). The foundations of turbo-generator suffered differential settlement and caused misalignment of the turbine shafts. Extensive structural damage also occurred in the plant during the earthquake. Manjil hydro-power plant (built 1963), was located near the earthquake's main fault break. The capacity of HPP was 5x17.5 MW. The framed foundations of the turbines were damaged and one of the steel entrance gates of the penstock was severely deformed by the earthquake. The control room was a reinforced concrete structure which suffered damage due to the collapse of URM infilled walls and other non-structural elements.

At the switchyard, the heavy transformers rose over the rails and displaced about 25 cm in horizontal directions indicating the considerable effect of the vertical component of the earthquake (Eshghi, 1990).

3.2 Electrical transmission facilities

Three electrical substations were failed due to the structural and equipment damage. The equipment damage was attributed to the failure of ceramic components which were primary structural members in many of them. Transformers were not anchored, thus rolled, slid and bounced off their rails or foundation pads (Fig. 6). Temporary restoration allowing basic operation of substations were achieved in a matter of weeks.

High-voltage transmission lines and towers performed satisfactory in the Manjil earthquake. Only a few number of transmission towers in the epicentral region were damaged or destroyed, mostly due to rockfalls or foundation failure.

3.3 Distribution facilities

Damage to overhead line reticulation system which supplied by national grid was severe, mainly due to falling parts of residential buildings. Distribution wires warped around each other, and became entangled. Modes of failures were as follows; Insulations being pulled off houses of poles; Overhead lines breaking under stress, poles moving out of alignment, Pole-mounted transformers shifting

of platforms; Oil leaked from transformers on utility poles; Transformers fell from utility poles; and some poles collapsed. The system returned to normal conditions within one year of the event.

4 TELECOMMUNICATIONS SYSTEM

Telecommunication systems including central dial offices (central collection and switching stations), conduits and poles for wires, damaged due to the earthquake in relatively vast region.

Manjil and Rudbar telecom centers, main building of TCI, three telephon exchange building in Rasht and also many dial office buildings damaged due to the partial or total collapses of structures. Performance of essential equipment within these offices was unsatisfactory due to lack of any equipment anchorage and bracing system. Many wood telephone poles snapped at rotted bases and toppled or overturned due to rock-falls. The microwave network relay including steel aerial (antenna) towers, The network and its towers performed very well, during the quake.

Many aftershocks caused new rockfalls, and made it impossible to carry out a rapid repair and restoration operation, hence it took more than one year to complete the operation. A portable microwave station was used to link the stricken towns and cities together within 24 hours, after the event. However, a mobile telephon exchange was operated about 100 days after the earthquake.

5 WATER SUPPLY SYSTEM

Water supply facilities of the area were comprised of intersecting gridworks of pipelines, storage facilities, pumping plants, treatment plants, under-river collector wells, water wells and springs. During Manjil earthquake, Water supply systems of three cities and many villages were damaged extensively and in more than 280 villages had been destroyed by more than 70%. Full restoration of water supply system to normal conditions extended more than one and half years.

5.1 Pipelines

During this earthquake, water distribution pipelines suffered moderate to severe damages. Service pipes leading from the main to the consumer were cast iron and asbestos cement and main transmission pipelines were prestressed concrete. Earthquake damage to water supply networks in the affected area was widespread. Most of the damage occurred to cement asbestos pipes. Some of the pipes were bent because they partially sank, other pipes were broken in the axial direction, and others cracked at junctions.

In mountainous areas, pipe ruptures have

been mainly caused by large ground deformations as a result of extensive landslides, wide ground cracks, and settlements of uncompacted soil deposits.

In lowland regions, the damage to the water pipes have been mainly due to liquefaction resulting in severe dynamic soil instability and large permanent vertical deformations of the ground.

5.2 Wells and pumping plants

Water wells suffered cracking or shearing of the well casing and disruption of aquifer due to unstable soil conditions, ground movements and soil liquefaction.

Pumping plants were damaged where pumps and emergency generators were not properly anchored and/or located on soft soils. Loss of electric power caused many long-termed shutdowns at undamaged pumping plants in the region.

5.3 Water towers

There were many steel and R/C water towers in the flatted areas of the region. Steel water towers performed well during the earthquake, Fig. 7 shows a steel water tower in Manjil, despite of rupturing steel rod-bracing, the structure performed well and remained stable.

A 1500 m³, 46.5 meter high water tower constructed 25 years ago and supplying the city of Rasht was overturned and totally collapsed after the main shock in Rasht (Fig. 8). The structure consisted of a R/C shaft and a prestressed concrete tank which was about two-third full of water during the quake. Two similar 2500 m³, 46.5 meter high water towers in this city were under final stages of construction when the earthquake occurred, and were thus empty. They sustained horizontal cracks at the perimeter of lower part of the shaft. These water towers behaved like an inverted pendulum during the earthquake and lacked suitable structural form and detailing to withstand seismic loads, hence collapsed (Eshghi, 1991b).

6 CONCLUSIONS

The Manjil-Iran earthquake of June, 1990 provided full-scale laboratory tests on lifeline systems over a large metropolitan area and an invaluable insight into the weaknesses inherent in the design procedures used for these essential facilities.

Analysis of performance indicate that well-engineered structures, facilities, and equipment performed well in this earthquake. Failures were often associated with lack of seismic design and detailing, lack of equipment anchorage or bracing system, lack of good connection design, or failure to consider differential displacement of support points.

The experiences through the Manjil earthquake of 1990, along with some foreign earthquakes demonstrate the special need to have a safe and dependable lifeline system, to consider the possibility of functional paralysis of whole lifeline system by partial damage to the major system components, as well as the seriousness of the influence of their functional damage on urban activities.

Performance of secondary equipment systems and non-structural elements was poor during the earthquake. Therefore greater levels of conservatism should be considered in their design.

Ground failures were the primary cause of damage to buried pipes, and a frequent cause of damage to structures, especially where liquefaction occurred. Microzonation is an effective method to upgrade design requirements for poor soil conditions.

It is generally most important to make an assessment of the earthquake damage potential of lifeline facilities and to retrofit them by means of new design approaches and requirements.

ACKNOWLEDGMENTS

The research, on which this paper is based, was partially supported by International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, pertaining to Seismic Performance of Lifeline Systems and Industrial Facilities During 1990 Manjil Earthquake.

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Fig. 3 Damage to Rasht-Qazvin highway.

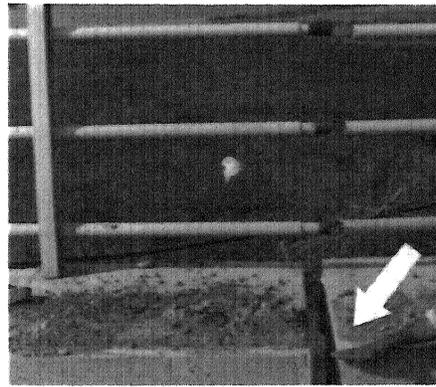


Fig. 4 Displacement of a R/C bridge deck.

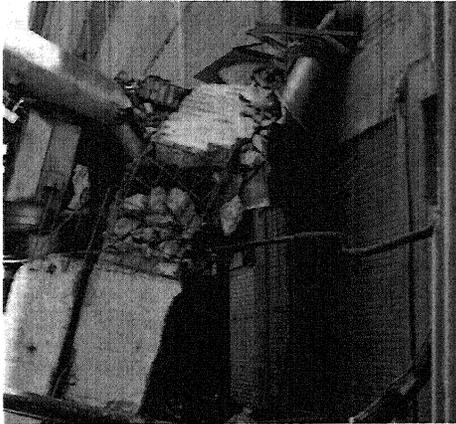


Fig. 5 Damage to bus-duct of Lowshan power plant due to non-structural elements.

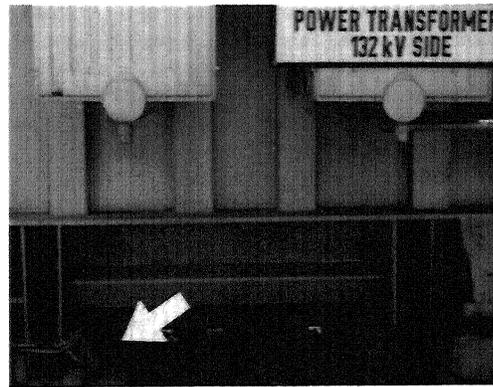


Fig. 6 Damage to the transformer support.

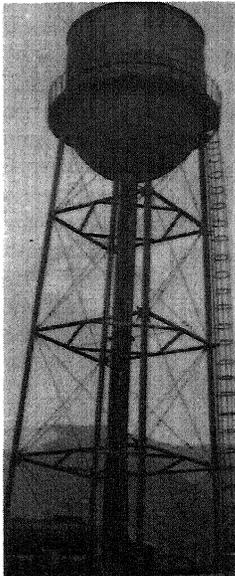


Fig. 7 Steel water tank in Manjil, survived the earthquake.

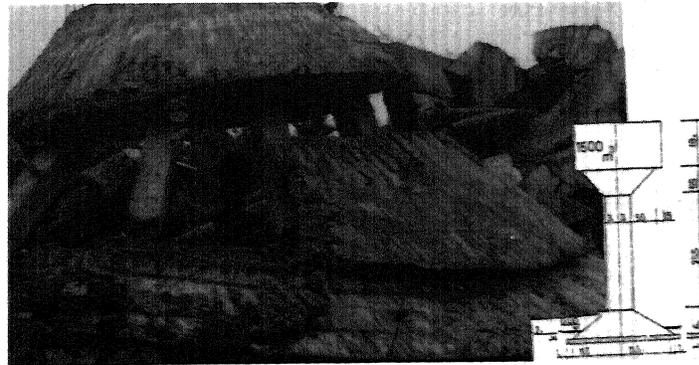


Fig. 8 Collapsed water tower of Rasht.