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Tehran vulnerability analysis

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ABSTRACT: In this paper vulnerability analysis of Tehran the largest city and capital of Iran, considered as a metropolis in the region, is presented. Investigations have been done in five different aspects including seismotectonic and seismicity, soil conditions, structural design and construction, life-line systems, and socio-economic situation. Investigations have resulted in: a) a probable earthquake with $M_s \geq 7$, b) predicted surface maximum acceleration of .4g, c) damage ratio up to 60% for most of residential buildings, d) disruption of most of lifeline services over than 4 weeks, and e) predicted life loss of minimum 400,000 people. These results show that earthquake in Tehran can be a catastrophic event, so a full scale organized attempt for disaster prevention is necessary which fortunately has been commenced and is presently on progress.

1 INTRODUCTION

Iran has been known as one of the most earthquake prone regions in the world. Tehran as the capital and the largest city of the country, which is at present a metropolis, has also suffered some historical earthquakes and recent seismotectonic studies show that this city is located in the high seismic activity zone.

Concentration of all government administration centers in Tehran, and many of other important civil and industrial facilities, and specially relief bases in Tehran make any disruption of ongoing activities in this city a great impact to the whole country. Therefore vulnerability analysis of Tehran has been considered as the most vital study in IIEES. For this analysis an organized investigation has been arranged consisting of five main parts including seismotectonics and seismicity, soil conditions, structural design and construction, lifeline systems, and socio-economic problems. A short description and brief results of these studies are presented in this paper.

2 SEISMOTECTONIC AND SEISMICITY OF THE REGION

Seismic studies includes two main divisions.

2.1 Seismotectonic studies

Tehran is situated in an enlargement along Alborz Mountain front, filled with alluvial materials originating from the rise of Alborz Range. The abrupt change of about 2750m in elevation between the city and the nearest summit of the northern mountain range is a striking topographic feature, which to a great extent is the consequence of vertical movement along the major mountain-bordering reverse fault, that is, the North-Tehran fault as reported by Tchalenke et.al. (1974).

Quaternary faulting is the basic tectonic activity in the region. Most of faults in the area are longitudinal faults following the Alborz fold-thrust mountain belt shown in figure 1.

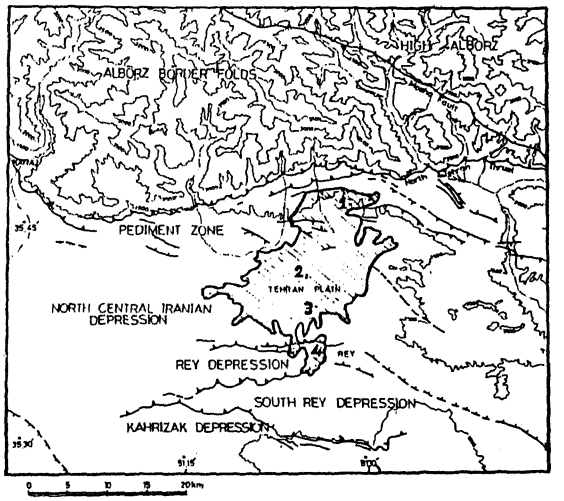


Figure 1. Fault traces in the region, and locations of chosen points for geotechnical experiments (numbers 1 to 4)

The Quaternary mountain-bordering faults which have been responsible for the formation of present physiographic features, are the most seismogenic faults in the region (Berberian, 1981) and can be considered as the most likely responsible for future earthquakes. Besides, many minor faults are widespread throughout the city and reactivation of major Quaternary faults may cause some movement along the minor faults. Investigation of these minor faults is now being performed as the basic part of microseismic study of the city.

2.2 Seismicity studies

To find the mechanism and epicenter of the responsible seismogenic faults of previous earthquakes in the region, a seismicity analysis has been done. Despite the limited available seismic data, a short review of the historical earthquakes in Tehran indicates that the region is highly seismic and has experienced several destructive earthquakes, as summarized in table 1, showing that Mosha fault has been responsible for most of historical earthquakes.

Table 1. Some of big historical (pre-1900) earthquakes of the Tehran region

Year	M_s	Region	Fault	MMI
300 BC	7.6	Rey-Eyvanekey	Parchin, Rey	X
743	7.2	Caspian Gate	Garmasar	VIII$^+$
855-6	7.1	Rey	Rey,Kahrizak	VIII$^+$
958	7.7	Rey-Taleghan	Mosha, N.Tehran	X
1117	7.2	Rey-Karaj	North-Tehran	VIII$^+$
1665	6.5	Damavand	Mosha	VIII$^+$
1815	?	Damavand	Mosha	V$^+$
1830	7.1	Damavand	Mosha	VIII$^+$

In addition to historical earthquakes, a short review of instrumental teleseismic data of 20th century earthquakes in the Tehran region indicates recent activity of a few faults as given by table 2.

Table 2. Some of instrumental teleseismic data of the Tehran region

Year	M (M_s)	F.D. (km)	No. of St.	Ref.
1930	5.2	?	32	IIS
1930	?	33N	14	NMS
1945	4.7	?	15	IIS
1945	?	33N	10	NMS
1951	5	?	31	ISS
1967	?	16	7	USCGS
1969	3.0	29	?	
1974	4.3	33N	23	
1977	?	16	6	
1982	5.4	33N	42	
1983	5.4	33N	161	

Based on seismotectonic studies Mosha thrust fault is predicted to be the responsible for future earthquake with M_s>7. On the other hand, seismicity studies show that the return period for a strong earthquake with M_s>7 is 158 years. The last big earthquake with M_s=7.1 has occurred in 1830. Therefore the occurrence probability of a strong earthquake in the Tehran region within next few years is more than 70%.

3 SOIL CONDITIONS

Soil conditions and their effects on Tehran vulnerability can be considered in two parts.

3.1 Soil amplification

The classification of young alluvial deposits in the region, based on the age, is shown in table 3.

Table 3. Alluvial formations of the region

Class	Formation	Thickness	Mech. Strength
A	Hezardarreh	<1200m	high
B	North-Tehran	<60m	variable
C	Tehran	<60m	mostly high
-	Khorramabad	10m	unknown
D	present	variable	variable

The deposits are mostly consisted of homogeneous Conglomerate with fine to coarse gravels filled in between with sand and silt and in some cases clay. Groups of young deposits are: (I) consisted mostly of alluvial of class (A), and (II) of alluvial of classes (C) and (D). Group II itself is divided into fine graded (II-A) and coarse graded (II-B).

To obtain the soil amplification factors, four points have been chosen for geotechnical field experiments, which their distance to seismogenic faults and thickness of deposits are different, as shown in figures 1 and 2, showing respectively the location of points and the related soil profiles. Geotechnical characteristics are as shown in table 4.

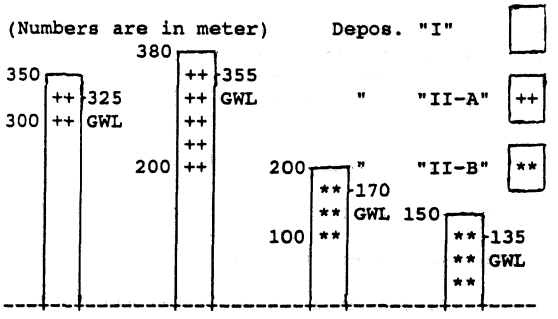


Figure 2. The soil profiles of four chosen points in different parts of Tehran

Table 4. Geotechnical characteristic of the four chosen places

Param.	Bedrock	Allov.I	Allov.II-A	Allov.II-B
Density	2.3	2.11	1.92	1.92
Damping	-	3%	5%	5%
Vs (m/s)	1520	1110	560	240

Based on the risk analysis for the Tehran region, the DBE horizontal ground acceleration for the chosen places are .27-.31g. Regarding that there is not any recorded earthquake on bedrock in the region, records of two earthquakes, Adak of Alaska in 1971 and Pasadena of U.S.A. in 1952 have been scaled and used as probable earthquakes. These earthquakes have different durations and cover a wide range of frequencies. SHAKE program has been used for surface response analysis, which considers the nonlinear or equivalent linear behavior for soil media. The shear modulous of soil

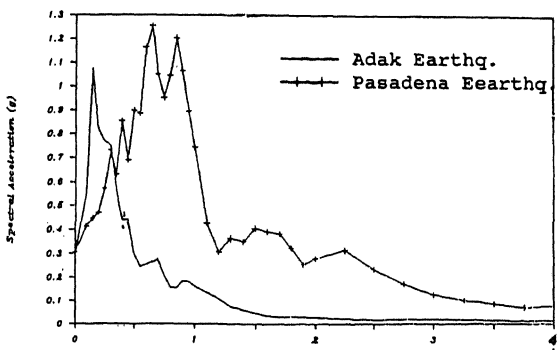
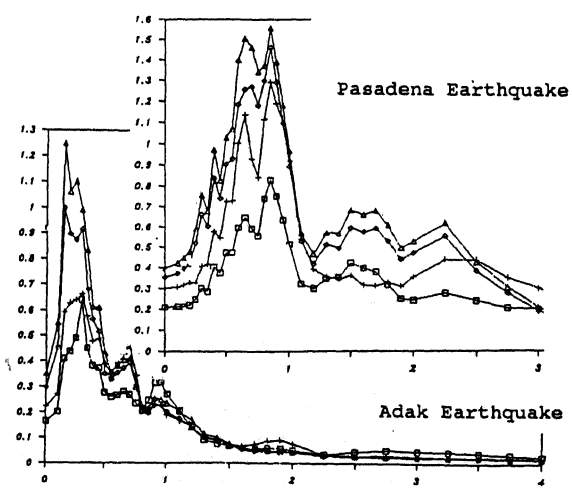


Figure 3. Acceleration spectra on the bedrock for selected earthquakes



▲ Point 1 ◇ Point 2 + Point 3 □ Point 4

Figure 4. Acceleration response spectra on the surface in four chosen places

layers have been obtained by experiment, and their damping ratios have been chosen based on the research done by Seed and Idriss (1970). Figure 3 shows acceleration response spectra of selected earthquakes for 5% damping. Acceleration response spectra on the surface in four chosen places are shown in figure 4. Based on these curves maximum amplification factor is 1.25 in the northern part of the city making a maximum horizontal acceleration of about .40g for the natural period range of .5 to 1.0 second. Generally predicted acceleration is .15-.40g for the natural period range of .25 to 1.0 second.

3.2 Liquefaction Potential and Land Slide

Regarding the texture of soil layer in the region which is mostly coarse graded materials, generally liquefaction potential in the region is not high. The depth of water table in different parts of the city is between 5 to 125m depending on the season. At present a thorough investigation is on progress to determine the liquefaction potential in all parts of the city.

There are many slopes mostly commanding one or both sides of highways in north of the city which on some of them high rise buildings are located. Stability of these slopes is a critical problem for the function of highways, as well as the buildings locating on them and is presently under investigation.

4 STRUCTURAL DESIGN AND CONSTRUCTION

This part of vulnerability study, as the most important aspect, covers a great variety of systems including ordinary and residential buildings, important buildings and special structures. To estimate the vulnerability of these systems, at first a visual screening have been done and then in case of necessity a thorough investigation has been arranged, which in now on progress. Results of visual inspection are as follow.

4.1 Ordinary buildings

Existing buildings in Tehran can be divided, based on age and construction materials, into three main classes, including old and historical buildings made by traditional methods, ordinary buildings of medium and short age mostly having 2-7 storeys with masonry, steel, r/c or composite construction, and tall buildings mostly more than 10 storeys with entirely steel or r/c structures.

Class one buildings are located mostly in the central part of the city containing Bazar, the main commerce and trading complex of the city. In addition to several historically important buildings as old mosques, shrines, palaces and museums, many of government administration centers are also included in this class. The second class contains most of residential buildings, schools,

business and government offices and other public centers. The third class comprises some residential complexes in west, north, and east of the city, big hotels, and some trading and government centers.

The construction materials used in the first class are adobe, brick, stone, and wood. Materials of the second class are brick, steel, unreinforced and r/c. In spite of using steel and r/c in this class, incorrect design and low construction quality nullify the advantages of these materials. As a matter of fact, because of the lack of earthquake knowledge in the society and specially the people who have been involved in building design and construction, in past decades, no lateral resistance has been considered for buildings. A very common type of construction for more than 80% of ordinary buildings has been bearing walls as the main supporting system, and steel beams filled in between with Jack arches as floors. The buildings which are considered to have steel or r/c skeleton are in fact an improper combination of columns and beams with quite weak connections which can bear only vertical loads. In a few steel skeletons, bracing has been used, but in most of these cases the stiffness asymmetry of the buildings make them potentially torsional systems without any resistance to torsion. This is true for buildings with r/c structures having shear walls or infilled frames. The third class of buildings can be considered as the only engineered group of structures in the city. But this group consists less than 5% of buildings.

Classification of buildings based on age and materials are given in tables 5 and 6.

Table 5. Classification of Tehran buildings based on the age

Age	Number	Percentage
>35	122'956	10.65
25-35	130'678	11.32
15-25	381'068	33.00
<15	520'044	45.03

Table 6. classification of Tehran buildings based on materials

Materials	Number	Perc.
steel or r/c skeleton	141'563	12.26
bearing walls and steel roofs	924'824	80.09
bearing walls and timber roofs	41'650	3.61
hollow cement block masonry	5'092	0.44
brick or stone masonry	6'136	0.53
wood	1'962	0.17
adobe and wood	12'412	1.07
adobe and mud	2'793	0.24
other materials	4'002	0.35
not realized	14'312	1.24

By use of the curve presented by Tavakkoli et.al.(1992) relating the damage ratio to the PGA, and regarding the surface acceleration of .15-.40g, the damage ratio is obtained 10 to 50%. But regarding the dominant type of buildings the damage ratio is predicted up to 60% for most of residential buildings due to the resonance phenomenon.

4.2 Important buildings

Relief centers, hospitals, and fire stations are three kinds of facilities in Tehran which have been considered as important buildings because of the high importance of their services to the city before and specially after the earthquake.

The main authority responsible for disaster relief is the Red Crescent Organization having buildings included in the 2nd class mentioned before, which unfortunately are not resistant enough. There are 145 hospitals in Tehran, which unfortunately most of them have not been designed according to the code. Fire station are 27 in total, which 4 are quite unresistant, 18 semi-resistant, and 5 resistant.

Regarding the aforementioned deficiencies, a thorough investigation is now being performed by IIEES for planning a retrofiting, rebuilding, and developing program of important buildings.

5 LIFELINE SYSTEMS

Regarding the large size, interconnectedness, and service orientation of lifeline systems, Tehran lifelines included water and waste water, electricity, gas, telecommunication, roads, railway and subway networks, traversing the region, crossing faults and areas of unstable soil, are recognized as uniquely vulnerable systems. Study of lifeline vulnerability as an important parts of Tehran vulnerability analysis has begun with a preliminary study and at present is continuing by thorough investigation. Hereafter a summary of preliminary results are presented.

5.1 Water supply

The sources of water supply for the region are: 1) Karaj river regulated by the Karaj dam located at west of Tehran, (57%); 2) Lar and Latian rivers regulated by Lar and Latian dams located at north-east of Tehran, (32%); and 3) the underground resources at south of Tehran, (11%). The city has been divided into separate interconnected supply zones around more than 45 reservoirs, which are generally flat roofed r/c structures totally having 1.5 million m^3 capacity. They are up to 40 years old and have not been designed for seismic loads. Distribution system supplies 260 km and installed pipe length is 6,600,000 m. The system includes four water

treatment plant and many pumping stations none having standby power supply.

It is predicted that the system will suffer widespread damage throughout the city. Pipe joints and connections are highly vulnerable. Although the damage is likely to be of a more localized and minor nature, but returning to normal conditions can extend for several months. The pressure main system, constructed mostly of cast iron, is particularly vulnerable (Eshghi, 1990). There is a significant inter-relationship between water supply and other services like electricity, which its outages will shut down the operation of the treatment plant pump station since there is only minimal emergency power facility.

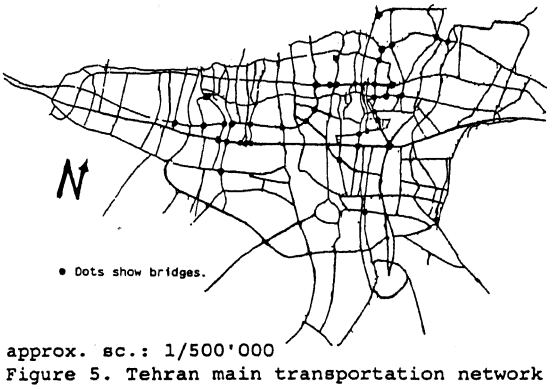
Presently no sewage disposal system is serving the city. This system is under construction with aseismic considerations.

5.2 Gas supply

Gas is supplied into Tehran by National Iranian Gas Company (NIGC). Two transmission lines enter the areas from south and the west through two major central gates (City Gates). Both lines are welded steel pipe operating at approximately 250 PSI pressure. The pipeline and pressure reducing stations are not more than 10 years old. The pipe material is API 5L Grade B steel provided with cathodic protection. Gas supply system in the severe ground shaking zone is vulnerable to equipment damage and disruption to monitoring, control and communication systems (Eshghi, 1990).

5.3 Transportation system

Two major Karaj and Qom highways provide land access into the region from west and south. The city road system has a complicated network as shown in figure 5.



approx. sc.: 1/500'000
Figure 5. Tehran main transportation network

In general, disruption is expected to be very extensive from a variety of effects. For instance, there would be a high chance of damage to some of overpass concrete bridges (Eshghi, 1991). Tehran International Airport lies at west of the city serving both domestic and international flights. An extensive damage to the runway, taxiway and apron, and some damage to hangars is likely due to earthquake. Extensive structural damage and equipment falling are also likely in terminal areas. The airport would certainly be closed for weeks to normal traffic and would take many days to reopen to reduced emergency traffic. No railway system is serving Tehran presently but an underground system is under construction to come to operation by 1944.

5.4 Electric power system

The electrical distribution system of Tehran comprises a regional supply from the National Power Network of Iran, operated by Regional Power Authority of Tehran. This system has an extensively interconnected distribution network with approximately more than 100 ground mounted substations. Most of high voltage circuits are overhead lines and there is not a program for undergrounding the main overhead reticulation. During an event a complete loss of power to Tehran would most likely occur. Transformers are susceptible to toppling. Damage in older substations would result in up to %100 loss of function (Eshghi, 1991). Restoration of the system to pre-quake status would take over one year.

6 SOCIO-ECONOMIC PROBLEMS

The socio-economic aspect can be considered form three different points of view.

6.1 Population and housing standards

Tehran population, living in 515 km^2, has increased from 6 to 10.5 million during the last five years. Population density in Tehran is quite variable as shown in figure 6.

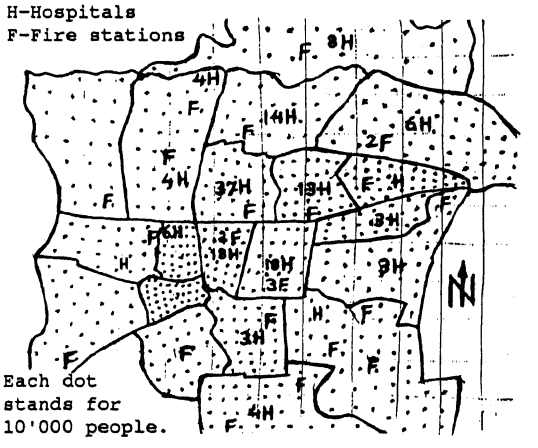


Figure 6. Population density in Tehran, and distribution of vital facilities

While almost 24% of the population live in 52% of the area another 24% live in 7%. The south-west part of Tehran with the population density of almost 40,000 per km^2 with older and smaller dwellings comparing to the northern part with less than 5,000 population per km^2 is more prone to disaster damages.
Tehran has a young age structures. 18% of population are under five years, and 40% between six and twenty four. It has often been observed that children and elders are more vulnerable than others in any disaster situation (Shadi Talab,1991). Therefore, more than 60% of Tehran population are extremely vulnerable to earthquake. On the other hand the number of families living in Tehran is more than 1.4 million which considered the number of affected dwellings, at least 400,000 families will lose their cohesion. Poverty and inequality of life in the city make the situation more complicated. Groups with the highest level of income are living in the north of the city with high standards of housing, while the majoring of people living in south, in quite unsafe dwellings are barely surviving. If disaster occurs, the population living in south and south-west will lose very little economic-wise, because they have little to lose, but that little might be all they have.

6.2 Social Integrity and Organization

Tehran is the political and decision making center of the country. Almost 71% of the capital's labor forces including government agencies are engaged in service sector, providing social and economic services to the city and the country. Therefore any disaster in this city will disrupt administration processes and social integration and might even affect the social power and privileges structures of the whole country, as has happened in Bangladesh after the cyclone in 1970, and the floods in 1974, in Nicaragua after the 1972 earthquake, and in Ethiopea after the 1972-74 drought.

6.3 Relief and emergency management

Regarding the nonuiform distribution of hospitals, fire stations and other relief foundations in the city as shown in figure 6, and the dependence of functioning of relief centers on the road network function, it obvious that the life loss will be quite different in various parts of the city. The worst case can be predicted to be in the south-west with the highest population density and the lowest number of relief bases and access roads.

7 RESULTS AND CONCLUSIONS

Based on the presented investigations the following results can be expressed:

a) The most seismogenic fault in the region is Mosha thrust, which has potential to make a big earthquake with M_s>7. The occurrence probability of this earthquake for a 170 year period is more than 70%.

b) Soil amplification factors in the city are varying from .75 to 1.25 for the natural period range of .25 to 1.0 second, which regarding the average bedrock DBE acceleration of .3g will cause surface horizontal acceleration of .15-.40g.

c) Damage ratio for more than 95% of residential buildings is predicted up to 60%. The condition for important building is not better, which make the situation more crucial.

d) Tehran lifelines are particularly vulnerable, and full restoration of lifeline systems is predicted to take up to one year.

e) Based on the predicted damage ratio for buildings, and considering the 10.5 million population of the city, a minimum 1.6 million casualties and unfortunately 400,000 deaths is predicted.

f) Concentration of all main government centers and near to 20% of the country population in Tehran will impose a great impact to the whole country, if the earthquake occurs.

Regarding the above alarming matters a full scale attempt has been planned by IIEES for risk mitigation in the region which has commenced and is on the progress presently.

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