TEHRAN PROVINCIAL WATER AND WASTEWATER COMPANY (TPWWC) THE ISLAMIC REPUBLIC OF IRAN

# THE STUDY ON WATER SUPPLY SYSTEM RESISTANT TO EARTHQUAKES IN TEHRAN MUNICIPALITY IN THE ISLAMIC REPUBLIC OF IRAN

# Volume III Appendix

November 2006

JAPAN INTERNATIONAL COOPERATION AGENCY

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#### PREFACE

In response to a request made by the Government of Islamic Republic of Iran, the Government of Japan decided to conduct the Study on Water Supply System Resistant to Earthquakes Tehran Municipality in the Islamic Republic of Iran and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Iran a study team headed by Mr. Koichi IWASAKI of Nihon Suido Consultants Co., Ltd. between May 2005 and November 2006. The study team was composed of members from Nihon Suido Consultants Co., Ltd. and Tokyo Engineering Consultants Co., Ltd. JICA also established an Advisory Committee headed by Mr. Haruo IWAHORI, Senior Advisor, Institute for International Cooperation JICA, which, from time to time during the course of the study, provided specialist advice on technical aspects of the study.

The team held discussions with the officials concerned of the Government of Islamic Republic of Iran and conducted field surveys at the study area. Upon returning to Japan, the team conducted further studies and prepared present report.

I hope that this report will contribute to the promotion of this project and to the enhancement of friendly relationship between our two countries.

Finally, I wish to express my sincere appreciation to the officials concerned of the Government of Islamic Republic of Iran, Tehran Provincial Water and Wastewater Company and Tehran Water and Wastewater Company for their close cooperation extended to the team.

November, 2006

Ariyuki Matsumoto Vice-President Japan International Cooperation Agency

November, 2006

Mr. Ariyuki MATSUMOTO Vice-President Japan International Cooperation Agency

## Letter of Transmittal

Dear Sir,

We are pleased to submit to you this Final Report on the Study on Water Supply System Resistant to Earthquakes in Tehran Municipality in the Islamic Republic of Iran. This report incorporates the views and suggestions of the authorities concerned of the Government of Japan, including your Agency. It also includes the comments made on the Draft Final Report by TPWWC (Tehran Provincial Water and Wastewater Company), TWWC (Tehran Water and Wastewater Company), MPO (Management and Planning Organization) of the Government of the Islamic Republic of Iran and other government agencies concerned of the Islamic Republic of Iran.

The Final Report comprises a total of three volumes as listed below.

Volume I	: Executive Summary
Volume II	: Main Report
Volume III	: Appendix

This report contains the Study Team's findings, conclusions and recommendations derived from the three phases of the Study. The main objective of the Phase I was to conduct a reconnaissance survey. That of Phase II was to perform damage estimation of the water supply system and to set the target of earthquake resistant system, whilst that of the Phase III was to formulate an earthquake resistant plan for Tehran water supply system.

We wish to take this opportunity to express our sincere gratitude to your Agency, the Ministry of Foreign Affairs and the Ministry of Health, Labour and Welfare of the Government of Japan for their valuable advice and suggestions. We would also like to express our deep appreciation to the relevant officers of TPWWC, TWWC and MPO of the Government of the Islamic Republic of Iran for their close cooperation and assistance extended to us throughout our Study.

Very truly yours,

Koichi IWASAKI, Team Leader Study on Water Supply System Resistant to Earthquakes in Tehran Municipality in the Republic of Iran

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# **Abbreviations and Acronyms**

AL	Alarm
BCR	Benefit Cost Ratio
BHRC	Building and Housing Research Center
CP/CIP	Cast Iron Pipe
CVM	Contingent Valuation Method
DMS	Integrated Distribution Management System
DOE	Department of Environment
DP/DIP	Ductile Iron Pipe
DTSC	Diagnosis Table for Seismic Capacity
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
EPHC	Environmental Protection High Council
FIRR	Financial Internal Rate of Return
GIS	Geographic Information System
GOI	Government of Iran
GOIRI	Government of Islamic Republic of Iran
GOJ	Government of Japan
GTGC	Greater Teheran Gas Company
IEE	Initial Environmental Examination
IIEES	International Institute of Earthquake Engineering & Seismology
IRI	Islamic Republic of Iran
JICA	Japan International Cooperation Agency
JST	JICA Study Team
JWRC	Japan Water Research Center
JWWA	Japan Water Works Association
Lpcd	litter per capita per day
MOE	Ministry of Energy
MPO	Management & Planning Organization, Office of the President
NPV	Net Present Value
NIGC	National Iranian Gas Company
N-NO3	nitrate nitrogen
NRW	Non Revenue Water
O&M	Operation and Maintenance

OR	Operating Ratio
PE	Polyethylene Pipe
PGA	Peak Ground Acceleration
PGD	peak Ground Displacement
PGV	Peak Ground Velocity
PML	Probable Maximum Loss
PLC	Programmable Logic Controller
Pos.	Position
PR	Public Relations
PVC	Polyvinyl Chloride Pipe
PWUT	Power and Water University of Technology
RCS	Red Crescent Society of Islamic Republic of Iran
Res.	Distribution Reservoir
RTU	Remote Terminal Unit
RTWO	Regional Tehran Water Organization
SCADA	Supervisory Control and Data Acquisition
SCF	Standard Conversion Factor
Sel.	Select
SERF	Shadow Exchange Rate Factor
SP	Steel Pipe
Sw.	Switch
SWC	Staff per Thousand Water Connections
SWR	Shadow Wage Rate
TDMO	Tehran Disaster Management Organization
the Study	the Study on Water Supply System Resistant to Earthquakes in Tehran Municipality in the Islamic Republic of Iran
TPWWC	Tehran Provincial Water and Wastewater Company
TWWC	Tehran Water and Wastewater Company
UBC	Uniformed Building Code
UFW	Unaccounted-for Water
UPS	Uninterrupted Power Supply
WHO	World Health Organization
WTP	Water Treatment Plant
WtP	Willingness to Pay

# **APPENDIX-1**

# **SEISMIC MOTION ANALYSIS**

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# **Seismic Motion Analysis**

## **1.1 Outcomes of Recent Studies**

Several existing studies regarding seismic motion analysis and damage estimation have collected, analyzed and outlined the geological and geotechnical feature in and around Tehran city. The following two studies are typical ones.

(1) JICA, "The Study on Seismic Microzonation of the Greater Tehran Area in the Islamic Republic of Iran", March 2000,

(2) NIGC & GTGC, "Research Project for Strengthening and Control of Tehran Gas Network Against Earthquake", March, 2004.

These two studies cover the existing natural and social condition such as topography, geology, seismo-tectonic aspect, population, buildings urban facilities, lifeline. The outcomes of the studies are excerpted for utilization in this JICA study.

#### 1.1.1 Topographic, Geological and Geotechnical Feature in and around the Study Area

The outcome of topographic, geological and geotechnical feature is excerpted from the previous JICA study as shown below to the extent that is least enough for understanding the precondition for this JICA Study. More details shall be referred to the former JICA study report.

## (1) Topography<sup>(1-1)</sup>

The study area is located at the foot of the southern slopes of the Alborz Mountain Range. The area can be simply classified into 5 topographic units: (1) mountains, (2) hills, (3) old alluvial fans, (4) young alluvial fans and (5) alluvial plains. The distribution of each topographic unit is shown in figure 1.1. Their respective features are summarised below.

## Mountains

The Alborz Mountain Range is located in the northern part of the study area. The highest point of the Study Area is approximately 1800m above sea level and its average angle of the slope is 30 to 50 degrees. Some small valleys, such as the Darakeh, Farahazad and Sulequan valleys, exist in the area. These valleys are relatively shallow and steep. The Sepaieh and Bibi-Sharbanu Mountains are located in the eastern part of the study area. This eastern mountainous area is relatively flat.

#### Hills

Many hills are situated at the foot of the Alborz Mountain. Water erosion formed this topographical unit. The highest point in the Study Area is approximately 1500m above sea level. The average angle of slope is 20 to 30 degrees at the top and 30 to 40 degrees at the edge of the hills. These hills can be distinguished from other topographical areas by the high altitude, many valleys and relatively steep slopes at the edge of the area.

## Old alluvial fans

Old alluvial fans are widely spread at the foot of the Alborz Mountain Range. The elevation of the old alluvial fan area varies from 1100 to 1500m. This topographical unit can be distinguished from a hill and a young alluvial fan by the smooth gradient slopes measuring 5 to 10 degrees and the relatively deep valleys formed in the fan.

#### Young alluvial fans

Young alluvial fans are widely spread at the bottom and mouth of the valley in the old alluvial fan. The elevation of the young alluvial fan area varies from 1100 to 1400m. This topographical unit can be distinguished from old alluvial fans and alluvial plains by its less steep slopes and its less eroded surfaces. No remarkable valley can be seen in this topographical unit.

## **Alluvial plains**

Alluvial plains spread widely beyond the young and old alluvial fans. The elevation of the alluvial plain area varies from 1000 to 1100m. The surface of this unit is mostly flat but slightly inclined to the south. No remarkable valley can be seen in this topographical unit, but there exists a topographical discontinuity zone in the southern area. This discontinuity zone is thought to originate from an anticline of pre-tertiary sediments, but it may also be the result of water erosion.

## (2) Geology<sup>(1-2)</sup>

The geological map, which focuses on Cenozoic sediments in the Tehran region, was prepared in the JICA microzoning study by the Geological Survey of Iran (GSI). The geological map of the study area is shown in figure 1.2 and a general section of alluvial deposits of the Tehran region is shown in figure 1.3. As a study result, JICA microzoning study summarized the geological condition of the study area as follows

#### Bedrock

Rock units older than *A* formations in the map area are designated as "bedrock." In northern Tehran, where the Alborz Mountain Range is located (above the North Tehran Fault zone), this unit is basically composed of Eocene pyroclastics (green tuff) and volcanic rocks that form high outcrops north of the Tehran Plain. In the eastern Sepaieh and Bibi-Sharbanu Mountains, bedrock includes limestone and dolomite of the Triassic and Cretaceous ages, some conglomerate of the Paleocene age, volcanic rocks of the Eocene age, and intrusive rocks of the Tertiary (Oligocene) age.

In the south and southwest, bedrock is composed of Eocene volcanic rocks.

#### A formation (Hezardarreh formation)

The name of this formation originates from the geomorphic nature of outcrops of the formation. "Hezar" means "thousand" and "darreh" means "valley." Northern outcrops of A fm. are limited from the south to the 35°43' latitude, however, some outcrops of this unit are present in southern hills of the Tehran plain (south of the Kahrizak fault).

The ancient alluvial deposits of A fm. essentially include conglomerates with a few lenses of sandstone, siltstone and mudstone, and are recognizable by regular stratification, relatively thin

layers, small clasts, and advanced stages of decomposition of the constituents. Carbonate cementation is well developed in this formation, as compared to other younger units, resulting in higher relative mechanical competency. Based on the geological investigation in this study, most of the N value in this layer exceeds 50.

The clastics are almost totally composed of pyroclastic material and volcanic rocks of the Eocene age, derived from the northern highlands. Average grain size of the clastics is in gravel range (10-25 cm). Color is light gray and has a chalky appearance. Thickness is estimated to be about 1200 m. Relatively extensive cementation, high compaction, and presence of fine grained matrix renders the A fm. as an impermeable rock unit, as compared to other alluvial deposits of the Tehran region.

According to stratigraphic correlation with other parts of the Iranian plateau, the A fm. is considered to be of the Pliocene-Pleistocene age. The A fm. in the northeast and east of Tehran rests over the Upper Red fm. (Miocene). However, in a few places south of the Tehran plains, it overlies the volcanic rocks of Eocene age. Gradational contacts of the A fm. over the marl and mudstone of Upper Red fm. is reported in the east of the Tehran region.

The *A* fm. was folded and faulted during the earliest tectonic movements of Quaternary time, resulting in unconformable contacts of the *B* fm. with younger Quaternary deposits. The resulting high dip (up to 90° in some places) is, therefore, a diagnostic feature for the *A* fm.

#### **B** formation

This formation was first named and described by Rieben (1966) as Kahrizak fm. The formation is divided into a northern facies and a southern facies.

 $B_n$  formation (North Tehran inhomogenous alluvial fm.)

The  $B_n$  fm. unconformably overlies on the eroded surfaces of the A fm. and forms old alluvial fan topographic units in the north of the city of Tehran.

Thickness of the  $B_n$  fm. is estimated at about 60 m. The  $B_n$  fm. is a conglomeratic mixture of gravel, pebble, and cobble-size clastics, which include a silt and sand size matrix. Therefore, the  $B_n$  fm. is an inhomogeneous unit with poor sorting. The diameter of some boulders in the  $B_n$  fm. reach about 4.6 m. In many places, the conglomerate is of matrix supported type, which lacks any stratification. Cementation is poorly developed in the  $B_n$  fm., but its N value exceeds 50 in most parts. Color is reddish and yellowish brown, which makes the  $B_n$  fm. darker than the underlying A fm. Several lenses of silt and sand in this formation appear to be of channel origin that are cut and filled by these deposits. In many places, a soft black and yellow cover, which is, respectively, of magnesium and iron oxide composition, is present on pebbles within the formation. Permeability of the  $B_n$  fm. is very good.

Thickness of the  $B_n$  fm. decreases towards the south, and its outcrops are limited from the south to the 35°43' latitude. It is suggested that the  $B_n$  fm. was deposited within alluvial fans formed

by a series of outwash flows of glaciers from the Alborz Range. Presence of large blocks of clastics supports the concept of this formation's a glaciofluvial origin.

The  $B_n$  fm. is considered to be of Pleistocene age. The  $B_n$  fm. is faulted in many places, however, it is not affected by any major folding event; therefore, bedding is generally horizontal with a maximum dip of 15°.

B<sub>s</sub> formation (South Tehran clayey silt or Kahrizak fm.)

The  $B_s$  fm. is widely distributed under the topographical plain unit. Outcrops of the  $B_s$  fm., which are exposed as a result of faulting, form the badland scenery in the southern parts of the Tehran plain. However, the soil condition of this area is not so strongly consolidated, and, from the engineering geotechnical point of view, these outcrops may belong to the *C* formation.

The  $B_s$  fm. is composed of reddish brown-, cream- and beige-colored silt with some clayey component. Small calcareous nodules are scattered within this formation in many places. Composition of the  $B_s$  fm. is much more homogenous, as compared to the  $B_n$  fm. in the north, however, no sharp stratification is present within it. The  $B_s$  fm. is considered as the southern equivalent of the  $B_n$  fm. that was presumably deposited within an old lake basin. The northern and eastern part (i.e., nearer to the mountain area) of this deposit is composed of coarser material (sand rich material) and its N value is relatively high. The south-western part of this layer is composed of homogeneous, fine material (clay rich material) and N value is relatively low. These clay rich deposits are considered as overconsolidated and cemented. The N value for most of the  $B_n$  fm. is more than 50. However, soft clay lenses with an N value less than 20 can be found in some parts.

The lower contact of the  $B_s$  fm. is not exposed; however, it is postulated that it overlies the A fm. and the bedrock (Eocene volcanic rocks). Thickness of the  $B_s$  fm. is uncertain, but it is possibly much thinner than its northern equivalent, the  $B_n$  fm. In this Study, three boreholes were drilled to depth of 200m in the southern area. However, no lower contact of the  $B_s$  fm was found in this investigation.

Faulting has affected the  $B_s$  fm. in many places; however, it lays horizontal without any tilting.

#### C formation (Tehran alluvial fm.)

The C fm. includes conglomeratic young alluvial fan deposits. Lithology of the formation includes homogenous conglomerates, composed of gray to brown coloured gravel and pebble size clastics, which have a silt and sand size matrix. Color of the C fm. becomes red to reddish brown in the eastern Tehran region because of a difference in rock type of the source area (Sepayeh Mountains). The stratification within the C fm. is better than within the B fm., but less developed than within the A fm. Among the old alluvial fans, where this formation was deposited, the old fan of the Kan River (western Tehran) is still visible in aerial photographs. The Karaj Fan, which is now covered with the  $D_2$  unit, is also composed of the C fm. The

extreme southern outcrops of this formation are limited to the  $35^{\circ}39'$  latitude. A considerable part of Tehran is constructed over the *C* fm.

The maximum thickness of this formation is estimated at be about 60 m. Several (up to 4) major depositional cycles may be defined within the C fm. These cycles are easily recognised by a change in the colour from gray to white into brownish red (bottom to top). The white and red colourings are attributed to the presence of caliche and iron oxide, respectively. Cross bedding is present in few places within the middle part of the C fm. Age of the C fm. is estimated to be between 50,000 and 10,000 years (late Pleistocene).

The C fm. is more competent as compared to its underlying and overlying stratigraphic units (B and C formations, respectively). This phenomenon is a result of the relatively higher cementation and compaction of this stratigraphic unit. However, permeability of the C fm. is high so that it constitutes the major aquifer of the northern Tehran region.

Minor faulting is present within the C fm.; however, no tilting is visible in this formation.

The N value of the C fm. is slightly lower than that of the A and B fm. but exceeds 50 in most of the C fm.

## **D** formation (Recent Alluvium)

The D fm. is the youngest stratigraphic unit within the Tehran region and is present as alluvial and fluvial deposits. In this study, the D fm. is subdivided into two different stratigraphic units, named  $D_1$  and  $D_2$  units.

**D**<sub>1</sub> **unit** (Khoramabad alluvial fm.)

The  $D_I$  unit, as a veneer, covers the Bs fm. in the south and forms a topographic plain unit. This unit is composed of fine silt with a grayish cream and gray colour, and is sandy and pebbly in places. Basically, sandy material is richer in the northern and eastern parts of the plain. Fine material, such as silt and clay, is predominant in the south-western part of the plain. No sharp stratification is present within the  $D_I$  unit. The  $D_I$  unit is considered to be both the distal facies and slightly older equivalent of the  $D_2$  unit in the northern Tehran region. Age of the  $D_I$  unit is considered to be younger than 4000 years (Holocene).

#### D<sub>2</sub> unit

The  $D_2$  unit is composed of poorly consolidated to unconsolidated gravel- and pebble-sized calstics, which have a silt and sand size matrix. The colour is gray to dark gray. This unit has an alluvial and fluvial origin, similar to the C fm.; however, the lack of cementation, lesser compaction, and lack of caliche and iron oxide may easily distinguish it from the latter. Competency of this unit is lower than that of the C fm. The young, active alluvial fans and flood plains in the northern Tehran region are composed of the  $D_2$  unit.

The general geological cross section of the Study Area is shown in figure  $1.4^{(0-4)}$ .



Figure 1.1 Distribution of each topographic unit



Figure 1.2 Geological map of the study area



Source: JICA Microzoning Study: (Geological Observations on Alluvial Deposits in Northern Iran, H. Rieben, Geological Survey of Iran, Report No.9, 1966).







## (3) Geotechnical Model<sup>(1-3)</sup>

JICA microzoning study report also describes the ground model with the grouping of subsurface soil. This soil classification is used for stability of foundation for facility. The description is referred to as below.

The subsurface soil is classified into 4 types, i.e. clayey soil, sandy soil, sand and clay (mixture or alternation), and gravely soil. Each soil type is divided into 4 groups according to its N values, as shown in table 1.1. The ground is classified into 41 types as shown in figure 1.5. The distribution of each soil type is shown in figure 1.6. Figure 1.5 and 1.6 are excerpted from JICA microzoning study for use of structural analysis of treatment and reservoir facility.

The characteristics of the ground condition in the Study Area are as follows:

- Many types of soil such as gravel, sand, silt and clay are distributed in the Study Area. Most of the soil are over-consolidated and cemented. The engineering characters of these soil types are very similar to each other. Geological structure is simple and soil properties are relatively homogeneous.

- Near ground surface (GL-0 to 30m), Soft clay, silt and loose sand are distributed in the alluvial plain. This soft deposit is regarded as the youngest deposit, namely  $D_I$  formation.

- Below the  $D_1$  formation, a very thick clay layer is deposited at the eastern plain of the study area. This layer is regarded as the *Bs* formation. The bottom of this formation could not be confirmed with 200m-deep boreholes. The strength of the soil increases gradually in its depth direction. Some relatively soft clay and/or sandy clay layers are embedded in the layer. The thickness of these layers is a few meters.

Basically, the  $D_1$  formation is composed of relatively soft silt and clay. The particle size of this formation becomes coarser toward the alluvial plain edge. Alternation and/or mixture of sand and clay are predominant in this area and these are considered as the transition zone between  $D_1$  and  $D_2$  formations.

Most parts of the C,  $B_n$  and A formations are composed of dense gravel with sand and clay. Soft to stiff clay or loose sand is distributed in the Darrus and Qolhak areas, both in north central Tehran. This layer is considered as the lacustrine sediment of an old lake in this area.

Soil Name	Soft Clay	Firm Clay	Hard Clay	Very Hard Clay
Symbol	C1	C2	C3	C4
Average N Value	15	35	75	100
Soil Name	Soft Clay and Sand	Firm Clay and Sand	Hard Clay and Sand	Very Hard Clay and Sand
Symbol	CS1	CS2	CS3	CS4
Average N Value	15	35	75	100
Soil Name	Loose Sand	Medium Dense Sand	Dense Sand	Very Dense Sand
Symbol	S1	S2	S3	S4
Average N Value	15	35	75	100
Soil Name	Loose Gravel	Medium Dense Gravel	Dense Gravel	Very Dense Gravel
Symbol	G1	G2	G3	G4
Average N Value	15	35	75	100

Table 1.1Soil Condition, Symbols and N Values for the Ground Model

Source: JICA Microzoning Study, November 2000

Model No.	Depth (GL-m)																									
Model No.	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	110	120	130	140	150	
1	C1	C1	C1	C1	C1	C1	CS3	CS3	CS3	CS3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C4
2	C1	C1	C2	C2	C2	C2	CS3	CS3	CS3	CS3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C4
3	C1	C1	CS1	CS1	CS1	CS1	CS3	CS3	CS3	CS3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C4
4	C1	C1	C2	C2	C2	C2	C2	C2	C2	C2	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C4
5	C1	C1	C1	C1	C1	C1	C2	C2	C2	C2	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C3	C4
6	C2	C2	C2	C2	C2	C2	CS3	CS3	CS3	CS3	C2	C2	C2	C2	C2	C2	C2	C2	C2	C4						
7	C1	C1	C2	C2	C2	C2	C2	C2	C2	C2	C3	C3	C3	C3	C4											
8	C1	C1	C2	C2	C2	C2	CS2	CS2	CS2	CS2	CS3	CS3	CS3	CS3	C4											
9	C2	C2	CS2	CS2	CS2	CS2	C3	C3	C3	C3	C2	C2	C2	C2	C4											
10	C1	C1	CS2	CS2	CS2	CS2	C3	C3	C3	C3	C2	C2	C2	C2	C4											
11	C2	C2	C3	C3	C3	C3	CS3	CS3	CS3	CS3	C2	C2	C2	C2	C4											
12	C2	C2	C2	C2	C2	C2	C2	C2	C2	C2	C4					_										
13	C2	C2	C2	C2	C2	C2	CS3	CS3	CS3	CS3	CS4															
14	C2	C2	C2	C2	C2	C2	CS2	CS2	CS2	CS2	CS4															
15	CS1	CS1	C2	C2	C2	C2	CS3	CS3	CS3	CS3	CS4															
16	C2	C2	C2	C2	C2	C2	CS3	CS3	CS3	CS3	CS4															
17	C2	C2	CS1	CS1	CS1	CS1	CS3	CS3	CS3	CS3	CS4															
18	G2	G2	CS1	CS1	CS1	CS1	G3	G3	G3	G3	G4															
19	C3	C3	C3	C3	C3	C3	G3	G3	G3	G3	G4															
20	C2	C2	C3	C3	C3	C3	CS3	CS3	CS3	CS3	CS4															
21	CS2	CS2	CS3	CS3	CS3	CS3	CS3	CS3	CS3	CS3	CS4															
22	C1	C1	C1	C1	C1	C1	C4																			
23	C2	C2	C2	C2	C2	C2	C4																			
24	CS2	CS2	CS2	CS2	CS2	CS2	CS4																			
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33	C3	63	C3	G4	-04	l							AV	Graye		ue	6	J 1	5 0			3	- IL			
25	63	63	63	G4									٨٧	erado		lue	1	5	2	5	7	5	1/	 10		
33	33 (22)	33	33	G4									AV	ciage	v v Vd	ue		J	3	J	/	J		.0		
37	C33	C1	C1	G4								1														
38	()	C2	() ()	G4										G4	1	Fnain	pprin	n sais	mic h	edroc	k and	its so	il type			
39	63	G3	G4	-04	l									-04	I	Ligiti	Conny	9 3013			it unu	13 30				
40	Pre	-Mioc	ene																							
40	Tie	Rock	ene																							
41		NUCK																								

Source: JICA Microzoning Study, November 2000

# Figure 1.5 Classification of Soil type



Figure 1.6 Distribution of each Soil Type for Stability of Foundation for Facility

## 1.1.2 Seismotechtonic in the Vicinity of the Study Area

Gas research project describes the major faults with known seismic background, other major and minor faults in and around Tehran area. Their characteristics are introduced based on the results of Gas Research Project.

## (1) Major Faults with Known Seismic Background<sup>2-1)</sup>

The major faults with known seismic background are those with the characteristics of the quaternary and long fault. Due to their youngness and great length, these faults are dangerous.

## (a) Mosha Fault

This is a seismogenic fault with length of more than 200 kilometers. In its direction, High Alborz Zone is thrust over Alborz Border Folds from the North to the South. This fault has ESE - WNW strike and has sinusoidal shape on the map and takes east-west strike on the eastern section. This fault always dips about 35 to 70 degrees towards North. Its dip angle is about 75 degrees directed towards North.

Mosha Fault is an active and seismogenic fault and the available data show that the following earthquakes have been caused by this fault (Berberian et al. 1979 or 1985)<sup>3), 4)</sup>:

- Earthquake of Damavand, 1665, Ms 6.5
- Earthquake of Damavand and Mazandran area, 1802
- Microearthquake of Damavand, June 20, 1811
- Microearthquake of Damavand, June 1850
- Damavand Shemiranat Earthquake, Ms 7.1, March 27, 1830
- Aftershock of Damavand Shemiranat, April 6, 1830
- Ah- MobarakAbab Earthquake, Ms 5.2, October 2, 1930 and its aftershocks of October 6 and 7, 1930
- Mosha Earthquake, mb 4, November 24, 1995
- Earthquake of January 10, 1974
- Lavasanat Earthquake of September 1974

At least three destructive historical earthquakes have ruptured three adjacent segments with a total length of 200 kilometers along Mosha Fault. These three earthquakes are:

- The earthquake of 958, Ms 7.7, that caused the rupture of the eastern segment.
- The earthquake of 1665 (Ms 6.5) that caused the rupture of the eastern segment.
- The earthquake of 1830, Ms 7.1, that lid to the rupture of the central segment. This segment is the nearest segment of Mosha Fault to the gas pipeline route located on the north of Tehran. This segment is longer than 100 kilometers (Berberian and Yeats, 1999)<sup>5)</sup>.

The boundary between the ruptures of 958 and 1830 is characterized by sudden change along the fault, but the boundary between the rupture of 1830 and 1665 is not clearly defined by an evident geological discontinuity.

## (b) North Tehran Fault

This fault is 90 kilometers long and located on the north of Tehran. It has E-W to ENE-WSW strike

and has thrust mechanism. This fault has been traced in the North Tehran mountains from the east of Lashgarak (Saboo Village) in the northeast of Tehran To KazemAbad locality (2 km east of Kalak and north of Tehran-Karaj Expressway) and in the city of Karaj in the west. It is thought that this fault is a branch of Mosha Thrust Fault.

In most places including north of Tehran and at the foothills, this quaternary alluvia has caused the Eocene Karaj Formation (Alborz Border Folds) to be thrust over Hezardarreh and NTF (pediment zone of Central Iran).

The sudden change in height between the city of Tehran (with an average elevation of 1300 m) and its highest peak (Tochal, 3933 masl) in a distance of less than 10km is a significant topographic characteristic of Tehran for which North Tehran thrust movements are responsible (Tchalenko et al.,  $1974)^{6}$ .

The thrust dip of this fault is highly variable: 10-45 degrees towards north on the west of Kan, 27-40 degrees towards north on the east of Kan, 70-80 degrees towards NW at Farahzad, 40 degrees towards NNW on the west of Lashgarak Valley and about 30 degrees towards north on the NE of Saboo Village. It can be assumed anyway that the dip of NTF is milder than 75 degrees, because this fault is a branch of Mosha Fault. Hence, a milder dip than that of Mosha Fault should be considered for it to reach Mosha Fault in depth.

This is a seismogenic quaternary alluvia considered as a branch of Mosha Fault. Contrary to Mosha Fault, this quaternary alluvia doesn't have a distinct fault scarp (Berberian and Yeats, 1999)<sup>5)</sup>. Due to the scarcity of data, its seismic history is not clearly known, but the following earthquakes have been probably caused by this fault (Berberian et al., 1985)<sup>4)</sup>:

- The earthquake of Feb 23, 958 B.C., with an estimated Ms 7.7(ISC) and 7.4 (Ber)
- The earthquake of May 1177 between Shahr Ray and Qazvin, estimated Ms 7.2
- The earthquake of December 24, 1895, Tehran
- The epicenter of the earthquake of Roodbar Qasran, M4.1, has been determined 25 and 35 km north of North Tehran thrust in the north of the city of Tehran, and this earthquake has probably resulted from the movement of this fault, but there is no strong reason to support this idea.
- The earthquake of Najjarkola NE of Tehran, Oct 26, 1989

As for the earthquakes of 855-856 (exact date not known) and 1177, the responsible quaternary alluvia or faults cannot be determined, but could have caused the rupture of NTF.

The estimated dip angle of north Tehran fault together with north Ray and other faults are shown in figure 1.7.

#### (c) North Ray Fault (NRF)

NRF is a seismogenic quaternary alluvia that is seen as an eroded wall near AzeemAbad locality (south margin of Ray-Behesht Zahra Expressway). With a height of 2 m, strike of E-W and length of 17 km. This quaternary alluvia might be responsible for the following earthquakes:

- The earthquake of 4<sup>th</sup> century B.C. of Ray-Eyvanaki, with an estimated magnitude of Ms 7.1
- The earthquake of 855-856 A.D. of Ray with estimated Ms 7.1

- The earthquake of 864 A.D. with estimated Ms 5.3

- The Ray earthquake of 1383-4 with estimated Ms. 5.5 (Melville, 1978)<sup>7)</sup>

This quaternary alluvia has thrust mach with dip towards north. Along the fault, Kahrizak clayey silt (Bs) is thrust from north over the quaternary alluvia (D) and its activity has caused the formation of Shahr Ray Depression Plain (Berberian et al. 1985)<sup>4)</sup>. Towards east and west (the Karaj River fan) the extension of North Ray Fault disappears under young river and plain deposits. Aerial photos show that North Ray Fault should consist of two segments that overlap at the middle section. Besides, there is seen a left lateral displacement along the quaternary alluvia based on the displacement of water channels (on the aerial map) at the middle section.

According to the measured piezometric levels, there is an anomaly at the groundwater table (Ministry of Water and Power, 1970; Knill and Jones, 1968<sup>8</sup>); Tchalenko et al. 1974<sup>6</sup>) along North Ray Fault that shows the significance and role of these quaternary alluvia in the displacement of the groundwater table of the Plain.

### (d) South Ray Fault (SRF)

South Ray Fault is an active quaternary alluvia that appears like an eroded low wall (1-2 m high) in the south of the ancient hill (Ghar Hill) of Qal'ehno locality (southwest of Shahre Ray) extending towards southwest. This quaternary alluvia strikes ENE-WSW and dips NNW. The same earthquakes as listed in North Ray fault might have been caused by this fault:

It has thrust mechanism considering its winding geometry as evidenced from Kahrizak Clayey Silts (Bs) that are thrust along it from north over the quaternary deposits (D) in the south (Berberian et al. 1985)<sup>4)</sup>. Its eastern and western extensions disappear under young plain and river deposits (the Karaj River fan).

## (e) Parchin (Eyvanaki-AminAbad) Fault

This fault clearly crosses the alluvial deposits of the plain at the eastern part of Jajrud valley, creating a triangular facet. Its strike lies south of Parchin Mountain and the end of the Jajrud River in Varamin Plain along the boundary between the Hezardarreh Formation (A) and the Varamin plain. It has NW-SE strike and thrust mechanism and dips NE. Towards SE, (Eyvanaki) and NW (south of Bibishahrbanoo Mountain) this quaternary alluvia forms the boundary between mountain and plain, but its line is not as visible as at Parchin area due to being covered by colluvium or fluvial and aldep. Its total length (from the southeast of Eyvanaki to Aminabad) is about 73 km.

This fault might be responsible for the earthquake of the 4th century B.C. of Ray Eyvanaki with a probable magnitude of Ms 7.6 (Berberian et al., 1985)<sup>4)</sup>

#### (f) Kahrizak Quaternary Alluvia

This quaternary alluvia is seen 10 km south of Shahr Ray as a high wall (1-10 m) with an E-W strike and a length of more than 4 km. towards east and west (the Karaj river fan) the strike of this quaternary alluvia disappears under the young river and plain deposits. Although its dip is not visible on the ground, Kahrizak quaternary alluvia has thrust mechanism and dips with northward dip. Along this fault, the north Kahrizak Clayey Silts (BS) are thrust over the southern quaternary

alluvia (D) (Berberian et al. 1985)<sup>4)</sup>. The series of Ray faults (NRF, South Ray Fault, Kahrizak quaternary alluvia) might be responsible for the same earthquakes listed above.



Source: Gas research Project

## Figure 1.7 Estimated sketch of dip angles of North Tehran and Ray Faults

## (2) The Other Major Faults and Minor Faults

The other major faults and minor faults in and around the Tehran city are listed in table 1.2

according to the report of Gas Research project.

Major Fault	Minor Fault
1)Niyavaran fault/2)Mahmoodyeh fault,	1)Baghfeyz Thrust/ 2)Hmashin fault/
3)Lower Telo fault/ 4)Shiyan and Kowsar	3)Davoodiyeh fault/ 4)Hemmat fault,
fault,	5)Bibisharbanoo fault/ 6)The fault on the
5)Qasr Feeroozeh fault/ 6)Latyan fault, Upper	North and South of Chitgar Park/
7)Telo fault/ 8)Sorkheh Hesar fault	7)Television fault/ 8)Vanak fault,
9)South Mehrabad fault	9)Shahrak Cheshmeh fault/
	10)Abbasabad fault,
	11)Takht-e-Tavoos fault/ 12)Narmak fault,
	13)Sa'adat Abad fault/ 14)Television E-W
	fault

Table 1 2	The other	maior faul	ts and mino	r faults in and	l around the	Tehran city
1abic 1.2	I ne otnei	major faur	is and mino	I laults ill alle	i alounu the	Tem an city

## (3) Characteristic of Some Important Faults in and around Tehran city

Table 1.3 shows the characteristics of some important faults in and around Study area.

Fault names	Approximate.	Mechanism	General trend	Max attributed
	Length (Km)			magnitude (M)
North Tehran	90	Thrust	E-W	7.3
Niyavaran	18	Thrust with left	ENE-WSW	6.5
		lateral strike-slip		
		component		
Mahmoodiyeh	11	Thrust	E-W	6.2
Davoodiyeh	4.5	Thrust	E-W	5.7
South Mehrabad	10	Thrust	NE-SW	6.2
North Ray	17	Thrust	E-W	6.5
South Ray	>18	Thrust	ENE-WSW	>6.5
Kahrizak	>40	Thrust	E-W	6.9
Parchin	73	Reverse	NW-SE	7.2
Qasr Feeroozeh	18	Reverse	NW-SE	6.5
Shiyan Kowsar	15	Thrust	NW-SE	6.4
Upper Telo	10	Thrust	NW-SE	6.2
Lower Telo	20	Thrust with right	NW-SE	6.5
		lateral strike-slip		
		component		
Latyan	11	Reverse	WNW-ESE	6.2
Baghfeyz	4.5	Thrust with right	NW-SE	5.7
		lateral strike-slip		
		component		
Sorkhesar	22	Thrust	E-W to WNW-ESE	6.6
Hamsin	9	Thrust	E-W to WNW-ESE	6.1
Bibishahrbanoo	5	Thrust	WNW-ESE	5.8

## Table 1.3 Characteristics of Some Important Faults in and around Tehran city

Source: Gas Research Project

Figs.1.8 to 1.13 show fault location and main intersect locations of water supply pipelines and faults

in and around the city of Tehran.



Figure 1.8 Fault Location in and around Tehran city



Figure 1.9 Intersect Points between Faults & Main Transmission Pipes (18 Points)



Figure 1.10 Intersect Points between Faults & Transmission Tunnel and Water Treatment Plant



Figure 1.11 Intersect Points between Faults & Transmission Pipes (42 Points)



Figure 1.12 Intersect Points between Faults & Main Distribution Pipes (76 Points)



Figure1.13 Intersect Points between Faults & Distribution Pipes (426 Points)

## (4) Historical Earthquake Record<sup>1-4)</sup>

Fortunately, Tehran has not suffered any severe damage due to an earthquake in over 150 years. Some earthquakes that might have affected the Tehran area were picked out from the historical earthquake catalogue. Due to the spatial extent of the Greater Tehran Area, a sample site was selected for peak ground acceleration (PGA) computations. This point was the centre of the city of Tehran. It is near Ferdowsi Square and a highly populated area. Its latitude is 35.70N and its longitude is 51.45E. PGA was calculated according to Campbell et al. (1997) for a dip-slip type earthquake and alluvial ground conditions. Radius or distance was assumed as infinite.

Table 1.4 shows the major historical earthquakes by which Tehran was affected up to now. The largest observed PGA was 412 gal due to the earthquake in 855. The second-largest acceleration occurred in 1830, and the third in 958. Berberian et al. (1999) suggested that the events in the years 958, 1830 and 1665 occurred on segments of the Mosha Fault. It has also been suggested that the event in 855 may have occurred at the South/North Ray Fault. Seismic activity on the North Tehran Fault is vague. Berberian et al. (1983) associated the events in 958 and 1177 to the North Tehran Fault. Epicentre of italicised earthquake was shown in Figure 1.14

year	month	day	Mw	Latitude (degrees)	Longitude (degrees)	Epicentral distance (km)	Assumed PGA (gal)
743			7.1	35.30	52.20	81	49
855			7.0	35.60	51.50	12	412
856	12	22	7.9	36.20	54.30	263	17
864	1		5.4	35.70	51.00	41	34
958	2	23	7.7	36.00	51.10	46	161
1119	12	10	6.4	35.70	49.90	140	13
1177	5		7.1	35.70	50.70	68	63
1301			6.6	36.10	53.20	164	12
1485	8	15	7.1	36.70	50.50	140	23
1608	4	20	7.6	36.40	50.50	116	44
1665			6.4	35.70	52.10	59	44
1687			6.4	36.30	52.60	123	15
1809			6.4	36.30	52.50	116	17
1825			6.6	36.10	52.60	113	21
1830	3	27	7.0	35.80	51.70	25	208
1868	8	1	6.3	34.90	52.50	130	13
1930	10	2	5.4	35.78	52.02	52	24
1957	7	2	6.7	36.20	52.60	118	21
1962	9	1	7.1	35.54	49.39	187	15
1983	3	26	5.3	36.12	52.21	83	10
1990	6	20	7.4	36.96	49.39	232	14
1994	11	21	4.5	35.90	51.88	45	14

# Table 1.4 Historical earthquakes affected to Tehran

Source: JICA Microzoning Study, November 2000



**Figure 1.14 Historical Earthquake Distribution around Tehran** Source: JICA Microzoning Study, November 2000

## 1.1.3 Research and Selection of Scenario Earthquake for Tehran Lifeline Facility

The investigation and the study of active faults as well as historical earthquake records in and around Tehran city was carried out through the collection and analysis of the available related information and data in the previous JICA microzonation study and Gas research Project. As a result of those studies, Mosha Fault, South Ray Fault, North Ray Fault and North Tehran Fault are selected as most dangerous active faults for the Tehran city and surrounding area.

Besides, the water supply area of Tehran Water and Wastewater Company in 20 districts of Tehran city is almost covered by the gas supply one of Great Tehran Gas Company. Therefore, earthquakes due to active faults, which may occur in the supply area of Tehran Water and Wastewater Company and its vicinity, are selected following to the result of Gas research project.

Then the following 5 scenario earthquakes are selected including a historical earthquake. The historical earthquake means an earthquake of which ground motion corresponds to the earthquake with a certain return period obtained by statistical analyses of the past earthquakes in Tehran area listed in table 1.4.

- 1. Historical Earthquake around Tehran
- 2. Earthquake due to Mosha Fault
- 3. Earthquake due to South Ray Fault
- 4. Earthquake due to North Ray Fault
- 5. Earthquake due to North Tehran Fault

#### 3.1.4 GIS Database Development

There are several GIS databases developed in the previous JICA study and Gas research project. The databases listed below are main GIS databases developed in the above study and research and useful for our JICA study.

- 22 district of Tehran city
- Census zone
- Tehran Building distribution
- Geological Condition
- Topography Condition
- Ground/Soil Condition
- Ground water Table
- Active Faults distribution
- Public facility: Firefighting stations, Hospital, Parks, Universities, Schools, etc.

#### **1.2 Selection of Seismic Motion Analysis Method**

As aforementioned, the first seismic microzonation study was performed to the infrastructure and lifeline in the Greater Tehran Area by JICA with the cooperation of Iranian counterparts CEST in 2000. TAKADA S. et. al also performed the similar study especially to Tehran water supply system almost at the same time.

After that, National Iranian Gas Company & Greater Tehran Gas Company performed the research project for Tehran gas network with respect to strengthening and control against earthquake during 2002 to 2003. Parsconsult Engineers et. al. recently performed the study on earthquake resistant design for Tehran water supply system, December, 2004.

Each study or research performed respective seismic motion analysis and had the feature as mentioned before in 2.4.2 Characteristic of Each Study. Seismic motion analysis applied in gas research project is basically similar to that applied in TAKADA's Study.

The following aspects are recommended to consider within the time and budgetary frame of our JICA study so as to select the most suitable seismic motion analysis for the study, based on the idea that maximum utilization of the previous study results are expected, that review and upgrade of the study result will be relatively easy to implement as well as that suitable technical cooperation and transfer is attained.

- a. Appropriate utilization and effective incorporation of a method applied to the existing earthquake motion analyses for lifeline facility,
- b. A sustainable method for review and upgrade of the database with common ground among the other study for lifeline facility, especially for, water supply facility
- c. Appropriate method for the damage estimation for such lifeline facility as water pipeline network, gas pipeline network,
- d. Suitable method for counterpart, TPWWC, in the context of technical cooperation and technical transfer,

The seismic motion analysis method applied in "GAS Research Project" seems the most suitable method considering the above aspects, because of the following reason:

(a) It has incorporated the similar idea to that applied to Japanese design codes and standards, which was the state of the art idea of the water works design in Japan and derived from earthquake disaster experience in Japan. Historical earthquake model correspond to the level 1 earthquake and the other earthquake scenario, level 2 as mentioned briefly below. With regard to civil and structural engineering field in Japan, Japan Society of Civil Engineers

(JSCE), Architects Institute of Japan(AIJ), Japan Road Association(JRA),

Japan Water Works Association (JWWA), etc. revised the seismic design codes and standards after Kobe earthquake (Great Hanshin Earthquake). The revised seismic design codes and standards introduce the following two kinds of seismic motion level.

\* Seismic Motion Level 1:

The level has a return probability of once or twice in the service life of the facility. The level is equivalent to the conventional seismic motion level applied in many civil and structural engineering structures.

## \* Seismic Motion Level 2:

The level has a smaller probability than that of the above but is greater in magnitude. The level is equivalent to the seismic motion generated in areas with faults or in inland area where big scale tectonic plates border, such earthquake motion as Kobe earthquake. However the probability is very low that water supply facility experiences Seismic Motion Level 2, the influence of the seismic motion on the water supply facility is considered enormous.

- (b) It has incorporated the JICA study results with respect to selection of scenario earthquakes and other database such as base topography, building distribution, which constitute common database between JICA study,
- (c) It seems appropriate method for the damage estimation for such lifeline facility as water pipeline network, gas pipeline network because it considers previous JICA study results as well as state of the art idea derived from the Japanese earthquake disaster experience,
- (d) It is basically the same method which was applied to the study by Prof. TAKADA except for historical earthquake model,
- (e) Therefore, it seems more familiar method to TWWC and, if necessary, a sustainable method for review and upgrade of the study results with common ground among the other study for lifeline facility, especially for, water supply facility.

## 1.3 Procedure and Condition of Seismic Motion Analysis

## 1.3.1 Procedure of Seismic Analysis and Damage Estimation

A procedure of seismic motion analysis and damage estimation for water supply system in TWWC is shown in Fig.1.15.

## Scenario Earthquakes

- Historical Earthquake around Tehran
- Earthquake due to Mosha Fault
- Earthquake due to South Ray Fault
- Earthquake due to North Ray Fault
- Earthquake due to North Tehran Fault

Modes of Seismic Load

- Strong Ground Motion
- Surface Fault Dislocation
- Ground Displacement Caused by Liquefaction



Figure 1.15 Flow chart of seismic motion analysis and damage estimation

#### 1.3.2 Condition of Seismic Motion Analysis

#### (1) Seismic Force

As the external force caused by 4 major active fault earthquakes in 5 scenario earthquakes shown in section 3.1.3, following 3 types of external earthquake forces are selected under considering geological condition, topography and ground/soil condition. These are used as the input for seismic response analyses of water supply facilities.

- 1. Strong Ground Motion
- 2. Surface Fault Dislocation
- 3. Ground Displacement caused by Liquefaction

Historical earthquake is what is derived from the statistical analysis of the earthquake record entries in table 3.3. The scale and the return period of the anticipated earthquake are estimated through the statistical analysis based on the Poisson's process. Parchin and Kharizak fault are used for the statistical ground motion analysis in the same manner as in the Gas research project.

It is, however, said liquefaction potential area may exist in the southern part of Tehran, the liquefaction potential is confirmed low by the borehole investigation at the suspected area in the Gas research project. Therefore even the ground displacement is calculated, the calculated result seems negligible. Then, the result is not used for subsequent assessment. As for landslide, it seems that no landslide occurs in the area where water supply facility exists based on the site reconnaissance. Therefore, landslide is also not referred to in subsequent assessment.

#### (2) Geotechnical Data

Soil condition database are developed in JICA Microzoning Study and Gas Research Project. In this study the ground model used in Gas Research Project is applied. As mentioned in 3.1.1(3), subsurface soil model developed in JICA microzoning study is applied for the stability analysis of the structural component in water treatment and reservoir facility.

The Ground model in the Gas Research Project is classified into 20 types of geotechnical soil model based on ground condition as shown in Figure 1.16 and 1.17, and the distribution of the types with scenario fault model lines is shown in Figure 1.18. At first engineering seismic base is chosen and after that the surface ground is modeled as a horizontal layer. The density, shear velocity, damping and depth of ground water are defined in the layer.

The greater the number of geologic column type becomes, the harder soil stiffness becomes. So the figure shows that soil stiffness in southern area of Tehran city is comparatively soft.

Outline description of the geotechnical data is excerpted as below from Gas Research Project<sup>2-2</sup>);

The types of soil at the surface layers are various in Tehran areas. Stone, gravel, sand, clay and silt are mains in the layers. Here the soil conditions at the surface layers are divided into four types. These are rock, coarse aggregate, transition and fine aggregate. In the north and west of Tehran soil layers are formed by coarse aggregate, transitions in the middle and fine aggregate in the south. Soil condition changes from coarse to fine aggregate gradually from north toward south. In the most part

of north and west of Tehran, soils are gravel and sand in GW (gravel well graded), GP (gravel poorly), GM (silty gravel), SM (silty sand) and SW (sand well graded) groups (Unified Soil Classification) are very dense. The N value is about 25 in surface layers and about 50 in the layers below 10 meters. Soil is formed by gravel, sand and clay in the center and south of Tehran area. The N value in these areas is from 10 to 45 in the surface layers. Soil is formed by sand, clay and silt and the N value is about 10 to 25 in the surface layers in south east of Tehran.

There are two rivers in Tehran, Karajrood (in the west) and Jajrood (in the east) which supplies more than 60 percent of Tehran water needs and both are out of the boundary of the city. Furthermore, there are many streams and floodways in the Tehran area, of which the important ones from the west to the east are, Chitgar seasonal river, Latman floodway, Kan seasonal river, Hesarak floodway, Vesk floodway, Vanak, Velenjak, Darband, Manzarieh, Shahabad and Sorkhehhesar floodways. They are mainly directed from the north to the south of Tehran. These rivers and floodways have an important role in Tehran aquifer discharge and also the amplification of ground motions and liquefaction phenomena.



Figure 1.16 Geotechinical soil model (1)

Source: Gas Research Project



Figure 1.17 Geotechinical soil model (2)

Source: Gas Research Project





## (3) Ground Water Level

In JICA microzoning study, ground water level data was developed. In this study the data is used as ground water level data. Figure 1.19 shows the distribution of ground water level, with scenario fault model lines

Ground water conditions in the Tehran area are briefly explained according to the Gas Research Project<sup>2-3)</sup>.

a) South west of Tehran

It shows that the ground water depth is varying between more than 100m and less than 10 meters. In the east-side, the ground water depth is less than the west-side. The Tehran Water Organization has controlled the ground water level by pumping the water from several deep wells.

## b) South east of Tehran

The ground water table in south-east is variable between more than 60m and less than 10m. In this zone the direction of the ground water flow is from north to the south following the topography. The water table in the north is deeper than the south. The alluvial sediments at the north are coarse while at the south are fine, so there is more or less infiltration, which makes the velocity of ground water decrease. This may be the main cause of uprising the water table in the south.

c) North of Tehran

In this region ground water depth is variable between 150 m and 50 m, from the northeast to the southwest. But the depth is not decreasing uniformly. For example in the center of this region ground water depth is about 30m due to the masses of clay. In whole Tehran, ground water depth changes in different times during a year and the maximum depth is in November while the minimum one is in May.



Figure 1.19 Distribution of ground water level. with scenario fault model lines

#### (4) Seismotectonic Features and Fault Parameter

## 1) Seismotectonic Features<sup>2-4)</sup>

### (a) Seismotectonic Provinces

The territory of Iran has been divided by researchers into seismotectonic provinces with different characteristics. The works performed by Berberian (1976)<sup>12)</sup>, Nowroozi (1976) Nogol Sadat (1983) and IRCOLD (1996) can be pointed out as examples of such activities. According to the zoning by Berberian and IRCOLD the project area within radius of hundred kilometers around the Ferdossi square is located in Alborz Seismotectonic Province (the northern part of the project area) and Central Iran Seismotectonic Province (the southern part of the project area).

#### a) Alborz Seismotectonic Province

Alborz Mountain Range constitutes the northern part of Alpine -Himalaya Mountain Range in the west of Asia. The northern margin of these mountains is an evident mountainous boundary against a quaternary coastal plain. In the project area, part of Mosha Fault and Tehran North Fault constitute the southern boundary of Alborz. The east and west boundaries of Alborz are not well defined from structural point of view.

The rate of slide in Alborz varies from about 17 mm per year (with 28 degrees azimuth) in the northwest to 6 mm per year (40 degrees azimuth) in the southeast. On the average, the rate of slide accompanied by the release of seismic energy is estimated to be between 6-16 mm per year and N 40E (maximum shortening, Jackson and McKenzie, 1988)<sup>13</sup>. These studies show that 50- 100 percent upper crust seismogenic deformation takes place in the Alborz Mountain Range.

In the Central and West Alborz, the earthquakes are generally of left lateral strike-slip and reverse mechanism on nodal planes with northwest -southeast strike. For example, the earthquakes of March 26, 1983, Jan. 20, 1990 and June 20, 1990 that all have left -lateral strike-slip mechanism with compression component as well as the earthquakes of July 2, 1957 and July 22,1983 that have thrust mechanism.

#### b) Central Iran Seismotectonic Province

The area between Alborz and Kopehdagh Mountains in the north and Zagros in the south and southwest of the country is referred to as Central Iran Seismotectonic Province by Berberian (1976)<sup>10)</sup>. It is clear that there are evident differences in the geological, tectonic and seismotectonic characteristics of different zones of Central Iran Province (such as Azarbayjan, Makran area, Sanandaj-Sirjan Zone). Ambraseys (1974)<sup>10)</sup> states that the data related to a short period of time in one century are misleading considering the relative tranquility of Central Iran. Therefore, this province is not going to be subdivided here and what follows is a description of its general characteristics.

The seismotectonic map of Iran (Berberian, 1976)<sup>12)</sup> shows that Central Iran is not a linear seismic zone and seismic activities are scattered in this province. In general, the seismic pattern of Central Iran includes earthquakes with relatively high magnitudes, long return periods and small number of events. Seismic activity in this province is not usually continual and its earthquakes are usually

shallow depth. Great events in this province are usually accompanied by surface faulting.

The earthquakes of Boinzahra (1962)<sup>11)</sup> with Ms 7.3, Bayaz Plain (1968) with Ms 7.4 (Ambraseys, 1982)<sup>9)</sup> and Tabas (1978) with Ms 7.3 (Ambraseys) are important 20th century earthquakes of this province all of which had been accompanied by surface faulting.

#### (b) Focal Depth of Earthquakes

The area with a radius of 100 kilometers surrounding Tehran is located in Central Iran and Alborz seismotectonic provinces where the earthquakes are of shallow depth. The studies performed on the earthquakes focal depth show that the error in the calculation of the focal depth of earthquakes is much greater than that in the epicenters recorded by instruments (Jackson and McKenzie, 1984)<sup>14</sup>. This necessitates the introduction of focal depth as a seismogenic bed.

Considering the seismic microzoning of the Greater Tehran area performed by Japan International Cooperation Agency (JICA, 2000)<sup>15)</sup> and the location of the project area and Alborz and Central Iran seismotectonic provinces the depth of 8-16 kilometers can be proposed as seismogenic layer. Thus, the depth of 8-10 kilometers is considered as Upper Transit Ion Layer, 10-14 kilometers to as Seismogenic Layer and 14-16 kilometers as Lower Transition Layer.

## (c) Description of Seismotectonic Modelling

a) Tehran water supply facility are located inside the city of Tehran which is located in the boundary between Alborz and Central Iran seismotectonic provinces. Almost the upper half of the project area (with a radius of 100 kilometers around Ferdosse square) is located in Alborz and its southern half in Central Iran. And give faulting in Alborz and Central Iran has caused earthquakes with Ms 7.2 in 1972 (Boinzahra Earthquake) and Ms 7.4 in 1978 (Tabas Earthquake Golshan) and Ms 7.4 in 1990 (Manjil Earthquake).

b) Most of the earthquakes occurred in Tehran are of shallow type and some of them of medium depth. Considering the recent studies (JICA, 2000) and recording of the related microearthquakes related to Mosha and South Ray Faults in the time period of 1996-1999 and also considering the location of the project area in Alborz and Central Iran Seismotectonic Provinces. The depth of the seismogenic layer is considered 8-16 kilometers.

c) The rate of occurrence of earthquakes in Alborz and Central Iran is less than in Zagros but their magnitudes are great to medium and fair return periods are longer. Instruments at earthquakes in these provinces are usually accompanied by surface faulting.

d) Mechanism of earthquakes in the project area is usually compressional and sometimes with right lateral strike-slip component.

e) Important seismic sources for Tehran water supply facility are: Mosha, North Tehran, North Ray, South Rat, Kahrizak and Parchin faults all of which have known seismic history. North Tehran Fault with a length of about 90 kilometers and North Ray and South Ray Faults, each with 20 km length can most affect the water supply facility in case of movement.

**f)** The mechanism of most faults in the project area is of thrust type with left lateral strike-slip component. The general strike of faults in this area is northwest -southeast to east- west and they

dip either north or south. Therefore, the general strike of the principal stress in the study area is estimated to be north east -southwest.

In general, there are two groups of faults in the studied area: 1-the faults dipping north (North Tehran, North and South Ray, Kahrizak, Niavaran Faults etc.) and, 2-the faults dipping south (such Mahmoodyeh, Davoodyeh, Sorkhesar, Shiyan Kowsar, Lower Telo and Hamsin). The major faults of the project area are included in the first group, but the second group of faults seems to have been created due to the uplift of the foot wall of North Tehran Fault (Berberian and Yeats, 1999)<sup>5)</sup>.

**g)** Considering the faults of the project area and seismic characteristics of the region and the occurrence of earthquakes with Ms equal to or greater than 6.0, displacement will be likely in case of earthquakes with greater magnitudes. This should be considered in the seismic design of the water supply facility.

## 2) Fault Parameter

Considering above results, we assumed the fault parameter of scenario earthquakes used to simulate strong ground motions as shown in Table 1.5.

Fault	Magh		North		North	South	Darahin	Kabrizak	
Parameter	WIOSH	1	Tehrai	1	ray	Ray	Parchin	Kannzak	
Length (km)	20	80	40	28	17	17	73	50	
Width (km)	20	20	22	22	9	9	28	20	
Moment magnitude (Mw)	7.1	7.3	7.2	7.2	6.5	6.6	7.2	6.9	
Small moment magnitude (Mw)	5.3	5.3	5.3	5.3	5	5	5.3	5.2	
Dislocation (m)	1.25	1.58	1.41	1.58	0.63	0.7	1.41	0.99	
Rise time $\tau(sec)$	1.25	1.58	2.16	2.16	1.21	1.85	6.76	4.63	
Shear wave velocity (km/sec)	3.5	3.5	3.5	3.5	3	3	3.5	3.5	
Mass density (tf/m3)	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	
Strike angle (degree)(clockwisefromat western edge)	282	298	270	260	266	257	250	260	
Slip angle (degree)	90	90	90	90	90	90	90	90	
Dip angle (degree)	75	75	75	75	75	75	75	75	
Number of synthesis	8	10	8	8	5	6	9	7	
Depth of upper edge (km)	5	5	5	5	5	5	5	5	

 Table1.5 Fault Parameter of Scenario Earthquakes

#### **1.4 Strong Ground Motions**

## 1.4.1 General<sup>2-5)</sup>

There are two approaches, probabilistic approach and determination approach of scenario faults, to estimate strong ground motions and acceleration at the seismic base rock. In the probabilistic approach, peak ground acceleration is calculated based on the statistical analysis of available earthquake catalogue entries for a certain return period. In the determination approach of the scenario faults, we choose the scenario fault that may cause damage and a hypothesis based on the worst damage scenario that is considered as basic and indispensable approach to assess the earthquake resistance of the water supply network..

## 1.4.2 Statistical Ground Motions<sup>2-6)</sup>

In this method, at first the probabilistic event of earthquake with magnitude M at distance R is calculated. The seismic hazard will be obtained based on area and line source with random variable and Poisson process. The procedure to obtain the probabilistic ground motions is as follows:

(1) Annual occurrence probability of earthquakes  $\nu$  is the reverse of an average return period of earthquakes  $T_R$ , which is obtained by the average earthquake occurrence number n in the period of  $T_N$  as follows:

$$T_R = T_N / n \tag{3.1}$$

$$\nu = 1/T_R \tag{3.2}$$

(2) The exceedance probability, in which the maximum ground intensity Y exceeds a level of y is :

$$P(Y \ge y) = n_y / n \tag{3.3}$$

where,  $n_y$ : the number of earthquakes with the larger intensity than y during the period  $T_N$ .

(3) The annual exceedance probability  $p(Y \ge y)$  is a product of  $P(Y \ge y)$  and v.

$$p(Y \ge y) = v \cdot P(Y \ge y) \tag{3.4}$$

(4) Under the assumption of Poisson's process, the earthquake occurrence probability during the period  $\Delta T$ , in which the intensity Y is over y, is given as this;

$$P(\nu; \Delta T) = 1 - \exp(-p(Y \ge y) \cdot \Delta T)$$
(3.5)

Table 1.6 lists the result of seismic hazard risk for target area. Figures 1.20 and 1.21 show excess probability of ground motion for given return periods. Fig.1.22 shows the procedure to simulate earthquake ground motion. First, a ground motion time history is simulated for faults listed in table 1.7. Prachin and Kharizak faults are selected due to that the fault parameter is known and the distance of epicenter is within 40km of Tehran city. Then, an earthquake velocity response spectrum is determined from velocity response spectra of 8 cases. Next, by using the determined spectrum, a sample time history for the statistical ground motion is obtained. We call the ground motion obtained here as "historical earthquake".

EQ. occurrence rate			0.0159		
Max. Acc.	100gal over	200gal over	300gal over	400gal over	500gal over
Excess probability	0.15	0.15	0.05	0.05	0.00
Annual excess probability	0.00238	0.00238	0.00079	0.00079	0.00
Occurrence probability during 50years	0.1124	0.1124	0.03897	0.03897	0.00

**Table 1.6 Seismic Hazard Risk** 



Note: "Obs." means observed records.

"Est." means estimation by statistical method.





Figure 1.21 Earthquake occurrence probability during a given return period

CASE	Fault	L (km)	W (km)	Small M	Moment M	D (m)	T (sec)	θ (°)	δ (°)	Λ (°)	n	Upper depth of fault (km)
CASE1	Parchin	73	28	5.3	7.2	1.41	6.76	250	75	0	9	5
CASE2	Parchin	73	28	5.3	7.2	1.41	6.76	250	75	90	9	5
CASE3	Parchin	73	28	5.3	7.2	1.41	6.76	250	75	180	9	5
CASE4	Parchin	73	28	5.3	7.2	1.41	6.76	250	75	270	9	5
CASE5	Kahrizak	50	20	5.2	6.9	0.99	4.63	260	75	0	7	5
CASE6	Kahrizak	50	20	5.2	6.9	0.99	4.63	260	75	90	7	5
CASE7	Kahrizak	50	20	5.2	6.9	0.99	4.63	260	75	180	7	5
CASE8	Kahrizak	50	20	5.2	6.9	0.99	4.63	260	75	270	7	5

 Table 1.7
 Fault parameters of for static ground motion



Figure 1.22 Ground motion compatible to velocity response spectra

## 1.4.3 Generation Synthetic Ground Motions

## (1) Method for Generation Synthetic Ground Motions<sup>2-7)</sup>

In this method the area are divided into mesh by 500 m x500 m. Geographic Information System (GIS) is usually used and time-histories of seismic base motion are generated for different meshes. For calculating the bedrock motion we applied synthetic wave method by using a computer program. This program is written by Takada et al<sup>16), 17)</sup>. For generating a wave associated with small quakes, the Boore's<sup>18)</sup> statistical simulation method is used. Following the spectrum model of the source fault, different initial random numbers are applied in the spectrum to generate the waveform of the

small quakes. A regional wave attenuation value and empirical screening of the duration time are used in the calculation. In this empirical wave synthetic method, it is not necessary to evaluate the characteristics of wave propagation route and the ground. Although the advantageous features of the empirical Green Function are not fully used, the rupture propagation on the fault surface and the geometrical relation between the fault and any arbitrary point are well considered in the computation.

For generating a synthetic wave, the Fourier Spectrum of acceleration induced by a fault rupture is calculated from summation of spectrums due to the fracture of small zones as shown in Fig. 1.23.



Figure 1.23 Fault model for synthetic wave generation<sup>19)</sup>

In this figure:

- $R_{ii}$ : Distance from the rapture start point of zone (i, j) to the observed point on ground
- $R_0$ : Distance from the focus of the large earthquake to the observed point on ground
- $W_L$ : Width of fractured zone of a large earthquake
- $L_L$ : Length of fractured zone of a large earthquake
- $W_S$ : Width of a small fractured zone
- $L_S$ : Length of a small fractured zone

Therefore, we can write:

$$A_{L}(f) = \sum_{i=1}^{n_{L}} \sum_{j=1}^{n_{w}} A_{S}(f) \exp(-if \cdot t_{ij}) + \sum_{i=1}^{n_{L}} \sum_{j=1}^{n_{w}} \sum_{k=1}^{(n_{d}-1)n'} A_{S}(f) \exp(-if \cdot t_{ijk})$$
(3.6)

where,

 $A_L(f)$ : Fourier Spectrum of acceleration (due to rupture of whole fractured zone in the fault),

 $A_{S}(f)$ : Fourier Spectrum of acceleration for the small fractured zone

In Eq. (3.6) the first term in the right side gives the effect of time delay (attenuation) between the focus of large quake (start point of the fractured zone of the fault) and the focus of small quake (start point of a zone (i, j)), while the second term is the effect of time delay between the start and end points of the zone (i, j) (attenuation during the fracture time in a small quake).

The other parameters are as follows:

- $t_{ij}$ : time delay between focus of the large earthquake and small quake due to zone (i, j)
- $t_{ijk}$ : time delay due to the fracture propagation in zone (i, j)
- $n_L$ : number of the zones along the length of the fractured part of the fault
- $n_W$ : number of the zones along the width of the fractured part of the fault
- $n_d$ : ratio of the time delay in length direction to the one in the width direction
- n': adjusted coefficient for demolishing the apparent period due to the fractions of fractured time of a small zone.

Considering attenuation due to distance from the fault and wave propagation  $Q_s$  in infinite medium, the acceleration spectrum for a small fractured zone can be written as<sup>18</sup>:

$$A_{S}(f) = \frac{R_{\theta\phi}}{4\pi\rho\beta^{3}} \cdot \frac{1}{R} \cdot M_{0} \cdot S(f) \cdot \exp(\frac{f \cdot R}{2Q_{S}\beta})$$
(3.7)

where,

 $R_{\theta\phi}$ : radiation directivity characteristics for shear wave (0.63)

 $\rho$ : mass density (2.7gr/cm<sup>3</sup>)

 $\beta$ : shear wave velocity (3.0 km/s)

- R: distance from a fault
- $M_0$ : earthquake moment
- S(f): frequency of filtered waves
- $Q_S$ : wave propagation in infinite medium

After using by-pass filtration we may write the spectrum shape A(f) of a small earthquake wave for a point R from the epicenter and the moment of  $M_0$  are obtained as:

$$A(f) = C \cdot M_0 \cdot S(f, f_c) \cdot P(f, F_{smax}) \frac{1}{R} \exp\left(-\frac{\pi f R}{Q_s \beta}\right)$$
(3.8)

Where:

C: radiation characteristic coefficient

f : frequency

 $f_c$ : corner frequency

 $P(f, F_{s \max})$ : high frequency filter

 $Q_S$ : wave propagation related to the attenuation of shear wave

 $S(f, f_c)$ : low frequency filtered waves is related to  $f_c$ 

C and  $S(f, f_c)$  are expressed as Eq. (3.9) and Eq. (3.10) respectively.

$$C = \frac{R_{\theta\phi} \cdot FS \cdot PRTIN}{4\pi\rho\beta^3}$$
(3.9)

where,

FS: frequency correction at free surface (here is 2.0 for the bed-rock)

*PRTIN* : reduction ratio where the energy distribution is considered for two horizontal directions (here,  $1/\sqrt{2}$ ).

$$S(f, f_c) = \frac{(2\pi f)^2}{1 + (f/f_c)^2}$$
(3.10)

The corner frequency  $f_c$  is calculated from the Brune<sup>20)</sup> relation.

. .

$$f_c = 4.9 \times 10^6 \cdot \beta (\Delta \sigma / M_0)^{1/3}$$
(3.11)

The stress drop parameter  $\Delta \sigma$  is in bar and the earthquake moment  $M_0$  is in dyne.cm.

 $P(f, F_{s \max})$  is given as:

$$P(f, F_{s\max}) = \frac{1}{\sqrt{1 + (f/F_{s\max}^{2u})}}$$
(3.12)

Although u is determined by the reduction ratio at high frequencies, Boore<sup>18)</sup> uses u = 4.0 based on the recorded spectra forms. The high frequency limit  $F_{s \max}$  of a small earthquake is given as a function of  $M_0$ .

$$F_{\rm smax} = 7.31 \times 10^3 \cdot M_0^{-0.12} \tag{3.13}$$

The 1/R term and the exponential part in Eq. (3.8) show the effect of geometrical and material internal damping, respectively.  $Q_s$  is related to the attenuation of S wave. In this study we calculate the  $Q_s$  based on the research result <sup>21)</sup>.

$$Q_s = 90.9 f^{0.5} \tag{3.14}$$

After setting these parameters, Fourier amplitude spectrum of acceleration A(f) is obtained. However, without the phase characteristics, the time-history wave form cannot be obtained. The Boore<sup>16)</sup> method is used for the phase characterization. A random phase is used for the phase characterization to generate a small quake that satisfies Eq. (3.13). However, if we use the random phase, the amplitude envelope forms a regular uniform wave. Therefore, in order the non-stational characteristics in a time-history form, we employ an envelope function w(t) given as:

$$w(t) = at^{b}e^{-ct}H(t)$$
(3.15)

where, H(t): heaviside step function (0 or 1), whose shape is determined by b and c.

By assuming the maximum amplitude at the time  $\mathcal{E}T_w$ , the envelope is determined by adjusting the maximum amplitude at  $T_w$  to be decreased  $\eta$  times of the one at the time  $\mathcal{E}T_w$ ,. By using the envelope of about 20 strong motion records Brune<sup>20)</sup> has empirically determined as  $\mathcal{E} = 0.2$ .

$$b = -\varepsilon \ln \eta / [1 + \varepsilon (\ln \varepsilon - 1)]$$
(3.16)

$$c = b/(\varepsilon T_w)^b \tag{3.17}$$

Also the value for standardization is calculated as follow;

$$a = [e/(\varepsilon T_w)]^b \tag{3.18}$$

Here, the duration time  $T_d$  is as given as:

$$T_d = 10^{(M-2.5)/3.23} \tag{3.19}$$

In this equation,  $T_d$  is the time at which the maximum amplitude becomes equal to 1/10 ( $\eta$ =0.1).

## (2) Predicted Ground Motion

Fig. 1.24 and Fig. 1.25 show result of Fourier spectra and accelerogram of predicted ground motion at base rock as an example of the North Tehran earthquake.



Figure 1.24 Fourier Spectra of acceleration



Figure 1.25 Acceleration

## (3) Generated Base Rock Acceleration

Figs. 1.26 to 1.29 show the distribution of base rock acceleration for each scenario earthquake.



Figure 1.26 Base Rock Acceleration North Tehran Fault



Figure 1.27 Base Rock Acceleration North Ray Fault



Figure 1.28 Base Rock Acceleration South Ray Fault



Figure 1.29 Base Rock Acceleration Mosha Fault

## 1.4.4 Surface Ground Motions<sup>2-8)</sup>

Surface ground motion analysis method is described as excerpted below from the Gas Research Project report:

Acceleration on the base rock can be calculated by using above methodology. Next we would like to obtain acceleration on the surface ground by introducing an amplification on the sites. The characteristic of an amplification of seismic wave is changed based on rigidity, damping and thickness of soil layer and the depth of ground water. The rate of amplification is changed by seismic base acceleration as well as soil conditions. For calculating the acceleration and velocity on the surface ground and the rate of amplification we used the SHAKE program.

SHAKE is a program for the equivalent linear seismic response analysis of horizontally layered soil deposits. The program computes the response of a semi-infinite horizontally layered soil deposit overlying a uniform half-space subjected to vertically propagating shear waves. The analysis is done in the frequency domain, and, therefore, for any set of properties, it is a linear analysis. An iterative procedure is used to account for the nonlinear behavior of the soils. Calculated peak ground motions for surface ground acceleration, velocity and displacement are shown in figure 1.30 to 1.41.



Figure 1.30 Surface Acceleration North Tehran Fault



Figure 1.31 Surface Acceleration North Ray Fault



Figure 1.32 Surface Acceleration South Ray Fault



Figure 1.33 Surface Acceleration Mosha Fault



Figure 1.34 Surface Velocity North Tehran Fault



Figure 1.35 Surface Velocity North Ray Fault



Figure 1.36 Surface Velocity South Ray Fault



Figure 1.37 Surface Velocity Mosha Fault



Figure 1.38 Surface Displacement North Tehran Fault



Figure 1.39 Surface Displacement North Ray Fault



Figure 1.40 Surface Displacement South Ray Fault

![](_page_69_Figure_0.jpeg)

Figure 1.41 Surface Displacement Mosha Fault