No.

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 II
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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

SUMMARY OF EARTHQUAKE RESISTANT PLAN

The earthquake resistant plan hereunder is aiming at realization of measures for Tehran water supply system to be resistant to earthquake. When essential measures such as relocation of a water treatment plant are taken, the earthquake resistant plan becomes very costly, while it does not generate any increase of water sales income. These measures are excluded from the plan hereunder, because they are apt to raise water tariff greatly in case no subsidy is given for the execution. It is also important to secure emergency water supply bases, which are included in the plan.

Earthquake resistant measures for raw water transmission mains and water treatment plants are firstly studied. Available data on raw water transmission mains are insufficient and they are located out of the study area. However, these are so fundamental and important facilities to convey water to Tehran city that preliminary review of the mains is made in the study.

As explained in the chapter 4, facilities on faults would be damaged by a scenario earthquake. However, such upstream facilities as raw water transmission mains to treatment plants are difficult to be reinforced completely, and their countermeasures are set as minimization/mitigation of damage effect , which is described in the target setting of the chapter 5. These countermeasures include installation of by-pass pipelines, water transmission from other alive facilities or relocation to a safe area when their life is over.

In case of Tehran water supply system, principal measures are thought as water transmission from other usable facilities. This concept is obtained considering the conditions of facility dispersion. There exists four surface water systems in addition to an abundant ground water sources and WTP No.6 and No.7 are planned to be constructed in the future. Moreover, clear water transmission network is already developed and considerable amount of water can be conveyed to a designated area through the network.

It is also suggested countermeasures to enhance necessary facilities for satisfaction of Code 2800, which is considered as design criteria against a designated earthquake with acceleration of 350gal and return period of approximately 100 years. The return period is assumed from the ISO-acceleration contour map of Tehran-Ray region prepared by Geological Survey of Iran.

By the structural analysis according to Code 2800, it is found that some parts or members of facility structures and buildings are insufficient in bearing capacity and their reinforcement becomes necessary. There are mechanical and electrical equipment of unstable installing conditions and they might cause second disaster occurrence. Measures for the equipment are studied in the chapter 6.

Measures for downstream facilities from clear water transmission mains to distribution networks are studied. As for transmission main, its reinforcement is employed as a principal measure for minimization of damage occurrence. Estimated damage points of reliability 70% and below, by scenario earthquakes, are 23 locations at fault crossing and 30 locations at connection of pipes to massive structures, and all of estimated points are to be reinforced under the plan. The points of reliability 70% and above at the fault crossing will be strengthened in the future. However, all of weak pipe connections to the structures will be reinforced considering easiness and inexpensive cost for execution.

Important section of distribution trunk mains is planned to be reinforced for minimization of damage occurrence, while principle measures for water distribution mains are emergency water supply and restoration. Trunk mains at fault crossing and connection to structures in northern part would be reinforced. Damages on other trunk mains and sub mains will be covered by emergency countermeasures.

Regarding to measures for such facilities as reservoirs and pump stations, installation of by-pass pipelines, conveyance of water from other alive facilities and relocation of the facilities to a safe area in the future when their life is over will be appropriate measures which are similar to those for water treatment plant.

Bearing capacity of some facilities and structures are partially insufficient and not satisfy Code 2800 just like WTP. In addition, some mechanical and electrical equipment are not installed properly and there is possibility of second disaster occurrence. These facilities and equipment are planned to be reinforced properly.

Project period and target year are determined considering implementation program of JICA M/P, the future plan of TWWC and feasibility of the project.

Project period in JICA M/P is defined as 12 years, and it is divided into three stages; short term stage for the first three years, middle term stage for next four years and long term stage for the last five years. While TWWC set the target period of its future plan as 2021, 15 years from the present, it is considered that 15 or 20 year period is too long as far as a realistic program is discussed.

Therefore the project period is set as 12 years after one year preparation and the target year of the project is set in 2019. Same as JICA M/P, the short term stage is set for three years from 2008 to 2010, the middle term stage is set for four years from 2011 to 2014 and the long term stage is set for five years from 2015 to 2019 as shown in *Table S.1*.

Table S.1 Proposed Project Period

<table>
<tr><td>Year</td><td colspan="5">2007 2010 2014 2019</td></tr>
<tr><td rowspan="2">Period</td><td>Preparation</td><td>Short Term</td><td>Middle Term</td><td>Long Term</td><td>Future</td></tr>
<tr><td>1 year</td><td>3 years</td><td>4 years</td><td>5 years</td><td></td></tr>
</table>

Estimation of Preliminary Project Cost

Project cost is estimated based on TWWC information, assistance of local consultants and data from "Price List of Goods and Service (MPO)". As stated earlier, work items of the earthquake resistant project consists of measures for pipeline system, facilities and equipment and emergency water supply. Majority of the work items for the project is considered locally available while some of them would be imported from foreign countries. Therefore, the estimated costs are divided into local and foreign cost.

Construction cost is preliminarily estimated as approximately US$22Million and the total project cost is estimated as US$28.5million as described in *Table S.2*. The estimated project cost corresponds to US$2.5Million/year which is 3.5% of the annual water sales income in the last year.

Table S.2 Preliminary Project Cost

(unit: US$)

	Cost Items		Short Term	Middle Term	Long Term	Total Cost
1	Construction Cost		3,628,600	6,243,900	12,395,200	22,267,700
	Pipelines					0
		Min. Occurrence	150,000	700,000	6,290,000	7,140,000
		Min. Effect	—	—	—	—
	Facility (Structure)					0
		Min. Occurrence	992,800	1,609,900	744,200	3,346,900
		Min. Effect	—	—	—	—
	Equipment					0
		Min. Occurrence	171,800	—	—	171,800
		Min. Effect	286,000	1,336,000	2,431,000	4,053,000
	Emergency Supply		2,028,000	2,598,000	2,930,000	7,556,000
2	Administration Fee (8 %)		290,288	499,512	991,616	1,781,416
3	Consultant Fee (10%)		362,860	624,390	1,239,520	2,226,770
4	Contingency (Approx.10%)		362,252	624,198	1,237,664	2,224,114
5	Preliminary Project Cost		4,644,000	7,992,000	15,864,000	28,500,000
6	Annual Project Cost		1,548,000	1,998,000	3,172,800	

Priority of implementation for each work item is studied considering emergency, importance, social condition, cost and benefit. Other than these evaluation items, there is the most important item for considering implementation of the earthquake resistant plan. That is investigation of fault locations, which is considered to take three to four years to complete, before arranging pipe reinforcement. Therefore cost for short term program is set small, while cost for long term is estimated bigger as shown in *Table S.2*.

It should be noted that Iranian side is very progressive for realization of the earthquake resistant project described in the above. One of the evidence is that TWWC and MPO plan to employ local consultants to execute further study and design of the project, while IIEES announced to undertake investigation of the existing fault locations.

THE STUDY ON WATER SUPPLY SYSTEM RESISTANT TO EARTHQUAKES IN TEHRAN MUNICIPALITY IN THE ISLAMIC 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

CHAPTER 1 INTRODUCTION

1.1 Background of the Study

Tehran City, the capital of IRI is located on the southern foot of Alborz Mountains which is the Iranian central mountain range. There is an elevation difference of 760m between the lowest area-1,040m in the South and the highest area-1,800m in the North. Especially, the slope becomes progressively steeper from the central area of the city to the northern area. The seasonal difference in temperature is large and the annual precipitation is below 300mm. The city is positioned in a semi-arid region.

As for the population of the city, its growth is estimated stable during the past ten years from 1996 which is the latest census year, and the population in 2005 is estimated as 7,230,046. However, inferring from the latest development of housing areas implemented all over the northern part of the city, the increase in the population would be considered to be bigger than the past years..

In Tehran the annual drinking water amounts to 924 million cubic meters (as of 2004) which is supplied from surface water sources (approx. 70%) and groundwater sources (approx. 30%). In the southern area where population density is high, all the water is taken from wells. The surface water is treated in the existing water treatment plants in the city and the groundwater is supplied after chlorination in distribution reservoirs. The deterioration of groundwater quality is occurring in the city due to the excessive groundwater use which lowers the groundwater table. In addition, because of the large elevation difference among the areas, various measures have been undertaken to control the water pressure in the water distribution system. In the southern area, water supply is getting more difficult because the strengthening of pipe network cannot catch up on the increasing water demand due to the rapid population increase.

Furthermore, the areas surrounding Tehran is well-known as an earthquake hot spot. Although surveys have been conducted on the past earthquakes in the city, the crisis management in earthquake disasters has not always been well established in terms of water supply. Therefore, there are concerns that a large scale earthquake will cause the breakdown of intake pumps, the destruction of concrete pipes, stoppage of water supply, etc. in the city. Moreover, the renovation of the existing water supply facilities established in 1952 is considered imperative because the facilities are significantly aging.

The amount of Unaccounted-for Water (UFW) is reported to have reduced greatly from 33.75% in 1996 to 27.52% in 2002. Tehran Provincial Water and Wastewater Company (TPWWC) has strengthened its countermeasures to use the limited water resources effectively with the target

UFW reduction of 20%.

In response to the request of the Government of Islamic Republic of Iran (GOIRI), the Government of Japan (GOJ) decided to conduct the Study on Water Supply System Resistant to Earthquakes in Tehran Municipality in the Islamic Republic of Iran (the Study) in accordance with the relevant laws and regulations in force in Japan.

Accordingly, the Japan International Cooperation Agency (JICA), the official agency responsible for the implementation of the technical cooperation programs of the GOJ, was assigned to undertake the Study in close cooperation with the authorities of GOIRI.

The Scope of Work and Minutes of Meeting for the Study were agreed upon on November 24, 2004 between JICA and TPWWC which is affiliated to the Ministry of Energy. In accordance with the Scope of Work, JICA appointed a joint venture, Nihon Suido Consultants Co., Ltd. in association with Tokyo Engineering Consultants Co., Ltd., to conduct the Study and formed the JICA Study Team (the Team) in February 2005.

Under these circumstances, the Team has studied water supply system and the required information of Tehran city, executed ground motion analysis and damage estimation of the system, and prepared an appropriate earthquake resistant plan including emergency countermeasures. In addition, advices on UFW reduction and improvement of PR activities of TPWWC/TWWC are made by the Team. The team also transferred necessary technology to the counterparts.

1.2 Objectives of the Study

The objectives of the Study are:

To clarify concrete countermeasures against earthquakes and their priorities through the preparation of an earthquake-resistant plan for TPWWC to establish water supply systems which are resistant against earthquakes or which could be restored in a short time even if damaged by earthquakes.

To pursue technology transfer to the counterpart personnel in the course of the Study, in particular, with respect to the methodologies for formulating a water supply system improvement plan.

1.3 Study Area

The Study area shall cover Districts No. 1 to No.20 as shown in Figure 1.1.

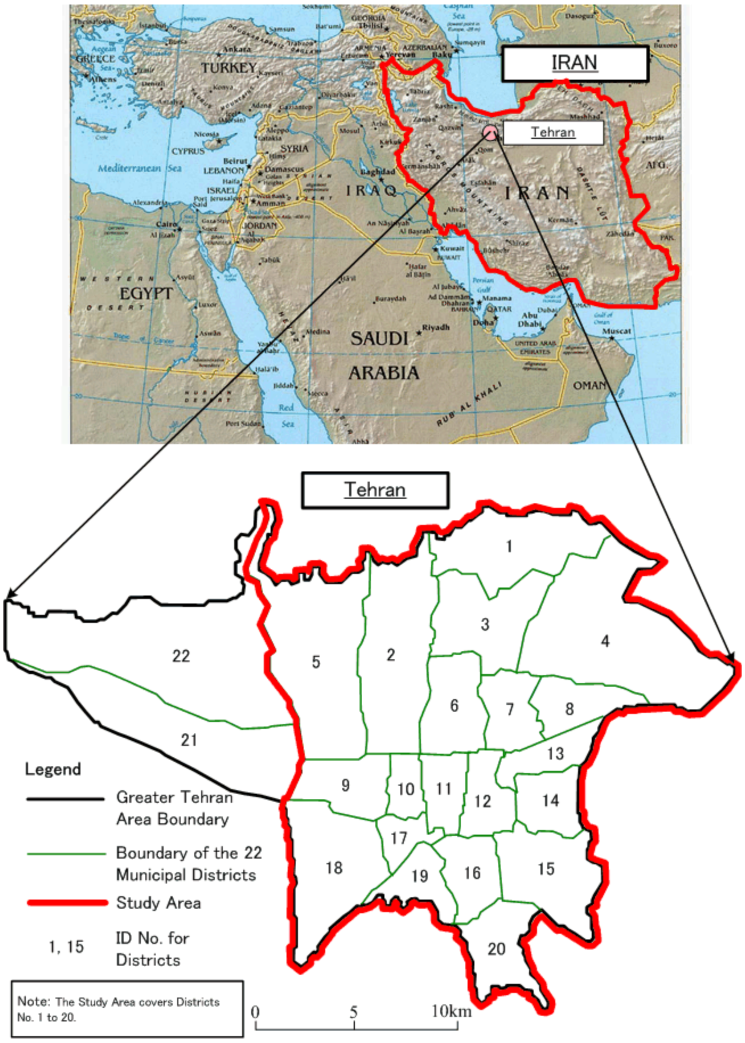


Figure 1.1 Study Area

1.4 Framework of the Study and its Progress

The implementation flow of the Study on water supply system resistant to earthquakes in Tehran municipality is as shown in Figure 1.2.

As shown in the figure, a draft inception report was prepared in March 2005 and it was discussed and agreed by JICA advisory committee in Japan on 4th March and 11th May 2005. The JICA Study Team visited Tehran and commenced Stage-1 Site Survey on 15th May 2006. On 25th May, the team had an inception meeting with the steering committee of Iranian side and JICA advisory committee, and the inception report was agreed at the meeting.

During Stage-1 Site Survey, the study team has extensively discussed with the counterpart team of TWWC and related organization, collected various data and information and visited the existing water supply system of Tehran city. The team prepared the progress report of the study and presented at the work shop titled "Making Water Supply System Resistant to Earthquake in Tehran" held on 24th August 2005.

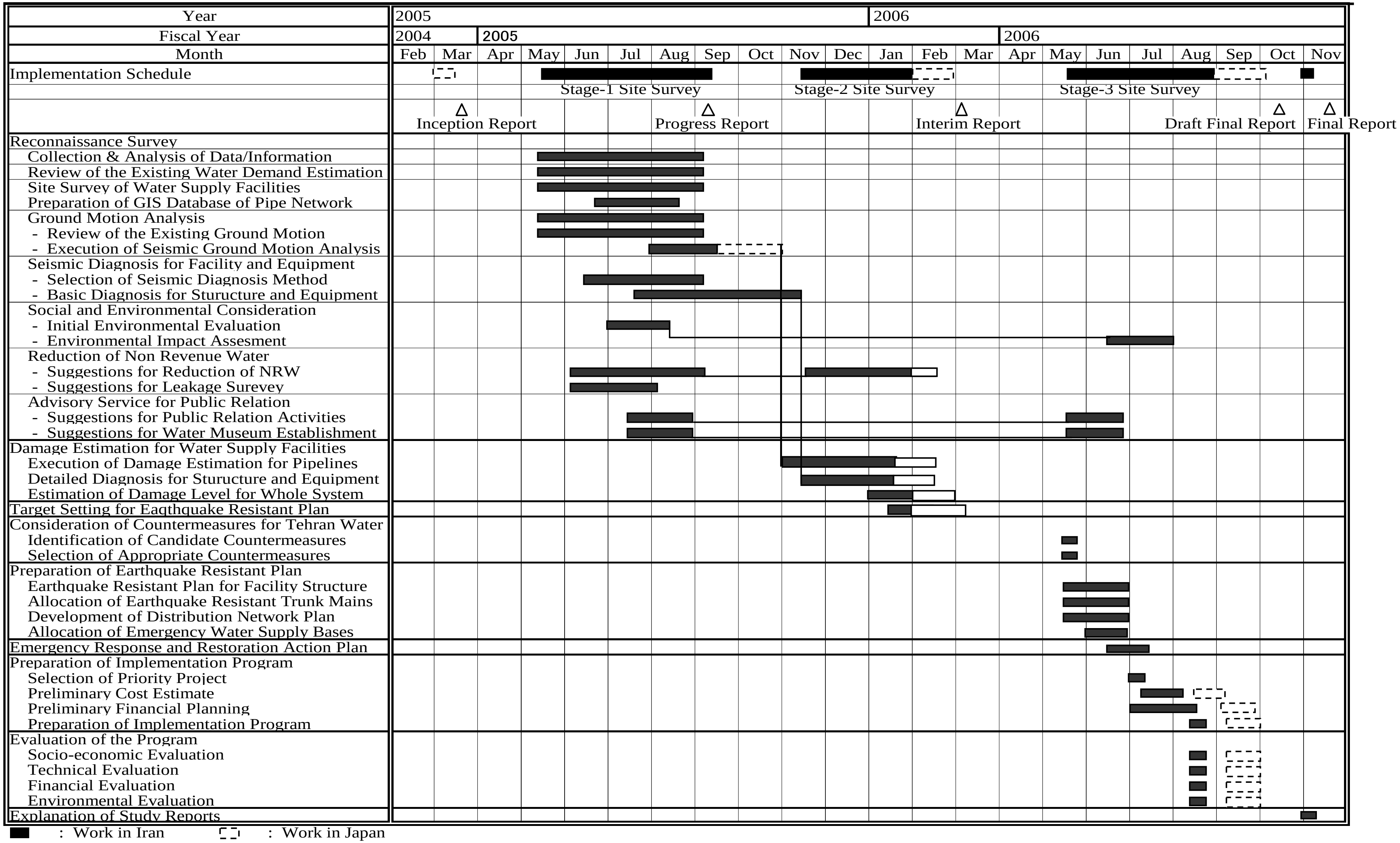
The main purpose of Stage-2 Site Survey, the present stage of the study which has started on 22nd November 2005, is to set up target for an earthquake resistant plan for Tehran water supply system. Damage estimation of water pipelines and detailed diagnosis for facility structures and equipment are executed on the basis of the seismic ground motion analysis and the basic diagnosis of the facilities, both of which have been performed at Stage-1 Site Survey. The target for the earthquake resistant plan has been set based on the results of the damage estimation and the detailed diagnosis together with findings from past activities by related organizations.

At the same time, reduction of non revenue water has been further studied with more data and information obtained in this stage in addition to the descriptions made in the progress report.

An earthquake resistant plan has been formulated in Stage-3 Site Survey. The plan consists of variety of countermeasures necessary before or after an earthquake occurrence. Preliminary cost estimate of the project, its implementation program, and its financial plan were worked out. The project was evaluated form various aspects.

The team has prepared a draft final report describing the earthquake resistant plan for Tehran water supply system. The report also includes advices on UFW reduction and improvement of PR activities of TPWWC.

Figure 1.2 Implementation Flow of the Study for the Whole Stages



1.5 Basic Concept of the Study

Basic concept of the Study is, as mentioned in JICA's terms of reference and the inception report prepared by JICA Study Team, to make progress emphasized on "Measures to be Realized" shown in Table 1.1.

Table 1.1 Basic Concept of the Study

Important Items for the Study	Measures to be Realized
Cooperation with Iranian Consultants and Use of Existing Database Resources	There are various studies on improvement, operation and maintenance of Tehran water supply system prepared by the Iranian consultants. These present studies are referred to the Study.
Review and Selection of the Existing Earthquake Ground Motion Analysis	In Tehran municipality, the aseismatic studies have been conducted or being conducted on the water supply system and other lifeline systems. The method of earthquake ground motion analysis for the Study is selected among the previous studies with due consideration.
Lessons from Past Earthquake Disasters	The earthquake-resistant plan in the Study shall become practical by reviewing the earthquake disaster in Bam which occurred in December 2003 and Lowshan-Manjil in the northwestern part of IRI in June 1990.
Damage Estimation for Water Transmission and Distribution Pipes	Damages on water transmission and distribution pipelines are estimated and proposed on the basis of the past studies in Tehran municipality and Japanese guidelines.
Earthquake Damage Estimation for the Whole Water Supply System	Damage estimation of the water supply system discussed in this study has taken into account not only the system but the damage estimation and the impact on the other lifelines as well.
Earthquake-resistant Structures	Design criteria or standards applicable for the seismic diagnosis and earthquake-resistant design for water supply facilities and equipment are evaluated from Iranian, Japanese and the other applicable criteria or standards. The criteria or standards are determined through the discussions with TPWWC.
Technical Assistance for the Planning of Non Revenue Water (NRW) Reduction and Leakage Survey	Since, a non revenue water of 20% is TWWC's goal to be achieved in 2020. The middle/long-term NRW reduction plan is proposed in the Study.
Advisory Service for the Establishment of a Water Museum	Proposal is to be made on planning the effective display and public communication methods for the water museum on the basis of similar experiences in Japan.

CHAPTER 2 RECONNAISSANCE SURVEY

2.1 Collection and Analysis of Data/Information obtained in Iran

The reports and books relevant to the Study have been collected in Tehran in addition to the reports and books collected by the Preparatory Study Team of JICA. The study team has collected the various data and information through the site survey and interviewing persons concerned in their offices.

2.1.1 Data and Information Collected

The study team has evaluated and assessed the various data and information by means of hard copies or soft copies in active cooperation with TWWC. The study team has collected and evaluated such data and information as the previous aseismatic studies, CAD data of pipelines, microfilms of the water supply facilities, administrative data of TWWC, etc. Therefore the situation on the Tehran water supply system and its management are familiar with by the team.

2.1.2 Site Survey

Seeing is believing. In order to grasp the water supply system of Tehran municipality and its management, the study team has aggressively visited the water supply facilities from the dam reservoirs to water distribution networks and various offices concerned as well whose water supply management or operation & maintenance activities have been heard.

(1) Site Survey of Water Supply Facilities

The study team has aggressively investigated the water supply facilities and equipment to have an understanding of the Tehran water supply system at an earlier stage of the reconnaissance survey and in order to carry out a preliminary seismic diagnosis of the water supply facilities and equipment by its experts. Especially, almost all of the dams, intake stations, well facilities, water treatment plants and reservoir stations have been visited by the study team at least once and the important facilities have been visited by the team several times so far.

(2) Visit to Offices Concerned

The study team has visited for many times the offices and departments in TWWC including the operation department, the design and development department, the finance and backup department, the public relations and awareness office and has interviewed counterpart staff regarding the conditions of the water supply facilities and equipment, their operation and maintenance, and so on. The study team has visited and collected information from related offices such as IIEES, TDMO, GTGC, PWUT, Eshafan water and waste water company, etc. and JICA Experts for the water sector as well.

2.2 Review of the Existing Water Demand Estimation

2.2.1 Served Population and Water Consumption

The present served area of Tehran water supply system is from district 1 to district 20 out of 22 districts in the city as shown in Figure 1.1. Districts 21 and 22 are newly built up areas and will be served by the city water in the near future. The area served by the system is 533 km^2 at present. Served population and water consumption of Tehran water supply system in the past are as listed in Table 2.2.1.

As shown in Table 2.2.1, the served population and water supply amount have steadily increased every year except for year 2001. The daily maximum production is over three million m^3 at present. In 2001, the surface water supply decreased sharply due to the continuation of the drought period since 1999 to 2000. In the drought year 2001, the amount of groundwater used was more than the amount of surface water used (Figure 2.2.1). However, in summer season, the production capacity decreased so much that the water supply did not reach to a satisfactory level for the customers need. And consequently the per capita consumption in 2001 was recorded only as much as 213 liters.

Afterwards, since rate of precipitation became normal and non revenue water (NRW) decreased, the per capita consumption recovered to as much as 274 liters in 2004, showing an increase by 30% compared with 213 liters (Figure 2.2.2). Thus, the customers had been supplied with enough amount of water. While taking measures on NRW reduction, water demand reduction and consumption management would be needed so as to conserve the valuable water resources.

Figure 2.2.1 Raw Water Intake and Production

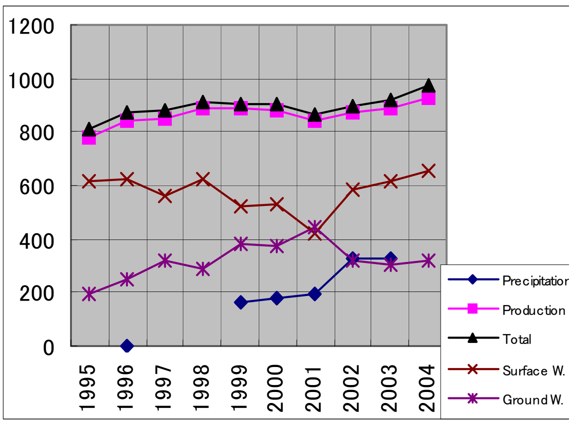
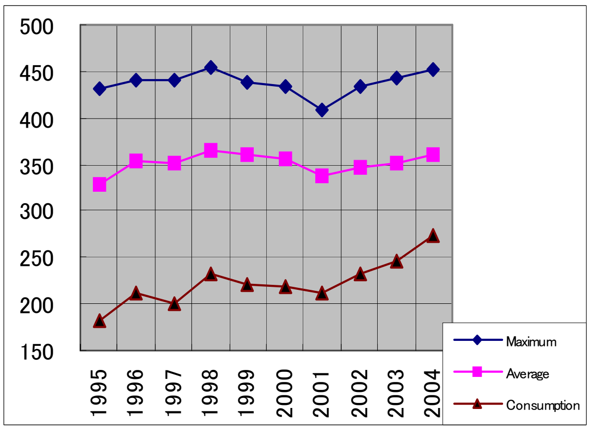


Figure 2.2.2 Per Capita Supply and Consumption



The per capita consumption is being compared with those of Tokyo and Yokohama cities as shown in Table 2.2.2. The per capita consumption in Tehran municipality is almost the same as Tokyo and Yokohama cities which possess a comparatively larger amount of water sources.

The reason why the per capita consumption in Tehran municipality became similar to Tokyo and Yokohama cities is considered to be the reduction measures of NRW.

The trend of reduction of NRW is shown in Figure 2.2.3. In the Figure, the NRW in Tehran has decreased from 45% to less than 25% in a relatively short time period of ten-years. This trend is considered similar to the case of Osaka in 1950's also shown in the same figure. For the reduction of NRW, various measures should be taken as leakage reduction programs on water distribution network and service connections, settlement of unbilled authorized consumption, termination of illegal use and connection, replacement of water meters, improvement of accuracy of meter reading, etc. TWWC has promoted synthetically many of the above measures for these years and succeeded to lower NRW ratio greatly.

However, reducing NRW to an amount lower than the present values is indeed difficult and a time-consuming program as shown in the graphs of Japan and Osaka in the figure. If the Tehran's transition curve of NRW should be continuous the same as the curve of Japan, the NRW will reach at 15% in 2021 which is above the target which is 20% for NRW Tehran. The target of Tehran's NRW may be validated by modifying the rate of 20% to some 15% in case of TWWC taking further activities continuously. Suggestions for the future NRW reduction are given in Chapter 4 of this report.

Table 2.2.2 Per Capita Use and NRW

City	Yokohama	Tokyo	Tehran	Tehran
Year	2000	2000	2004	2021
Domestic	244	246		
Others	78	110		
Consumption	322	356	274	240
NRW(%)	8.0	8.7	23.9	20.0
NRW	28	34	86	60
Supply	350	390	360	300

Figure 2.2.3 Trend of NRW in Japan and Tehran

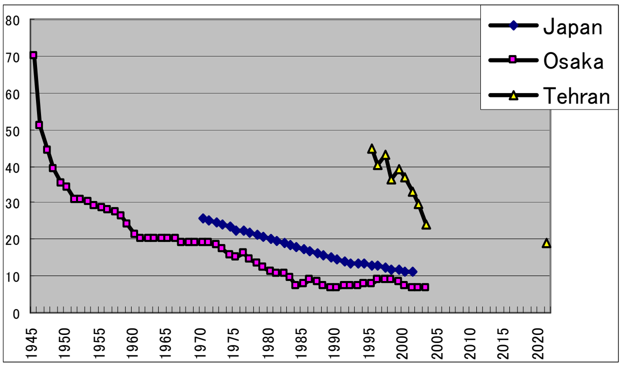


Table 2.2.1 Past Served Population and Consumption of Tehran Water Supply System

year	Unit	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Tehran Population	person										
Served Population	person	6,465,191	6,513,935	6,583,009	6,652,394	6,722,066	6,791,994	6,863,300	6,934,300	6,956,800	7,019,600
Numbers of Connections	numbers	787,088	814,368	837,958	853,210	856,706	866,005	875,934	884,352	890,419	897,615
Person per Connection	Person	8.21	8.00	7.86	7.80	7.85	7.84	7.84	7.84	7.81	7.82
1) Annual Supply and Consumption Basis											
Total raw water supply	m3/year	809,757,349	869,890,504	877,573,685	914,911,486	907,399,821	904,515,825	862,486,329	899,189,070	918,652,891	972,222,881
Annual Production	m3/year	776,474,692	842,385,156	846,530,397	886,155,615	885,413,864	882,692,275	845,102,272	876,014,462	889,582,850	923,646,992
Water Sold (Consumption)	m3/year	431,225,887	506,430,041	484,086,939	563,826,283	540,936,681	540,779,448	533,206,868	586,979,742	625,705,546	704,985,506
NRW by TWWC (Sold/Raw)	%	46.75%	41.78%	44.84%	38.37%	40.39%	40.21%	38.18%	34.72%	31.89%	27.49%
Sum of Surface Water	m3/year	611,820,584	619,915,872	559,840,358	626,688,946	523,557,151	532,435,705	421,920,630	582,069,407	618,225,200	655,862,720
Karaj Dam	m3/year	323,174,110	328,791,548	278,563,533	337,633,193	266,095,380	283,575,959	209,301,330	329,804,807	346,798,260	343,216,420
Lar and Latyan Dam	m3/year	288,646,474	291,124,324	281,276,825	289,055,753	257,461,771	248,859,746	212,619,300	252,264,600	271,426,940	312,646,300
Sum of Groundwater	m3/year	197,936,765	249,974,632	317,733,327	288,222,540	383,842,670	372,080,120	440,565,699	317,119,663	300,427,691	316,360,161
Deep Wells Tehran	m3/year	197,936,765	249,974,632	317,733,327	288,222,540	373,942,670	356,201,546	429,703,563	302,413,577	290,825,875	314,052,211
Deep wells jajrood	m3/year					9,900,000	15,878,574	10,862,136	14,706,086	9,601,816	2,307,950
2) Daily Supply and Consumtion Basis											
Daily Maximum Production	m3/day	2,793,000	2,863,000	2,901,000	3,015,000	2,941,000	2,945,000	2,803,000	3,005,000	3,079,000	3,173,495
Daily Average Production	m3/day	2,127,328	2,301,599	2,319,261	2,427,824	2,425,791	2,411,728	2,315,349	2,400,040	2,437,213	2,523,626
Daily Maximum Factor		1.31	1.24	1.25	1.24	1.21	1.22	1.21	1.25	1.26	1.26
Water Sold (Daily Consumption)	m3/day	1,181,441	1,383,689	1,326,266	1,544,730	1,482,018	1,477,539	1,460,841	1,608,164	1,714,262	1,926,190
Ratio of NRW (Sold/Ave. Prod.)	%	44.46%	39.88%	42.82%	36.37%	38.91%	38.74%	36.91%	32.99%	29.66%	23.67%
Per Capita Supply											
Daily Maximum Supply	lpcd	432	440	441	453	438	434	408	433	443	452
Daily Average Supply	lpcd	329	353	352	365	361	355	337	346	350	360
Daily Consumption	lpcd	183	212	201	232	220	218	213	232	246	274
Total raw water supply	m3/day	2,218,513	2,376,750	2,404,311	2,506,607	2,486,027	2,471,355	2,362,976	2,463,532	2,516,857	2,656,347
Karaj Dam	m3/day	885,409	898,338	763,188	925,022	729,028	774,798	573,428	903,575	950,132	937,750
Lar and Latyan Dam	m3/day	790,812	795,422	770,621	791,934	705,375	679,945	582,519	691,136	743,635	854,225
Sum of Surface Water	m3/day	1,676,221	1,693,759	1,533,809	1,716,956	1,434,403	1,454,742	1,155,947	1,594,711	1,693,768	1,791,975
Deep Wells Tehran	m3/day	542,293	682,991	870,502	789,651	1,024,500	973,228	1,177,270	828,530	796,783	858,066
Deep wells jajrood	m3/day	-	-	-	-	27,123	43,384	29,759	40,291	26,306	6,306
Sum of Groundwater	m3/day	542,293	682,991	870,502	789,651	1,051,624	1,016,612	1,207,029	868,821	823,090	864,372

Source: Operation Department, TWWC

2.2.2 The Existing Water Demand Estimation

Regarding the existing water demand estimation for Tehran water supply, several kinds of estimation outcomes are in hand. One is prepared by LAR Consulting Engineering Company as shown in Table 2.2.3. Another one is listed in the draft preparatory report by JICA and its results are as shown in table 2.2.4. Future population in this estimation is described quoted from the master plan of country of Iran.

Table 2.2.3 Water Demand Estimation by LAR Engineering

Year	Unit	2002	2011	2021
Population	Person	7,121,384	7,870,302	9,250,728
Water Demand	m^3/day	2,358,792	2,668,368	3,268,800

Source: Identification Studies and Phase One of North Tehran Ring Route Water Supply

Table 2.2.4 Water demand estimation shown in JICA Preparatory Report

Year	Unit	1996	2001	2006	2011	2021
Population	1000person	6,760	7,460	8,290	9,140	10,720
Per Capita Supply	lpcd	353	332	337	324	315
Average Water Demand	1000m^3/day	2,386	2,477	2,794	2,961	3,377
	M m^3/year	870	908	1,019	1,081	1,233
Water Sources	M m^3/year	760	860	1,080	1,160	1,230
Surface Water	M m^3/year	420	590	810	890	1,000
Groundwater	M m^3/year	340	270	270	270	230

Source: Draft Preparatory Study Report on the Water Supply System Resistant to Earthquake in Tehran municipality December, 2004 JICA

The other estimation is prepared using predicted future population on the basis of population values of Statistic office of Iran as described in Table 2.2.5 and per capita water demand set by TWWC (Consumption Management Seminar on 5th November 2005) as shown in table 2.2.6.

Table 2.2.5 Population and Growth Ratio

Year	Population	Growth Ratio
1986	6,042,584	
1991	6,475,527	1.394%/year
1996	6,758,845	0.860
2001	7,042,891	0.827
2005	7,230,046	0.658

Table 2.2.6 Water demand estimation using Population based on Statistics Office

Year	Unit	1996	2001	2006	2011	2021
Population	1000person	6,759	7,148	7,292	7,611	8,292
Per Capita Supply	lpcd	353	376	357	338	300
Average Water Demand	1000m^3/day	2,386	2,688	2,603	2,573	2,488
	M m^3/year	871	981	950	939	908
Daily Maximum Demand	1000m^3/day	2,958	3,252	3,124	3,087	2,985
	m^3/sec	34.2	37.6	36.2	35.7	34.5
Water Sources	m^3/sec	26.6	27.4	37.5	46.6	46.6
Surface Water	m^3/sec	18.7	13.4	26.2	38.7	38.7
Groundwater	m^3/sec	7.9	14.0	11.3	7.9	7.9

Note: Assumed that day maximum factor =1.2 and No6 & No7 plants put in operarion in 2009.

Among the above results, JICA estimation is thought of as the rather high side prediction, because the future population is estimated based on a yearly growth ratio of 1.86%, while estimation based on the population trend by Statistics office is regarded as rather the lower side prediction.

The future population is estimated on a yearly increase ratio of 0.86% which is higher than the recent ratio as shown in Table 2.2.5 considering the latest development of housing area as mentioned in section 1.1 “Background of the Study”, but it is far smaller than the above JICA estimation. The future per capita water demand estimated by TWWC is also smaller than the one estimated by JICA study.

As to cope with water demand in the higher side estimation, it is mentioned in the JICA preparatory report that No.8 water treatment plant besides No.6 and 7 plants both of which are about to be put into implementation is needed to be constructed in the future. While in case of lower estimation, addition of No.6 and No.7 water treatment plants to the existing water production facilities is enough to meet with future water demand.

The water demand estimated by LAR Engineering is placed in between JICA and Statistics office estimations. The LAR estimation includes water demand distribution to small areas, reservoir zones, in the city of Tehran. Hence, the estimation is employed as a basis for hydraulic analysis to be mentioned in the section 4.3.

2.2.3 Water Demand Distribution

In order to study and prepare an earthquake resistant plan for Tehran water supply system, hydraulic analysis of water pipelines especially treated water transmission mains is indispensable. The transmission mains are composed of very complex networks for conveying water to each of 74 distribution reservoirs which is thought to be the most important water base for Teheran citizens.

By the hydraulic analysis, flow conditions to each reservoir are grasped and weak point of the network in terms of the flow conditions would be identified. The hydraulic analysis could be developed to estimate carrying capacity of damaged networks, number of population affected by water supply interruption as a result of earthquake. For the analysis, a provision of the appropriate network modeling is indispensable and also an appropriate area-wise distribution of the existing water demand/consumption should be identified.

In the study of so-called “Identification Studies and Phase one of Tehran Ring Route Water Supply Design” prepared by LAR Engineering, the water consumption in 2002 was allocated to

61 small zones by distribution reservoir. The zonal consumption is estimated on the basis of zonal population and zonal per capita water use. The former is based on population densities of the municipal districts and the latter is from actual billed consumption of TWWC for each reservoir zone.

This method the water consumption distribution is considered reasonable and is to be employed as a basis of hydraulic analysis to be executed in the section 4.3 of the report. Population and water consumption in each reservoir zone is as described in Table 2.2.7.

Table 2.2.7 Population and Water Consumption in Tehran Water Reservoir Zones in 2002 (1/2)

row	water zone	reservior number	covered area of reservoir regions (ha)	District no., surface area and population density included in each reservoir zone									population in each reservoir zone in 2002	per capita consumption (lpcd)	water consumption (m3/hr)
				district no.	surface area	population density	district no.	surface area	population density	district no.	surface area	population density			
1		28	181	1	181	71							12,851	416	223
2		33	82	1	82	71							5,822	416	101
3		32	181	1	181	71							12,851	416	223
4		30	63	1	63	71							4,473	419	78
5		26	765	1	765	71							54,315	416	941
6		91	240	1	240	71							17,040	423	300
7		82	338	1	206	71	2	132	94				27,034	416	469
8		38	506	2	506	94	3	150	86				60,464	416	1,048
9		72	398	2	398	94							37,412	416	648
10		37	908	2	908	94							85,352	416	1,479
11		14	751	3	601	86	6	150	116				69,086	416	1,197
12		21&22	1532	1	49	71	3	1284	86	4	199	105	134,798	416	2,336
13		19	1217	3	266	86	4	951	105				122,731	416	2,127
14		40	403	4	403	105							42,315	416	733
15	1	29	156	1	156	71							11,076	416	192
16		27	694	1	540	71	4	154	105				54,510	416	945
17		23	1398	1	491	71	4	907	105				175,246	416	3,037
18		41	412	1	412	71							29,252	416	507
19		24&20	1894	1	988	71	3	756	86				135,164	416	2,343
20		northen parts of district1	726	1	726	71							51,546	-	-
21		northen parts of district4	520	4	520	105							54,600		-
22		Lavizan forest park	1051	4	1051	0							-		-
23		sum of zone 1	14846										1,197,938	379	18,928
24		12	254	4	254	105							26,670	391	434
25		43	2482	4	2210	105	8	272	256				301,682	390	4,905
26		11	402	4	75	105	8	327	256				91,587	390	1,489
27		7	573	8	573	256							146,688	390	2,385
28		62	354	4	44	105	7	161	199	8	149	256	74,803	390	1,216
29	2	10	339	7	339	199							67,461	390	1,097
30		9	715	2	61	94	6	629	116	7	25	199	83,673	390	1,360
31		2	1036	7	821	199	8	114	256	13	101	196	212,359	390	3,452
32		1	498	6	380	116	7	118	199				67,562	390	1,098
33		71	412	4	412	105							43,260	390	703
34		48	606	4	606	105							63,630	390	1,034
35		sum of zone 2	7671										1,179,375	390	19,174

Table-2.2.7 Population and Water Consumption in Tehran Water Reservoir Zones in 2002 (2/2)

row	water zone	reservior number	covered area of reservoir regions (ha)	District no., surface area and population density included in each reservoir zone									population in each reservior zone in 2002	per capita consumption (lpcd)	water consumption (m3/hr)
				district no.	surface area	population density	district no.	surface area	population density	district no.	surface area	population density			
36		59	243	5	243	73							17,739	438	324
37		34	297	5	297	73							21,681	438	396
38		80	266	5	266	73							19,418	439	355
39		80	784	2	286	94	5	498	73				63,238	438	1,155
40		58	785	2	222	94	5	563	124				90,680	438	1,656
41		57	1495	5	1495	73							109,135	438	1,993
42		55	413	2	413	94							38,822	438	709
43		56	920	5	920	124							114,080	438	2,083
44		line 1850	1195	2	744	94	5	451	124				125,860	438	2,298
45	3	18	504	2	504	94							47,376	438	865
46		8	973	2	535	94	6	438	116				101,098	926	3,900
47		volume meters of SADR town elevated tank	215	5	139 215	73							15,695	439	287
48		northern parts of district 5 that have no resident	1372	5	1372	0							-		-
49		northern parts of district 5	629	5	629	73							45,917	-	-
50		northern parts of district2	396	2	396	94							37,224	-	-
51		sum of zone 3	10487										847,963	453	16,020
52		4	494	11	225	204	12	269	143				84,367	342	1,203
53		5	991	12	892	143	13	99	196				146,960	342	2,095
54		6	933	12	228	143	13	195	196	14	510	170	157,524	342	2,246
55	4	inlet 31	1425	13	1325	196	14	100	170				276,700	342	3,944
56		outlet 31	615	14	571	170	15	44	124				102,526	342	1,462
57		51	2158	14	1225	170	15	933	124				323,942	342	4,618
58		sum of zone 4	6616										1,092,019	342	15,567
59		3	952	11	952	204							194,208	288	2,330
60		13 & Azadi line	2765	9	1955	95	10	810	385				497,575	288	5,971
61		ring way line	1925	17	777	397	18	1148	100				423,269	288	5,079
62	5	souther parts of district 18 but not in district 5	2240	18	2240	100							224,000		-
63		sum of zone 5	7882										1,339,052	240	13,381
64		16&53&ringway line	4863	15	2021	245	16	1652	215	19	1190	148	1,026,445	288	12,317
65		36	2080	20	2080	116							241,280	288	2,895
66	6	parts of south of Tehran not in district 6	3455	15	1975	0	20	679	116	19	801	148	197,312		-
67		sum of zone 6	10398										1,465,037	249	15,213
68		**Total**	**57,900**										**7,121,384**	331	**98,283**
69		**Total Tehran annual water consumption (m 3)**											**860,955,230**		

Note: The above per capita consumtion is based on the billed consumption of TPWWC

2.3 Survey of the Existing Water Supply System

2.3.1 Water Supply Facilities

The first modern water supply system for the city of Tehran consists of No. 1 water treatment plant, Bilaghan intake and raw water transmission mains connecting them which have been installed in 1955. Served population at that time was only 0.9 million which has greatly increased to 7 million, approximately eight (8) times of the original served population. Tehran water supply system has developed along with increase of population of the city. The existing conditions of the water supply system are described hereunder.

(1) Water Sources

Sources for the water supply system consist of surface water impounded by dams and ground water being abstracted in central and southern part of the city. Present states of both kinds of water sources are presented below.

1) Surface Water

The number of storage dams as the water sources for the Tehran water supply system is four (4) as shown in Table 2.3.1. Of the four (4) dams, Karaj, Latiyan and Lar dams are supplying raw water continuously, while the Taleghan dam is supplying raw water supplementary to the No. 1 and No. 2 water treatment plants via the Bileghan intake during the drought period. In future, when the planned water treatment plant No.6 is constructed, the raw water will be transmitted to the Bileghan intake with a capacity of 5.0 m^3/sec. (The target capacity of the transmission mains are 12.2m^3/sec.)

The 5th dam called Mamloo is under construction with a deadline of year 2007, which will be a water source for the planned water treatment plant No. 7 with a capacity of 4.0 m^3/sec.

Table 2.3.1 List of Dams for Tehran Water Supply System

Name of Dam	Year of Completion	Type of Dam	Effective Capacity	Transmission destination
Karaj Dam	1961	Double Curvature concrete arch	195 M m^3	Water Treatment Plants No. 1 and No.2
Latiyan Dam	1967	Concrete Buttress	85 M m^3	Water Treatment Plants No. 3 and 4
Lar Dam	1980	Earthfill with Clay Core	860 M m^3	Water Treatment Plant No. 5
Taleghan Dam	2005	Earthfill with Clay Core	329 M m^3	Water Treatment Plants No.1 & 2 (Emergency Use)
Mamloo Dam	Under construction	Earthfill with Clay Core	250 M m^3	Water Treatment Plant No.7 (Planned)

As mentioned above, the Tehran water supply system has many water sources, which is a safety factor in case disasters occur to avoid the suspension of the water supply for the entire city. The water sources could be complemented by each other, i.e., the Karaj dam alternates with the Taleghan dam and the Latiyan and Lar dams alternate with the Mamloo dam.

2) Groundwater

As shown in Table 2.2.1, in recent years approximately 300 million m^3 of groundwater has been abstracted annually by means of deep wells. Before these years, over 350 million m^3 of groundwater or over 400 million m^3 in 2001 have been abstracted to supplement the insufficient surface water. In case of normal conditions of annual precipitation, amount of groundwater abstraction would be about half of the surface water intake. However in 2001, groundwater abstraction was bigger than the surface water intake and thus, Tehran city suffered from severe water shortage throughout the summer season of that year. Development of surface water sources are still needed for stable water supply conditions in Tehran.

On the other hand, the annual potentiality of extractible groundwater is about 250 million m^3 based on the results of studies made. Therefore the importance of further development of the surface water sources as described in the preceding section is evident. Fortunately, according to TWWC's future plan, the valuable groundwater sources shall be preserved by restricting the usage of groundwater through further developing the surface water. By the prevention of the fall in the groundwater table, the countermeasures using the groundwater sources could be taken against the surface water shortage as experienced in 2001. This issue must be realized.

(2) Raw Water Intake and Transmission Facilities

1) Surface Water

The existing intake and transmission facilities are as described in Table 2.3.2. The raw water transmission systems other than the Taleghan system are transmitting the raw water from the intake point to the water treatment plants; however, the raw water from the Taleghan dam is transmitted to the Bileghan intake from which the raw water is transmitted to the No. 1 and No. 2 water treatment plants.

As a result of our investigation on the raw water transmission pipeline route, since the existing reinforced concrete pipes, steel pipes and tunnels were installed in a low water pressure condition like an open channel, no leakage sections or damages have been found. However, as it will be discussed in Section 2.11.3, there are parts of raw water transmission facilities located across the faults. These parts of transmission facilities are predicted to get damaged due to earthquakes. In case earthquakes cause damages to these transmission facilities, raw water could not reach to the treatment plants despite the fact that Tehran water supply system has many water sources as described in the preceding subsection (1) Water Sources.

It is not easy for the transmission pipelines located across the faults to be an earthquake resistant facility. Therefore, it is imperative that raw water transmission facilities across the faults should be provided by a bypass pipelines. The earthquake-resistant measures on the raw water transmission facilities shall be carefully studied by Iranian consultants.

Table 2.3.2 Outline of Existing Raw Water Transmission Mains and Tunnels

Intake point	Transmission destination	Type of Conduit (diameter)	Construction year	Length
Bileghan Intake Point	Water Treatment Plant No. 1	Steel Pipe (1000mm x 2)	1955	73 km
Bileghan Intake Point	Water Treatment Plant No. 2	Concrete Pipe (2000mm x 2)	1963	67 km
Latiyan Dam	Water Treatment Plants No. 3 and No. 4	Tunnel	1968	9 km
Lar Dam	Water Treatment Plant No. 5	Tunnel	2003	26km
Taleghan Dam	Bileghan Intake Station （Emergency Use）	Steel Pipe (1800mmx1)	2001	62km

Source: the Draft Preparatory Study Report, JICA, etc.

2) Deep Wells

In the water supply service area, there are 429 deep wells as shown in Table 2.3.3, out of which 354 deep wells/82% are in operation. The specific features of water supply system using deep wells are that a group of so called well colony is composed of a number of wells as shown in Table below. The groundwater extracted from the deep wells is transmitted to the service reservoirs where chlorination is performed, and then distributed to the customers. The designed pump capacity of the wells in operation is 63,585m^3/hr. When the pump should be fully operated, the annual production capacity will reach 560 million m^3. However, the actual rate of production recorded is as described in the foregoing subsection (1) Water Source.

Moreover there are 17 deep wells in Jajirood area near the Lar dam which ware used to supplement the surface water supply in the drought year. These wells have not been used in recent years. In Tehran municipality area, besides the wells used for the water supply system, there are many deep wells used for the parks, tree irrigations and street cleaning, etc.

Table 2.3.3 Number and Capacity of the Existing Deep Wells

Colony	Name of	Number of Wells			Colony Capacity (m3/hr)			Name of
No.	Well Colony	in use	no use	Total	in use	no use	Total	Contact Reservoir
1	Tarasht	5	4	9	745	530	1,275	W.T No. 1 Jalalieh
	Naseri aqueduct	2		2	720		720	W.T No. 1 Jalalieh
2	Kan	14	10	24	1,780	450	2,230	W.T No. 2 (Res.56)
3	Yaftabad	6	1	7	2,560	500	3,060	Yaftabad
4	Esfahanak	10	24	34	5,440	2575	8,015	Esfahanak
5	Yaftabad	19	0	19	6,630	0	6,630	Yaftabad
6	Qolqoli	6	0	6	710	0	710	Res. No.13
6	Tarasht	30	1	31	3,980		3,980	Wt.No1 Jallaleh
7	Aqdasieh	15	2	17	2,190		2,190	Res.No.40 & 21
8	Eigehi	4	2	6	590		590	Res.No 31
9	Mehrabad	29	3	32	4,760	200	4,960	Res.No 15
-	Jalalie	9	3	12	1,750	180	1,930	W.T No. 1 Jalalieh
-	Moshirieh	12	2	14	1,405	150	1,555	Res.No 36
-	Qalehmorqi	11	4	16	1,170	240	1,410	Res.No 67
-	Maqsodbeyk	7	0	7	1,180		1,180	Res.No 22
-	Res.No 2	3	1	4	430	180	610	Res.No 2
-	Res.No 3	17	0	17	3,470	0	3,470	Res.No 3
-	Res.No 4	4	1	5	880	240	1,120	Res.No 4
-	Res.No 5	10	0	10	1,920	0	1,920	Res.No 5
-	Res.No 6	2	0	2	170	0	170	Res.No 6
-	Velenjak	4	1	5	380		380	Res.No 24
-	Resalat (Araqi)	28	1	29	4,080		4,080	Res.No 7
-	Res.No 11	4		4	375		375	Res.No 11
-	Res.No 13	18	5	23	2,965	340	3,305	Res.No 13
-	Res.No 16	7	1	8	1,690	520	2,210	Res.No 16
-	Ozgol	11		11	1,140		1,140	Res.No 19
-	Res.No 21	3	0	3	350	0	350	Res.No 21
-	Res.No 41	3	0	3	320	0	320	Res.No 41
-	Qasr-e-Firouzeh	3	0	3	310	0	310	Qasr-e-Firouzeh
-	Res.No 53	3	0	3	1,010	0	1,010	Res.No 53
-	Khaniabad	7	3	10	715	240	955	Res.No 65
-	Shahrak sadr	2	0	2	115	0	115	Res.shahrak sadr
-	Shariati	16	0	16	1,700	0	1,700	Res.No 66
-	Shahrak Valiasr	6	4	11	1,110		1,110	Res.No 68
-	Res.No 69	6	0	6	1,210	0	1,210	Res.No 69
-	Southern Tarasht	18	0	18	3,635	0	3,635	Res.No 96 (Tarasht)
Sum		**354**	**73**	**429**	**63,585**	**6,345**	**69,930**	

Note: There are units among no use (out of use) wells, whose capacities are unknown.

Source: Inventory of Deepwells by Technical & Engineering Service Office of TWWC

(3) Water Treatment Facilities

1) Capacity and Year of Commencement of the Facilities

Outline of the Existing Water Treatment Plants is as listed in Table 2.3.4. The No. 1 water treatment plant (Jalaliyeh) has been operated for more than 50 years, and No. 2 (Kan) and No. 3 (Tehranpars) water treatment plants for more than 40 years all of which are maintained well and function properly as well.

In the near future, No6 and No.7 water treatment plants are to be constructed. No.6 plant with capacity of 7.5 m^3/sec will be installed in the Western part of the city and No.7 plant with 5.0 m^3/sec in Eastern part. By these inputs to the Tehran system, stability against the earthquake would increase to a higher level than the present condition.

The cross sectional area of beams and columns of the No. 2 water treatment plant structures are larger than the ones of No. 1 water treatment plant. The structures of No. 2 water treatment plant seem to be more earth-quake resistant compared with No. 1 water treatment plant.

Table 2.3.4 Outline of the Existing Water Treatment Plants

No. of Plant	1	2	3	4	5	Total
Name of Plant	Jalaliyeh	Kan	Tehranpars		Panjom	
Year in Operation	1955	1963&1970	1968	1984	2003	
Maximum Capacity	3.0	9.0	4.5	4.5	9.0	30.0
Nominal Capacity	2.7	8.0	4.0	4.0	7.5	26.2
Elevation NCC	1257m	1343m	1515m		1686m	

Note: Unit of the capacity is m^3/sec.

2) Water Treatment Process

The same water treatment process is applicable to all the five water treatment plants, namely coagulation-sedimentation process plus rapid sand filtration. The flow chart of water treatment process is shown below.

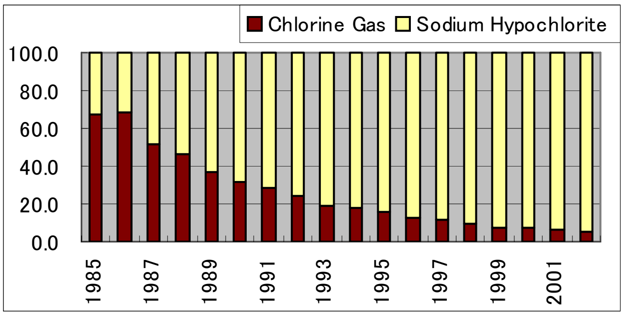
Raw Water Inflow → Pre-chlorination → Screening → (Desilting) → Coagulation → Sedimentation → Rapid Filtration → Post-chlorination → Storage → Transmission

As for the chemical treatment, liquefied chlorine is applied as pre-chlorination and post-chlorination, hydrated lime as pH control chemical and iron chloride as coagulant, which are commonly used in all the five treatment plants.

A TWWC chemical plant which is located five km to the west of No. 3 and No. 4 water treatment plants, was constructed in 1951 for production of liquefied chlorine required for disinfection. However, the production of liquefied chlorine has been suspended seven years ago to avoid damage to the residential area by chlorine gas leakage. At present, the chemical plant is producing four kinds of chemicals as hydrochloric acid, caustic lime, iron chloride and sodium hypochlorite. Of the chemicals produced, caustic lime and iron chloride are consumed in the water treatment plants. And sodium hypochlorite is being prepared in the plants for emergency usage. However, these products are insufficient in quantity for the usage of the treatment plants.

The liquefied chlorine applied for pre-chlorination and post-chlorination in the water treatment plants is now purchased from the liquefied chlorine plants located in Esfahan and Tabriz cities. There is a possibility of earthquake induced damages due to infirm foundation of the one-ton cylinder and lack of neutralization facility against chlorine gas leakage. In Japan, almost all of the chlorination facilities have shifted from the liquefied chlorine gas use to that of sodium hypochlorite as shown in Figure 2.3.1. The safety measures should be evaluated in the Tehran water supply system too, and use of sodium hypochlorite should be adopted as the oxidation or disinfection agent.

Figure 2.3.1 Amount of Chlorine Used in %



Source: Water Supply Statistics in JAPAN (JWWA 2004)

3) Water Quality

The source of surface water is precipitation on the watershed of the Alborz Mountains. Since there is almost no source of water contamination in the watershed or in the dam, the quality of raw water is kept in good status. However, TWWC applies pre-chlorination treatment to disinfect virus and microorganism in the intake stations or water treatment plants for a better quality of the water supply to the citizens.

The quality of the treated water is good enough to meet the water quality standards except for pH value which is comparatively high at around eight.

As for the quality of groundwater, almost all of the quality items meet the quality standard except for the concentration of nitrate. This problem should be resolved in the near future.

4) Summary of Water Treatment Facilities

The summary of facilities of No. 1 to No. 5 water treatment plants is shown in Table 2.3.5. The water treatment facilities are the same types among the water treatment plants as described in the above 2) Water Treatment Process.

Clarifier of No. 1 water treatment plant is Accelerator type. While, the other No. 2 to No. 5 water treatment plants are Pulsator type clarifiers. All of the filters are rapid sand filters having air and water backwashing type. Except the filters of No. 1 water treatment plant, those of all the other plants are Aquazur type.

Since TWWC employs similar or the same type treatment facilities which require also similar or the same operation and maintenance of the facilities from old to new, chance to improve performance or design of the facilities is considered to be large enough. It is obvious that the recently constructed filters in No. 5 water treatment plant have operated with the higher filtration rate compared with the other filters in No. 1 and No. 2 plants.

Table 2.3.5 List of the Existing Water Treatment Facilities

	No.1	No.2	No.3	No.4	No.5
Pre-sedimentation Tank	None	Nos: 2 Size: 110mx11.9mx5m Retention: 25min	None	Nos: 2 Size: 60mx12mx5.5m Retention: 30min	None
Rapid Mix Chamber	None	Nos: 8 Size: 4.8mx4.8mx5m	Nos.: 2 Size: 5.5mx4.5mx3.7m	Nos.: 2 Volume: $60m^3$	Nos.: 4 Volume: $175m^3$
Clarifier	Accelator Type Nos: 6 Capacity: $1,600m^3$ Retention: 30min	Pulsator Type Nos. 6 Size: 39.5mx38.5mx5.8 Retention: 30min	Pulsator Type Nos : 3 Size : 47.5mx33.5x5.5 Retention : 1.5hr	Pulsator Type Nos : 3 Size : 47.5mx33.5X5.5 Retention : 1.5hr	Pulsatpor Type Nos : 8 Size : 42.4mx28.7x5.0 Retention : 1.2hr
Filter	Gravity Sand Filter Nos: 40 units Size: 10m x 4.8m Filer Rate: 5.8m/hr	Aquazur N,T Type Nos: 84 units Size: 12.5m x 4.8m Filter Rate: 5.71m/hr	Aquazur Type Nos: 60 unit Size: 10.5mx4.0m Filter Rate: 5.71m/hr	Aquazur V Type Nos: 32 units Size: 17.0mx4.66m Filter Rate: 6.4m/hr	Aquazur Type Nos: 48 units Size: 16.0mx4.66m Filter Rate: 6.6m/hr
Filter Washing	Air and Water	Air and Water	Air and Water	Air and Water	Air and Water
Clear Water Reservoir	Nos: 1 Capacity: $3,000m^3$	Nos: 4 Capacity: $50,000m^3$, Total	Nos: 4 Capacity: $60,000m^3$	Nos.: 3 Capacity: $50,000m^3$	Nos: 2 Capacity: $20,000m^3$
Coagulant	Ferric-chloride	Ferric-chloride	Ferric-chloride	Ferric-chloride	Ferric-chloride
pH Regulation	Lime	Lime	Lime	Lime	Lime
Disinfectant	Pure Chlorine	Chlorine	Chlorine Gas	Chlorine Gas	Chlorine Gas
Recycling of Waste Water	No	No	No	No	No

(4) Distribution Reservoirs

1) Distribution methods of Tehran Water Supply System

As previously stated, in the city of Tehran, there is an elevation difference of 760 m varying from +1,040 m in the southern part to +1,800 m in the northern part. In the service area of the water supply system, there is the elevation difference of the same rate. Therefore, the service area in the system has been hydraulically divided into the water pressure zones by way of isolating valves or pressure reducing valves basically. From this point of view, Tehran water supply system is similar to the water supply system of Kobe city in Japan as shown in the following Table. On the whole, clear water transmission from treatment plant or deep wells to distribution reservoirs is made by combination of gravity flow and pumpage. Water distribution from the distribution reservoirs to the service areas is made by gravity flow in general.

Table 2.3.6 Comparison of the Service Area of Tehran and Kobe

Municipality	Population	Elevation Difference	No of Zones	Remarks
Tehran (Iran)	7,000,000 (2004)	760 m	72 zones	Service reservoirs placed in each zone
Kobe (Japan)	1,520,000 (2003)	400 m	121 zones	Service reservoirs placed in each zone

However, since hydraulic divisions of the service zones mentioned above are not completed yet, measures as to be described in “Suggestions on Telemetry System and Water Supply Zoning” of the subsection 2.3.2 (3) should be realized by all means.

2) Reservoirs Facilities

A large number and a big volume of the distribution reservoir facilities are considered as characteristics of Tehran water supply system. There are 114 distribution reservoirs and similar facilities in total including the existing 96 and the 18 planned ones as summarized in Table 2.3.7 and as presented in detail in Table 2.3.8. Out of the 96 existing facilities, the 69 facilities including the elevated tanks are solely used for absorption of hourly variation of water distribution.

The total capacity of the existing distribution reservoirs is 1,940,570 m^3 and that of the total reservoir facilities is 2,216,040. The former capacity is equivalent to 18.5hr for the average supply of 2,523,626 m^3 and 14.7hr for the maximum supply in year 2004. When half of the capacity is considered to be kept for variation of hourly consumption (e.g. the capacity of a distribution reservoir for hourly variation is 4 - 6 hours of daily water distribution in Japan), the remains of the total could be used as an effective measure for the emergency and firefighting usage at the primary stage of a disaster.

In the Tokyo Metropolitan Government, the bases for emergency water supply including emergency water tanks with a unit storage capacity of 1,500 m^3 or 100 m^3, are located at 187 locations in 2001. The target of the emergency water supply bases is planned to be placed within every 4 km interval so as for a citizen to access a water base within 2 km distance from any place in Tokyo.

If this idea of water bases is applied to Tehran water supply system, the bases necessary for the emergency water supply would become 42 where, N = 533 km^2 / (π/4 x 4km x 4km). Number of the existing distribution reservoirs already suffices this condition. However, in case of Tehran city, it should be checked that 2.0km intervals of the water bases are satisfactory according to the citizens, considering the estimated access road conditions to the bases.

In case the emergency access distance to a water base is assumed as 1km, numbers of the bases necessary would become 170 = 533 km^2 / (π/4 x 2km x 2km). Hence, 87 = 170 – (87-4) numbers of new reservoirs including emergency water tanks shall be constructed in addition to the existing reservoirs. Since the 18 future reservoirs are planned by TWWC already, the emergency water tanks to be placed would be 69 in numbers.

Table 2.3.7 Summary Table of Distribution Reservoirs

Reservoir and Similar Tank			Distribution Reservoir	Reservoir/ Contact Tank	Contact Tank	Elevated Tank	Clear Water Tank	Break Pressure Tank	Booster Station	Total
Existing	Number	in use	56	2	6		5	1	4	74
		not used	5			3		1		9
	Capacity	in use	1,858,300	40,000	98,700	950	141,000	2,400	—	2,141,350
		not used	111,800			3,000		2,500		117,300
Future	Number	Planned	17			1				18
		Chancelled	1							1
	Capacity	Planned	193,000			500				193,500
		Chancelled	—							0
Retention Time (hr) of Existing Reservoirs & Tanks										
Average Supply in 2004			17.7							20.4
Maximum Supply in 2004			14.1							16.2

Table 2.3.8 List of Distribution Reservoirs (1/2)

No.	Name of Facilities	Location	Capacity (m3)	H.W.L (+m)	L/W/L (+m)	Depth (m)	Existing / Future	Status
	Booster Station							
No.017	Booster Station	Chizar Booster					Existing	
No.104	Booster Station	Gisha Boosters					Existing	
No.105	Booster Station	Sepah Bank Boosters					Existing	
No.114	Booster Station	Tarasht Pump Station	4,870	1,259.00			Existing	
	Break Pressure Tank							
No.044	Break Pressure Tank	Majidieh Pressure Reducer	2,500	1,332.00	1,327.30	4.70	Existing	Not Used
No.076	Break Pressure Tank	Tehran Pars Pressure Reducer	2,400	1,364.00	1,359.00	5.00	Existing	
	Clear Water Tank							
No.092	Clear Water Tank	1st Treatment Plant Reservoir	3,000	1,247.00			Existing	
No.093	Clear Water Tank	2nd Treatment Plant Reservoir	50,000	1,330.00			Existing	
No.095	Clear Water Tank	3rd Treatment plant	34,000	1,509.00			Existing	
No.097	Clear Water Tank	4th Treatment Plant Reservoir	34,000	1,509.00			Existing	
No.099	Clear Water Tank	5th Treatment Plant Reservoir	20,000	1,689.00			Existing	
	Contact Tank							
No.052	Contact Tank	Esfahanak	20,000	1,151.00	1,146.30	4.70	Existing	
No.065	Contact Tank	Khaniabad	19,000	1,096.00	1,092.00	4.00	Existing	
No.066	Contact Tank	Shariati	17,000	1,103.00	1,099.00	4.00	Existing	
No.069	Contact Tank	Ferdows	20,000	1,140.00	1,133.20	6.80	Existing	
No.073	Contact Tank	Yaftabad	20,000	1,144.00	1,140.00	4.00	Existing	
No.096	Contact Tank	Southern Tarasht	2,700	1,214.00	1,209.50	4.50	Existing	
	Reservoir & Contact Tank							
No.068	Reservoir & Contact Tank	Valiasr	20,000	1,121.00	1,114.20	6.80	Existing	
No.089	Reservoir & Contact Tank	Freshfruit & Vegetable Square	20,000	1,090.00	1,084.20	5.80	Existing	
	Distribution Reservoir		98,700					
No.001	Distribution Reservoir	Yousefabad	75,600	1,307.00	1,302.25	4.75	Existing	
No.002	Distribution Reservoir	Bisim	74,000	1,307.00	1,302.50	4.50	Existing	
No.003	Distribution Reservoir	Amirabad	55,500	1,239.00	1,234.50	4.50	Existing	
No.004	Distribution Reservoir	Behjatabad	55,500	1,239.00	1,234.50	4.50	Existing	
No.005	Distribution Reservoir	Bahar	55,500	1,239.00	1,234.50	4.50	Existing	
No.006	Distribution Reservoir	Eshratabad	55,500	1,239.00	1,234.50	4.50	Existing	
No.007	Distribution Reservoir	Resalat - Majidieh	55,500	1,307.00	1,302.33	4.67	Existing	
No.008	Distribution Reservoir	Upper Amirabad	57,600	1,307.00	1,302.33	4.67	Existing	
No.009	Distribution Reservoir	Lower Yousefabad	18,500	1,367.00	1,360.33	6.67	Existing	
No.010	Distribution Reservoir	Abbasabad	36,500	1,359.00	1,352.33	6.67	Existing	
No.011	Distribution Reservoir	Narmak	38,400	1,359.00	1,352.33	6.67	Existing	
No.012	Distribution Reservoir	Sepah Bank	5,000	1,552.00	1,547.30	4.70	Existing	
No.013	Distribution Reservoir	Karaj Road	55,500	1,239.00	1,233.75	5.25	Existing	
No.014	Distribution Reservoir	Upper Yousefabad	25,000	1,448.00	1,443.30	4.70	Existing	
No.015	Distribution Reservoir	Mehrabad	55,500	1,163.00	1,157.75	5.25	Existing	
No.016	Distribution Reservoir	Soleymanieh	55,500	1,163.00	1,157.75	5.25	Existing	
No.018	Distribution Reservoir	Gisha	2,500	1,417.00	1,412.25	4.75	Existing	
No.019	Distribution Reservoir	Mobarakabad	20,500	1,444.00	1,439.30	4.70	Existing	
No.020	Distribution Reservoir	Lower Hesarak	33,000	1,676.00	1,668.00	8.00	Existing	
No.021	Distribution Reservoir	Chizar	27,000	1,526.00	1,521.30	4.70	Existing	
No.022	Distribution Reservoir	Vanak	37,000	1,522.00	1,517.30	4.70	Existing	
No.023	Distribution Reservoir	Niavaran	31,600	1,669.00	1,661.40	7.60	Existing	
No.024	Distribution Reservoir	Mahmoudieh	34,000	1,665.00	1,657.40	7.60	Existing	
No.025	Distribution Reservoir	Lower Manzarieh	31,000	1,669.00	1,661.40	7.60	Existing	
No.026	Distribution Reservoir	Upper Hesarak	52,500	1,753.00	1,745.00	8.00	Existing	
No.027	Distribution Reservoir	Upper Manzarieh	12,000	1,753.00	1,745.40	7.60	Existing	
No.028	Distribution Reservoir	Darband	7,000	1,807.00	1,799.40	7.60	Existing	
No.029	Distribution Reservoir	Azargah	6,700	1,807.00	1,799.00	8.00	Existing	
No.030	Distribution Reservoir	Velenjak	4,000	1,753.00	1,748.30	4.70	Existing	
No.031	Distribution Reservoir	Tehran now	37,000	1,239.00	1,234.30	4.70	Existing	
No.032	Distribution Reservoir	Aliabad + Ext.	22,200	1,807.00	1,802.30	4.70	Existing	
No.034	Distribution Reservoir	Shahran	7,700	1,442.00	1,437.60	4.40	Existing	

Table 2.3.8 List of Distribution Reservoirs (2/2)

No.	Name of Facilities	Location	Capacity (m3)	H.W.L (+m)	L/W/L (+m)	Depth (m)	Existing / Future	Status
No.035	Distribution Reservoir	Shahrake Ghods					Future	Cancelled
No.036	Distribution Reservoir	Moshirieh	43,700	1,137.00	1,132.30	4.70	Existing	
No.037	Distribution Reservoir	Lower Farahzad	45,000	1,522.00	1,514.40	7.60	Existing	
No.038	Distribution Reservoir	Evin + Ext.	64,000	1,665.00	1,657.40	7.60	Existing	
No.039	Distribution Reservoir	Zargandeh	13,800	1,448.00	1,440.40	7.60	Existing	Not used
No.040	Distribution Reservoir	Pasdaran	14,300	1,526.00	1,518.50	7.50	Existing	
No.041	Distribution Reservoir	Saheb Qaranieh	27,500	1,582.00	1,574.40	7.60	Existing	
No.043	Distribution Reservoir	Tehran Pars	44,000	1,477.00	1,469.40	7.60	Existing	
No.045	Distribution Reservoir	Lavizan	20,000	1,582.00			Future	
No.046	Distribution Reservoir	Lower Lashgarak	20,000	1,669.00			Future	
No.048	Distribution Reservoir	Imam Hossein	20,000	1,582.00			Future	
No.049	Distribution Reservoir	Imam Hossein	10,000	1,669.00			Future	
No.050	Distribution Reservoir	Imam Hossein	10,000	1,753.00			Future	
No.051	Distribution Reservoir	Qasr-e-Firouzeh	65,000	1,239.00	1,231.20	7.80	Existing	
No.053	Distribution Reservoir	Soleymanieh No.2	33,000	1,163.00	1,157.80	5.20	Existing	
No.054	Distribution Reservoir	Aria Shahr	34,000	1,307.00			Existing	Not used
No.055	Distribution Reservoir	Bagh Feiz	42,000	1,372.00	1,364.40	7.60	Existing	
No.056	Distribution Reservoir	Kan	26,800	1,324.00	1,316.40	7.60	Existing	
No.057	Distribution Reservoir	Jannatabad + Ext.	47,000	1,392.00	1,384.40	7.60	Existing	
No.058	Distribution Reservoir	Lower Pounak + Ext.	44,200	1,462.00	1,454.40	7.60	Existing	
No.059	Distribution Reservoir	North Kan	30,000	1,462.00	1,454.40	7.60	Existing	
No.060	Distribution Reservoir	Molla Sadra					Future	
No.061	Distribution Reservoir	Northern Amirabad	32,000	1,367.00	1,360.30	6.70	Existing	Not used
No.062	Break Pressure Tank	Kazemabad	22,000	1,359.00	1,351.50	7.50	Existing	Not used
No.063	Distribution Reservoir	Upper Massoudieh	10,000	1,239.00	1,231.50	7.50	Existing	
No.064	Distribution Reservoir	Afsarieh Reservoir	16,500	1,171.00			Existing	
No.070	Distribution Reservoir	17th Shahrivar	12,500	1,155.00	1,151.00	4.00	Future	
No.071	Distribution Reservoir	Tehran Pars Treatment Plant	20,000	1,509.00	1,502.80	6.20	Existing	
No.072	Distribution Reservoir	Saadatabad	22,000	1,582.00	1,574.20	7.80	Existing	
No.074	Distribution Reservoir	Lower Aqdasieh	10,000	1,669.00	1,661.50	7.50	Existing	
No.075	Distribution Reservoir	Upper Aqdasieh	10,000	1,753.00	1,746.20	6.80	Existing	
No.077	Distribution Reservoir	Upper Baqlazar	10,000	1,838.00	1,833.50	4.50	Existing	Not used
No.078	Distribution Reservoir	Lower Sohanak		1,753.00			Future	
No.079	Distribution Reservoir	Upper Sohanak	10,000	1,838.00			Future	
No.080	Distribution Reservoir	Lower Hesarak	36,000	1,532.00	1,525.00	7.00	Existing	
No.081	Distribution Reservoir	Upper Hesarak	20,000	1,602.00	1,597.50	4.50	Existing	
No.082	Distribution Reservoir	Lower Kahrizak	10,000	1,753.00	1,748.50	4.50	Existing	
No.083	Distribution Reservoir	Upper Kahrizak	20,000	1,807.00			Future	Under Construction
No.084	Distribution Reservoir	Lower Moradabad	10,000	1,672.00			Future	
No.085	Distribution Reservoir	Upper Moradabad	17,500	1,742.00			Future	Under Construction
No.086	Distribution Reservoir	Lower Hor	17,500	1,149.00	1,143.75	5.25	Future	
No.087	Distribution Reservoir	Upper Hor	17,500	1,151.00	1,144.60	6.40	Future	
No.088	Distribution Reservoir	Northern Mehrabad					Future	
No.091	Distribution Reservoir	Upper Aliabad	12,000	1,877.00	1,872.50	4.50	Existing	
No.094	Distribution Reservoir	3rd Treatment Plant Reservoir	25,000	1,550.00			Existing	
No.098	Distribution Reservoir	Jey Garrison	8,000				Future	
No.103	Distribution Reservoir	6th Treatment Plant		1,560.00			Future	
	Elevated Tank							
No.033	Elevated Tank	Upper Darband	400	1,832.00	1,827.30	4.70	Existing	
No.108	Elevated Tank	Afsarieh elevated Tank	1,000	1,200.00			Existing	Not used
No.109	Elevated Tank	Shahran elevated Tank	500	1,680.00			Existing	Not used
No.110	Elevated Tank	17th Shahrivar elevated tank	500	1,181.00			Future	
No.111	Elevated Tank	Valiasr elevated Tank	1,500	1,153.00			Existing	Not used
No.112	Elevated Tank	Ferdows elevated Tank	500	1,170.00			Existing	
No.113	Elevated Tank	3rd Treatment Plant	50	1,580.00			Existing	

(5) Water Transmission and Distribution Mains

1) Definition of Pipelines

The data on existing transmission mains, distribution trunk mains and distribution sub mains which is summarized in Table 2.3.9 and listed in detail in Table 2.310 are analyzed using the pipeline GIS prepared by TWWC and JICA study team on the basis of TWWC CAD data.

The definition of pipelines here is as follows:

(a) (Clear water) Transmission mains are the pipelines between the water treatment plants and the service reservoirs, between the service reservoirs, between the deep wells, and between the deep wells and the service reservoirs.

(b) Distribution pipeline is the general term used for the pipeline which distributes clear water.

(c) In case distribution pipelines are classified in diameter:

i. Distribution trunk mains are the pipelines with diameters of 300 mm and larger.

ii. Distribution sub mains are the pipelines with diameters of 250 mm and smaller.

(d) In case distribution pipelines are classified in function:

i. Feeder mains are the pipelines which convey water from service reservoirs to distribution networks.

ii. Distribution networks are distribution pipelines which form distribution zones.

1) The Whole Water Pipelines

Total length shown in Table 2.3.9 is 7,553km with diameters of 25 to 2,200 mm.

Table 2.3.9 Total Length of Water Pipelines

Pipeline Category	Length (m)
Transmission Main	399,346
Distribution Trunk Main	768,179
Distribution Sub Main	6,385,927
Total Length (m)	7,553,452

There is important information on transmission and distribution pipelines as described in the section 2.11.2 (3). It is about the intersections of the pipelines and the existing faults. It is identified by GIS study that as many as 713 intersections of the pipelines and the faults exist including 8 locations of the raw water transmission main, 51 locations of the clear water transmission main, 73 locations of the distribution trunk pipelines and 581 locations of the distribution pipe network. These facts shall be reflected in the earthquake-resistant planning.

As the raw water transmission pipelines including tunnels, refer to Table 2.3.2 in the section 2.3.1.

2) Transmission Main

The total length of the transmission mains is 399.3km excluding the length of pipeline between deep wells, and between the deep wells and the distribution reservoirs. In general cases, the diameter size of the transmission pipelines is bigger, however, the smaller size pipelines are included because the Tehran water supply system has a lot of service reservoirs from large to small. With regard to the pipe materials, steel pipes, ductile iron pipes and reinforced concrete pipes are used in the transmission mains. Although diameter and length of the well pipelines are not known, materials of the pipelines are reported as mainly ductile iron pipes.

3) Trunk Distribution Main

The distribution trunk mains are mainly composed of steel pipes and iron pipes including ductile iron pipes. Large to small steel pipes have been installed, and cast iron pipes range from medium to small. The length of ductile iron pipes is four times as long as the length of cast iron pipes, but the ductile pipes are applied only to the pipes of small diameters.

3) Distribution Sub Main

70 % of pipes in distribution sub main are ductile iron pipe. Polyethylene pipes comprise 25% of the total length. In recent years, polyethylene pipes are installed as the secondary or tertiary pipes with diameters of 110 mm and smaller.

Polyvinyl chloride pipes (PVC) have been installed with the length of 30 km. As to be described in Chapter 6, most of the leakages were found on the pipelines made of PVC. The PVC pipes should be replaced as early as possible.

Table 2.3.10 List of the Existing Water Supply Pipelines

Diameter (mm)	Clear Water Transmission Main				Distribution Trunk Main					Distribution Sub Main						Grand Total
	Ductile Iron	Concrete Pipe	Steel Pipe	Total	Asbestos Pipe	Cast Iron Pipe	Ductile Iron Pipe	Steel Pipe	Total	Cast Iron Pipe	Ductile Iron Pipe	Asbestos Pipe	PVC	PE	Total	
25													20		20	20
50													116		116	116
56.8														706,212	706,212	706,212
60											572,119		30,221		602,340	602,340
80											821,775				821,775	821,775
90														323,004	323,004	323,004
100											1,573,785	15			1,573,799	1,573,799
110														579,929	579,929	579,929
125										9,188	823,644				832,832	832,832
150	203	0	0	203						136,896	367,943				504,839	505,042
175										105,294	204,198				309,492	309,492
200										61,955		34			61,989	61,989
225										32,053					32,053	32,053
250	0	0	8,072	8,072						37,526					37,526	45,598
300	2,729	0	8,924	11,653	3,890	24,947	201,829		230,666							242,319
350	204	0	0	204		30,665	48,408		79,074							79,278
400	5,854	0	48	5,901		26,823	94,731		121,553							127,455
450	0	0	855	855		11,812			11,812							12,667
500	22,266	0	4,228	26,494		12,511	108,416		120,927							147,421
550	0	0	0	0		6,400			6,400							6,400
600	18,339	0	1,192	19,531		6,861	48,148	3,730	58,738							78,269
650	0	0	0	0		2,126		271	2,397							2,397
700	13,703	3,059	6,614	23,376		623		46,480	47,103							70,480
750	0	0	0	0		819		12,843	13,662							13,662
800	0	0	24,188	24,188					0							24,188
900	0	9,712	60,177	69,889					0							69,889
1000	0	0	25,226	25,226		6,693		38,729	45,422							70,648
1050	0	0	0	0				4,388	4,388							4,388
1100	0	0	24,061	24,061				1,147	1,147							25,208
1200	0	5,069	63,101	68,170		3,902		6,361	10,264							78,434
1250	0	10,349	5,644	15,993				7,419	7,419							23,412
1350	0	6,234	0	6,234				1,168	1,168							7,401
1400	0	0	26,810	26,810					0							26,810
1600	0	153	18,314	18,467				6,039	6,039							24,506
1700	0	1,200	0	1,200					0							1,200
1850	0	21,773	0	21,773					0							21,773
2000	0	0	67	67					0							67
2200	0	0	979	979					0							979
Total	63,297	57,548	278,501	399,346	3,890	134,182	501,532	128,576	768,179	382,913	4,363,463	48	30,357	1,609,145	6,385,927	7,553,452

Souce: GIS data of TWWC as of August 2006

(6) Service Connections

As shown in Table 2.2.1, the number of connections is approximately 0.9 million at the end of the year 2004. Increase in number of the connections is 1.47% per year and larger than that of the served population 0.93%. Number of persons per connection is approximately 7.8, which is rather big compared with the average family number in urban area of Iran 4.63 in 2003. The reason for the difference may be due to existence of considerable numbers of bulk connections of housing and office buildings.

Recently, the building authority has made a regulation or an ordinance that the buildings with more than six storeys or having an area of 2,000 m^2 or more shall be metered individually. Since all the customers could pay water charge according to the actual consumption measured, the individual meter system to all customers is desirable. Thus, the customers' willingness to pay for water would be high in fairness. At the same time, the customers' awareness of saving water would be highly expected.

The details of classification of water meters are shown in Table 2.3.10. The water meters are classified into 29 categories, the table below however shows nine categories; the other 20 categories are shown as "Others". Of the total number of consumer meters below, 83% is allocated for the domestic users, out of which 1/2 inch sized water meter comprises 64%.

Table 2.3.11 Breakdown of Consumer Meters

Category ／ Diameter	0.50"	0.75"	1.00"	1.50"	2.00"	3.00"	4.00"	6.00"	8.00"	10.00"	12.00"	16.00"	Unknown	TOTAL	%
Residential	568,681	139,908	20,545	2,330	373	55	15	2	-	-	-	-	-	731,909	82.6%
Mixed Applications	49,292	8,174	1,980	367	46	10	3	1	1	-	-	-	-	59,874	6.8%
Commercial & Industrial	49,364	6,666	2,284	707	187	45	13	1	-	1	-	1	-	59,269	6.7%
Construction	12,803	5,096	655	110	29	3	2	-	-	-	-	-	-	18,698	2.1%
Educational Centers	681	2,340	479	211	110	17	4	2	-	-	-	-	-	3,844	0.4%
Domestic & Low Income	2,798	169	9	1	2	-	-	-	-	-	-	-	-	2,979	0.3%
Government & Public	739	1,026	603	277	223	53	17	3	1	-	1	-	-	2,943	0.3%
Bakeries	2,389	7	-	1	-	-	-	-	-	-	-	-	-	2,397	0.3%
Religious Places	1,589	431	48	16	6	-	-	-	1	1	-	-	-	2,092	0.2%
Others	453	454	277	379	286	175	17	12	2		3		163	2,221	0.3%
Total	688,789	164,271	26,880	4,399	1,262	358	71	21	5	2	4	1	163	886,226	100.0%

Source: TWWC data

TWWC is aggressively forwarding the renewal of the existing water meters with new ones. 713,117 new types of water meters have been installed since four years ago which corresponds to 80% of the total number of meters. Newly installed water meters are of class C type and higher accuracy than

Table 2.3.12 Replacement of Consumer Meters

Fiscal Year	Replaced	Remarks
2000	91,216	
2001	130,770	
2002	172,688	
2003	153,409	
2004	125,034	
2005	40,000	2005/3/20-2005/7/31
Total Replaced	713,117	79.4%
Total Meters	897,615	

Source: TWWC data

the former type C for reading as specified in ISO 4064 (Table 2.3.11).

2.3.2 Operation and Maintenance

(1) Organization Concerned

Operation and maintenance of Tehran water supply system is mainly performed by two organizations of TWWC, namely the operation department and the water and sewerage office in each of six districts as shown in Figure 2.3.2. The former operates and maintains the facilities from water intakes to distribution reservoirs, while the latter covers distribution networks and service installations.

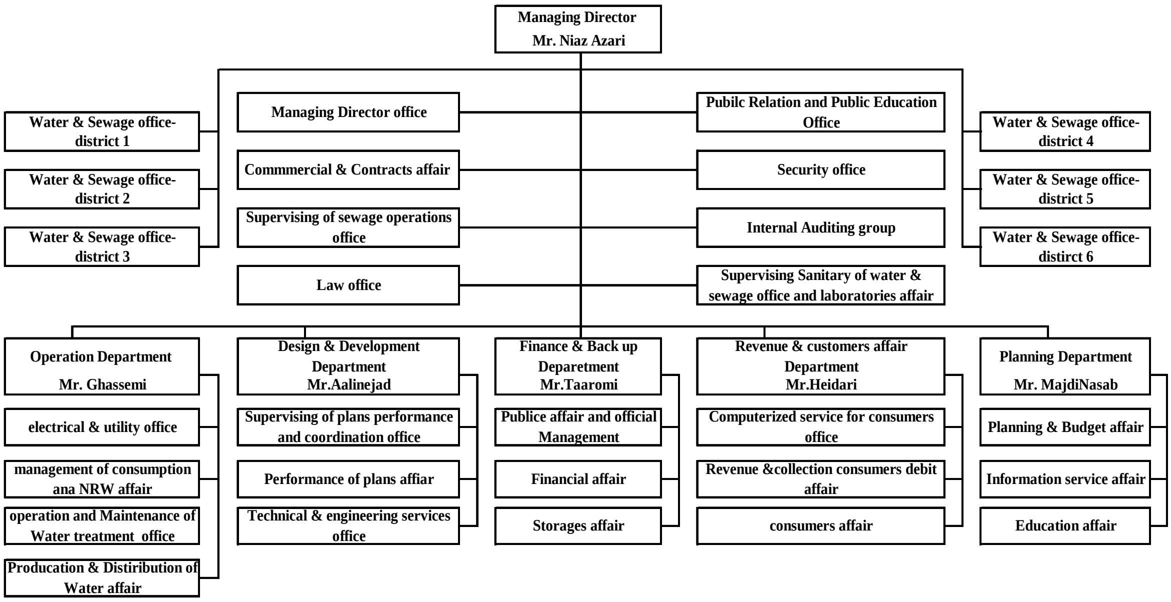


Figure 2.3.2 Organization Chart of TWWC

(2) Each Operation and Maintenance Item

1) Quantity Management

As described in the preceding sections, TWWC made every effort to cope with the water shortage experienced in 2001 through development of surface water sources. The water treatment plant No. 5 started its operation in 2005 for which the water source is the Lar dam. The raw water of the newly constructed Taleghan dam is transmitted to the Bileghan intake for the water treatment plants No. 1 and No. 2. After 2002, since the precipitation has been normal, the surface water supply amount has been recovered to meet the consumption of the customers. Furthermore, the construction of Mamloo dam located to the west of the municipality will be completed in 2007 which will be a water source of the planned water treatment plant No. 7 with a capacity of 4.0 m^3/sec.

As for the groundwater sources, in 2001 the extracted groundwater amounted to 440 million m^3, afterwards, the annual amount of groundwater has been reduced to about 300 million m^3.

In TWWC's future plan, the groundwater sources should be applicable to the emergency usage by preserving the annual amount of 250 million m^3 groundwater.

It should be noted that NRW has been decreased from 45% to less than 25% in a short period of 10 years in Tehran municipality. As a result of the NRW reduction measures, this saved amount of water equals the increase of supply capacity of 350,000m^3/day. Thereby, the importance of quantity management of TWWC has been emphasized and the outcome has been successful.

2) Pressure Control

As previously stated, in Tehran municipality, there is an elevation difference of 760m. Therefore, the pressure control is considered as a significant matter in Tehran water supply system. TWWC made effort to control the pressure in a wide-range plan.

At present, the pressure control has been monitored by dividing the area into the 72 water pressure zones in the service area, although not always hydraulically isolated from each other. TWWC is operating the pressure control with the above distribution zoning system and provision of pressure reducing valves in strategic locations. The installation of pressure reducing valves is done with the purpose of reducing the water pressure, i.e., from a maximum pressure at 60 m at one end to 20m at the other end of the distribution zone. TWWC controlling thusby has reduced NRW greatly. It is important to continue the pressure control procedure and to complete the hydraulically isolated distribution zones as stated elsewhere.

3) Quality Management

The surface water has a good quality which is treated and disinfected properly at the water treatment plants.

As for the water quality of groundwater, there is no possibility of contamination because chlorination has been done in the service reservoir. However, since the value of nitrite nitrogen and nitrate nitrogen exceeds the quality standards in many wells, this should be solved in the near future.

4) Facility Management

TWWC has been supplying water to customers and maintained water quantity and quality stability by the careful management of water supply facilities constructed 30 to 50 years ago. The management of the water supply facilities is oriented towards the reduction of operation cost and benefiting operation taking advantages of the gravity flow into account.

TWWC is aiming for the simplicity of the operation and maintenance of the water treatment facilities taking the unity of treatment process and the type of facilities into account. For the water distribution network, the pressure control is attained by the equalization of water pressure through the distribution zoning system and provision of pressure reducing valves, although their provision are not completed yet.

In the public communication center at the public relation and awareness office in TWWC, "Call 122" is ready to respond the customers' inquiries round-the-clock. There are 18 emergency posts under the district offices No. 1 to No. 6. They have mobile teams which are ready for 24-hour works and teams for repair work and leakage detection. Recently, the emergency posts have repaired 400 leakage cases a day.

5) Information Technology

As an advanced management system, the control center for telemetry and tele-control of the water supply systems is under construction on the TWWC headquarters' premises. The contract for this project is undertaken by Design-built system made between TWWC and the joint venture of MWH in Germany and Tooss Ab Consulting Engineering Company in Iran. The telemetry system will have the monitor and control system for data collection and analysis including water flow and pressure, water quality and remote control of the motor-operated valves. For detail, refer to the following subsection (3) "Telemetry and Tele-control System".

As for the accumulation of the data and information on the water supply system in TWWC, the drawings of the existing facilities are being kept as microfilms and the pipe data as CAD. Recently, TWWC is developing the new management system incorporating the existing spatial data and information on pipes with appurtenances and customers on the distribution network into the database of GIS (Geographic Information System). Preparation of the new system with GIS is undertaken by the Iranian consultant Heler Rayaneh Co., Ltd.

(3) Telemetry and Tele-control System

1) Project Description

Telemetry and tele-control system for Tehran water supply system is underway of renovation by replacing the existing old telemetry system. The existing telemetry system is over 30 years old and has not been any longer fulfilling TWWC vision of an overall integrated distribution management system (DMS).

The design and implementation of a suitable DMS is considered to be of paramount importance to the overall management and operation of the distribution network. In the initial phase of the project, the key requirement is to provide telemetry and SCADA, however, it is envisaged that the chosen platform would also provide the basis to integrate other data and related technologies such as GIS.

a. Objective

The main function of this system is to provide information for level, temperature, flow, pressure, chlorine, turbidity, power monitoring, control functions, centralized supervision, and data storage in order to operate the Water Company's supply, treatment, transmission and distribution facilities in an optimal way.

b. Facilities and Equipment for supervision or control

The telemetry and tele-control system consists of a central control room installed in the premises of Treatment Plant No.1 and 121 out stations. Valves, flow meters, pressure meters, quality test apparatus are installed for supervision or control at each facility. Total numbers of inputs and outputs of the telemetry system are as shown in Table 2.3.13.

Table 2.3.13 The total number of Inputs and Outputs

Items	Inputs (Supervision)	Outputs (Control)	Items	Inputs (Supervision)	Outputs (Control)
Analog Inputs and Outputs			Digital Inputs and Outputs		
Flow Rate	364		Digital Valve Pos.	2844	
Residual Chlorine	206		Mains Failure AL.	121	
Pressure	745		HH and LL AL.	412	
Level	206		UPS AL.	121	
Temperature	6		General AL.	121	
Turbidity	2		Pump/Motor Failure AL	338	
Oil Sensor	1		Security AL.	121	
Voltage	581		Sel. Sw. Pos.	2490	
Current	581		Pump/Motor State	676	
Valve Position	581	457	Valve Open/Close		2,880
Active Power	581				
Reactive Power	581				
Power Factor	581				

c. Operation

Total water input and water demand is determined from the historical water consumption trends and the underlying data. The operation of the facilities is based on the principle of balanced utilization of the existing water resources, the treatment plant capacities and pumping capacities, according to the estimated water input and water demand.

d. Measures against earthquake or power failure

Five emergency generators are installed at WTP1, where the control center building is built. The capacity of fuel tank is 50,000 liter x 2 sets, which can operate those generators for 3 days or more continuously.

UPS is installed at central control room and all the outstations, whose battery can supply power to PLC, SCADA, RTU (Remote Terminal Unit), and instruments unit for 24 hours continuously.

2) Necessity of Water Supply Zoning

After the completion of the telemetry and tele-control system installation in Tehran water supply system, as a matter of course, it shall be followed by a water supply zoning in the system. At present, the whole water distribution networks of the system are hydraulically connected. Without hydraulic isolation, flow or pressure in a given zone would be affected by other zones. Thus, it is difficult to control adequately the hydraulic conditions by the telemetry system alone. In other words, by provision of the water supply zoning, TWWC could supply water with adequate flow, water pressure and water quality (residual chlorine).

By provision of the hydraulically isolated water supply zones, the following advantages are obtained in the water supply system:

- To enable TWWC to control water supply with adequate flow, pressure and quality in an individual water supply zone,
- To enable TWWC to reduce water leakage which is a major component of NRW,
- To enable TWWC to identify a zone with larger leakage occurrence compared to the other zones,
- Thus, to enable TWWC to prioritize leakage reduction measures in the zones,
- Even in case a zone is affected in earthquake disaster, the other zones are not affected,
- The affected zone could receive emergency water from neighboring zones by operating connecting valves,
- Further, in case an affected zone has water supply sub zones, water could be supplied continuously to the other sub zones by isolating them through the operation of connecting valves.

For the most adequate water supply zoning in Tehran water supply system, the above mentioned telemetry and tele-control system would be very useful.

3) Suggestions on Telemetry System and Water Supply Zoning

It is obvious that water supply zoning should be hydraulically isolated as early as possible by addition of necessary valves and pipelines as described in the foregoing subsection “Necessity of Water Supply Zoning”.

At present, there are distribution zones not corresponding to reservoirs. Or more specifically, water is supplied to distribution zones directly from transmission pipeline not through reservoirs. Unfortunately the telemetry and tele-control system plan does not include installation of flow meters on these pipelines. It is strongly recommended to provide flow meters on the pipelines from the stand point of the effective telemetry system. By this measure, hydraulic condition of all of the water supply zones could be compared with each other.

2.3.3 Water Rates and Financial Conditions

(1) Tariff and Water Rates

The current tariff structure is based on a fixed fee by the type of customer group and on a volumetric charge in accordance with increasing block-tariffs. The volumetric charge is based on complex formulas, and there would be no volumetric charges if water consumptions are below 5 square meters per month. Beyond this minimum threshold, charges are supposed to increase with the level of consumptions in accordance with the different groups of customers. The tariff table of TWWC for the financial year 2005 is shown in *Table 2.3.14*. TWWC presently adopts a customer group rate system classified in four groups such as residential, public, commercial-industrial and other groups. The tariff rate structure is rather complex for both volumetric rates and connection fees with 28 categories in these 4 groups.

Due to its complexities, the current tariff structure is lacking in transparency, which makes the incentive information more ambiguous to consumers. However, any reform is being postponed since the Economic Council has been freezing all tariffs and other fees since the financial year 2004 (1383). It is required to annually increase tariffs at least at the current inflation rate so as to enable TWWC to cover the increase in operating and maintenance costs. Major findings in the current water rates as well as the tariff structure are summarized below.

a) Categories of customers are classified into 28 sub-divisions, and this complicated structure seems to be less understandable for customers. TWWC employs increasing-block tariffs, partly because those tariffs lead to cross-subsidies from large water users to small water users. Increasing-block water tariffs are also supposed to encourage water savings. However, if the tariff structure is too much complicated, most water users have difficulties in understanding the signals of the tariffs to customers such as income distribution and efficiency promotion.

b) Customers are not charged in case residential consumptions are less than 5 square meters per month. This tariff exemption system seems to be undesirable from a view point of stable and fair financial management, taking into account the fact that TWWC is required to invest on large-scale constructions and to spend daily operation and maintenance costs.

c) It is a widely accepted principle that a water tariff for residential customers should not be fixed at higher level than that for other customer groups. However, at the current tariff structure, tariffs for some non-residential users are even lower than those for residential users.

d) There is a uniformed volumetric threshold of 20 square meters per month for each consumption block. However, this uniformed threshold should be changed in accordance with customer groups, since the consumption amount fluctuates in each customer group.

e) It is necessary to explore a possibility of introducing the water tariff system based on pipe diameters of customers' service connections. It is often criticized that there are unfair treatments among various customer groups.

f) The basic philosophies for the tariff rate design are not clear. The clear-cut standards and regulations by which the tariff level is fixed should be theoretically specified.

Table 2.3.14 Tariff Table for TWWC for 2005

Category of subscription	Code of connec- -tion	Connection Utilitiy Code in detail	Tariff for 2005		Application of Seasonal Price
			<= 20 m^3 (Rials)	> 20 m^3 (Rials)	
Residential	1	Residential	Table-1	Table-1	Applicable
Residential	7	Multi family domestic	Table-1	Table-1	Applicable
Commercial-residential	6	Commercial & residential	Table-1	Table-1	Applicable
Public	24	Army & police centers	859	859	Applicable
Public	8	Firefighting	1,418	1,911	Applicable
Public	12	Government healthcare & sanitary centers	1,128	1,519	Applicable
Public	11	Government, nongovernment eduction sports centers	86	86	N/A
Public	22	Metered green space water	469	631	Applicable
Public	16	Orphanages	223	223	N/A
Public	2	Public & government	1,128	1,519	Applicable
Public	4	Religious places	223	223	N/A
Public	10	Vicinity bulk quantity	758	1,020	Applicable
Commercial-industrial	14	Bakeries	202	202	N/A
Commercial-industrial	5	Commercial & industrial	1,288	1,737	Applicable
Commercial-industrial	28	Free water	2,636	2,675	Applicable
Commercial-industrial	13	Nongovernment healthcare & sanitary centers	1,289	1,737	Applicable
Commercial-industrial	15	Private cultural centers	645	868	N/A
Commercial-industrial	3	Public bathrooms	223	223	N/A
Commercial-industrial	26	Teheran refinery water	773	1,042	Applicable
Commercial-industrial	21	Temporary workshop water	2,636	2,675	Applicable
Commercial-industrial	9	Under construction	2,636	2,675	Applicable
Others	17	Commercial & industrial raw water	542	730	Applicable
Others	19	Forestry raw water	222	222	N/A
Others	18	Governmetn & nongovernment institutes raw water	316	425	Applicable
Others	20	Public raw water	0	0	N/A
Others	23	Nonmetered green space water	Diameter:0.5	372,900	Applicable
Others	23	Nonmetered green space water	Diameter:0.75	625,860	Applicable
Others	25	Tank water	2,636	2,675	Applicable
Others	27	TWWC extension companies water	250	250	N/A

Table-1 Tariff of the Residential Use

Household range of consumption/month	Price/m^3 FY2005 21-3-2005 to 20-3-2006
X <5	Y= 0
5<= X <=18.5	Y= 212
18.5< X <22.5	Y= 223
22.5<= X <45	Y= 27.11X - 339
45<= X <65	Y= 28.2X - 319
65<= X <74	Y= $0.59X^2$ - 977
74<= X	Y= 2,345

Note: X=consumption/month; m3, Y=price/m3; Rials

(2) Financial Conditions

As for past and present financial conditions of TWWC, refer to section 9.2.2 Current Financial Status of TWWC.

2.4 Review of Seismic Ground Motion Analysis and Earthquake Resistance Study

2.4.1 Review of Recent Studies

(1) Recent Studies Conducted

Within years, various studies on earthquake resistance or preparedness of infrastructure and lifeline of Tehran municipality as described below have been conducted. Abbreviations for the respective studies as described in the table are applied in this section.

Table 2.4.1 Recent Studies and Their Abbreviations

No	Title of the Report	Abbreviation
1	The Study on Seismic Microzonation of the Greater Tehran Area in the Islamic Republic of Iran	Seismic Microzonation Study
2	A Study on Seismic Risk, Impact by Service Interruption and Earthquake Preparedness on Tehran Water Supply System	TAKADA's Study
3	Comprehensive Master Plan Study on Urban Seismic Disaster Prevention and Management for the Greater Tehran area in the Islamic Republic of Iran	JICA Master Plan Study
4	Research Project for Strengthening and Control of Tehran Gas Network Against Earthquake	Gas Research Project
5	A Study on Strengthening of Water Supply System of Tehran	Pars Consult Study

(2) Outline of Recent Studies

Outline of the resent studies are summarized in *Table 2.4.2*.

Table 2.4.2 Outline of Recent Studies

No	Title of Report	Client/Author	Published	Outline of the Study
1	Seismic Microzonation Study	JICA TDMO	November, 2000	The study was carried out to compile seismic microzonation maps which can serve as a basis for the preparation of a regional and urban seismic disaster prevention plan of the Greater Tehran Area. This study was based on the results of earthquake ground motion analysis and damage estimation for infrastructure and lifeline systems including water supply facilities.
2	TAKADA's Study	TPWWC Takada S., et al.	March, 2000	The study was carried out for the water supply system in Tehran a) to evaluate earthquake ground motion, vulnerability of the water supply facilities and effects of water supply shut down, and b) to discuss strategies for rehabilitation and reconstruction of the water supply facilities based on the damage estimation through seismic ground motion analysis of the water transmission and distribution network.
3	Gas Research Project	NIGC & GTGC	March, 2004	The research project was carried out to assess the earthquake-proofing performance of the gas network systems in Tehran and to propose earthquake prevention measures, because gas supply system is exposed to such danger potentialities as gas emission, explosion, fire, in case the gas supply system suffers immediate and serious damage in an earthquake.
4	JICA Master Plan Study	JICA TDMO	March, 2005	The study was to formulate the comprehensive master plan for urban seismic disaster prevention in the Greater Tehran Area against heavy earthquake based upon the results of the microzonation study mentioned in the above item (1).
5	Pars Consult Study	TPWWC	October, 2004	The study was performed to review, evaluate, and assess the followings for the water supply system in Tehran a) to review the existing study of geology and seismology b) to evaluate earthquake ground motion c) to assess the vulnerability of the water supply facilities during earthquake, and d) to discuss seismic disaster management as for the water supply system

2.4.2 Characteristics of Each Study

(1) Seismic Microzonation Study

1) Ground Motion Analysis

a) Ground Classification and Subsurface Soil Condition

Ground classification was analyzed and classified to construct the ground model for seismic analysis.

In this study fifty bores, three of which were 200 m deep were drilled in the study. Shear wave velocities of ground were measured. The data on about 400 bores were utilized to analyze subsurface soil condition.

b) Scenario Earthquake and Seismic Motion Analysis

The earthquake that would affect Tehran city would occur on faults in or near the vicinity of the city. The most potentially hazardous fault models were (1)Mosha Fault model, (2) North Tehran Fault model, (3) Ray Fault model (The South Ray Fault is modeled because of the better continuation of surface trace and higher micro seismic activity, but this model is representative of both the South Ray and North Ray Faults.), in addition, (4) Floating fault model was considered to reflect the hidden faults anywhere underneath the city of Tehran. The amplification of the subsurface soil was analyzed using one dimensional response analysis. The non-linear effect was not considered because the soil was stiff enough to ignore the non-linearity.

c) Faults parameters, peak ground Acceleration and seismic intensity

Faults parameter, peak ground acceleration and seismic intensity were calculated as shown in Table 2.4.3.

Table 2.4.3 Estimated Peak Ground Acceleration and Seismic Intensity

Characteristics \ Fault model		Ray Fault (RF)	North Tehran Fault (NTF)	Mosha Fault (MF)	Floating Fault (FF)
Length(km)		26	58	68	13
Width(km)		16	27	30	10
Moment Magnitude(Mw)		6.7	7.2	7.2	6.4
Peak Ground Acceleration (PGA: gal)	Northern Area	500 and over	200 and less	200 and less	300 to 400
	Southern Area	200 and less	400 and over	200 and less	300 to 400
Seismic Intensity (MMI scale)	Northern Area	8	8 to 9	7	8 to 9
	Southern Area	9	7 to 8	7	8 to 9

2) Damage Estimation

a) Water supply pipelines

Damage ratio is calculated based on Kubo and Katayama formula. This formula combines the values between damage ratio and peak ground acceleration. Using the formula, the damage ratio is supposed to be 1.5 points/km in case of 400 cm/cm^2 ground acceleration. The formula is based on past earthquake data, therefore the resulted values are the averaged ones. Numbers of breakage points are calculated for all cases of faults movement in each district. Total damaged points are huge in number occasionally exceeding 3000 points.

b) Water supply facilities

Water facilities are not mentioned in the report. Damage estimate was carried out for general buildings including schools and residential houses using fragility function. Numbers of damaged buildings are calculated in each district.

(C) Countermeasures

Countermeasures are not described in the paper.

(2) TAKADA's Study

1) Ground Motion Analysis

a) Ground Classification and Subsurface Soil Condition

Ground classification was analyzed and classified to construct the ground model for seismic analysis. IIEES owned 450 borehole data, 50 deep well borehole data and several data from trench excavation in southwest part and 400 bores, 60 wells and also several trench excavation data of the same kind in southeast part of the city of Tehran.

Research result by IIEES was, however, utilized for modeling the subsurface soil condition, the soil profile for the northern part was assumed due to the lack of borehole data considering the continuity of subsurface soil from the southern part.

b) Scenario Earthquake and Seismic Motion Analysis

The earthquake that would affect the city of Tehran would occur in faults in or near the vicinity of the city. The most potentially hazardous faults modeled were (1) North Tehran Fault model, (2) North Ray Fault model. The amplification of the subsurface soil was analyzed using one dimensional response analysis. The non-linear effect was considered.

c) Faults parameters, peak ground Acceleration and seismic intensity

Faults parameters, peak ground acceleration and seismic intensity were estimated as shown in *Table 2.4.4*.

2) Damage Estimation

For concrete pipe damage, fragility ratio obtained in Kobe was used. The results of Japan water research center are applied for other kinds of pipe material. The data are arranged with damaged points per unit length and total failure points are obtained by multiplying pipeline length. The damage of pipeline in liquefaction prone area is included in the above calculation. Also landslide prone area is mentioned along the transmission line, but analysis was not carried out. Water facilities damage was not calculated.

Table 2.4.4 Estimated Peak Ground Acceleration and Seismic Intensity

Fault model / Characteristics		North Ray Fault (RF)	North Tehran Fault (NTF)
Length(km)		16	75
Width(km)		8	27
Moment Magnitude(Mw)		1.99*E26	4.02*E+26
Peak Ground Acceleration (PGA: gal)	Northern Area	Almost 300 to 400	Almost 500 to 800 over
	Southern Area	300 to 700	300 to 700

3) Countermeasures

Some brief qualitative analysis comments are mentioned including dams, wells, pumping stations and reservoirs.

(3) Gas Research Project

1) Ground Motion Analysis

a) Ground Classification and Subsurface Soil Condition

Ground condition was analyzed and classified to construct the ground model for seismic analysis. IIEES owned 450 borehole data, 50 deep well borehole data and several data from trench excavation for southwest part and 400 bores, 60 wells and also several trench excavation data of the same for southeast part of the city of Tehran.

Research result obtained by IIEES was, however, utilized for modeling the subsurface soil condition, the soil profile for the northern part was assumed due to the lack of borehole data considering the continuity of subsurface soil from the southern part.

b) Scenario Earthquake and Seismic Motion Analysis

Followings are the models of the faults which have the potentiality to lead to the most risky earthquakes for GTGC's service area.

i)Historical earthquake model, ii) North Tehran Fault model, iii) Mosha Fault model, iv) North Ray Fault model, v) South Ray Fault model.

Synthesis of the seismic waveform at the bedrock was made by applying statistical Green's function. The amplification of the subsurface was analyzed using one dimensional response analysis. The non-linear effect was not considered. The waveform at the ground surface is calculated from the waveform at the engineering bedrock and surface amplification function.

c) Faults parameters, peak ground motion for surface ground acceleration, etc.

Faults parameters, peak ground motion for surface ground acceleration, velocity and displacement were estimated as shown in Table 2.4.5.

Table 2.4.5 Faults parameter, peak Ground Acceleration, velocity and displacement

Fault model / Characteristics		Historical Earthquake(HE)		Mosha Fault (MF)	South Ray Fault (SRF)	North Ray Fault (NRF)	North Tehran Fault (NTF)
		Parchin Fault	Kharizak Fault				
Length(km)		73	50				
Width(km)		28	20	20	20	17	30
Moment Magnitude(Mw)		-	-	22	10	9	30
Peak Ground Acceleration (PGA: gal)	Northern Area	110 to 150		100 to 260	0 to 120	0 to 240	140 to 680
	Southern Area	150 to 190		50 to 150	120 to 620	0 to 610	0 to 10
Peak Ground velocity (PGV: kine)	Northern Area	8.4 to 12		3.4 to 7	0 to 8.4	0 to 17	0.4 to 47
	Southern Area	12 to 14		3.4 to 11	8.4 to 42	0 to 42	0 to 19
Peak Ground Displacement (PGD: cm)	Northern Area	0.65 to 0.87		0.26 to 1.26	0 to 0.58	0 to 0.65	0 to 4.18
	Southern Area	0.65 to 1.08		0 to 0.76	0.58 to 2.89	0 to 3.23	0 to 1.68

2) Damage Estimation

Damage estimation of pipelines was done using seismic deformation method, which is obtained according to pipe strains caused by earthquake. Three damage modes are considered, there are strong ground motion, liquefaction and fault dislocations. Only minor damage was expected according to the strong ground motion. The major damage was caused by large fault dislocation. The probability of damage caused by liquefaction is small even though liquefaction areas do exist.

The reason for minor damages caused by strong ground motion is adopting relatively large values of allowable strain which are 0.3% to 3.0%. Damage caused by faults dislocation occurs only in limited areas. Pipeline reliability is calculated for each pipe link. Reliability is high except for faults crossing places.

Residential house damage was estimated, for these data are necessary to measure the damage of gas meters. No estimation was included in the study about damage of factories or commercial buildings. The structures of these residential houses are quite different from water distribution structures, and therefore there is no description similar to water facilities.

3) Countermeasures

Specified countermeasures are not described.

(4) JICA Master Plan Study

1) Ground Motion Analysis

Ground motion analysis was not executed in this study. Necessary data were derived from seismic microzonation study.

2) Damage Estimation

Damage data are derived from seismic microzonation study, too. Number of water pipe breakage is 3900 points for Ray fault scenario. In case of North Teheran and Mosha fault movement, numbers of breakage points are 800 and 10 respectively. Quantity of building damage is derived from seismic microzonation study, too. These are for buildings generally , nothing specified to water structures.

3) Countermeasures

There are some comments about strengthening the water system. Alternative pipeline is recommended as means of transmission from water intake to water treatment plant. Distribution facilities are important as water supply bases in case of emergency, therefore improvement of these facilities are necessary. Replacement of house connection pipes with stainless steel pipes is recommended.

(5) Pars Consult Study

1) Ground Motion Analysis

a) Ground Classification and Subsurface Soil Condition

Geotechnical charts of boreholes and dug well prepared by Tehran municipality, Tehran train organization and engineering department of TWWC are utilized for ground classification and subsurface soil condition.

b) Scenario Earthquake and Seismic Motion Analysis

It is supposed that the following faults are the most risky earthquakes for water supply service area.

North Tehran Fault	Mosha Fault	North Ray Fault	South Ray Fault	Kahrizak fault

c) Peak ground acceleration

Peak ground acceleration was calculated. 0.42 to 0.6 gal could be observed at central south part of city of Tehran.

2) Damage Estimation

a) Water supply pipelines

Damage fragility ratio is introduced based on Kubo and Katayama formula. General description regarding pipe material is mentioned in the study.

Case study about pipeline was done selecting some places.

b) Water supply facilities

Water tank risks including chlorine cylinder are described. Facilities damage possibilities such as electric panels are mentioned, too.

Each facility in the water treatment plants area is investigated in detail. Building damage is estimated using fragility formula. Bileghan intake structures are checked, too.

3) Countermeasures

As a conclusion, replacement of pipes to polyethylene is recommended. Costs are estimated in case of such replacement.

2.4.3 Earthquake Resistant Measures by the Previous Studies

Earthquake resistance measures found by the previous studies including 1) Seismic Microzonation Study, 2) TAKADA's Study and 3)JICA Master Plan Study are summarized in the table 2.4.6 as below. From the earthquake resistant system to the preparedness for emergency response, various and plentiful countermeasures for earthquake disasters are identified and summarized. These will be important factors for target setting for the earthquake resistant plan as well as for study of the earthquake resistant measures for Tehran water supply system together with results of the damage estimation of the system, all of which are to be made in Chapter 3 to 5 of this report.

Table 2.4.6 Earthquake Resistant Measures by the Previous Studies

Items		Study Results
1) Earthquake resistant system		
	Dam & water intake	Any dam for Teheran water supply system is located relatively near North Tehran fault. As Latian dam is in higher risk of damage among others, alternative water sources are necessary.
		Water intakes should be strengthened.
	Deep wells	Deep wells located in south of Tehran should be strengthened by more flexible rings, when deemed necessary by stability diagnosis.
		In order to have enough groundwater in case of earthquake disasters, it is necessary to lower use during the normal conditions.
		Emergency backup system for pumps of the wells is also necessary.
	Raw Water Pipeline	As raw water transmission pipelines are passing through lands with possibility of landslides and faulting, it is firstly recommended to identify all these locations, and subsequently simple and practical methods should be applied as countermeasures.
		Raw water transmission facilities should be strengthened and alternative channels need to be prepared.
	Treatment plant	Materials used for expansion joint of water treatment facilities including steel plates are not flexible enough for severe shaking. It is recommended to check their seismic flexibility.
		Chlorine facility should be strengthened to lower the risk of human lives (from liquid chlorine to ozone or sodium hypochlorite).
	Pump station	Building structures of some pump houses are not always strong enough in case of severe ground shaking. It is recommended to check their design analysis with seismic loading and criteria.
		Some electric and control equipment are not stably installed against heavy

		shaking. They should be fixed against any type of movement or overturning.
	Distribution Reservoir	As most distribution reservoirs are of reinforced concrete and built as semi-buried in the soil, there is possibility of large relative displacement in their columns or walls by earthquake occurrence. It is recommended to check their seismic response according to the recent code and practice of Iran.
		All distribution reservoirs have no emergency shut off valves and effluent valves must be closed manually for stopping water discharge.
		Construction of new distribution reservoir is necessary especially in the district areas as described below.
	Pipelines	As the damage ratio of old pipes is very high comparing to new ones from past earthquake experiences, it is necessary to replace old pipes to seismic proof and durable ones.
		There is a need for replacement of non-flexible joint of pipes such as non-seismic joints and concrete pipes in the network.
		There are many critical points in the distribution network which are receiving water only through one route. It is recommended to modify the network in order to supply water at least through two independent routes.
		Database of water supply pipelines including their attributes should be provided. The pipeline database should be GIS type.
	House connection	House connection pipes which are reported having undergone many damages by an earthquake should be replaced by stainless steel pipes.
	Old Tehran & Bazar Area	These areas are of such conditions as old facilities, weak soils, high groundwater tables, high density population, business importance. More pump stations, more emergency water tanks are needed to be installed.
		Emergency water bases for earthquake disasters are necessary in districts No.10,11,12,13 and 20, especially in old towns where no reservoirs are installed yet.
		Since interruption of public power supply is expected in these areas in earthquake disasters, spare power units including diesel generators should be prepared.
2)Preparedness for emergency response		
	Cooperation	Have cooperation agreement with other cities considering their capacity and distance.
		The city should have a copy of Teheran water network and be familiar with the network for smooth assistance.
		Cooperation with Red Crescent Society is necessary.
		Cooperation with private companies which possess water tanker is needed.
	Man-power	Select and classify man-power for emergency operation and train them before an earthquake.
	Emergency tanks	Installation of emergency water tanks (reservoirs) is necessary.

2.5 Review of the Existing Available Data for Social and Environmental Consideration

In the course of and based on reconnaissance survey, IEE for this Study is carried out together with the counterpart of TWWC at the first half of the Study, with reference to and confirming the following information:

- Legal framework regarding environmental protection, including procedure of EIA, relevant local environmental regulations, role of organization in charge of environmental issue.
- Existing environmental condition

IEE result is carefully reviewed in the finalization stage of the Study incorporating the result of “Earthquake-resistant Plan for the Water Supply System in Tehran Municipality” and final evaluation in terms of social and environmental consideration is presented in Chapter 10.

CHAPTER 3 SEISMIC MOTION ANALYSIS

Seismic motion analysis executed in this chapter places its basis greatly on the following studies. Detail description of the analysis is made in the appendix xx as attached separately.

3.1 Outcomes of Recent Studies

The following two studies are typical ones among several existing studies regarding seismic motion analysis.

- JICA、"The Study on Seismic Microzonation of the Greater Tehran Area in the Islamic Republic of Iran", March 2000,
- NIGC & GTGC, "Research Project for Strengthening and Control of Tehran Gas Network Against Earthquake", March, 2004.

The outcomes of these studies cover the existing natural and social condition such as topography, geology, seismo-tectonic aspect, population, buildings, urban facilities and lifeline. The outcomes are maximum utilized in this study.

3.1.1 General Geological Cross Section of the Study Area

Figure 3.1.1 shows the general geological cross section of the Study Area,

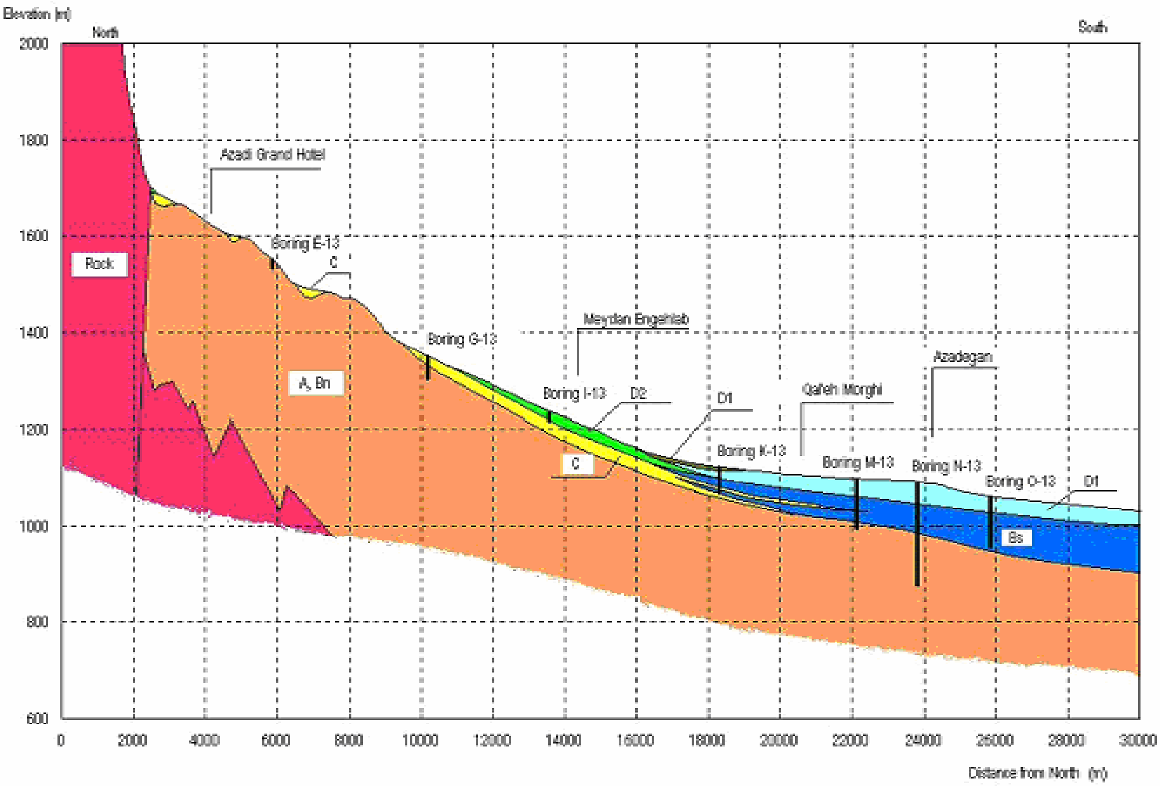


Figure 3.1.1 General Geological Cross Section of the Study Area

3.1.2 Seismotectonic in the Vicinity of the Study Area

(1) Major Faults

The faults characteristics are introduced following to JICA microzoning study and Gas research results and scenario faults are, also, selected as follows according to their outcomes. Fault location around Tehran City is shown in *Figure 3.1.2*.

1) 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. It is thought that this fault is a branch of Mosha Thrust Fault.

It can be assumed anyway that the dip of NTF is milder than 75 degrees, because this fault is a branch of Mosha Fault.

2) North Ray Fault (NRF)

North Ray fault 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.

3) 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. It has thrust mechanism.

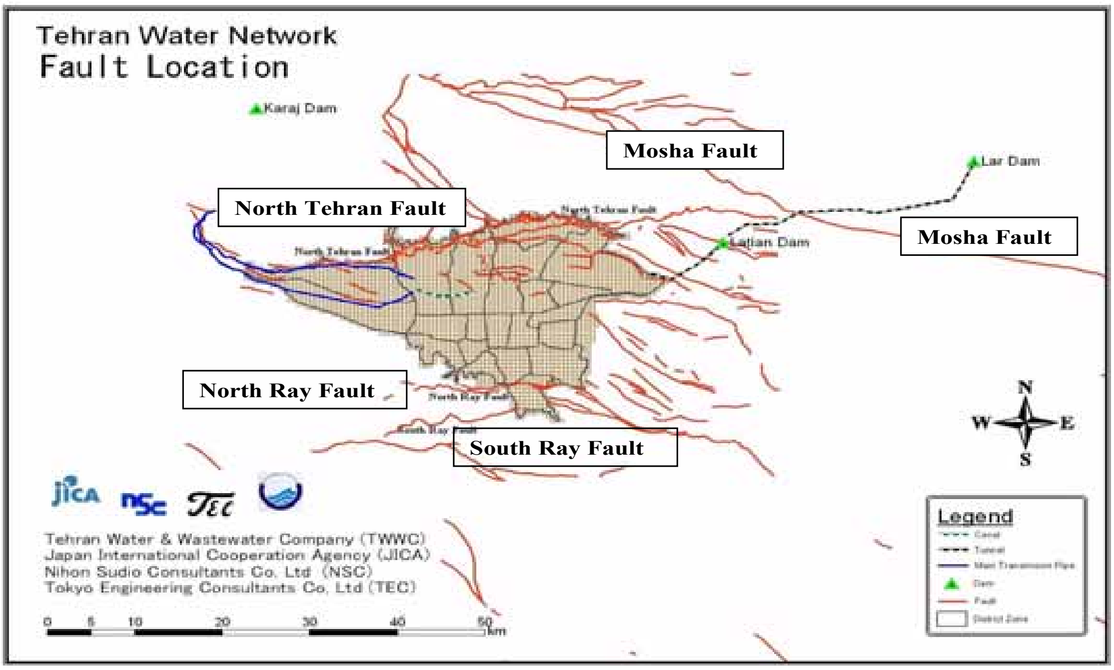


Figure 3.1.2 Fault Location around Tehran City

4) 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, has sinusoidal shape on the map and takes east-west strike on the eastern section. Its dip angle is about 75 degrees directed towards North.

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

Table 3.1.1 shows the characteristics of some important faults in and around Study area.

Table 3.1.1 Characteristics of Some Important Faults in and around Tehran City

Fault names	Approximate. Length (Km)	Mechanism	General trend	Max attributed magnitude (M)
North Tehran	90	Thrust	E-W	7.3
Niyavaran	18	Thrust with left lateral strike-slip component	ENE-WSW	6.5
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 lateral strike-slip component	NW-SE	6.5
Latyan	11	Reverse	WNW-ESE	6.2
Baghfeyz	4.5	Thrust with right lateral strike-slip component	NW-SE	5.7
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

Source: Gas Research Project

(4) Intersect Locations of Water Supply Pipelines and Faults

Figure.3.1.3 to Figure *3.1.8* show fault location and main intersect locations of water supply pipelines and faults in and around the city of Tehran. The intersect locations are up dated as water transmission mains (47 locations), main distribution pipes (95 locations) and distribution sub mains (552 locations) as of August 2006.

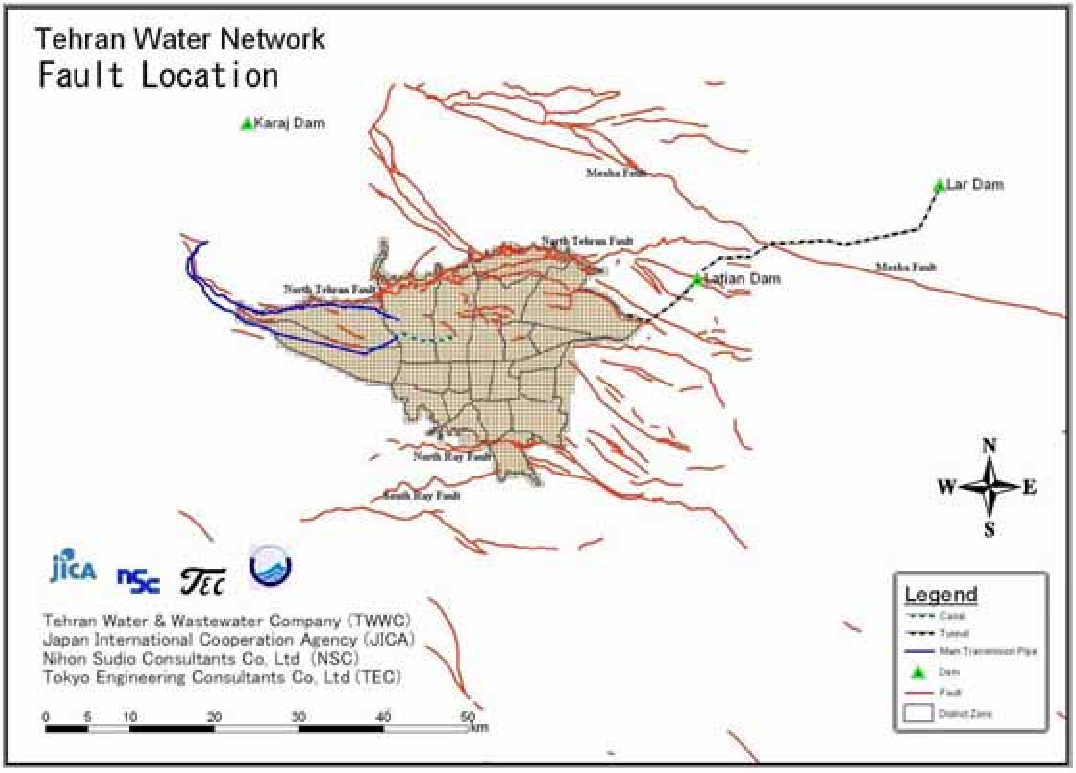


Figure 3.1.3 Fault Location in and around Tehran City

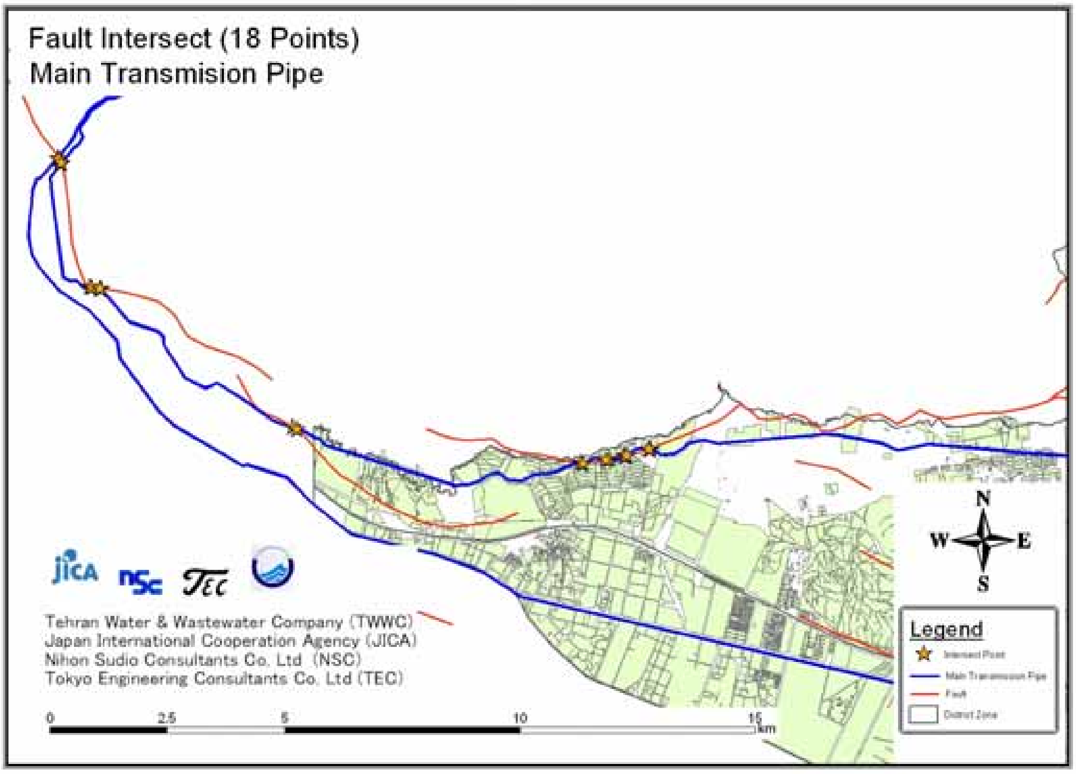


Figure3.1.4 Intersect Points between Faults & Raw Water Main

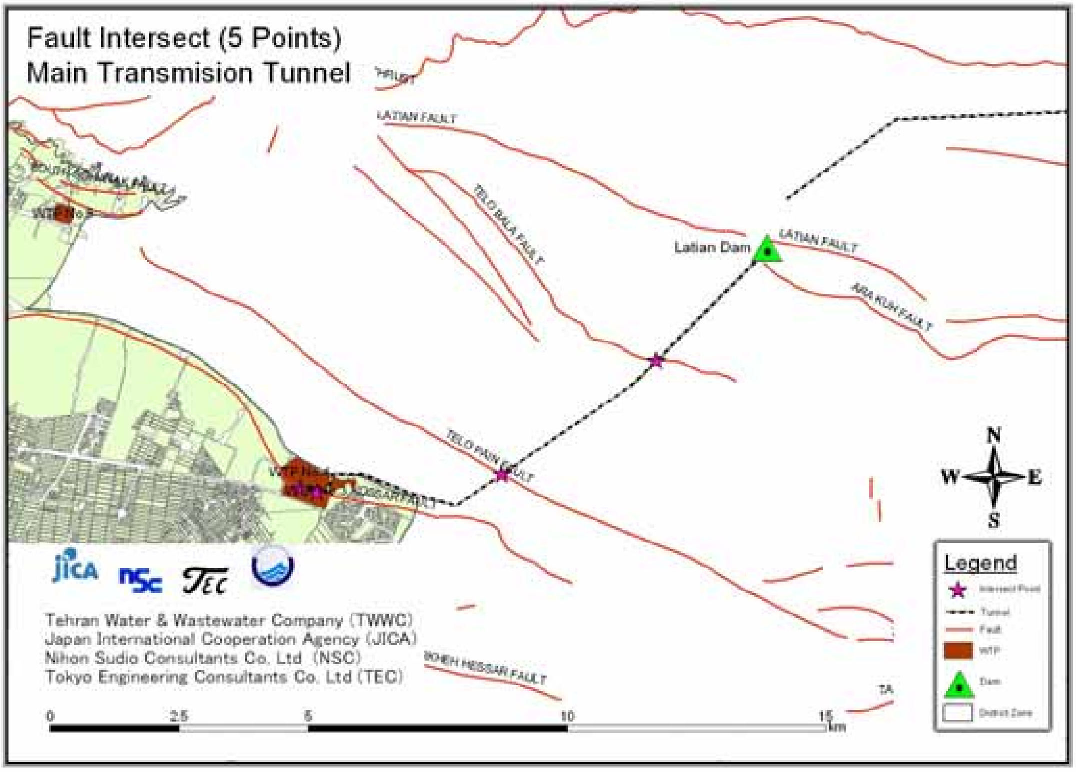


Figure 3.1.5 Intersect Points between Faults and Raw Water Tunnel & WTP

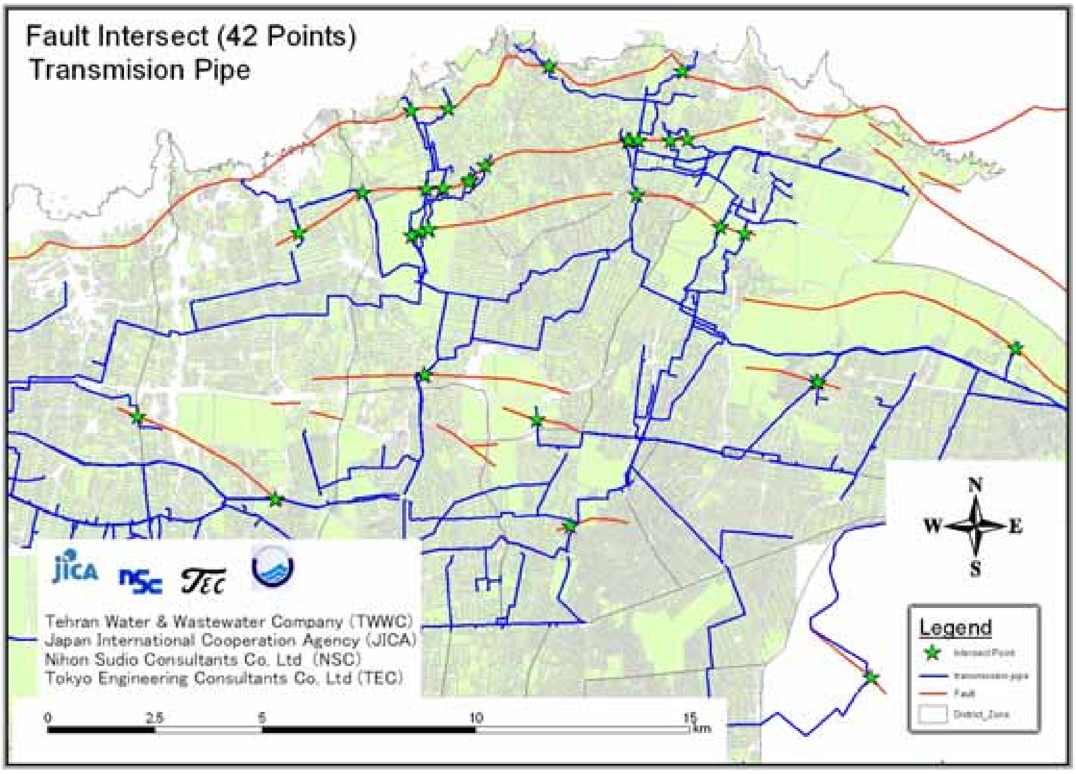


Figure 3.1.6 Intersect Points between Faults & Transmission Main

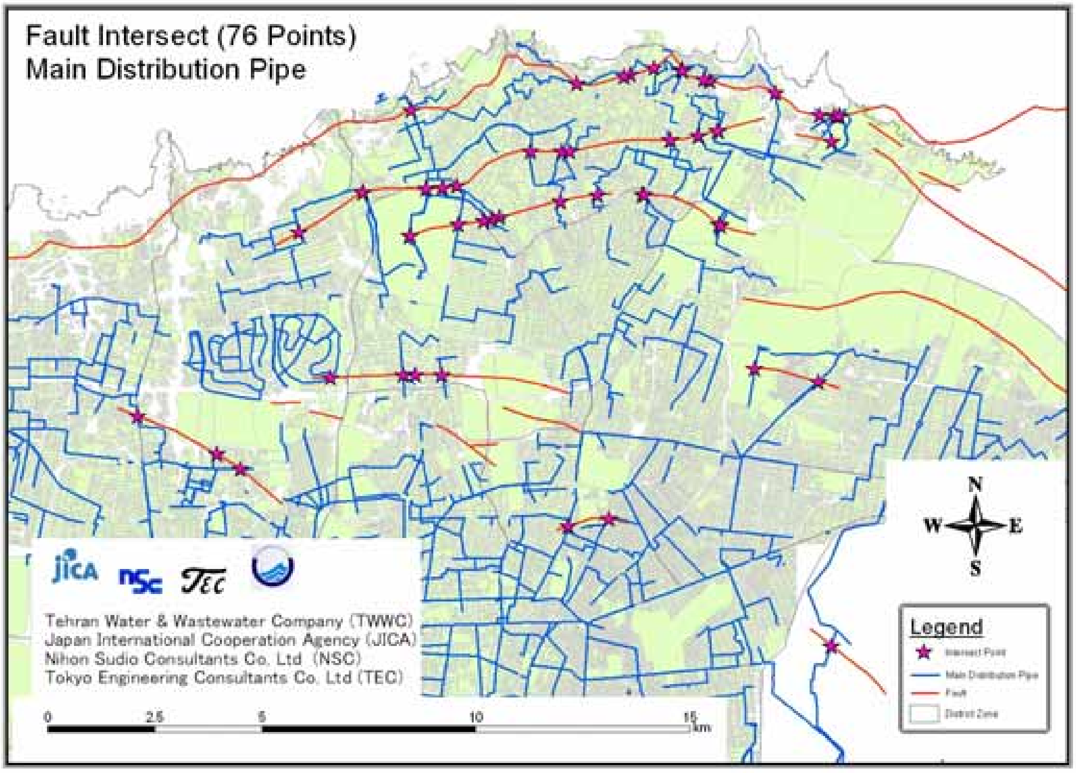


Figure 3.1.7 Intersect Points between Faults & Distribution Trunk Main

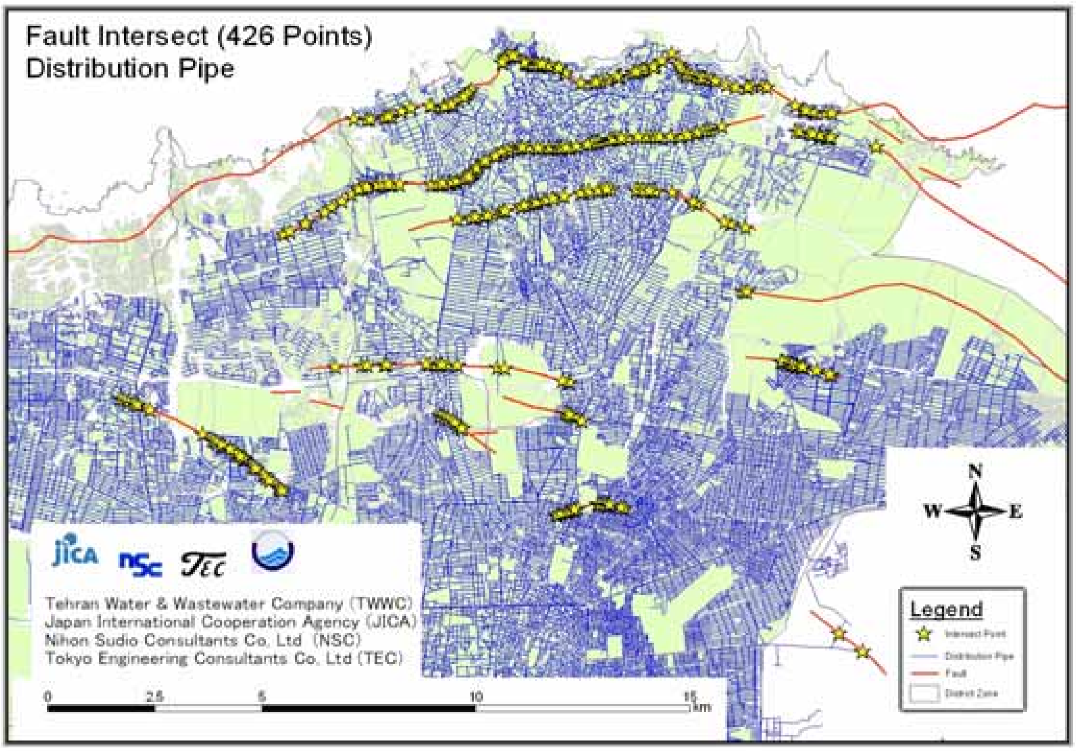


Figure 3.1.8 Intersect Points between Faults & Distribution Sub Main

(5) Historical Earthquake Record

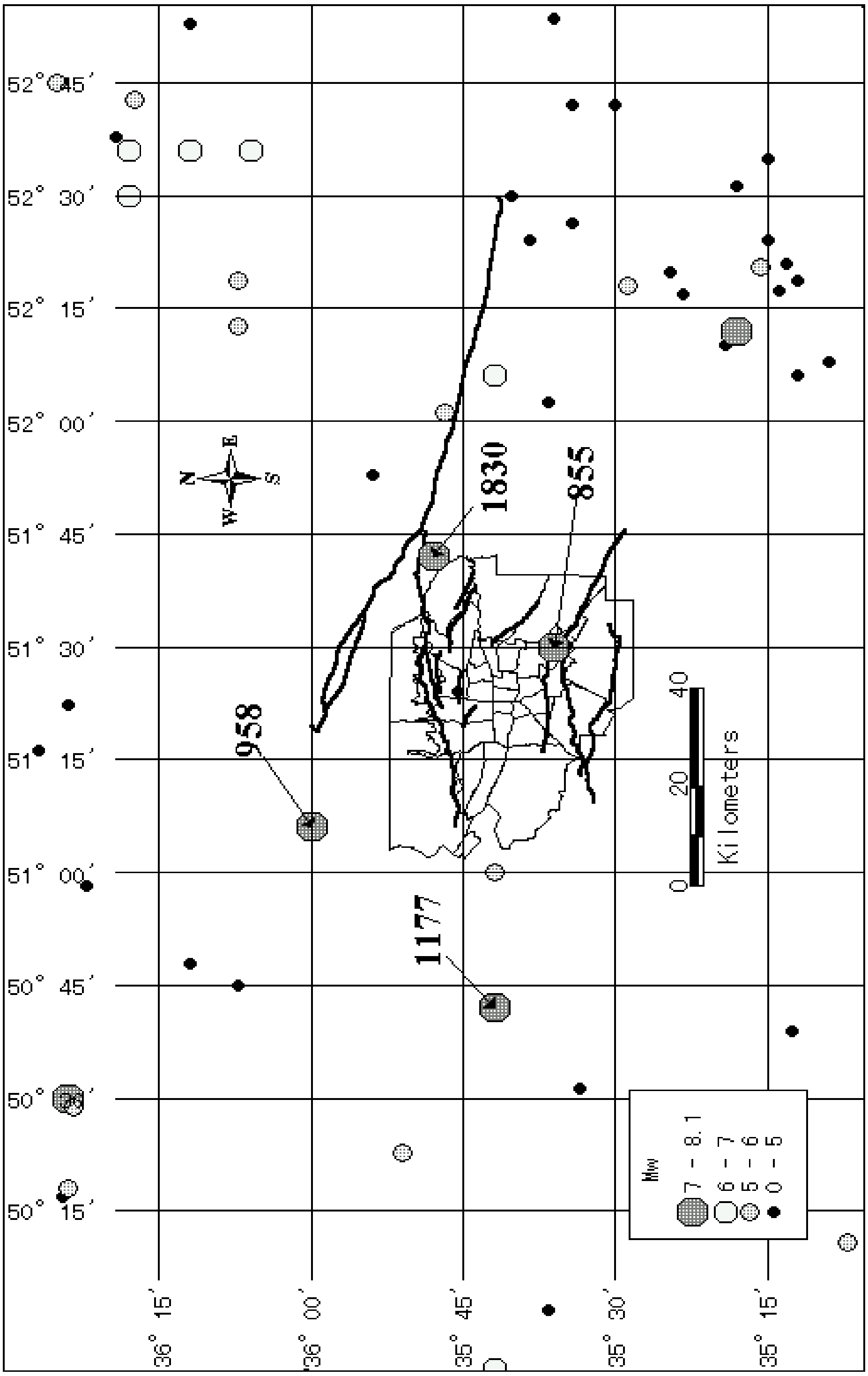
Fortunately, Tehran has not suffered any severe damage due to an earthquake in over 150 years. Some earthquakes that might have affected the Tehran area were picked out from the historical earthquake catalogue. Due to the spatial extent of the Greater Tehran Area, a sample site was selected for peak 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 3.1.2 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 3.1.9*

Table 3.1.2 Historical Earthquakes Affected to Tehran

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

Source: JICA Microzoning Study, November 2000



Source: JICA Microzoning Study, November 2000

Figure 3.1.9 Historical Earthquake Distribution around Tehran

3.1.3 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 as listed in *Table 3.1.2*.

- 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

3.2 Selection of Seismic Motion Analysis Method

3.2.1 Criteria for 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.

- Appropriate utilization and effective incorporation of a method applied to the existing earthquake motion analyses for lifeline facility,
- 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
- Appropriate method for the damage estimation for such lifeline facility as water pipeline network, gas pipeline network,
- Suitable method for counterpart, TPWWC, in the context of technical cooperation and technical transfer.

3.2.2 Method Selected

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

- 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.
- 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,
- 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,
- It is basically the same method which was applied to the study by Prof. TAKADA except for historical earthquake model,
- 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.

3.3 Procedure and Condition of Seismic Motion Analysis

3.3.1 Procedure of Seismic Motion Analysis and Damage Estimation

A procedure of seismic motion analysis and damage estimation for water supply system in TWWC is shown in *Figure 3.3.1*.

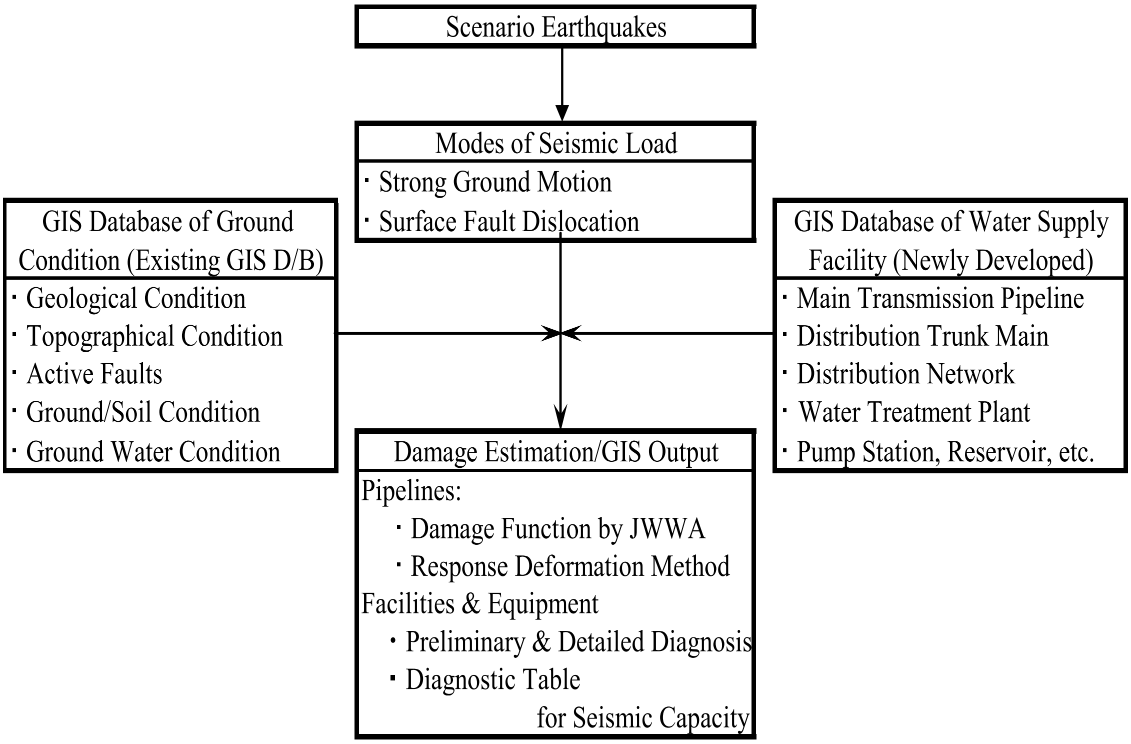


Figure 3.3.1 Flowchart of Seismic Motion Analysis and Damage Estimation

3.3.2 Condition of Seismic Motion Analysis

(1) Seismic Force

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

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

Historical earthquake is what is derived from the statistical analysis of the earthquake record entries. 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 shown in the Gas research project that liquefaction potential is confirmed low in the southern part of

Tehran. Therefore, 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 and Ground water level

In this JICA study the ground model used in Gas Research Project and the ground water level data in JICA Microzoning Study are applied.

3) Fault Parameter

Fault parameters used in this JICA study are shown in the *Table 3.3.1*.

Table 3.3.1 Fault Parameters used in the Study

Parameter	Fault							
	Mosha		North Tehran		North Ray	Sout h Ray	Parchin	Kahriza k
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 τ(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) (clockwise from north at 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

3.4 Analysis of Strong Ground Motion

3.4.1 Historical Earthquake

(1) Analysis Method

In this method, at first the probabilistic event of earthquake with magnitude M at distance R is calculated and the seismic hazard is obtained based on area and line source with random variable and Poisson process. Next, a ground motion time history is simulated for given faults. Then, an earthquake velocity response spectrum is determined and a sample time history for the statistical ground motion is obtained based on it.

(2) Statistical Ground Motion

Figure 3.4.1 shows excess probability of ground motion for given return periods.

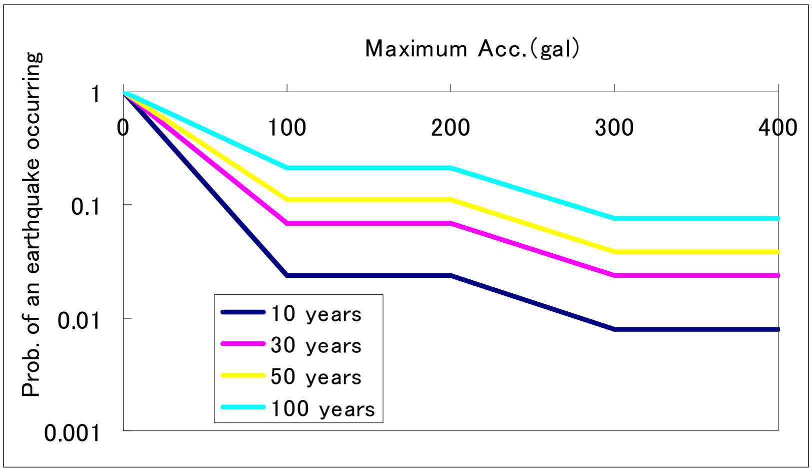


Figure 3.4.1 Earthquake Occurrence Probability during a Given Return Period

3.4.2 Scenario Earthquake

(1) Analysis Method

1) Method for Generation Synthetic Ground Motions

Boore's statistical simulation method (Statistical Green's Function Method) is used for generating a wave associated with small quakes. The computer program written by Prof. Takada et al is used for calculating bed rock motion.

2) Method for Surface Ground Motions

SHAKE program is used for calculating the acceleration, velocity and displacement on the surface ground motion and the rate of amplification after bed rock motion is calculated.

3) Method for Fault Dislocation

The equations by Okada (1983) based on the Steketee's (1958) "elastic dislocation theory" was applied to analyze earthquake induced ground displacement.

(2) Analysis Result

Peak ground acceleration is shown in *Figure 3.4.2* to *Figure 3.4.5* for each scenario earthquake. Peak surface ground velocity and displacement are shown in *Figure 3.4.6* to *Figure 3.4.7* for North Tehran earthquake as examples. The surface fault dislocation is shown in *Figure 3.4.8* for North Tehran earthquake as an example.

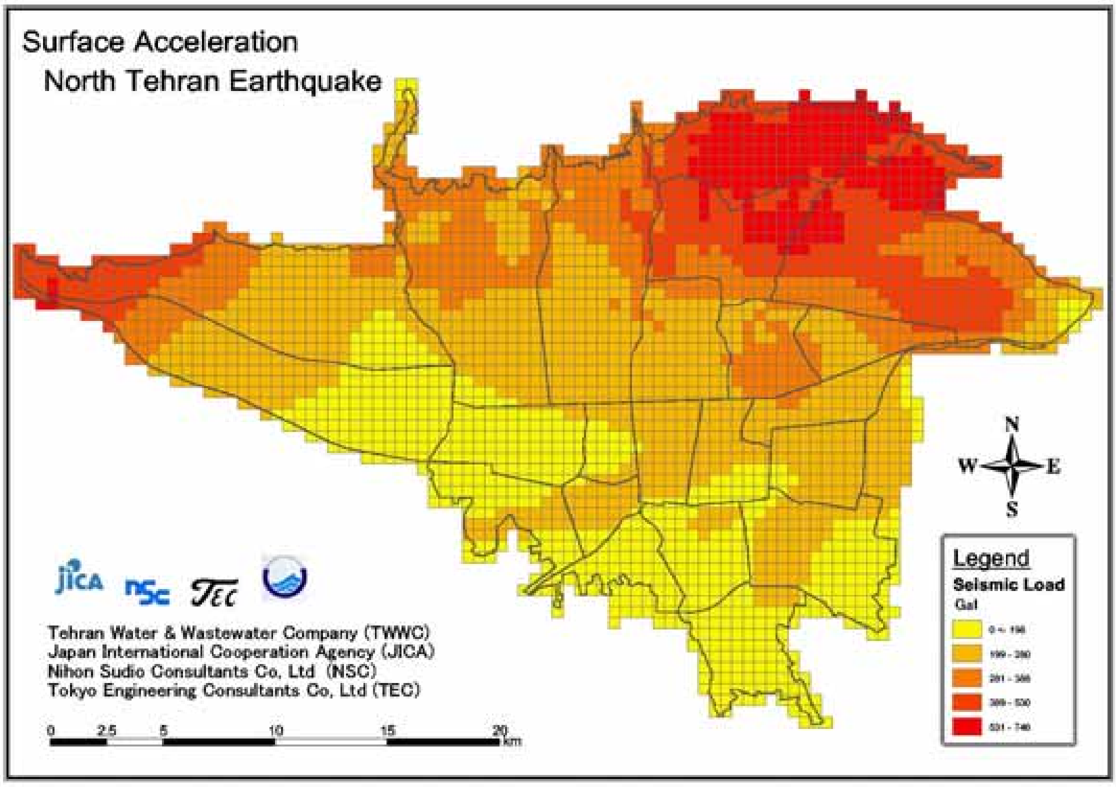


Figure 3.4.2 Surface Acceleration -North Tehran Earthquake-

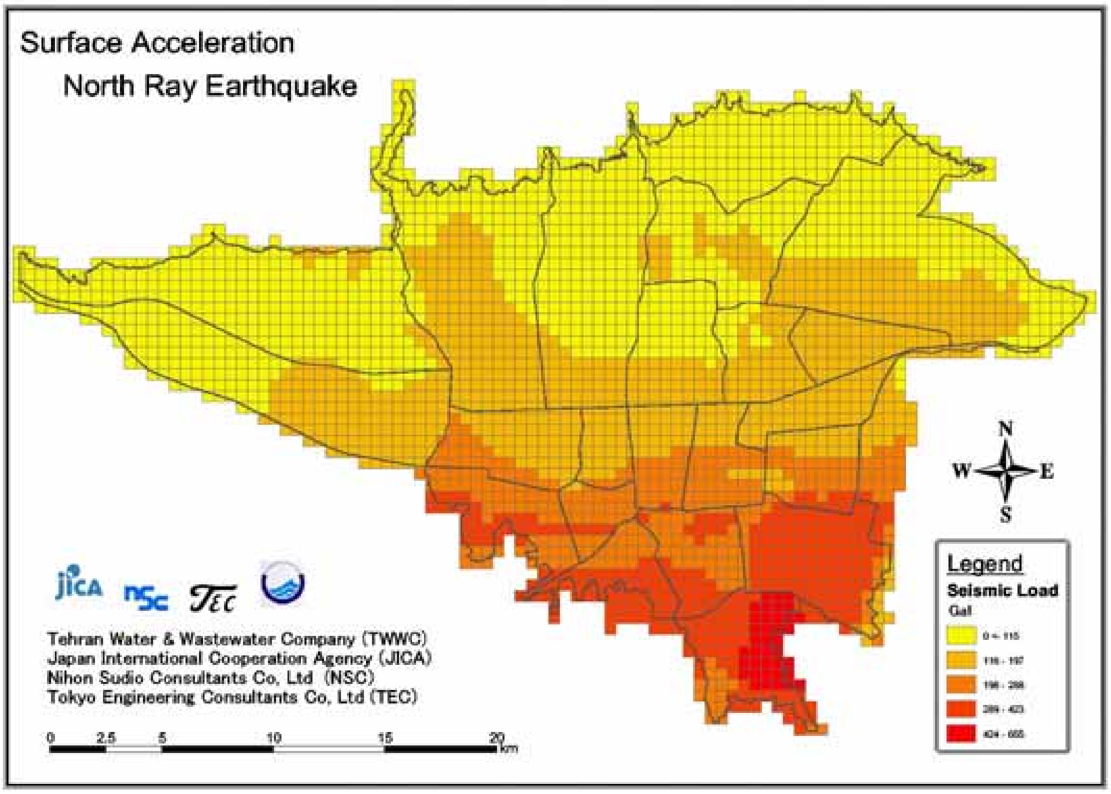


Figure 3.4.3 Surface Acceleration -North Ray Earthquake-

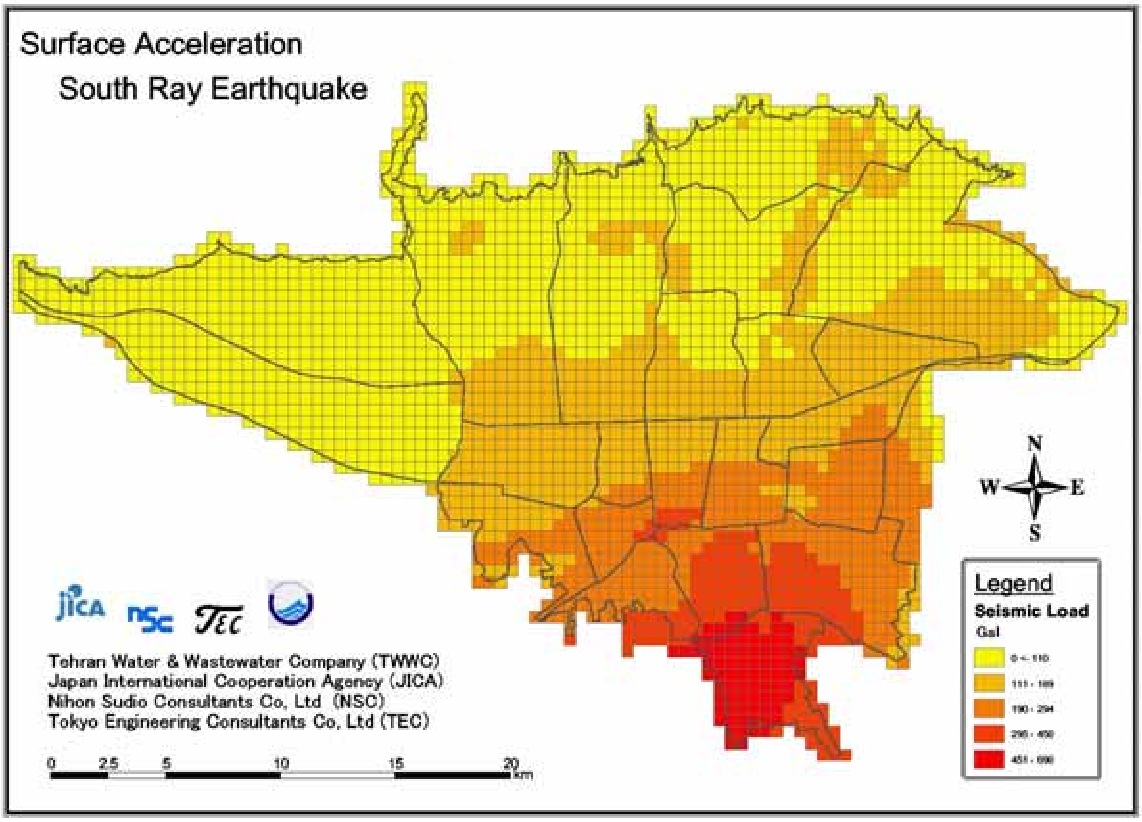


Figure 3.4.4 Surface Acceleration -South Ray Earthquake-

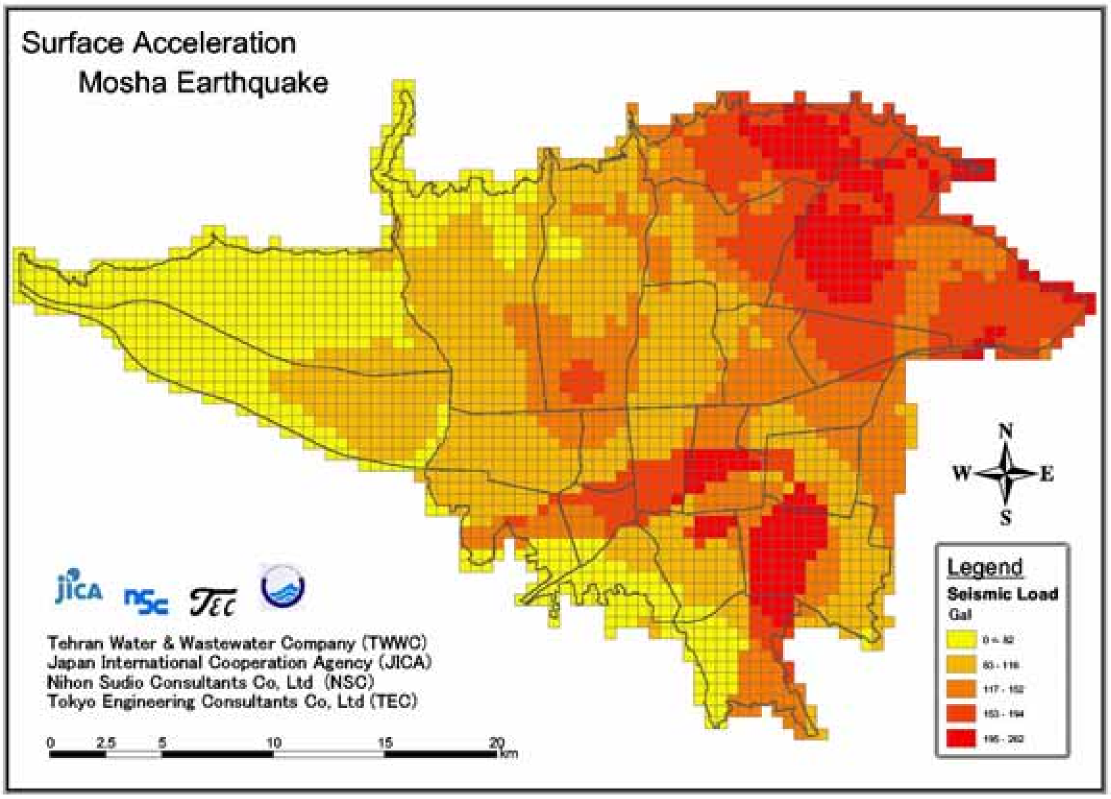


Figure 3.4.5 Surface Acceleration -Mosha Earthquake-

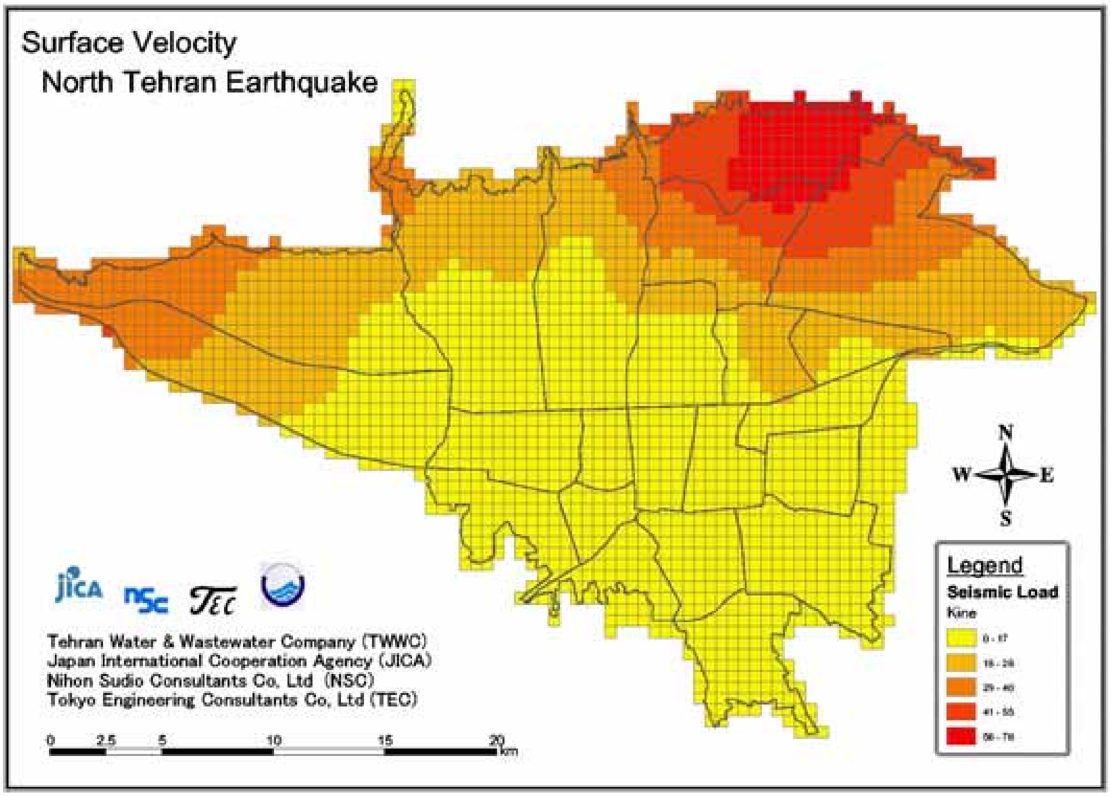


Figure 3.4.6 Surface Velocity -North Tehran Earthquake-

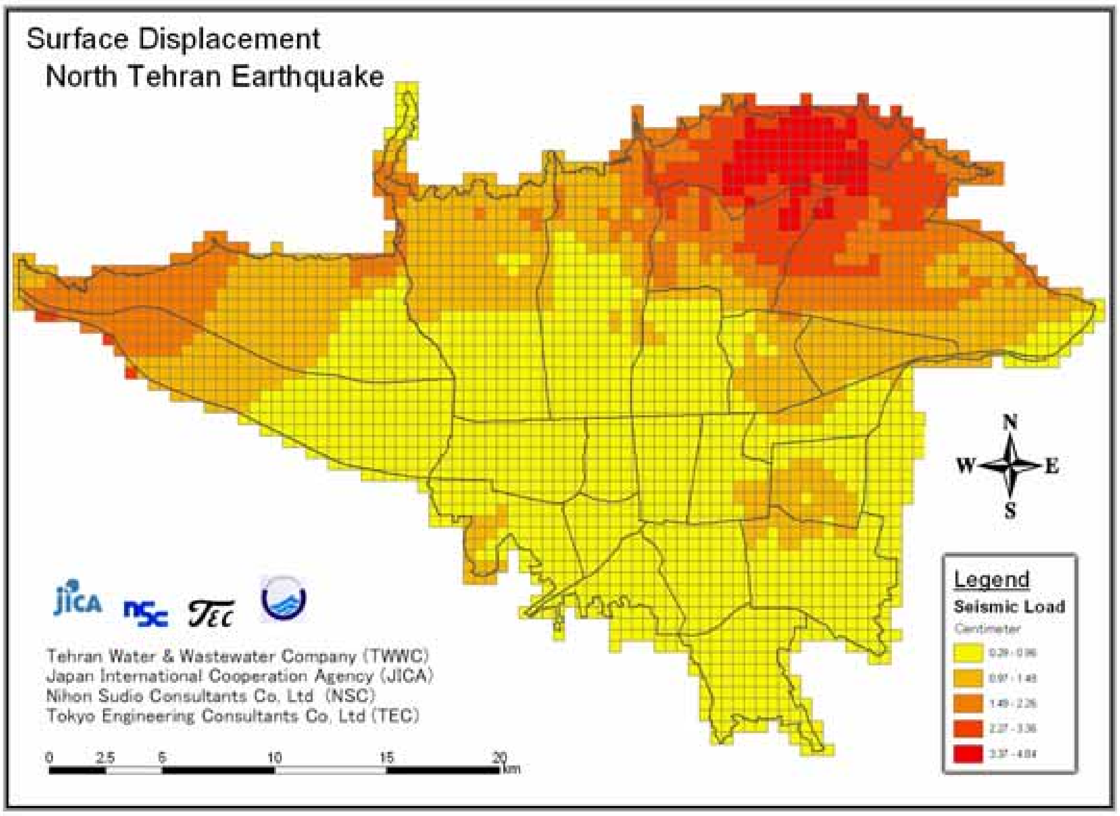


Figure 3.4.7 Surface Displacement -North Tehran Earthquake-

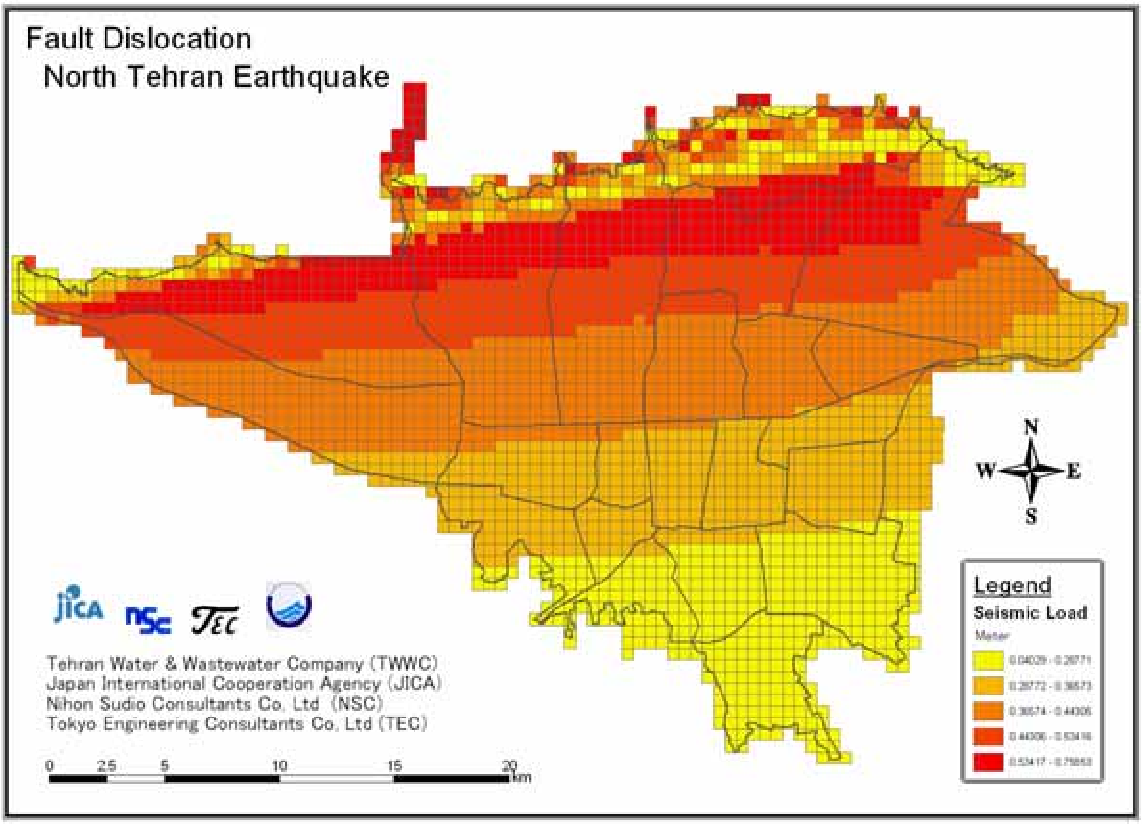


Figure 3.4.8 Surface Fault Dislocation -North Tehran Earthquake-

3.4.3 Summary of Analysis Results

Summary of the analysis results are listed in *Table 3.4.1*.

Table 3.4.1 Summary of Analysis Results

Item	Unit	N.Tehran	S.Ray	N.Ray	Mosha	Historical
Max PGA	cm/sec^2	746	286	343	262	221
Max PGV	cm/sec	76.0	56.5	52.3	17.7	19.8
Horizontal Displacement	cm	48.8	6.6	5.7	13.0	
Vertical Displacement	cm	75.9	12.0	14.1	6.2	

3.5 Estimation of Building Damage

3.5.1 Purpose of Buildings Damage Estimation

The purpose of damage estimation of buildings in Tehran city is to estimate damage to service pipelines installed in the building premises and to estimate a number of peoples who lost their houses in order to prepare emergency response measures.

3.5.2 Damage State of Buildings

The extent and severity of damage to buildings are categorized three damage states Major damage, Moderate damage, and Minor damage. Fragility curve of the buildings is following to Gas research project. Building is classified into 4 categories, Steel, RC, Brick & Steel and others same as those in Gas research project.

3.5.3 Numerical Results

Table 3.5.1 shows the building number in Tehran City as per 1996 census. *Figure 3.5.1* shows building distribution. The results of damaged estimation for each scenario earthquake are listed in *Tables 3.5.2* and one of the results is shown in *Figure 3.5.2* as the most severe case, North Tehran Earthquake case. The case provides 27 % of all buildings in major damage and also same 27 % in moderate damage. 380 thousand buildings would collapse in number.

Table 3.5.1 Building Number in Tehran City

Type	STEEL	RC	Brick & Steel	Others	Total
Number	601,120	166,027	605,108	59,545	1,431,800

Table 3.5.2 Building Damage Estimation Result

	North Tehran Fault	North Ray Fault	South Ray Fault	Mosha Fault
Major	384,796	177,807	166,137	62,341
Moderate	387,244	261,940	217,987	129,748
Total	772,040	439,747	384,124	192,089

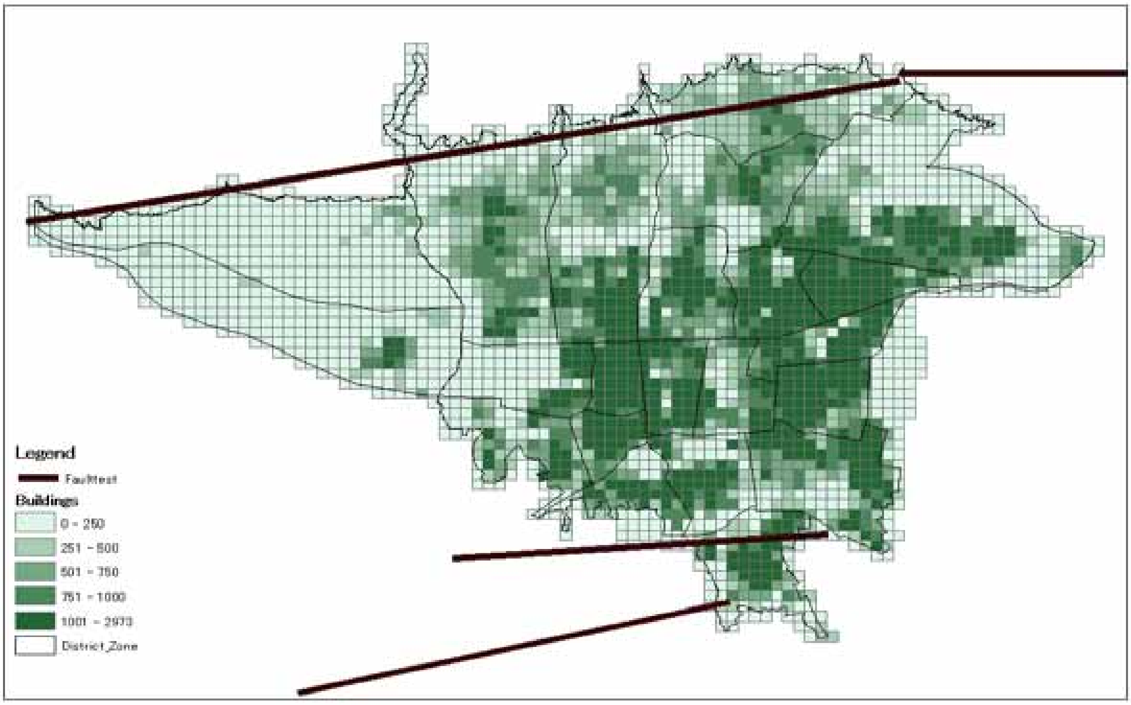


Figure 3.5.1 Distribution of Buildings in Tehran City

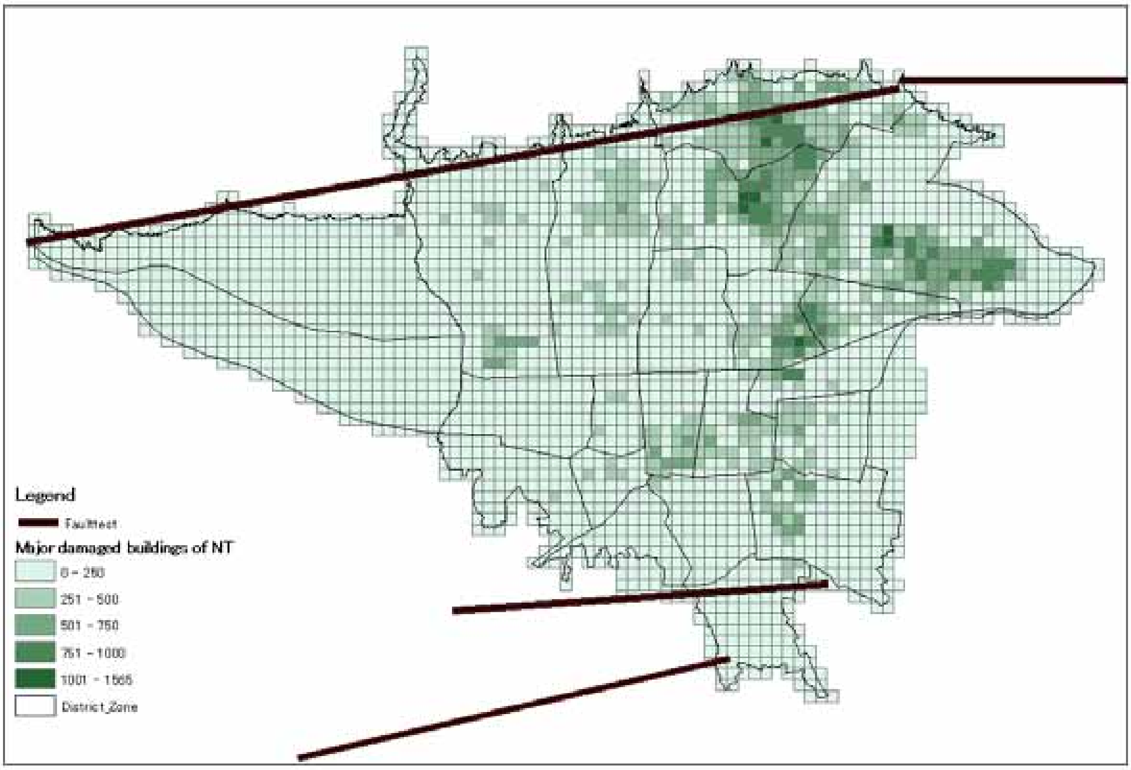


Figure 3.5.2 Major Damaged Buildings of North Tehran Earthquake

CHAPTER 4 DAMAGE ESTIMATION OF WATER SUPPLY SYSTEM

4.1 Damage Estimation of Pipeline System

4.1.1 General View of Pipelines

Pipeline length in Tehran exceeds 7500 km including small diameter distribution pipes. These pipelines can be classified as following.

(1) Raw Water Transmission Main

These are pipelines from raw water intakes to water treatment plants (hereinafter referred to as WTP). Lines from Bileghan intake to WTP No.1 (Jalaliye) and to WTP No.2 (Kan) are located in the west of Tehran. The former line was installed in the first stage and consist of 1000 mm diameter steel pipe with mechanical joints. The latter is concrete pipelines with 2000mm diameters. In east of Tehran, there are tunnels for the purpose of raw water transmission. One is from Latiyan dam to WTP No.3&4 (Tehran Pars) and the other is from Lar dam to WTP No.5 (Sohanak) via Kalan power plant. Investigation for these raw water transmission mains is not included in this report, due to insufficient data obtained as well as the fact that the main purpose of the study is earthquake influence in Tehran city area. Nevertheless these lines are quite important and once water supply stops, the whole area might be subject to severe water shortage conditions. Therefore some effects will be included even though detailed analysis can not be done.

(2) Transmission Main

These main lines consist of lines from WTP to distribution reservoir and connection lines between reservoirs. These lines' function is to supply water to distribution reservoirs from WTP as long as WTP has enough water to produce. Therefore these lines comprise one of the most important lines. In this study, detailed analysis was done based on exact data. Total length of the transmission mains used in this analysis exceeds 300 km.

(3) Distribution Trunk Main

These mains transport water from reservoirs to distribution sub mains. In this study pipes greater than 300 mm in diameter including 300 mm are classified as distribution trunk main. Total length of the main exceeds 750 km.

(4) Distribution Sub Main

Pipes with less than 300mm in diameter in the reservoir zone are adopted as sub mains. Total length exceeds 6000 km.

Pipe joints are mechanical type even for the steel pipes. Therefore damages are considered to be concentrated in their joints. And the main type of joint failure is the slip out of the pipe from the adjacent pipe.

Buried pipeline conditions are classified to general area and special places. Special places refer to such points as fault crossings or connections to massive structures. The term “massive” structure means concrete buildings or relatively massive objects compared to pipes. Typical structure of the above mentioned massive structure is the distribution reservoir.

Three types of damage models are considered when analyzing safety of pipelines in Tehran. First is damages caused by strong ground motion. Second is dislocation of faults which causes pipe shearing once fault moves laterally. Third is slip out of pipe joints at the place of pipe connection to massive structures.

4.1.2 Modeling for Damage Estimation

There are three types of damage model as mentioned above. In this section details of these models will be described.

(1) Pipeline Network

Water network is composed of links and nodes. The link is a segment joining two nodes. Water network has either loop or branch graph shapes. Both graph shapes exist in transmission mains. Link reliability is considered in this study under the condition of the above described three damage models. For these damage models can explain actual failures phenomena.

Reliability of pipe segment is not always related (or proportional) to numbers of damage in the segment, it might be acceptable though. Even though, ninety nine percent reliability of the segment may be accepted as to recognize 1 damaged joint in 100 joints in the segment.

(2) Pipeline Damage Caused by Strong Ground Motion

Two major methods are applied to calculate damage rates of buried pipeline. One is the analytical method using response displacement method and the other is based on statistical data, i.e., data acquired from past experience.

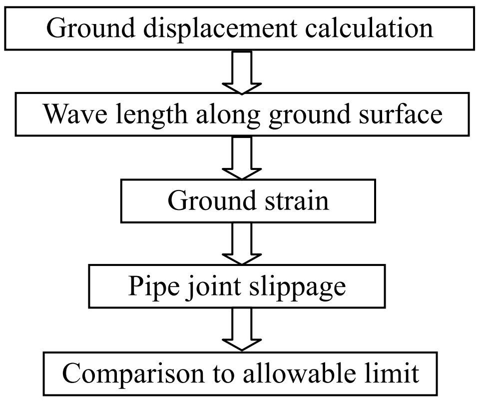
Response displacement method is commonly used for analyzing buried structures such as under river tunnels or large diameter sewage tunnel ducts. This method is applied for buried pipes especially large diameter sizes. The method is based on generated ground strain. This strain transferred to pipe body and strains are accumulated to their joints which cause slippage of the joints. Once joints are detached, pipes do not function anymore. This method is considered to be the engineering procedure.

Statistical method is an easier method to know the overall damage. Furthermore damage data for calculation are based on such factors as ground velocity or ground acceleration which is relatively easy to obtain from earthquake data. Considering barriers applying the method, there are neither enough data to get the accurate condition of damage nor the actual cause. In fact, several causes of damage are combined, however it is hard to separate the essential causes. On the other hand, it is considered that varieties of surrounding condition are included in the statistical data. Therefore it seems to be practical when applying the method to small diameter size pipes.

Based on the above consideration, analytical methods are applied to the main lines such as transmission mains and statistical method is used for small diameter pipes like distribution sub mains.

1) Response displacement method

Response displacement method is an engineering measure to analyze buried pipeline. Rough flow of analysis is shown below.



2) Statistical method

Pipe damage is calculated using both pipe characteristics and surface ground velocity or acceleration. The pipe characteristics are pipe diameter, and material as well as soil conditions. Number of damage points for each unit length of pipeline is obtained based on the conditions.

In this study, Japan waterworks association (JWWA) formula was adopted.

(3) Analysis of Fault Crossing Points

Scenario earthquakes applied in this study are based on motion of active fault near Tehran city. On the other hand there are many secondary faults in the city. There are many fault intersecting points with transmission mains and distribution trunk mains. These secondary faults do not always move as a result of active faults' motion. Nevertheless some offsets may occur after large ground dislocation along active fault. Under such conditions pipes suffer large deformation which might cause joint detachment. Motion pattern along secondary faults are considered to be vertical or horizontal slides. Such offset values are far larger compared to earthquake motion amplitude and as a result permanent displacement remains. These permanent ground displacements are obtained from ground motion analysis. These offsets do not always coincide with slide length along secondary fault line. Furthermore from the aspect of strength, if fault face is strong enough there is no possibility of slippage. Nevertheless considering the worst case for water supply pipeline crossing the fault, such assumption might be considered appropriate. Therefore this type of damage modeling is adopted. Analysis sequence is as follows.

Calculation of Permanent Ground displacement at fault crossing

⇩

Pipe Joint angle deformation

⇩

Comparison to Allowable limit

(4) Pipe Connection to Structures

Generally speaking surface ground has a natural frequency or natural period which shows different characteristics from those of the structures. Pipes buried in ground are moved with their surrounding soil. Under such condition once an earthquake motion hits, ground including pipes vibrates with different phase from that of massive structures because of rigidity difference. Such phase difference or response magnitude which is defined according to natural frequency causes relatively different displacement of these adjacent structures. This phenomenon might induce pipe joint detachment.

Many pipe joint damages are observed near structures in actual earthquakes, therefore pipes with earthquake resistant joints or flexible joints should be used. The flexible joints are also effective as countermeasures for unequal ground settlement.

It is difficult to estimate the precise values of these discrepancies. Nevertheless it is considered that structure rarely responds far beyond the ground motion except in case of the ones with low rigidity. Therefore maximum amplitude value which is obtained from ground motion analysis is adopted as the maximum relative displacement. Analysis sequence is as follows.

Calculation of relative displacement

⇩

Calculation of pipe joint slippage

⇩

Comparison to allowable limit

4.1.3 Details of Analysis Method

(1) Analysis of Strong Ground Motion Effect by Response Displacement Method

Pipe joint slippage for transmission mains and distribution trunk mains are calculated with response displacement method. Concept of data variation is adopted. Joint slippage obtained from calculation is not a fixed value and has some distributed values. *Figure4.1.1* shows the concept of this variation. Even when estimated joint slip is below the allowable limit, there is some probability which exceeds the limit. Normal distribution is adopted in this study and exceeding probability is shown as shaded in the figure. This concept is applied to analysis of both fault crossing cases and connection to massive structure ones. Details of response displacement method are described in several text books such as those issued by Japan waterworks association.

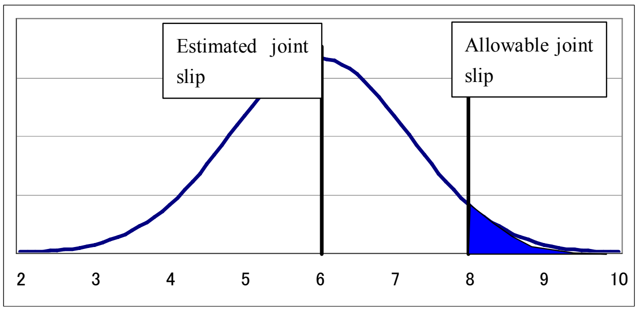


Figure 4.1.1 Normal Distribution Curve

(2) Damage Caused by Fault Dislocations

Fault crossings which are considered in this study are mainly located inside Tehran city, i.e., secondary fault. There are some pipe intersections with active fault such as North Tehran fault. However the numbers of cross points is far larger in case of secondary faults.

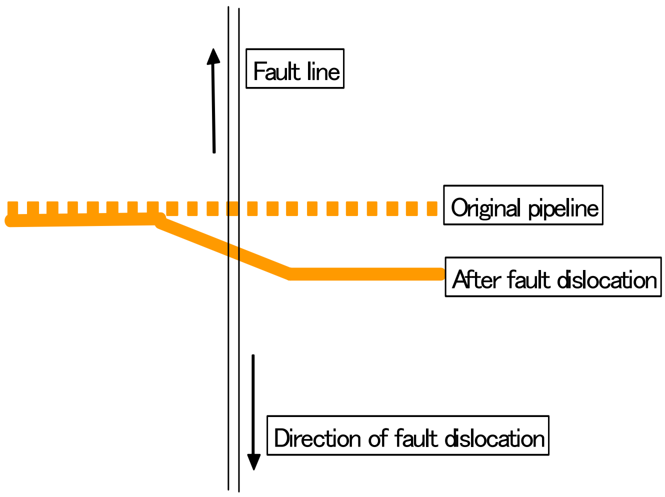


Figure 4.1.2 Pipe Dislocation at Fault Crossing

These secondary faults might dislocate under the condition of active faults motion and ground strain exceeding the durable limits at these secondary faults. Therefore it can be concluded that these faults do not always move when an active fault moves, nevertheless possibility of motion still remains. However in view of assuming the worst case it is more appropriate to apply such assumption. Dislocation shape is considered to be vertical or horizontal or combined slip by compressive force and the opening of fault face is not considered.

Permanent ground displacement value is adopted as dislocation along fault face. This value is considered maximum in any case and actual slip value is considered below this level.

Figure 4.1.2 shows conceptual modeling of the fault crossing. Fault slippage is absorbed by two pipe joints as shown. Therefore capability of pipe joint becomes important. *Figure4.1.3* shows the detailed shape of pipe joints. If the edge of joint remains in neighboring pipe after pipe joint is deformed with a certain angle such as shown in the figure, pipe is considered to be safe. Allowable angle is obtained with consideration of slippage limit, pipe diameter and pipe unit length.

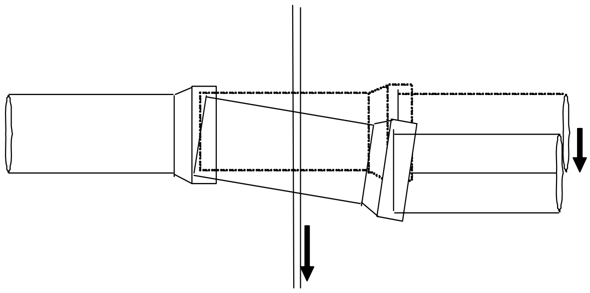


Figure 4.1.3 Pipe Joint Deformation at Fault Crossing

(3) Effect of Pipe Connections to Massive Structure

There are many places where pipes are connected to massive structures such as concrete reservoir tanks. Natural frequency of those structures is different from surrounding soil. This effect might cause independent motion of these components. As a result of this motion, there might be detachment between structure and soil. This motion causes pipe joint slip near structure. Such phenomenon is included in this study. Maximum motion amplitude is adopted as discrepancy. *Figure 4.1.4* shows model of the phenomenon.

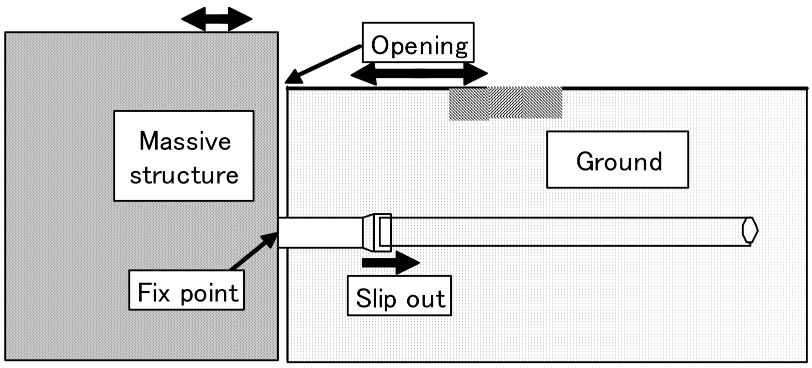


Figure 4.1.4 Pipe Joint Slippage at Structure Connection

4.1.4 Fundamental Data and Preliminary Analysis

(1) Pipe Data

Pipe data are shown in *Table 4.1.1* together with their joint slippage allowance. Pipe joint slippage allowance is assumed as half of joint sliding property. This means edge of inner pipe at joint is located in the middle of outer pipe edge and end of outer pipe body. Under this condition pipe joint will detach in case of exceeding allowable limit. Therefore steel pipes with "Viking Johnson" type joint have large allowance for slippage. On the other hand, ductile iron pipes have relatively small allowance. The allowance of ductile iron pipe is based on "Tyton" joint, for bolt type joint allowance is larger than that of "Tyton" type. Therefore smaller value is adopted considering safety of joints. Concrete pipes and cast iron pipes have weak joints compared to those of steel and ductile iron pipes even though they have enough pipe body strength. These joints are especially easy to break under impact force or lateral force. These are the reasons to reduce slippage allowance for concrete and cast iron pipes. Other material pipes such as asbestos pipes are considered to be of similar conditions. Reduction rate is considered 3, for the past earthquake data show that concrete and cast iron pipes damage ratio is about three times compared to those of ductile iron and steel pipes.

Table 4.1.1 Basic Pipe Data

Pipe ID	Pipe material	Pipe diameter (mm)	Unit pipe length (m)	Allowable joint slippage (mm)
ST-250	Steel	250	7.6	50.0
ST-300	- ditto -	300	7.6	50.0
ST-400	- ditto -	400	7.6	50.0
ST-500	- ditto -	500	7.6	50.0
ST-600	- ditto -	600	7.6	50.0
ST-650	- ditto -	650	7.6	50.0
ST-700	- ditto -	700	7.6	50.0
ST-800	- ditto -	800	7.6	50.0
ST-900	- ditto -	900	7.6	50.0
ST-1000	- ditto -	1000	7.6	80.0
ST-1050	- ditto -	1050	7.6	80.0
ST-1100	- ditto -	1100	7.6	80.0
ST-1200	- ditto -	1200	7.6	80.0
ST-1250	- ditto -	1250	7.6	80.0
ST-1300	- ditto -	1300	7.6	80.0
ST-1350	- ditto -	1350	7.6	80.0
ST-1400	- ditto -	1400	7.6	80.0
ST-1600	- ditto -	1600	7.6	80.0
ST-2200	- ditto -	2200	7.6	80.0
RC-600	Concrete	600	6.0	12.5
RC-700	- ditto -	700	6.0	12.5
RC-900	- ditto -	900	6.0	12.5
RC-1000	- ditto -	1000	6.0	12.5
RC-1250	- ditto -	1250	6.0	12.5
RC-1350	- ditto -	1350	6.0	12.5
RC-1700	- ditto -	1700	6.0	12.5
RC-1850	- ditto -	1850	6.0	12.5
RC-2000	- ditto -	2000	6.0	12.5

Pipe ID	Pipe material	Pipe diameter (mm)	Unit pipe length (m)	Allowable joint slippage (mm)
AC-300	Asbestos	300	5.5	5.0
CI-200	Cast Iron	200	5.5	5.0
CI-300	- ditto -	300	5.5	5.0
CI-350	- ditto -	350	5.5	5.0
CI-400	- ditto -	400	5.5	5.0
CI-450	- ditto -	450	5.5	5.0
CI-500	- ditto -	500	5.5	5.0
CI-550	- ditto -	550	5.5	5.0
CI-600	- ditto -	600	5.5	10.0
CI-650	- ditto -	650	5.5	10.0
CI-700	- ditto -	700	5.5	10.0
CI-750	- ditto -	750	5.5	10.0
CI-800	- ditto -	800	5.5	10.0
CI-900	- ditto -	900	5.5	10.0
CI-1000	- ditto -	1000	5.5	10.0
CI-1100	- ditto -	1100	5.5	10.0
CI-1200	- ditto -	1200	5.5	10.0
DIP-250	Ductile iron	250	5.5	15.0
DIP-300	- ditto -	300	5.5	15.0
DIP-350	- ditto -	350	5.5	15.0
DIP-400	- ditto -	400	5.5	25.0
DIP-500	- ditto -	500	5.5	25.0
DIP-600	- ditto -	600	5.5	30.0
DIP-700	- ditto -	700	5.5	30.0
DIP-800	- ditto -	800	5.5	30.0

(2) Ground Strain Caused by Strong Ground Motion

Ground strain caused by strong ground motion is one of the essential figures when analyzing with response displacement method. Strains are transferred to the buried pipes and these strains accumulate at pipe joints and joint slip occurs as a result.

Ground strain is given as follows.

$$\varepsilon_G = \frac{\pi U_h}{L}$$

where ε_G : Ground strain
U_h : Horizontal amplitude of earthquake
L : Equivalent wave length

4.1.5 Damage of Transmission Main

(1) Summary of Transmission Main

Total length of transmission main exceeds 300km. Three forth of total length consists of steel pipeline, and length of concrete pipe is less than 20% (see *Table 4.1.2*). Ratio of concrete pipe is high for large diameter pipes. This comes from the fact that there are parallel concrete mains of 1850mm diameter pipes starting from WTP No.2 (Kan WTP).

Ductile iron pipe is used in northern part of Tehran to connect neighboring reservoirs with pipes of small size diameter.

Intersection with fault is around 40 places and pipe connection to reservoir structure is around 147 points. They are included in analysis.

Table 4.1.2 Transmission Mains in the Study

Diameter (mm)	Ductile Iron Pipe	Concrete Pipe	Steel Pipe	Total
250	1.91		0.93	2.84
300	2.00		0.26	2.26
400			3.18	3.18
500	5.77		4.02	9.79
600	5.01	3.76	5.01	13.78
700	1.82	5.68	15.52	23.01
800			25.60	25.60
900		11.96	55.46	67.41
1000			14.02	14.02
1100			21.78	21.78
1200			59.10	59.10
1250		13.53	4.45	17.98
1350		5.18		5.18
1400			22.92	22.92
1600			18.11	18.11
1700		2.90		2.90
1850		19.32		19.32
2200			2.45	2.45
Total	16.51	62.32	252.79	331.62

(2) Presuppositions

Strong ground motion, fault crossing and connection to massive structures are considered as cause of pipeline damage. Fault crossing of 40 and connection to structure of 147 are included in calculation.

Standard deviation of normal distribution of joint slippage is taken as 20% of average value. Allowable slippage limit is set constant in this study.

(3) Damage Estimation

Damage is calculated based on pipeline link reliability. Pipelines are divided into links and nodes which are branching points of pipelines or reservoir connections. Three damage models are adopted i.e., damages caused by strong ground motion, fault crossing, and connection to massive structures. Allowable slippage limits for concrete pipes and cast iron pipes are reduced because of the weakness of the joints. Therefore link reliabilities of these pipes indicate low compared to those of steel and ductile iron pipes. Damage probability is shown in *Table 4.1.3.* Severe damage in the table means link reliability of less than 50%. Severe damage occurs mainly in case of North Tehran fault earthquake. There is possibility of 12 points damage. Some occur due to fault crossings and the others occur as a result of connection to massive structures. There is no place where damage is caused by strong ground motion. Eight places out of 12 places are concrete pipes, 3 are ductile iron pipes and one is steel pipe.

There is one severe damage record in case of North Ray fault earthquake. Material of this link is steel. Generally speaking steel joints have relatively large slippage allowance therefore steel pipe joint damage is rare. However ground displacement amplitude caused by North Ray fault earthquake exceeds 50 mm in several areas, which causes joint slippage at connection to massive structures in southern area of Tehran.

Figure 4.1.5 to *Figure 4.1.8* show the results of analysis. Yellow marking shows location of faults. Red line shows link with less than 50% reliability which means probability of severe damage.

Table 4.1.3 Damage of Transmission mains

	North Ray	South Ray	North Tehran	Mosha
No. of Damage Links	1	0	31	3
Slight Damage (Reliability>=50%)	0	0	19	3
Severe Damage (Reliability<50%)	1	0	12	0

Link reliabilities are shown in *Fiure.4.1.5*. in case of North Ray fault earthquake. Reliability of one link located in southern part of Tehran is less than 50%. This comes from the fact that ground motion amplitude exceeds 5 cm. In such case, pipe connection to structures even if it is a steel pipe can not resist the force exerted upon. This implies attention must be paid to points of connection to massive structures.

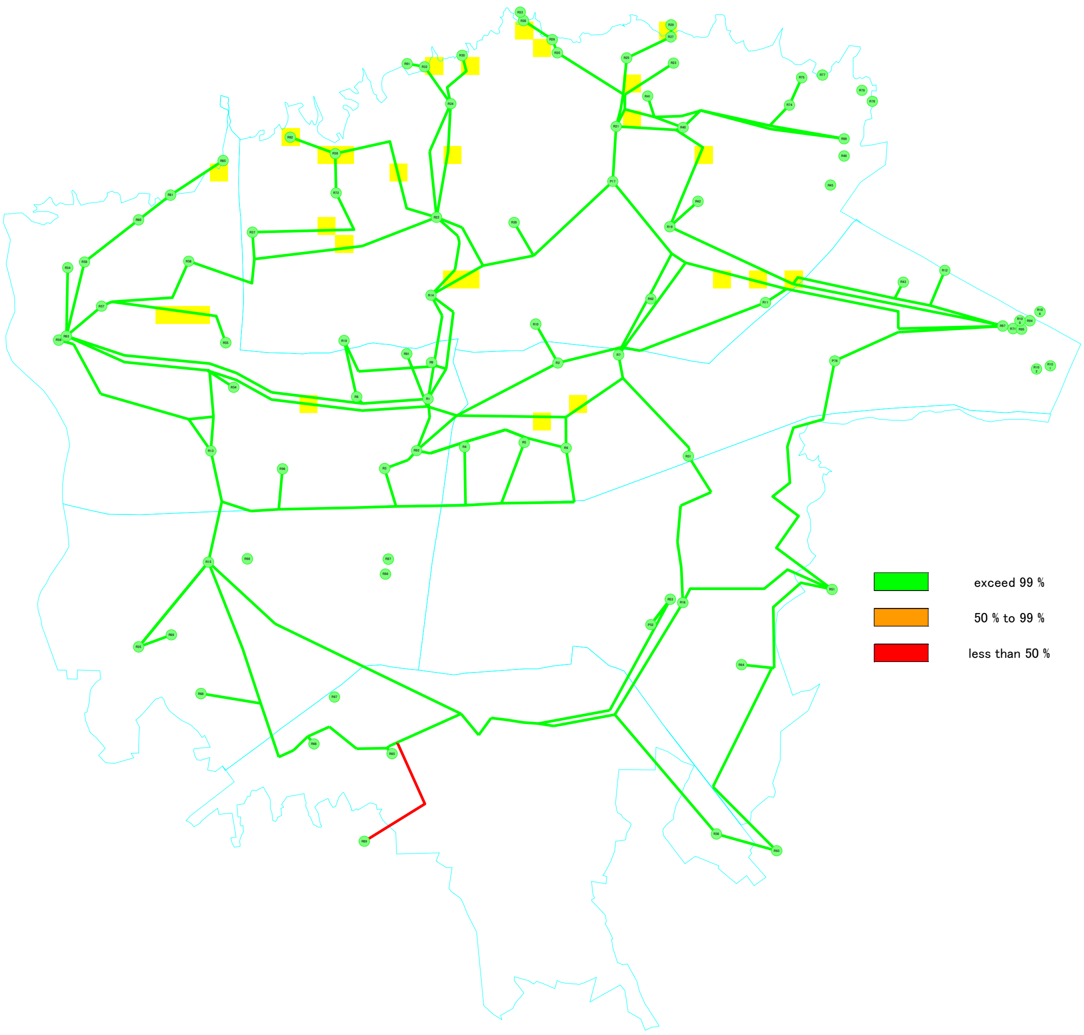


Figure 4.1.5 Pipe Link Reliability after North Ray Earthquake

Fure4.1.6 shows link reliability results in case of South Ray fault earthquake.   No damage is expected, not even a slight damage.

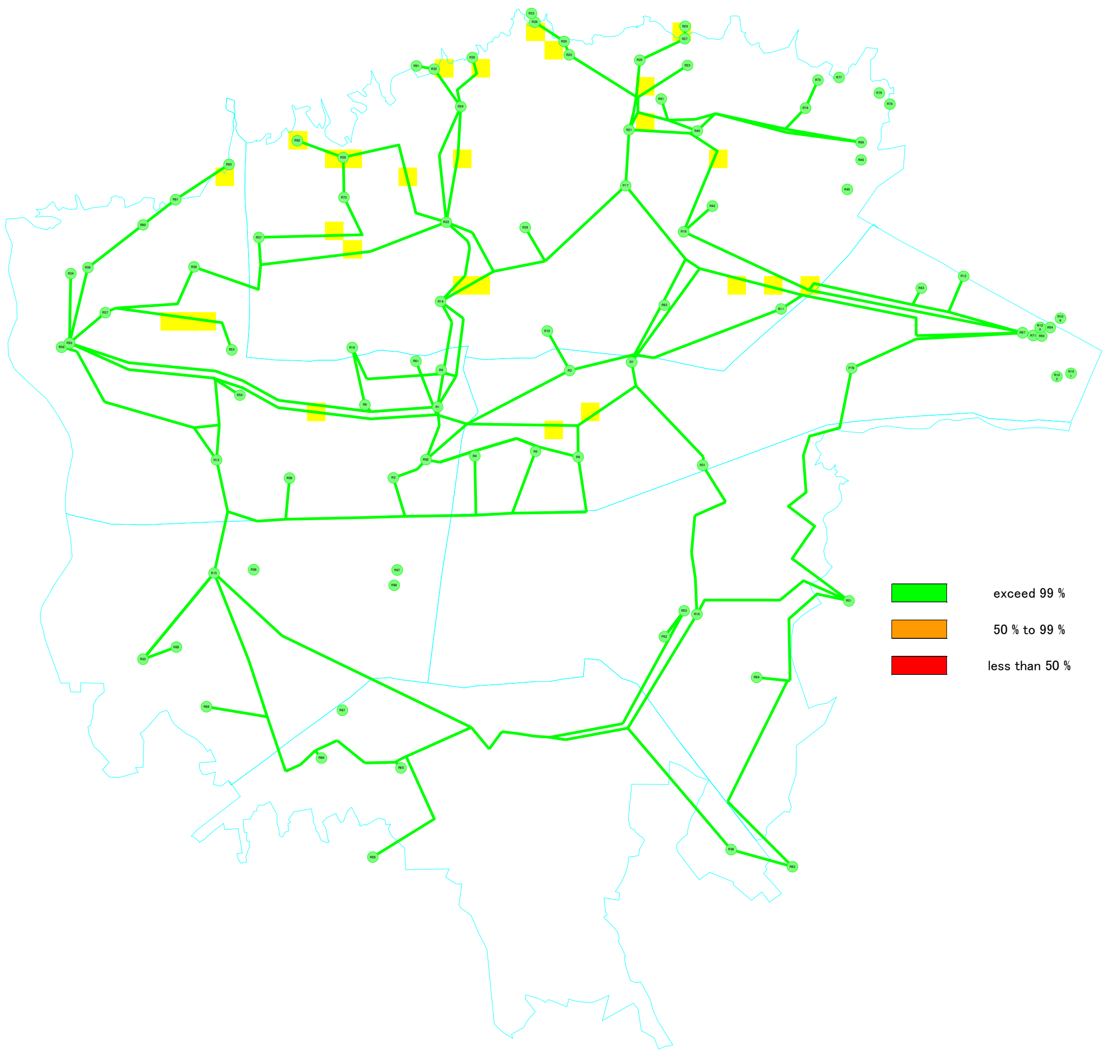


Figure 4.1.6 Pipe Link Reliability after South Ray Earthquake

Figure4.1.7 shows link reliability results in case of North Tehran fault earthquake. There are many damage points expected to be. Main damage links are at concrete pipes. Concrete pipes' joint allowances are set relatively small considering their characteristic brittleness. This is one of the reasons inferred from the results.

Concrete pipe line with 1850mm diameter from WTP No.2 (Kan) might get damaged at fault crossings. Furthermore these are parallel mains and trunk mains to transport water to the center of city.

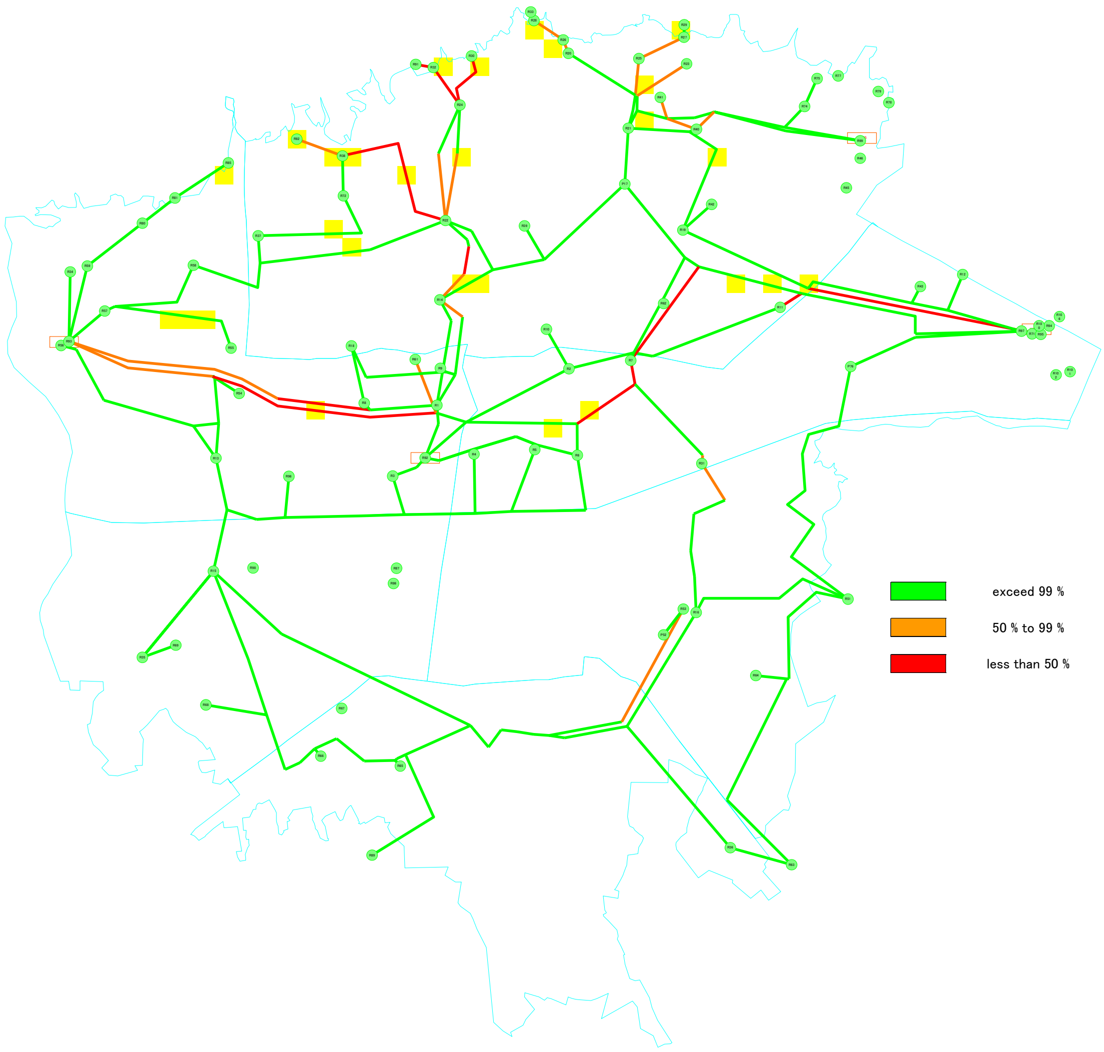


Figure 4.1.7 Pipe Link Reliability after North Tehran Earthquake

Figure 4.1.8 shows link reliability results in case of Mosha fault earthquake. All of the links with orange line shows the probability of damage at fault crossing points however the damage probability is small.

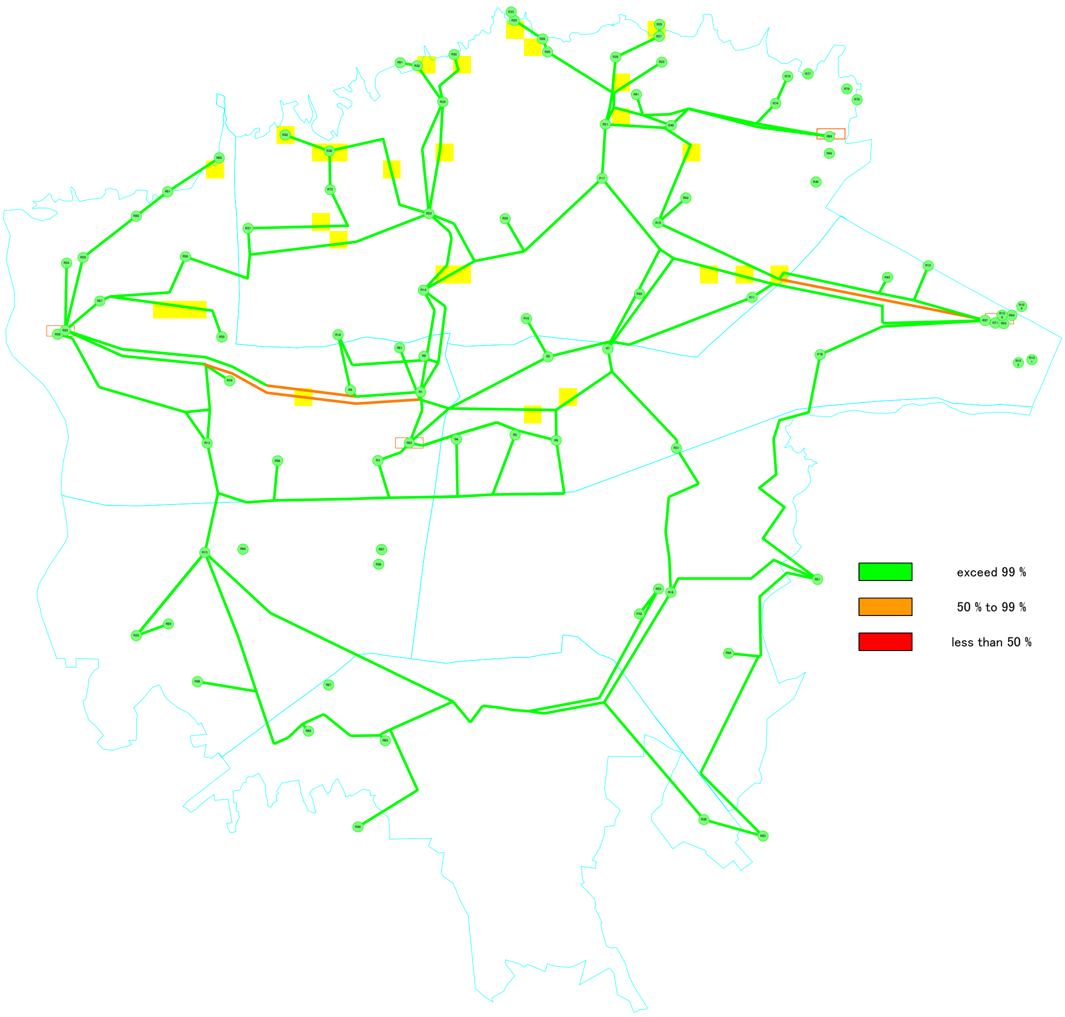


Figure 4.1.8 Pipe Link Reliability after Mosha Earthquake

4.1.6 Damage of Distribution Trunk Main

(1) Summary of Distribution Trunk Main

Distribution trunk main, which consists of pipes with diameters of 300mm and above, is about 750 km long. *Table 4.1.4* shows detail of pipeline length used in this analysis. In the analysis, lines from wells are not included.

Table 4.1.4 Length of Distribution Trunk Main

Diameter (mm)	Asbestos Pipe	Cast Iron Pipe	Ductile Iron Pipe	Steel Pipe	Total
300	3.89	24.95	201.83		230.67
350		30.67	48.41		79.07
400		26.82	94.73		121.55
450		11.81			11.81
500		12.51	108.42		120.93
550		6.40			6.40
600		6.86	48.15	3.73	58.74
650		2.13		0.27	2.40
700		0.62		46.48	47.10
750		0.82			0.82
800				12.84	12.84
900		6.69		38.73	45.42
1000				4.39	4.39
1050				1.15	1.15
1100		3.90		6.36	10.26
1200				7.42	7.42
1250				1.17	1.17
1400				6.04	6.04
Total	3.89	134.18	501.53	128.58	768.18

Table 4.1.5 shows length in each Distribution Reservoir Zones.

Table 4.1.5 Length of Distribution Trunk Main in each Distribution Reservoir Zone

Distribution Reservoir Zone	Length (Km)	Distribution Reservoir Zone	Length (Km)
1	15.62	41	15.77
2	34.11	42	3.91
3	11.41	43	29.79
4	21.29	45	0.11
5	18.86	48	3.48
6	16.17	51	47.29
7	26.28	54	16.23
8	22.31	55	16.86
10	7.78	56	14.28
11	4.16	57	15.76
12	19.26	58	13.19
13	1.84	59	8.53
14	6.76	9-61	16.32
15-16-53	81.12	62	3.24
18	3.74	63	19.28
19	6.06	64	0.52
20	3.16	65	12.76
21	9.91	66	12.16
22	7.41	67	5.24
23	5.86	68	8.35
24	17.79	69	3.05
26	4.35	70	0.77
27	9.16	71	2.31
28	0.43	72	8.82
29	4.30	74	2.62
31	18.38	75	3.09
32	2.32	77	6.32
36	28.16	80	17.64
37	32.79	81	0.02
38	17.18	82	1.44
40	0.59	91	0.49
		Toal	768.18

Distribution reservoir zone identification numbers are shown in *Figure 4.1.9* with their length. Zone 15-16-53 has broad area and pipe length is huge.

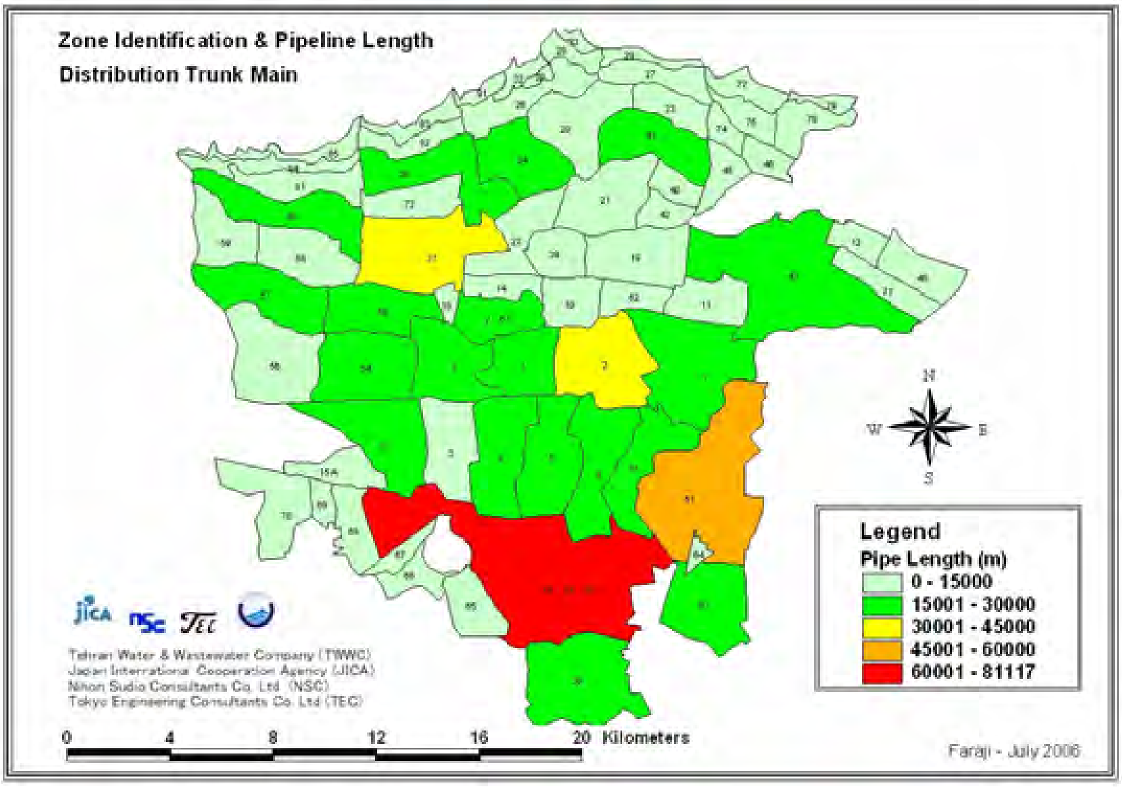


Figure 4.1.9 Zone Identification and Pipeline Length

(2) Presuppositions

Strong ground motion, fault crossing and connection to massive structure are considered to be the causes of damage. This assumption is similar to transmission mains case. Fault crossing places with clearly distinguished ones are taken into consideration. On the other hand connection places to the massive structures are not clear therefore a certain rate according to the length is adopted in the study. Supposing the rate to be about 0.2 places in each 1.0 km length, the total of 188 places have been taken into consideration as connection points.

Analysis is done in accordance with a method similar to that of transmission main. Variation is considered when judging safety of joint slip. Distribution of calculated joint slippage is considered to be normal distribution and 20% of average value is adopted as standard deviation. Allowance limits are considered fixed values.

(3) Damage Estimation

Total pipeline length in each reservoir zones vary widely, therefore it is more practical to use the unit defined as number of damage per unit of length. Such damage ratios per unit of length are shown also in *Table 4.1.6* in addition to the number of damage places.

Table 4.1.6 Damage Points and Damage per km

Distribution Reservoirs Zone	Length (Km)	Total Damge Points				Damage Points per 1Km			
		North Ray	South Ray	North Tehran	Mosha	North Ray	South Ray	North Tehran	Mosha
1	15622.0	1	0	1	0	0.06	0.00	0.06	0.00
2	34108.0	2	0	6	0	0.06	0.00	0.18	0.00
3	11413.4	2	2	2	0	0.18	0.18	0.18	0.00
4	21286.7	3	3	3	1	0.14	0.14	0.14	0.05
5	18855.6	2	2	2	1	0.11	0.11	0.11	0.05
6	16171.3	2	2	2	0	0.12	0.12	0.12	0.00
7	26281.5								
8	22312.1	0	0	1	0	0.00	0.00	0.04	0.00
10	7777.4								
11	4161.3								
13	19257.2								
14	1839.1								
15A	6757.4								
15-16-53	81116.6	13	0	1	0	0.16	0.00	0.01	0.00
18	3743.9								
19	6055.5	0	0	1	0	0.00	0.00	0.17	0.00
20	3162.1	0	0	1	0	0.00	0.00	0.32	0.00
21	9914.8	0	0	2	0	0.00	0.00	0.20	0.00
22	7406.3								
23	5864.0								
24	17792.4	0	0	6	0	0.00	0.00	0.34	0.00
26	4347.2								
27	9164.1	0	0	2	0	0.00	0.00	0.22	0.00
28	427.1								
29	4302.1	0	0	1	0	0.00	0.00	0.23	0.00
31	18384.7								
32	2316.6	0	0	1	0	0.00	0.00	0.43	0.00
36	28159.2	4	2	11	0	0.14	0.07	0.39	0.00
37	32790.2	0	0	2	0	0.00	0.00	0.06	0.00
38	17178.1	0	0	2	0	0.00	0.00	0.12	0.00
40	588.6	0	0	1	0	0.00	0.00	1.70	0.00
41	15766.4	0	0	9	0	0.00	0.00	0.57	0.00
42	3910.7								
43	29789.8	0	0	3	0	0.00	0.00	0.10	0.00
45	113.1	0	0	1	0	0.00	0.00	8.84	0.00
48	3479.7								
51	47285.5								
54	16232.9								
55	16861.0								
56	14277.6								
57	15760.6								
58	13187.8								
59	8532.3								
9-61	16315.2								
62	3243.4								
63	19276.0								
64	515.9								
65	12755.5	2	1	0	0	0.16	0.08	0.00	0.00
66	12157.3	1	0	0	0	0.08	0.00	0.00	0.00
67	5236.9	1	0	0	0	0.19	0.00	0.00	0.00
68	8354.5								
69	3045.4								
70	767.5								
71	2309.5								
72	8818.8	0	0	2	0	0.00	0.00	0.23	0.00
74	2624.2								
75	3087.3	0	0	1	0	0.00	0.00	0.32	0.00
77	6322.5	0	0	1	0	0.00	0.00	0.16	0.00
80	17641.1								
81	21.7								
82	1442.5								
91	490.7	0	0	1	0	0.00	0.00	2.04	0.00
Total	768,179	33	12	66	2	0.04	0.02	0.09	0.00

Results of North Tehran fault earthquake are shown in *Figure 4.1.10*. Most of the damages occur in the northern part of Tehran, i.e., near the scenario fault. There are also many damages in zone 36, due to many secondary faults which are located in the zone.

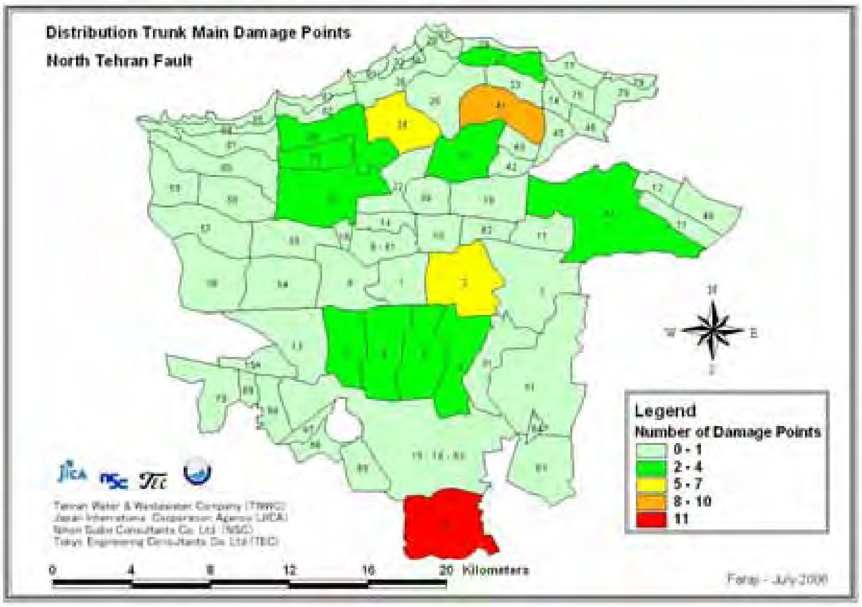


Figure 4.1.10 Number of Damage Points in Each Reservoir Zone
(North Tehran Fault)

Figure 4.1.11 shows average number of damage per unit of length, i.e., 1 km in case of North Tehran earthquake

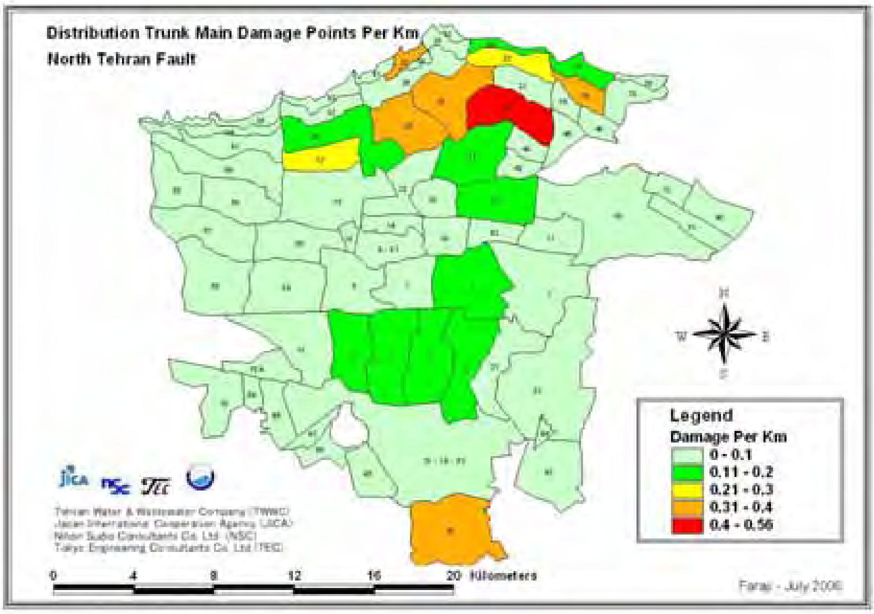


Figure 4.1.11 Number of Damage Points per Km in Each Reservoir Zone
(North Tehran Fault)

4.1.7 Damage of Distribution Sub Main

(1) Outline of Distribution Sub line

Length of distribution sub main is approximately 6500 km in study area. Diameter of pipes is below 300 mm. Length of pipeline in each reservoir zone is shown in *Table 4.1.7.*

Table 4.1.7 Length of Sub Main in each Distribution Reservoir Zone

Distribution Reservoir Zone	Length (m)	Distribution Reservoir Zone	Length (m)
1	85,867	39	19,818
2	187,026	40	32,104
3	186,972	41	65,770
4	179,887	42	36,949
5	207,145	43	371,742
6	290,105	45	13,783
7	264,341	48	16,863
8	89,988	51	242,434
10	53,854	54	116,678
11	103,086	55	130,747
12	12,329	56	32,929
13	186,600	57	102,485
14	36,667	58	96,544
15A	65,000	59	50,750
15-16-53	650,218	9-61	82,703
18	31,631	62	47,432
19	135,294	63	103,307
20	157,033	64	47,795
21	153,712	65	90,749
22	66,018	66	66,510
23	46,133	67	89,879
24	57,739	68	87,744
26	73,639	69	39,008
27	65,159	70	3,332
28	37,669	71	80,783
29	6,346	72	55,168
30	19,592	74	25,439
31	194,151	75	32,786
32	18,316	77	1,840
33	4,517	80	104,583
36	228,099	81	8,663
37	64,069	82	19,070
38	98,162	91	13,177
		Total	6,385,927

(2) Damage estimation

Damage function was proposed by Japan waterworks association whose method is based on historical data is applied to distribution sub mains with less than 300 mm diameters when estimating damage caused by strong ground motion. In addition to this damage, damages at fault crossings are calculated respectively. Connection to massive structure which was included in modeling of larger size pipes is not considered in these cases. Those effects are considered to be included in the damage function. Furthermore small diameter pipes are seldom connected directly to massive structures.

Number of damaged points is calculated based on each reservoir zone. *Table 4.1.8* shows analysis results.

Table 4.1.8 Damaged Points Numbers

Distribution Reservoir Zone	North Ray Fault	South Ray Fault	North Tehran Fault	Mosha Fault
1	0.00	0.00	0.02	0.00
2	3.93	3.32	10.53	4.41
3	2.16	0.05	0.00	0.00
4	1.85	0.20	0.00	0.00
5	0.43	0.00	0.00	0.00
6	1.02	0.00	0.05	0.00
7	0.00	0.00	1.26	0.00
8	0.00	0.00	0.00	0.00
10	0.00	0.00	8.23	0.02
11	0.00	0.00	0.69	0.00
12	0.00	0.00	0.24	0.00
13	0.29	0.00	0.00	0.00
14	0.00	0.00	5.10	0.01
15A	0.25	0.00	0.00	0.00
15-16-53	39.01	3.38	5.57	0.94
18	0.00	0.00	0.03	0.00
19	0.00	0.00	5.26	0.00
20	0.00	0.00	98.69	5.85
21	0.00	0.00	23.14	0.52
22	0.00	0.00	40.51	0.06
23	0.00	0.00	34.33	3.42
24	0.00	0.00	8.91	0.01
26	0.00	0.00	60.11	6.24
27	0.00	0.00	41.92	2.19
28	0.00	0.00	55.85	5.78
29	0.00	0.00	6.13	0.10
30	0.00	0.00	5.52	0.01
31	0.09	0.00	0.16	0.00
32	0.00	0.00	8.09	0.01
33	0.00	0.00	5.91	0.75
36	25.36	20.04	52.17	1.54
37	0.00	0.00	28.48	0.02
38	0.00	0.00	3.76	0.00
39	0.00	0.00	3.65	0.01
40	0.00	0.00	15.71	0.06
41	0.00	0.00	38.11	3.75
42	0.00	0.00	2.44	0.00
43	0.00	0.00	33.27	0.40
45	0.00	0.00	14.24	0.14
46	0.00	0.00	0.04	0.00
48	0.00	0.00	5.09	0.70
51	0.16	0.00	2.12	0.03
54	0.00	0.00	0.00	0.00
55	0.00	0.00	16.99	0.00
56	0.00	0.00	0.00	0.00
57	0.00	0.00	0.00	0.00
58	0.00	0.00	6.48	0.00
59	0.00	0.00	0.51	0.00
9-61	0.00	0.00	0.01	0.00
62	0.00	0.00	9.69	0.04
63	1.19	0.00	0.00	0.00
64	0.45	0.00	0.00	0.00
65	8.27	1.10	0.00	0.00
66	3.93	0.18	0.00	0.00
67	4.57	0.47	0.00	0.00
68	1.70	0.00	0.00	0.00
69	0.09	0.00	0.00	0.00
70	0.01	0.00	0.00	0.00
71	0.00	0.00	0.87	0.00
72	0.00	0.00	18.53	0.01
74	0.00	0.00	3.79	0.02
75	0.00	0.00	4.50	0.24
77	0.00	0.00	1.23	0.13
79	0.00	0.00	0.01	0.00
80	0.00	0.00	1.08	0.00
81	0.00	0.00	0.07	0.00
82	0.00	0.00	8.63	0.01
83	0.00	0.00	0.01	0.00
84	0.00	0.00	0.01	0.00
91	0.00	0.00	8.81	0.01
Total	95	29	707	37

Results in case of North Tehran fault earthquake is shown in *Figure 4.1.12*. Total estimated damage points are approximately 700. About 200 points are accompanied by strong ground motion and the remaining 500 points are located at fault crossing. There are many damaged places in reservoir zones near active fault line. Many damage places in reservoir zone 36 are shown in *Figure 4.1.12*. This comes from the fact that there are many secondary fault crossings in the area.

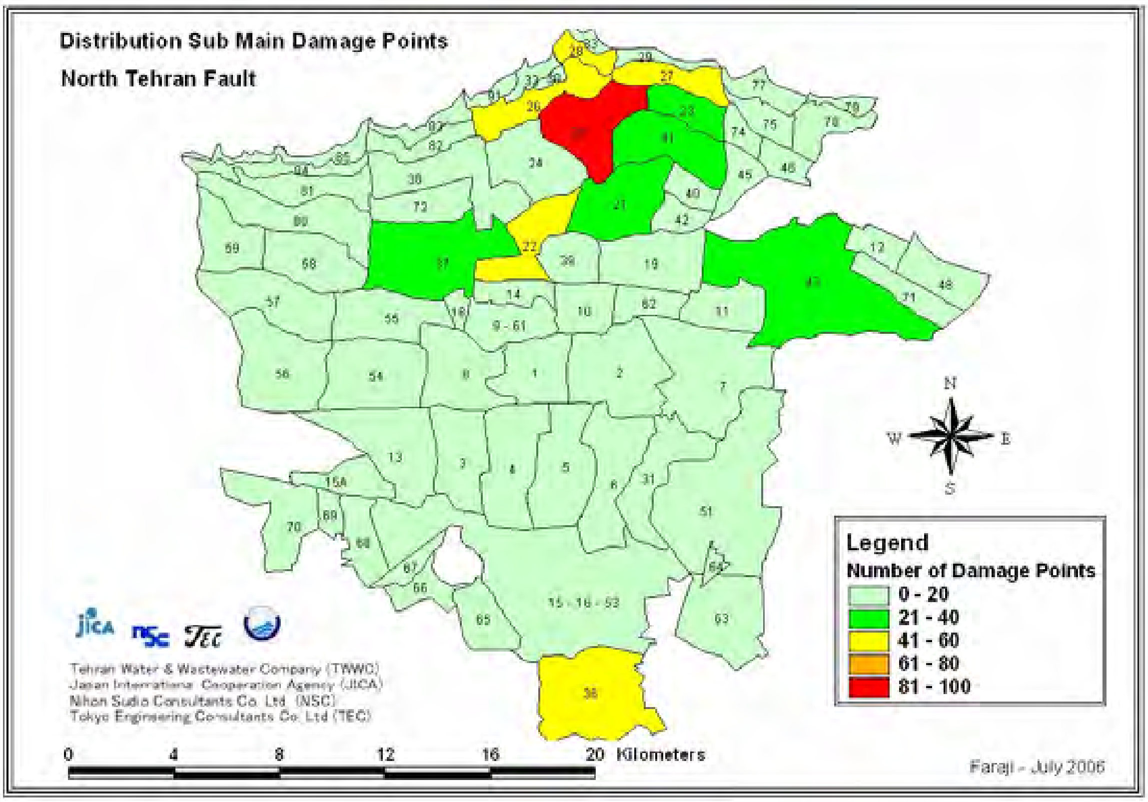


Figure 4.1.12 Number of Damage Points in Each Reservoir Zone
(North Tehran Fault)

Figure 4.1.13 shows damage per unit of length in case of North Tehran fault earthquake. Damage per unit length is far higher at places near the fault line.

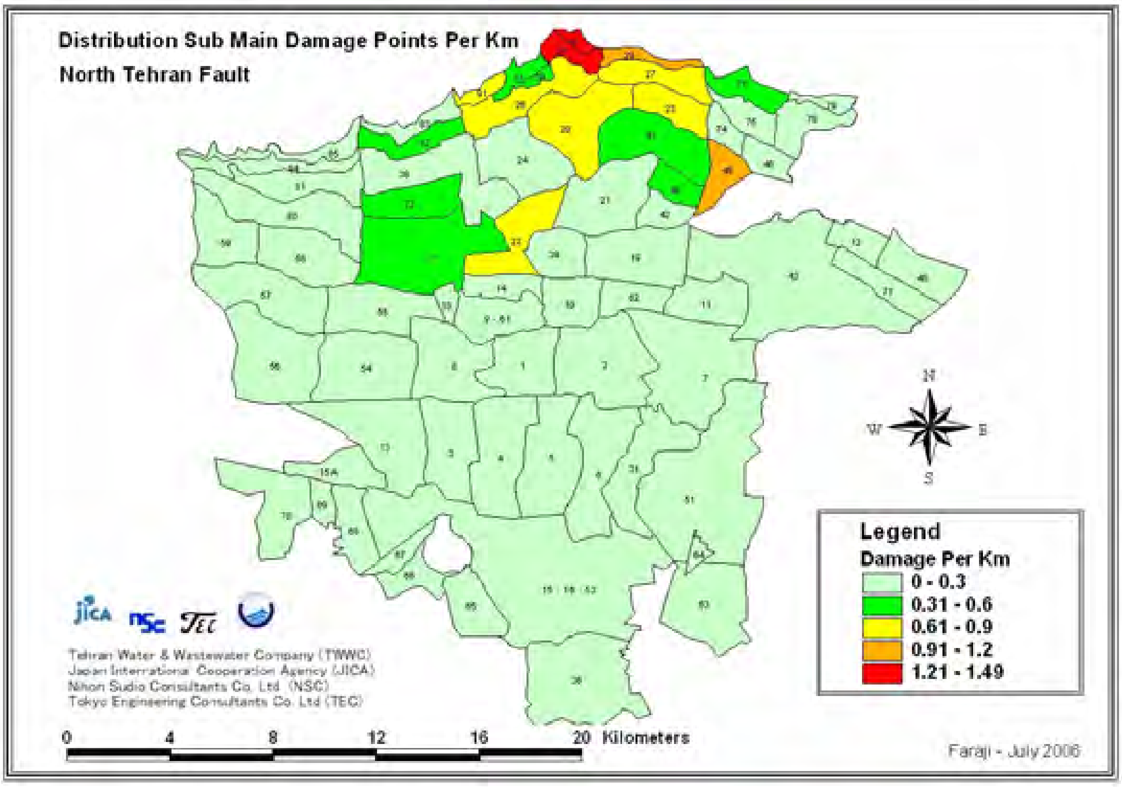


Figure 4.1.13 Number of Damage Points per Km in Each Reservoir Zone

(North Tehran Fault)

4.1.8 Damage Estimation of House Connection

(1) Summary of Damage Estimation of Buildings

Damage of the building is not an index to show the damage scale of the water supply facilities of TWWC. However, service connection, inside private premises, will be damaged by damage of buildings and then building damage shall be used as an index for calculation of the initial supply interrupted population immediately after the earthquake.

Table 4.1.9 shows the rate of building damage in each water district after North Tehran Fault Earthquake. Number of damages is considered as the rate of initial population supply interrupted by damage of service connections. The table indicates a high rate of damage in water districts No.1 and No.2, which are located near North Tehran Fault.

Table 4.1.9 Rate of Building damage in each water district

water districts	a Number of buildings	b Number of damage	b/a×100 rate(%)
1	211,980	153,060	72.2
2	259,970	91,280	35.1
3	223,350	48,860	21.9
4	245,440	39,450	16.1
5	226,600	23,840	10.5
6	227,810	22,080	9.7
Others	36,650	6,230	17.0
Total	1,431,800	384,800	26.9

(2) Damage of Service Connection

The damage of service connection can be classified into two categories, the damage up to consumer meters, which TWWC is liable for, and the damage in private premises after the meter.

For analysis of recovery by TWWC, damage of service connections from branch of distribution mains up to consumer meters have been taken into consideration.

Table 4.1.10 shows the estimated number of damage in the service connections which TWWC is responsible for, together with the damage in distribution mains. The damage in service connection is estimated as 5.0 times of that in distribution mains, considering the ratio of Hanshin-Awaji (Kobe) Earthquake in Japan since data on the rati in Iranian cases are not available.

Table 4.1.10 Number of damages on service connection in each water district

water districts	number of damages			rate(%)		
	distribution mains	distribution	Service connection	distribution mains	distribution	Service connection
1	36	494	2650	50.7	71.1	69.2
2	11	88	495	15.5	12.7	12.9
3	3	52	272	4.2	7.5	7.1
4	6	3	46	8.5	0.4	1.2
5	4	0	21	5.6	0.0	0.6
6	11	58	345	15.5	8.3	9.0
Total	71	695	3829	100.0	100.0	100.0

4.1.9 Concluding Remarks on Pipeline Damages

(1) Raw Water Transmission Mains

Analysis of raw water main has not been done due to insufficient data and the scope of this work. However these mains are located upstream of water supply system and are one of the most important components. Therefore some comments are made regarding these pipelines response against seismic forces.

There are 4 main lines from Bileghan to Tehran city area, 2 of which are 1000mm diameter steel lines installed in the 1950's and the remaining 2 lines are 2000mm concrete lines installed later.

The first two mains were installed to supply raw water to WTP No.1 (Jalaliye). Main steel lines are buried along Makhsus-Karaj highway and soil conditions are stable and the probability of natural hazards is considered to be low. However concrete encasements are seen in several areas such as river crossing at Chitgar and Kan River. The only place where some hazards could be expected is near Bileghan water intake where part of North Tehran fault crosses the pipeline in two points. Furthermore cliff is rather steep and siphon exists near the area. Therefore there are fears of land collapses and subsequently pipelines might get damaged by both such collapses caused by fault motion or by direct fault movement.

This line includes some concrete canal segments, the length of which is approximately 17 km. Canal damage caused by earthquake is considered small, for ground strain is small even in case of North Tehran fault earthquake. Maximum strain caused by the earthquake is less than 2000 μ even in the area near to North Tehran fault. Canal is located far away from the fault line and strain is far smaller. This level of strain causes only low stress level in structure. Furthermore there is no place that crosses the fault.

Concrete lines to WTP No.2 (Kan) are located to the north of the above mentioned steel lines along the foot of mountains. Probability of land slide is small considering slope angle of mountain foot except near Bileghan water intake. Damages are considered at several points of fault crossing. There are about 8 fault crossings along the line including 2 crossings near Bileghan where steel lines have been installed near by. Other places to be considered from the aspect of hazard probability are siphon areas. As reinforcing structures are used and motion characteristic of each component is different from the other, this might cause some damages. Examples of these areas are Kan River and Chitgar River intersecting points.

Tunnel lines are used to transport raw water from dams located in the east of Tehran. One is from Lar dam to WTP No.5 (Sohanak) and the other is from Latyan dam to WTP No.3,4 (Tehran Pars). The former tunnel crosses several faults including both North Tehran fault and

Mosha fault. Both faults are considered to be active. Once an earthquake occurs either of these faults, or tunnels can not withstand the influence of fault movement. Tunnels might collapse in the worst case and water can not get to treatment plant as the result. Taking countermeasures against such hazard is next to impossible, therefore other methods must be considered such as supply system through redundancy increase.

The line from Latyan dam is less in danger than the former one, because it is a little farther away from the above mentioned faults. Nevertheless there are two fault crossings including Telo fault. Mountain tunnels are said to be safe against seismic motion, for a tunnel moves the same as the surrounding mountain rock. Only fault crossings will create problems. We have experience in Japan that railway tunnel was sheered at face of fault after earthquake.

The worst case for raw water mains is large scale displacement of North Tehran fault. As the fault extend from east of Tehran to Bileghan, once such movement occurs most of the lines will get damaged, i.e., 3 lines will get damaged and the only exception would be the line from Latyan to WTP No.3&4.

Although adopting measures for tunnels is difficult as mentioned above, some countermeasures are considered necessary near Bileghan intake area to avoid severe shortage of water supply to treatment plants.

(2) Transmission Mains

There is low probability of damage caused by strong ground motion. Main reasons of damages are by faults crossings and connections to structures.

North Tehran fault earthquake gives the most influence among scenario earthquakes. Other scenario earthquakes affect the area to a limited degree.

(3) Distribution Trunk Mains

Influence of North Tehran fault earthquake is large. Even in this case damage by ground motion is small the same as damage in transmission mains case. These distribution trunk lines are important ones that supply water inside the reservoir zone therefore some measures to maintain water supply capacity in the area would be necessary. Especially countermeasures at fault crossings and at connection points to massive structures are necessary. Earthquake resistant joints should be used at least when using ductile iron pipes. Furthermore brittle joint pipes should be replaced by ductile joint pipes in accordance with replacing schedules.

(4) Distribution Sub Mains

Experimental method is used to calculate damages except those which take place due to fault crossings. Experimental calculation is considered to include the effect of connection to the structures. These effects and fault crossing damage reflect the result. Therefore the tendency is considered to be similar to the result of trunk mains.

Number of damage is smaller than estimation obtained by previous JICA comprehensive study. Possible reasons are listed below.

- Detailed pipeline data are updated and analysis is carried out based on them
- Fault effects become clear by recent other lifeline study and included
- Analytical method is applied for damage estimation for main lines instead of statistical method

As a result of analysis, damage in case of North Tehran fault earthquake is far larger than that caused by other scenario earthquakes. However probability of the North Tehran earthquake occurrence is not clear as of now. Expected return period of such large scale earthquake is longer than 100 years. However once a strong earthquake strikes the water facilities, the impact will become manifest in many fields, therefore it is indispensable to get prepared for.