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 I
Executive Summary

November 2006

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

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

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

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

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

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

November, 2006

Ariyuki Matsumoto
Vice-President
Japan International Cooperation Agency

November, 2006

Mr. Ariyuki MATSUMOTO
Vice-President
Japan International Cooperation Agency

Letter of Transmittal

Dear Sir,

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

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

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

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

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

Very truly yours,

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

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

Year	2007	2010	2014	2019	
Period	Preparation	Short Term	Middle Term	Long Term	Future
	1 year	3 years	4 years	5 years	

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

Volume I: Executive Summary

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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

S 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. 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.

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 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.

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.

1.2 Objectives of the Study

The objectives of the Study are as follows:

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 1.3.1*.

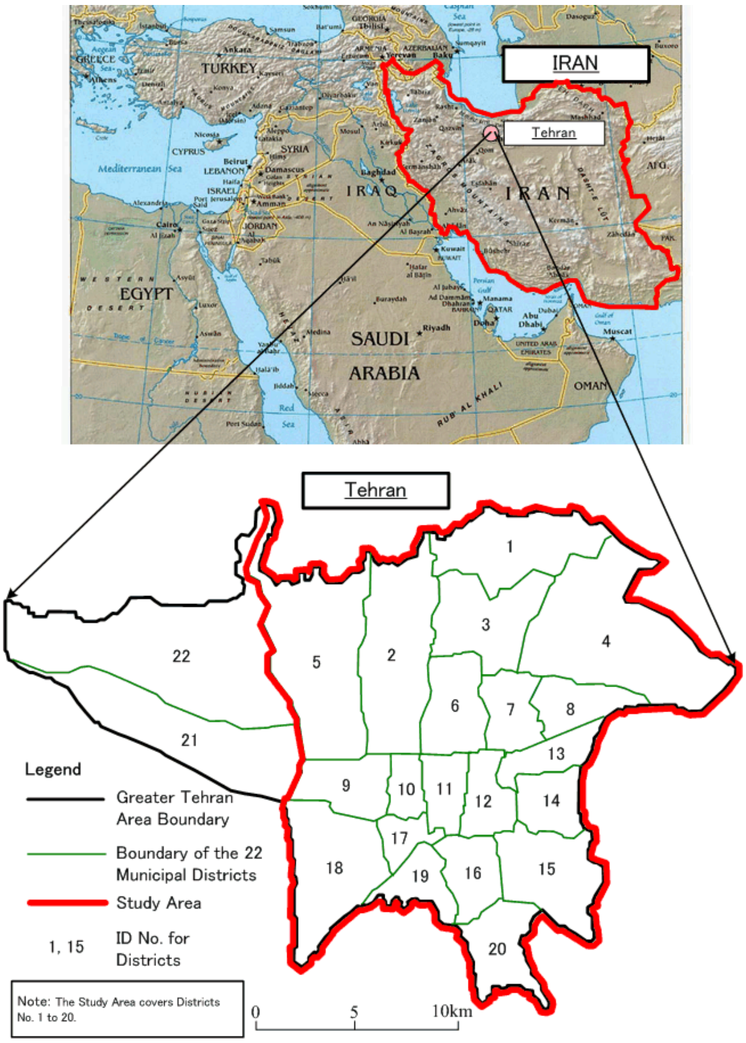


Figure 1.3.1 Study Area

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 1.4.1*. As shown in the figure, the study consists of three stages of site surveys. During Stage-1 site survey, the study team performed the reconnaissance survey and prepared the progress report.

The main purpose of Stage-2 site survey was to set up a 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. 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.

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. Then, the team has prepared a draft final report.

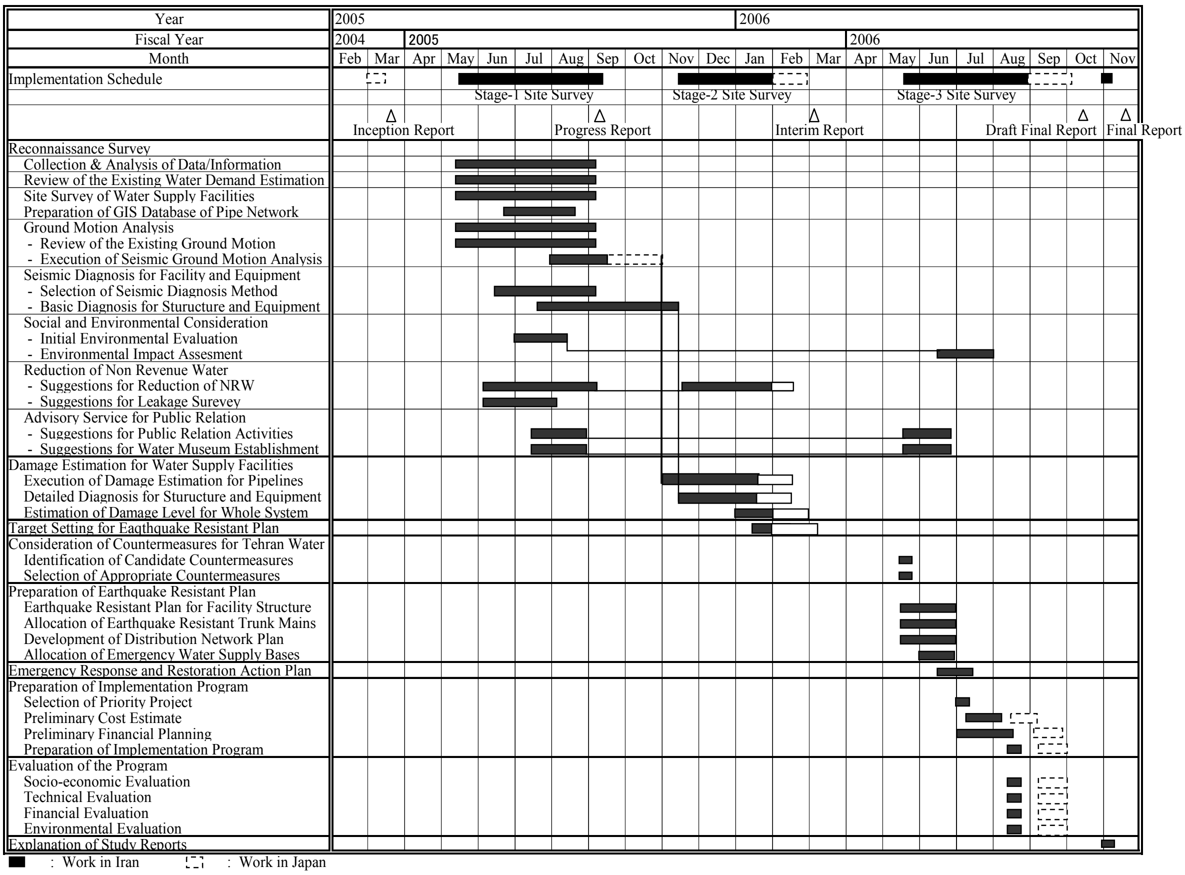


Figure 1.4.1 Implementation Flow of the Study for the Whole Stages

S 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.

2.2 Review of the Existing Water Demand Estimation

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 1.3.1*. 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*. By the great effort of TWWC, NRW ratio of 44.46% in 1995 reduced drastically to 23.67% in 2004.

Table 2.2.1 Population and Consumption

Service Index	Values
Served Population	7,019,600
Day Maximum Supply	3,173,495m^3/d
Per Capita Supply	360 lpcd
Per Capita Consumption	274 lpcd
NRW Ratio	23.67 %

As for future water demand, there are three kinds of forecasted values including one described in the report of JICA Preparatory team as shown in *Table 2.2.2*. Water demand in 2021 ranges from 2.99 M m^3/d to 3.38 M m^3/d. The low side forecast is obtained from future population estimated by Iranian Statistics Office and future per capita demand-300lpcd set by TWWC. Since TWWC intends to strengthen water saving activities and to reduce NRW, the low side demand is smaller than the value in 2004.

Table 2.2.2 Future Water Demand (2021)

	Population	Day Max. Supply	Remarks
1	9,250,000	3,270,000 m3/d	Local Consultants
2	10,720,000	3,380,000 m3/d	JICA Preparatory Team
3	8,292,000	2,990,000 m3/d	Low Side Forecast

2.3 Survey of the Existing Water Supply System

The first modern water supply system for the city of Tehran consists of No. 1 water treatment plant, Bileghan intake and raw water transmission mains connecting them, all of which have been installed in 1955. Tehran water supply system has developed along with increase of population of the city. The present water supply system such as dams, water treatment plants, distribution reservoirs and pipelines are listed in the *Tables 2.3.1* to *2.3.4*.

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 consturuction	Earthfill with Clay Core	250 M m^3	Water Treatment Plant No.7 (Planned)

Table 2.3.2 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.

Table 2.3.3 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 2.3.4 Total Length of Tehran 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

2.4 Review of Seismic Ground Motion Analysis and Earthquake Resistance Study

(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 below 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 the table below:

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

S3 SEISMIC MOTION ANALYSIS

3.1 Outcomes of Recent Studies

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

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

(b) 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 extensively utilized in this JICA study.

(1) General Geological Cross Section of the Study Area

Figure 3.1.1 shows the general geological cross section of the study area,

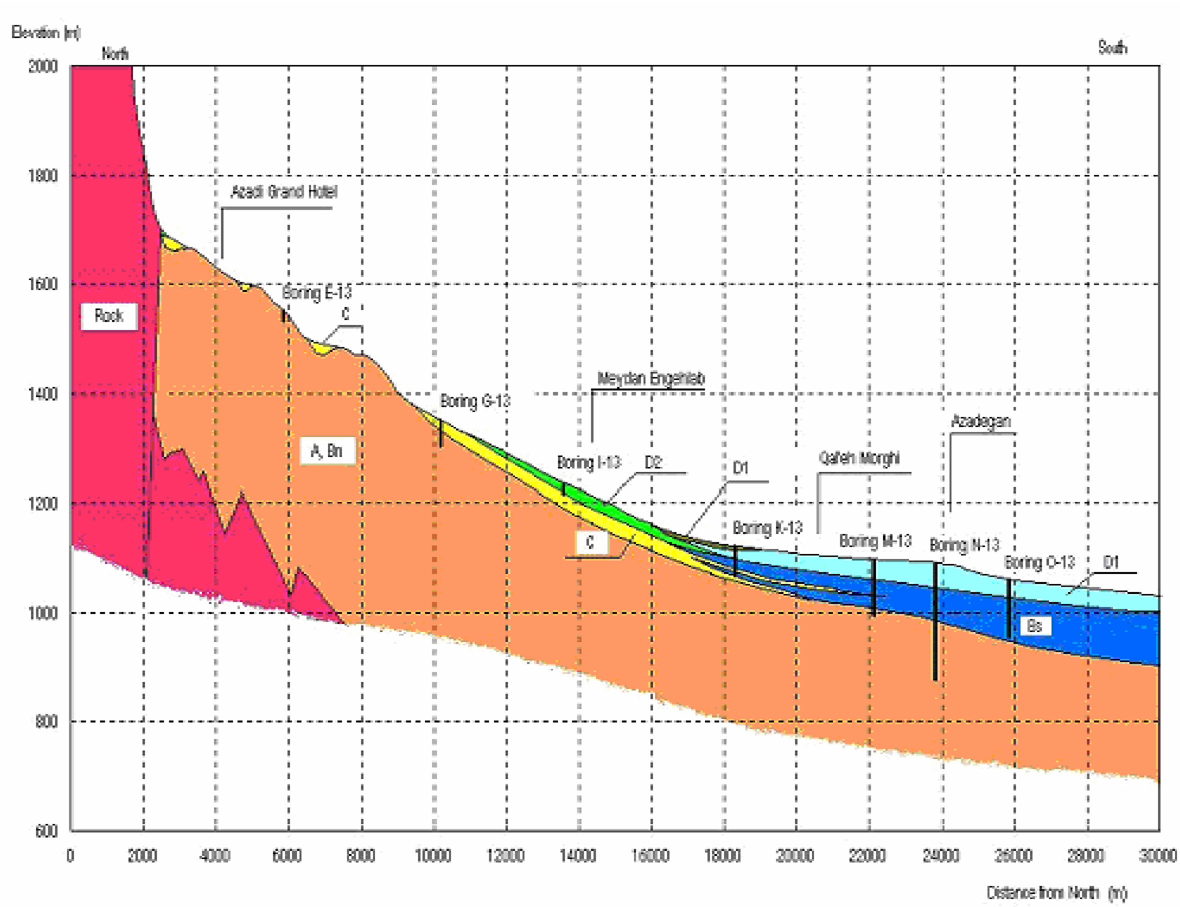


Figure 3.1.1 General Geological Cross Section of the Study Area

(2) Seismotechtonic in the vicinity of the study area

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.

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.

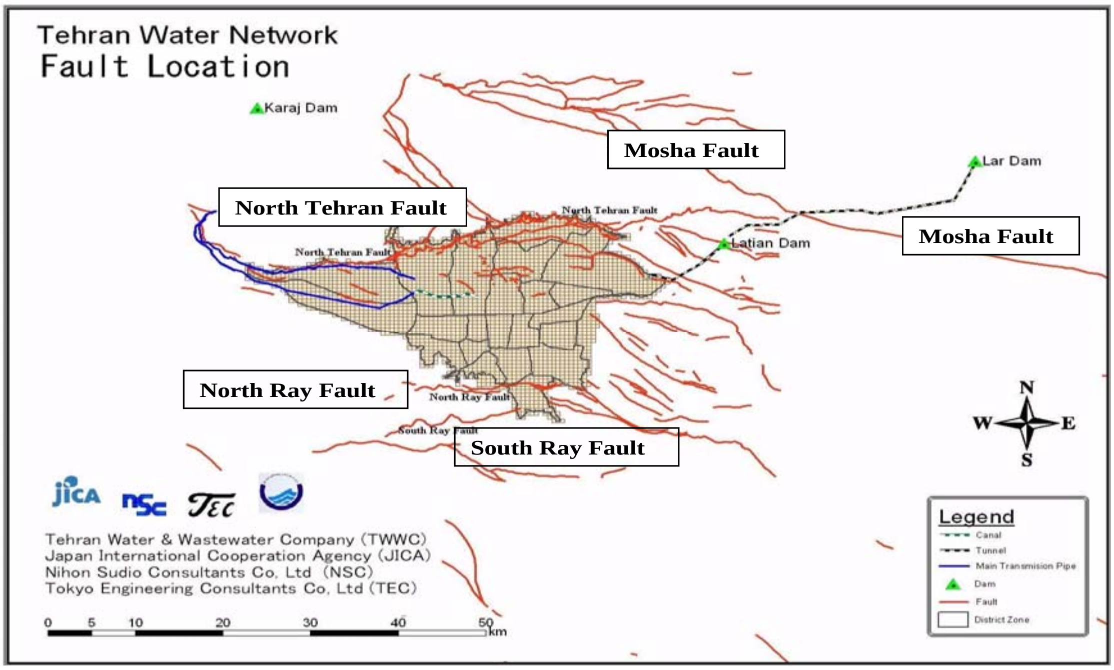


Figure 3.1.2 Fault Location around Tehran city

3.2 Selection of Seismic Motion Analysis Method

(1) Criteria for selection of seismic motion analysis method

The following aspects are considered so as to select the most suitable seismic motion analysis for the study, based on the idea that the previous study results are maximum utilized, that review and upgrade of the study result are considered relatively easy as well as that suitable technical cooperation and transfer is attained.

a. Appropriate utilization and effective incorporation of a method applied to the existing earthquake motion analyses for lifeline facility,

b. A sustainable method for review and upgrade of the database with common ground among the other study for lifeline facility, especially for, water supply facility

c. Appropriate method for the damage estimation for such lifeline facility as water pipeline network, gas pipeline network,

d. Suitable method for counterpart, TPWWC, in the context of technical cooperation and technical transfer,

(2) Selected method

The seismic motion analysis method applied in "GAS Research Project" was selected because it seems the most suitable method considering the above aspects

3.3 Procedure and Condition of Seismic Motion Analysis

(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 Fig.3.3.1.

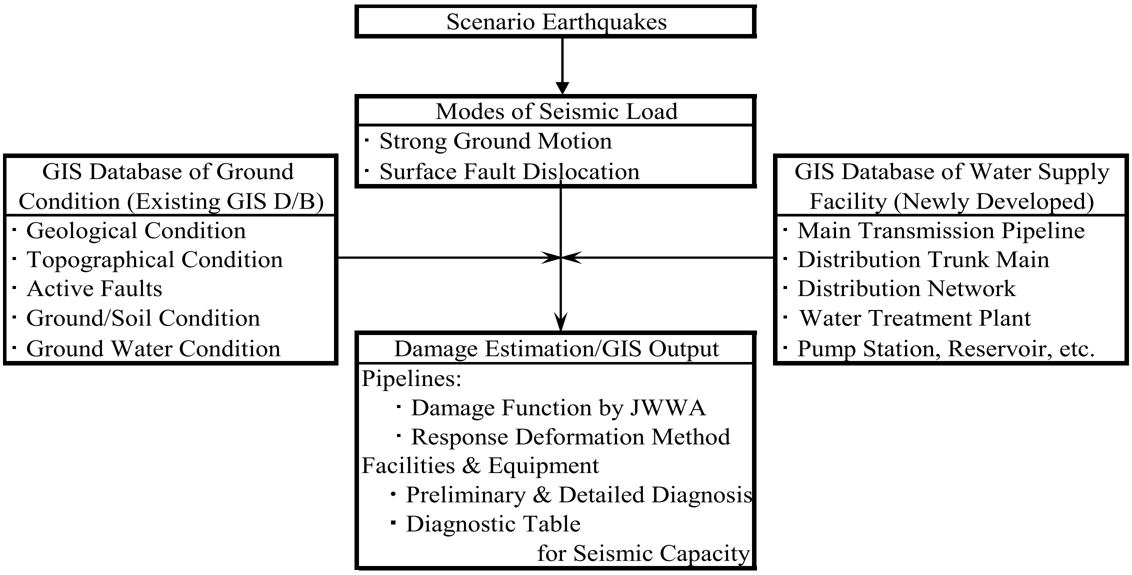


Figure 3.3.1 Flow chart of seismic motion analysis and damage estimation

(2) Condition of Seismic Motion Analysis

1) Seismic Force

As for the external force caused by 4 major active fault earthquakes, the 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 analysis of water supply facilities.

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

Historical earthquake is what is derived from the statistical analysis of the earthquake record entries. 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. However, it is suggested to study its occurrence in case of implementation.

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 this JICA study

Fault / Parameter	Mosha		North Tehran		North Ray	South Ray	Parchin	Kahrizak
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

(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

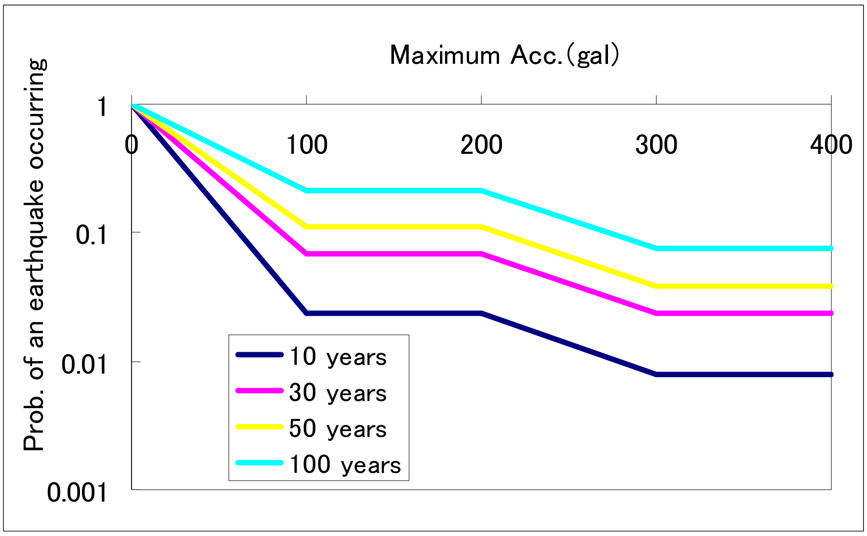


Figure 3.4.1 Earthquake occurrence probability during a given return period

(2) Scenario Earthquake

1) Analysis Method

(a) 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.

(b) 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.

(c) 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

Results of analysis including peak surface acceleration, peak surface velocity, peak surface displacement and surface fault dislocation are listed in *Table 3.4.1*. Peak surface acceleration is shown in *Figure 3.4.2* for North Tehran earthquake as an example.

Table 3.4.1 Results of Ground Motion Analysis

Analysis Items	Unit	North Tehran	South Ray	North 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
Max PGD	cm	4.8	5.0	5.8	0.8	
Max Horizontal Dislocation	cm	48.8	6.7	5.8	13.0	
Max Vertical Dislocation	cm	75.9	12.0	14.1	6.2	

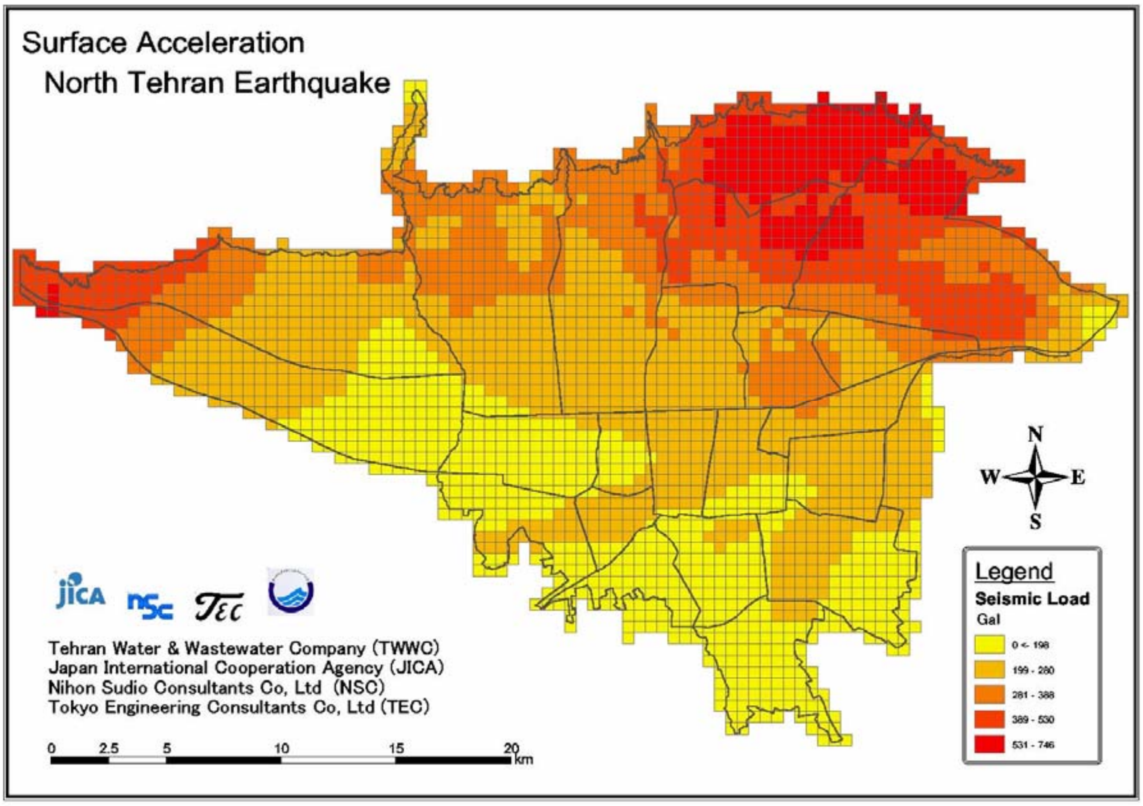


Figure 3.4.2 Surface Acceleration (North Tehran Earthquake)

S4 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 pipes, as classified below.

- Raw water transmission main
- Clear water transmission main with approximately 300km long
- Distribution trunk main with approximately 750km long
- Distribution sub main with approximately 6500km long

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, which refer to such points as fault crossings or connections to massive structures of concrete buildings and others. Typical structure of the massive structure is the distribution reservoir. Three types of damage models are considered for 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

Water network is composed of links and nodes. Link reliability was derived as index of influence.

(1) 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 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. 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. 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.

(2) Analysis of Fault Crossing Points

There are many secondary faults, which are crossing pipelines in the city. While these secondary faults do not always move as a result of active faults' motion, some offsets may occur. 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. Considering the worst case for water supply pipeline crossing the fault, such assumption might be considered appropriate and this type of damage modeling is adopted.

(3) 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. The maximum amplitude value which is obtained from ground motion analysis is adopted as the maximum relative displacement.

4.1.3 Summary 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 as shown in *Figure4.1.1*.

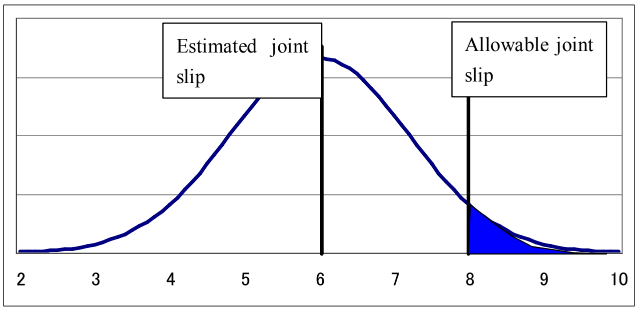


Figure 4.1.1 Normal Distribution Curve

(2) Damage Caused by Fault Dislocations

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

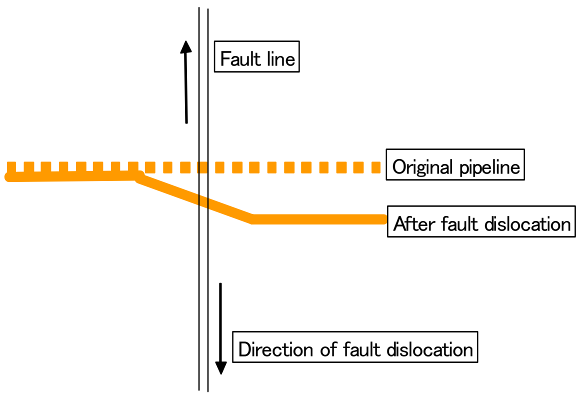


Figure 4.1.2 Pipe Dislocation at Fault Crossing

pipe joint becomes important. *Figure4.1.3* shows the detailed shape of pipe joints.

(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. *Figure 4.1.4* shows model of the phenomenon.

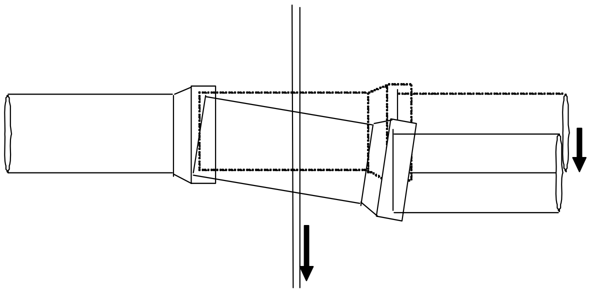


Figure 4.1.3 Pipe Joint Deformation at Fault Crossing

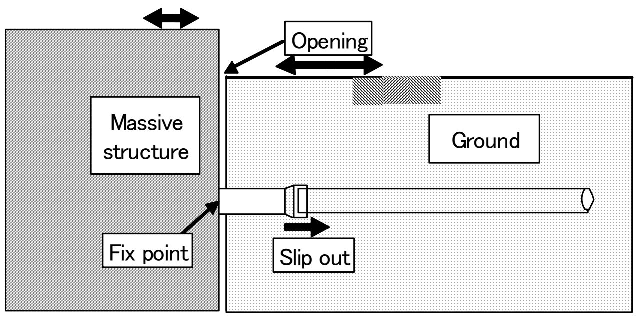


Figure 4.1.4 Pipe Joint Slippage at Structure Connection

4.1.4 Fundamental Data and Preliminary Analysis

(1) Pipe Data

Pipe data are shown in *Table 4.1.1* in main report. Please refer main report.

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

(2) Presuppositions

Strong ground motion, fault crossing and connection to massive structures are considered as cause of pipeline damage. Allowable slippage limit is set constant in this study.

(3) Damage Estimation

Damage is calculated based on pipeline link reliability. Damage probability is shown in *Table 4.1.3.* in main report. 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. *Figure4.1.5* shows link reliability results in case of North Tehran fault earthquake.

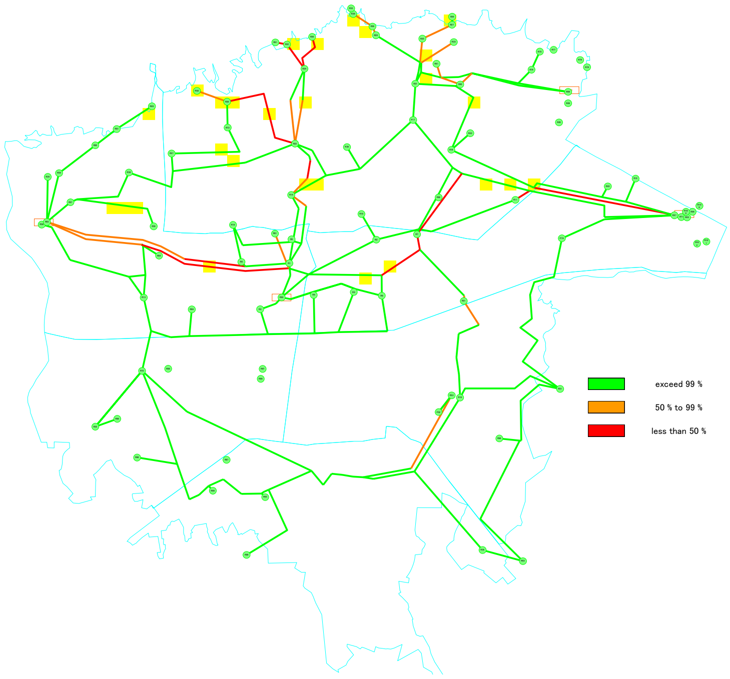


Figure 4.1.5 Pipe Link Reliability after North Tehran Earthquake

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* in main report shows detail of pipeline length used in this analysis. Distribution reservoir zone identification numbers are shown in *Figure 4.1.6* with their 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. Connection places to the massive structures are not clear. 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.

(3) Damage Estimation

Damage ratios per unit of length used for the analysis are shown also in *Table 4.1.6* in main report in addition to the number of damage places. Results of North Tehran fault earthquake are shown in *Figure 4.1.6.* Most of the damages occur in the northern part of Tehran, i.e., near the scenario fault. *Figure 4.1.7* shows average number of damage per unit of length, i.e., 1 km in case of North Tehran earthquake.

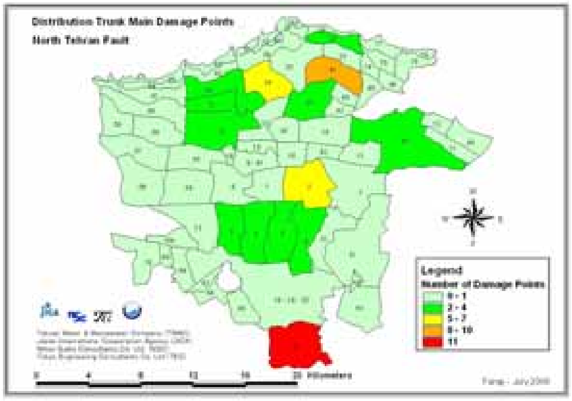


Figure 4.1.6 Number of Damage Points in Each Reservoir Zone

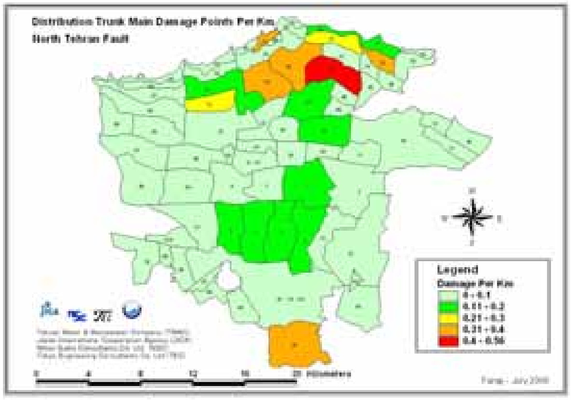


Figure 4.1.7 Number of Damage Points per Km in Each Reservoir Zone

4.1.7 Damage of Distribution Sub Main

(1) Outline of Distribution Sub line

Length of distribution sub main is about 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.*in main report.

(2) Damage estimation

Damage function was proposed by Japan waterworks association. In addition to this damage, damages at fault crossings are calculated respectively. *Table 4.1.8* in main report shows analysis results. Results in case of North Tehran fault earthquake is shown in *Figure 4.1.8*. Total estimated damage points are approximately 700. About 500 points are located at fault crossing. *Figure 4.1.9* 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.

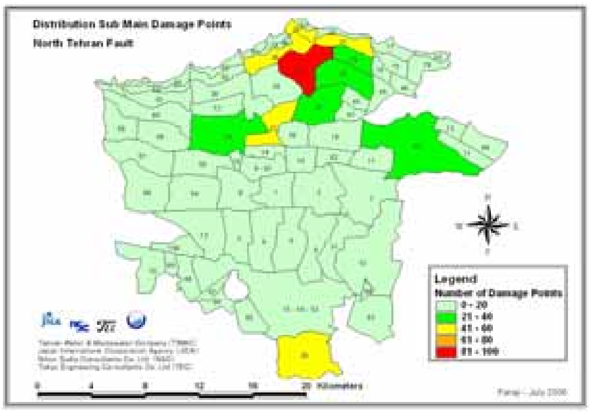


Figure 4.1.8 Number of Damage Points in Each Reservoir Zone

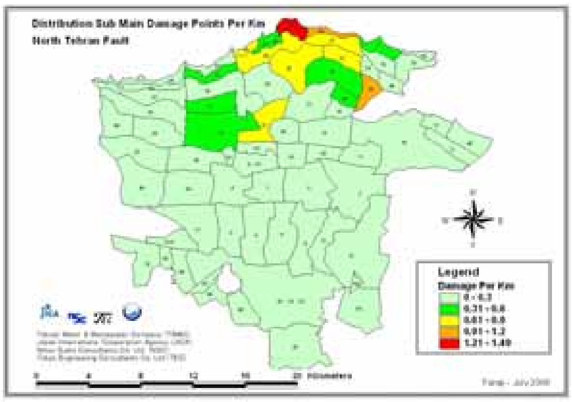


Figure 4.1.9 Number of Damage Points per Km in Each Reservoir Zone

4.1.8 Damage Estimation of House Connection

Damage of the building is used as an index for calculation of the initial supply interrupted population immediately after the earthquake. *Table 4.19* in the main report 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.

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 2 main lines of concrete lines and 2 steel lines from Bileghan to Tehran city area, crossing North Tehran fault. Therefore pipelines might get damaged. Tunnel lines are used to transport raw water from dams located in the east of Tehran crossing several faults. Although adopting measures for tunnels is difficult, 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.

(3) Distribution Trunk Mains

Influence of North Tehran fault earthquake is large. Main reasons of damages are by faults crossings and connections to structures just like transmission mains.

(4) Distribution Sub Mains

Experimental method is used to calculate damages except those which take place due to fault crossings. The tendency of damage is considered to be similar to the result of trunk mains.

4.2 Damage Estimation for Facilities and Equipment

Seismic diagnosis of facilities and equipment consists of preliminary seismic diagnosis and detailed diagnosis. Preliminary seismic diagnosis is done for finding defects by visual investigation. In detail diagnosis, earthquake-resistant evaluation and damage estimation are carried out by using a diagnostic table and some structure analysis.

4.2.1 Visual Investigation

(1) General

Earthquake resistance of facilities and equipment could be evaluated from past experience of damage. Damage examples are classified by category of facilities, structural or non-structural members, mechanical and/or electrical equipments. Followings are the list of structural members/ equipment which are easy to be damaged, and these are the points of site survey.

a) Structures connecting two different structural types such as breezeway, inlet and/or outlet pipes connected to the reservoir or pump station building etc.

b) A structure located on different foundations
Connection member between mat foundation and pile foundation is one of the examples. A pipe installed on a sand foundation and connected to the RC tank which is on the pile foundation, is another example.

c) Pipes in the soil with high liquefaction tendency

d) The equipments whose support conditions change
- Parts for the connection linked to structure, such as pipe and cable
- Distributor shaft which act as a coupling of a reducer and a Diesel engine etc.
- Distributor shaft which act as a coupling of a main pump (center gap)
- Fall of the baffle plate thickener of a sedimentation basin

e) The bolts used for equipments anchoring to their base

f) Non-structural member
Interior or external finishing material, fittings, curtain walls, etc.

g) Fixtures
Cupboards, chemicals, tools etc.

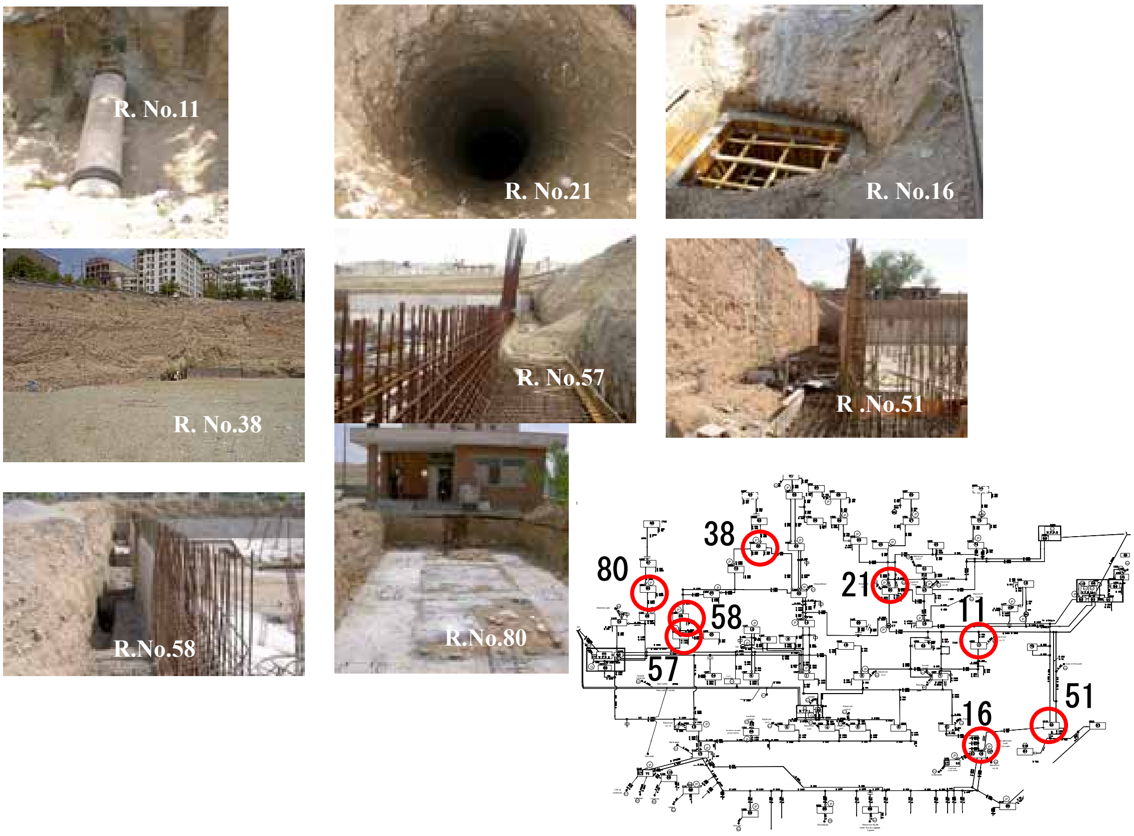
Furthermore degree of deterioration for every structure shall be considered.

(2) Ground Condition

Soil condition was found to be farily good against earthquake in Tehran, during visual investigation of facilities, by observation of the soil condition on extension field of Reservoir, construction site of manhole, excavation for piping and others. Picture 4.2.1 shows the good ground conditions.

- Reservoir No.11 in northeast: Exposure of inlet pipe
- Reservoir No.21 in north: Underground-pipe works and construction of chamber and sewage pit
- Reservoir No.16 in southeast: Construction site of manhole
- Reservoir No.38 in northwest: Ground wall
- Reservoir No.51 in west: Extension field of Reservoir
- Reservoir No.57 in northwest: Extension field of Reservoir

- Reservoir No.58 in northwest: Extension field of Reservoir
- Reservoir No.80 in northwest: Foundation works of telemetry house



Picture 4.2.1 Ground Condition on Reservoir Sites

Moreover, it is observed that soil is cohesive and that there is no ground water from the construction situations of reservoir No.16 in southern alluvial fan. Liquefaction is assumed to be low and circumference risks should be mentioned other than the foundation of facilities. Since the surface soil of northern cliff/slope has weathered, it tends to collapse. For risk avoidance, we propose to study renovation method of building on cliff/slope where collapse might occur in the future.

(3) Structure

a) Well

There are many examples of wells performing important roles as sources of emergency water supply at the time of seismic hazards in Japan, situation on Iran must be same. Generally, it is thought that earthquake resistance tendency of wells is high. That is concluded from the reason that horizontal force is small due to small pit weight.

b) Water Treatment Plant (WTP)

The principal structures such as water tanks or low stories buildings have high earthquake resistance in case if they are built on stable foundations. Based on this assumption, soil condition in Tehran is stiff enough for bearing capacity against earthquake. Some other structural problems were detected through the survey. The following is the ideas and methods proposed.

WTP No.1 : Since the slab burden area supported by each column is large in the generator house, the seismic resistance capacity would be very small, so structural calculation should be performed, and the frame of generator house has to be reinforced by the seismic resistant wall such as shear wall.

WTP No.2 : Concrete surface is exposed to large temperature fluctuation. In present conditions, repair and finish work is required on the beam of chemical dosing device house, Generator & Transformer house, and Pulsator.

WTP No.3 : The conditions of principal structure of water tanks and buildings look good, which is because of good ground, so they are highly resistant to earthquake. But as the cracks on Pulsator's piping duct are observed, repair of the cracks is needed.

WTP No.4

- The conditions of principal structure of water tanks and buildings look good because of good foundation, so they have high earthquake resistance.
- Although it is not directly related to the dependability of structure, water has leaked at Filter and it is necessary to repair expansion joint.
- Breezeway exists from Chemical House to Dosing Point. End support of Breezeway is a structure, which might be damaged at the time of earthquake due to twisting moment. Detailed study is required.

WTP No.5

- Earthquake design was applied to this WTP; therefore the principal structure has high earthquake resistance. But what the structures is located on the fault, had to be considered.
- Settlement of backfilled ground around Chemical House was observed. The influence was indicated by the existence of crack at external staircase or retaining wall, the cave-in of the ground, etc. The settlement has not affected beams or columns and the problem in a frame will not be serious because of small deformation. However, due to unstable condition of backfilled ground, there is high possibility of affecting the surrounding retaining wall. Therefore, a certain countermeasure is possibly required in the future.
- There is the possibility of curtain wall falling or detaching marble veneer used for the wall outer finishing or columns of the building. Since the probability of break of these non-structural members, including windowpane, is high in case of earthquake and it may harm human being, adequate measures are required to be taken.

c) Pump House

The oldest concrete of 50 years pump house is in a very good condition. The cross section of the design by subsequent Iranians is larger than the early design by the English. Old structure is classified into two categories (early design and subsequent Iranian design), and detailed earthquake-resistant diagnosis shall be performed based on structural analysis.

d) Reservoir

Since there is a top slab and seismic force is transmitted to the wall by the slab, seismic resistance of Reservoir is high. Due to a closed circumference, corrosion becomes a problem.

While inside of the tank could not be observed in many cases, its deterioration becomes apparent at ventilations. The level of degradation was observed through concrete of manhole or the ventilations and it became clear that degradation at No.6 and No.66 was remarkable.

(4) Mechanical and Electrical Equipment

Based on the observation of site survey, the following issues should be considered in earthquake-resistant plan. In consequence some hazard /improvement would be pointed out as described.

- Pump: Fixation of almost of all pumps are in good condition
- Surge tank: Fixation of many surge tanks except for pump station No.2, 22, 96 are fixed firmly.
- Chlorine dosing equipment: Some chlorine cylinders seem to be in danger of movement. If possible, introduction of sodium hypochlorite system is proposed
- Transmission or Distribution Pipes: Emergency shut-off Valve is not installed on piping
- Self-standing panel: Three types of electrical self-standing panels are applied. One type of them, viz. 400V panels are not fixed with foundation bolt
- Transformer: All Transformer wheels are not fixed with foundation bolt
- Battery: Except for the battery at Reservoir No.1, stopper or foundation bolts are not installed.
- UPS(Uninterruptible Power Supply): UPS is not fixed with stopper or foundation in any of the facilities
- Chemical Piping: Except for No.5 WTP, flexible pipe is not installed around the expansion joint of the structure
- Cable: There is not enough spare length of cable at the most facilities
- Oil tank: Anti-flowout fence under the oil tank is necessary to prevent a secondary disaster due to leakage of fuel.
- Electric post: The post at Reservoir No.22 (Vanak) is inclined.
- Others: Since the large oil tanks or equipments are supported by brick wall, additional supports are required for these walls.

4.2.2 Damage Estimations

(1) Diagnosis Method

Considering the number of facilities and complicated conditions, study was carried out systematically through three steps on the process of Risk Management.

In the first two steps, the risks were defined through site survey and brainstorming (1Risk Factor Analysis) and the damages were estimated on the basis of fourteen risks (2Risk Assessment) . On the next section, the last stage is undertaken which includes formulation and proposing of countermeasures on concerned risks (3Risk Control).

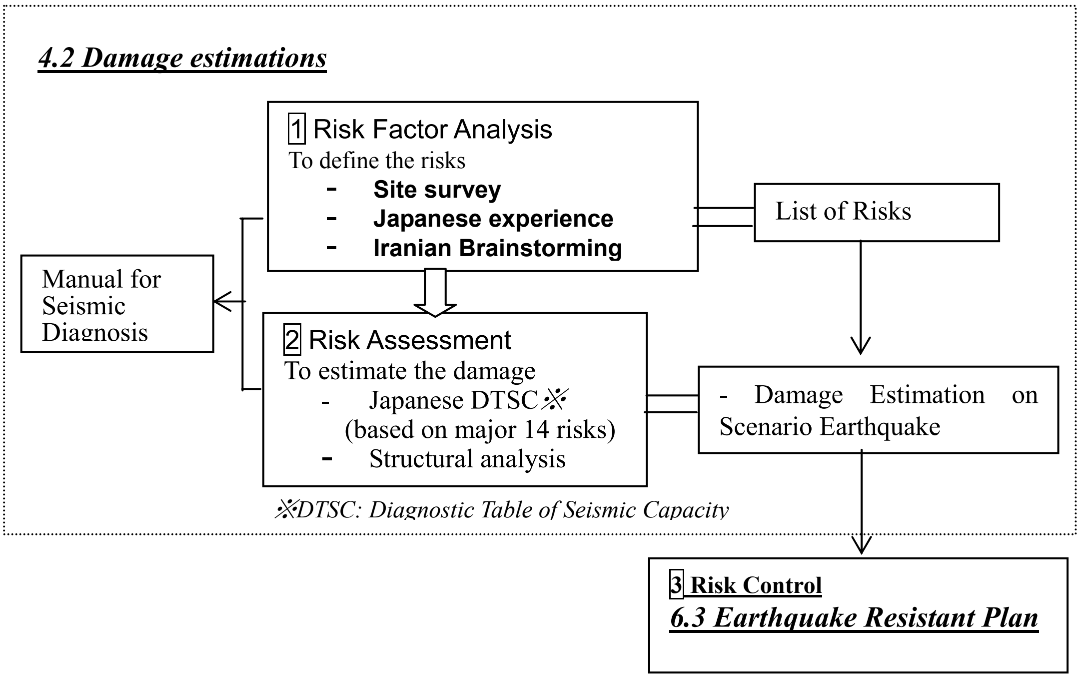


Figure 4.2.1 Flowchart for Damage Estimations and related tasks

(2) Risk Factor Analysis

We extracted the risk factors that were required for planning the measures for the facilities and equipments to make it earthquake-resistant, the risk factors were set up from the Japanese experience and the result of Brainstorming.

(3) Risk Assessment (Damage Estimation)

Damage Estimations, in terms of major fourteen risk factors, are performed by the Japanese Diagnostic Table for Seismic Capacity (hereafter refered to as DTSC) after some modifications to suite Iranian situation. The method of DTSC is the most objective evaluation method for assessment of damage. This DTSC is the method to evaluate the fourteen risk factors by the fragility point. The table was prepared by Health and Welfare Ministry in 1981, and the fragility point has been modified in 2005, based on the latest earthquake damage statistics in Japan, by Japan Water Research Center under a subsidy of Health, Labor and Welfare Ministry. Modified DTSC for structure with slab is summarized in *Table 4.2.13* in the main report.

(4) Outcome of Damage Estimation

Conditions on damage estimations are described below.

- DTSC is evaluated according to what we have done in the site survey of WTPs and sixty seven Reservoirs, only on the surveyed facilities.
- As structural analysis was accomplished, DTSC was modified a little.
- Damage estimation has been carried out considering four earthquake scenarios.
- Facilities on fault are located only in northern Tehran. DTSC has considered that the damages of these facilities are estimated seriously in the North Tehran fault scenario.

- The case of DTSC on the condition of Code 2800*1) would show present potential earthquake resistance. It must be recognized that this case is different with Damage Estimation Map.
- New Structure designed by code 2800 is also evaluated. It's seismic resistance must be high-level. When it is middle-level, evaluations were modified with a note on DTSC.
- Seismic resistance of Reservoir No.23 is estimated middle-level by DTSC, but by structure analysis, it is high-level, so DTSC changed.
- The earthquake resistance of Reservoir No.6, which is one of the oldest reservoirs, is evaluated as middle-level on DTSC. We carried out the structural analysis in addition and found out that earthquake resistance was also on middle-level because the bar arrangement of a partial walls is small while this is a rare case. While the earthquake resistance of the oldest Reservoirs No.1 to No.5 is evaluated to be high-level by DTSC and bar arrangement was not available, these Reservoirs must be of the same design as Reservoir No.6 because of the same construction age. Therefore we modified the evaluation as of middle-level earthquake resistance of Reservoirs No.1 to No.5 on DTSC by the condition of Code2800.

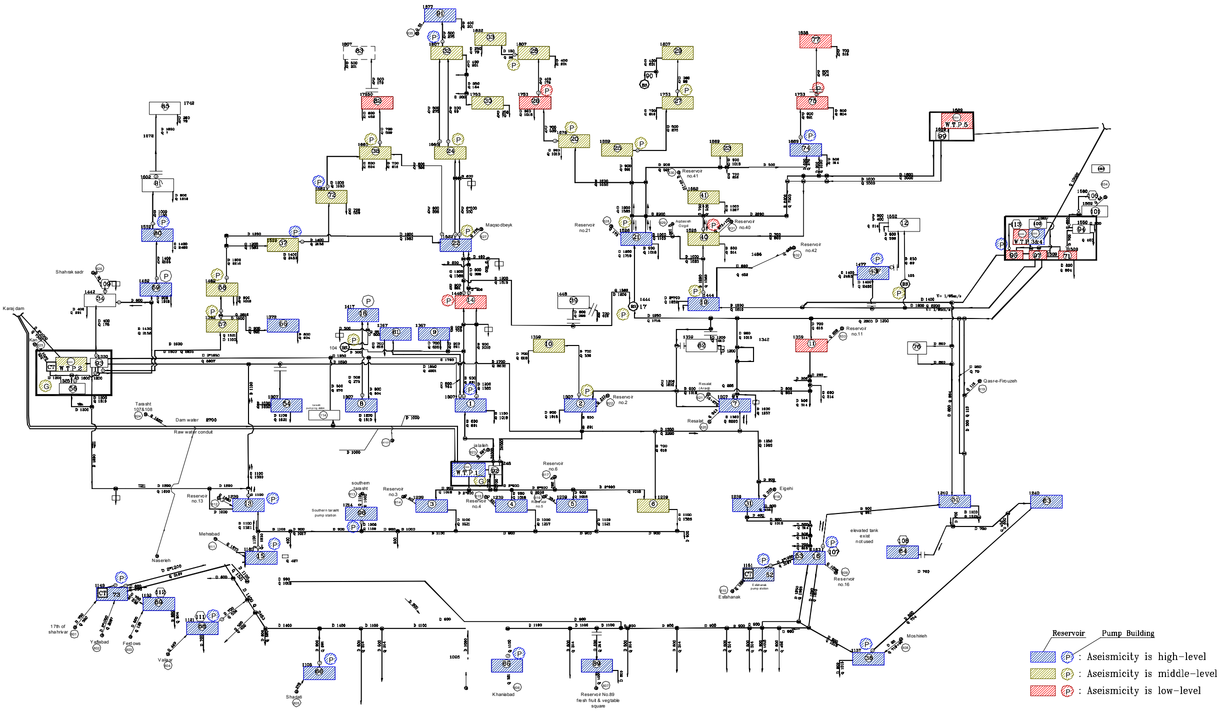


Fig 4-2-2 Damage Estimation Map (North Tehran Fault)

Note: Code 2800*1) ; Iranian Building Codes and Standrads, 2nd Eddition-1999, BHRC Publication No.S374, 2003

4.3 Hydraulic Analysis of Pipe Network of Tehran Water Supply System

Altitude of the served area of Tehran water supply system ranges so widely from 1,100m to 1,800m, that it is not easy to distribute water evenly throughout the served area. The served area is divided into many distribution zones, each of which principally has a distribution reservoir for its water source. At present, five water treatment plants transmit the clear water to 72 reservoir zones through a complicated water transmission network including pumping stations, pressure reducing valves, etc. as their components.

Water flow in the transmission networks is examined by a hydraulic analysis in order to grasp possible problems in an earthquake disaster and to find solution thereof.

As for distribution networks, hydraulic analysis of the networks in a few typical reservoir zones is executed for giving idea on improvement of their water supply conditions. For distribution network analysis, refer to the main report.

4.3.1 Criteria for Hydraulic Analysis of Transmission Networks

(1) Modeling of Transmission Networks

Model of the transmission networks for a hydraulic analysis consists of a great numbers of nodes, pipes, tanks, pumps, valves, etc. and is prepared as shown in *Figure 4.3.1*. Such components of the model as deep wells, well pumps, transmission pumps, distribution reservoirs are listed in Section 2.3 "Survey of the Existing Water Supply System" of the main report.

(2) Transmission Flow Rate

The day maximum water supply in 2005 is 3,172,996 m^3/day, which is applied for the hydraulic analysis. Adjusted production and production of each water treatment plant are summarized as shown in *Table 4.3.1*.

Table 4.3.1 Transmission Flow Rate for Hydraulic Analysis

	Supply	Production	Adjusted	Case-1	Case-2	Case-3	Case-4
Plant No.1		232,600	232,600	0	232,600	232,600	232,600
Plant No.2		769,000	787,026	787,026	0	787,026	787,026
Plant No.3		391,200	401,200	401,200	401,200	0	401,200
Plant No.4		387,700	397,700	397,700	397,700	0	397,700
Plant No.5		279,900	279,900	279,900	279,900	279,900	0
Subtotal		2,060,400	2,098,426	1,865,826	1,311,400	1,299,526	1,818,526
Ratio(%)		98.2	100	88.9	62.5	61.9	86.7
Groundwater		1,074,570	1,074,570	1,074,570	1,074,570	1,074,570	1,074,570
Total	3,172,996	3,134,970	3,172,996	2,940,396	2,385,970	2,374,096	2,893,096

As for analysis of transmission flow rate after an earthquake disaster, several cases thereof including interruption of treatment plants, interruption of pumping stations and damage of transmission mains are considered. The total transmission flow when a water treatment plant becomes out of operation is regarded as the total production of the other plants in operation as listed in *Table 4.3.1*.

4.3.2 Verification of Network Analysis

(1) Verification of the Model

Based on the above mentioned criteria, hydraulic analysis of the transmission networks are executed with the water CAD program. It is concluded that the model of the networks is practicable considering the following results of the analysis;

- Analyzed flow rate around distribution reservoir No.27 is similar compared to the flow rate actually measured.
- It is the same as the actual flow condition, which means that designated amount of flow can be satisfactorily conveyed to all of the distribution reservoirs according to the analysis.
- Extent of analyzed velocity in the transmission mains ranges within the normal values.
- Analyzed velocities in the transmission mains from plant No.3 to reservoir No.19 and from plant No.3 to reservoir No.51 are considerably large. However, this phenomenon corresponds to opinion of the operation staff of TWWC.

(2) Outcome of Hydraulic Analysis

Outcome of the hydraulic analysis generally shows that transmission pumps have sufficient capacity, while gravity pipelines are operated almost with designed capacity. As for capacity of individual facilities, all of the transmission mains from plant No.3 are operated with nearly full capacity. It is also considered that the existing transmission mains from plant No.5 to the central part or southern part of the city are insufficient comparing with the plant capacity.

4.3.3 Hydraulic Analysis in Earthquake Disaster

By using the network model, hydraulic analysis in earthquake disaster is undertaken. At first, cases to be analyzed are selected considering estimated damages of the water supply facilities studied in the previous sections.

(1) Case Setting

The following eight (8) representing cases are employed for hydraulic analysis:

- Case1 to Case4, each treatment plant becomes out of operation as shown in *Table 4.3.1*.
- Case5 to 7, large diameter concrete transmission mains become damaged.
- Case8, large scale pump station No.14 becomes out of operation.

(2) Results of Hydraulic Analysis

Results of the hydraulic analysis are summarized in *Table 4.3.2*. As shown in the table, cases which give biggest impact are case 2, interruption of WTP No.2 operation, and case 3, interruption of WTP No.3&4, capacities both of which are considerably large.

Among WTP No.2 system, large raw water transmission mains with 2000mm diameter, which are reinforced concrete pipes, are the most fragile in an earthquake. When the raw water mains get damaged, occurrence of water shortage in some service area is estimated because of insufficient coverage by other treatment plants. Appropriate measures for minimization of the water shortage should be studied including reinforcement of clear water transmission mains with diameters 1800mm and 1350mm concrete pipes connecting from WTP No.2.

Interruption in the operation of WTP No.3&4 system is also estimated to cause water shortage in its service area. Appropriate measures for minimization of the water shortage should be studied. Some measures for WTP No.2 and WTP No.3&4 systems are described in section 8.4.2.

Table 4.3.2 Estimated Damage Level

Cases	Maximum Change in Operation	Realistic Change in Operation
Interruption of treatment plant operation		
Case1	Plant No.1interruption doesn't affect much because water transmission from No.2 and No.3・4 is possible.	Transmission to some reservoirs becomes insufficient comparing with the left.
Case2	As plant No.2 has bigger production capacity and located in higher land than No.1, complete coverage by other plants could not be made. Several reservoirs with no inflow and others with insufficient inflow would appear.	More than 10 reservoirs with insufficient inflow in addition to several reservoirs with no inflow would appear. Interruption of plant No.2 operation widely affects citizen's water use.
Case3	As capacity of plant No3&4 is also large, neighboring several reservoirs with no inflow would appear. Other areas could almost be covered by plants No.2 and No.5.	Several reservoirs with no inflow and others with insufficient inflow would appear. Effective measures including water supply by tankers are necessary.
Case4	No.5 plant interruption doesn't affect much because water transmission from No.3・4 plant is possible at present.	Transmission to some reservoirs becomes insufficient.
Damage of water Transmission Mains		
Case5	In case of Damage of a twin 1,850mm concrete pipelines from plant No.2, several reservoirs connecting from the main would be empty and inflow of several others becomes insufficient.	Several reservoirs connecting from the main with no inflow and more than 10 reservoirs with insufficient inflow would appear. These pipelines are very important, and reinforcement should be made.
Case6	This 1,350mm pipeline is located downstream of case 5 pipelines, and damage is limited to the south east area of the city. Transmission to some reservoirs becomes insufficient.	Transmission to several reservoirs becomes insufficient, but conditions are not much different comparing with the left.
Case7	This is a combination of case5 and case6. As pipe size is far bigger and the pipe is located upstream, influence of this case is similar to case 5.	More than 15 reservoirs with insufficient transmission flow will appear. These pipelines are very important, and reinforcement should be made.
Interruption of pump station		
Case8	Pump station No.14 is large. But, service area by this station could be covered through pump station No.21 transmitted from plant No3&4. Influence of the station is small.	Damage influence would be larger than the left case. But, number of reservoirs influenced remains in some locations.

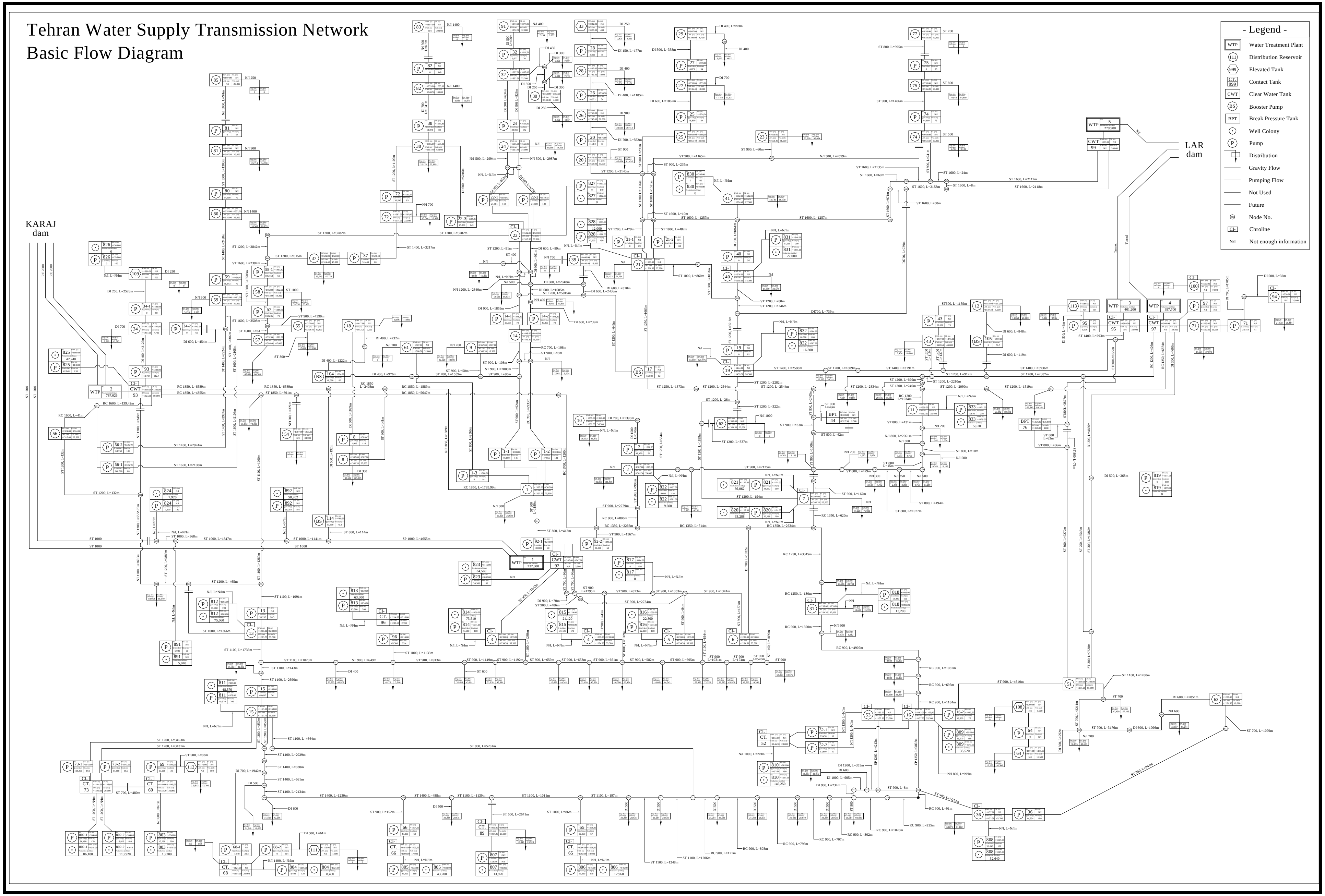


Figure 4.3.1 Tehran Water Supply Transmission Network – Base Flow Diagram

S 5 TARGET SETTING FOR EARTHQUAKE RESISTANT PLAN

5.1 General

Earthquake resistant plan in this study includes not only strengthening the water supply facility or system, but also supplying emergency water to the citizens or restoring damaged facilities urgently.

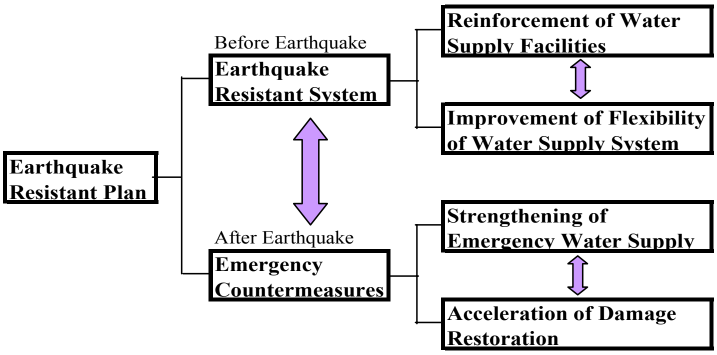


Figure 5.1.1 Earthquake Resistant Plan

Relationships between these plans are as shown in *Figure 5.1.1*, and they are in relation of trade-off with each other. Strengthening the facilities perfectly against an earthquake would be very costly and a long period of implementation should be considered. On the other hand, should no facility strengthening get executed, the facilities will suffer a great loss. Thus, the expenditure, man-power and restoration period to be required for the emergency measures would be enormous.

Considering all the measures and the relation mentioned in the above, the target for the earthquake resistant plan has to be set.

5.2 Basic Concept for Target Setting

The most significant elements affecting the target setting are the results of the damage estimation of the system. However, other related items such as characteristics of Tehran water supply system, lessons from the past earthquake disasters and experiences of the target setting in Japan would also affect establishing the target for the earthquake resistant plan. Basic concept for the target setting is set taking the above elements into account.

Key factors affecting largely to the earthquake resistant plan are extracted from the above four kinds of study results and summarized in *Figure 5.2.1*.

Since some existing facilities between water sources to water treatment plants are on the faults or near the faults, it is difficult to strengthen them completely against an earthquake. However, as they are already divided and dispersed into several systems, interruption of a water treatment plant operation could be considerably covered by water transmission from the transmission mains and pump stations, both of which receive clear water from the other plants in operation.

Role of clear water transmission mains is to convey water to distribution reservoirs which are the most important water bases for Tehran citizens. If the transmission mains get damaged in earthquake disasters, produced water at a plant could not be conveyed to the reservoirs. Hence, the principal measure to apply is set to strengthen the mains.

Since damages on distribution sub-mains and service connections are anticipated far more than the other water mains, it is difficult to strengthen all the lengthy pipelines. Emphasis for these pipelines should principally be placed on emergency water supply and emergency restoration of damaged pipelines. Increase of emergency water supply bases is also indispensable.

Thus, basic concept for the target setting is figured out as shown in *Figure 5.2.1*.

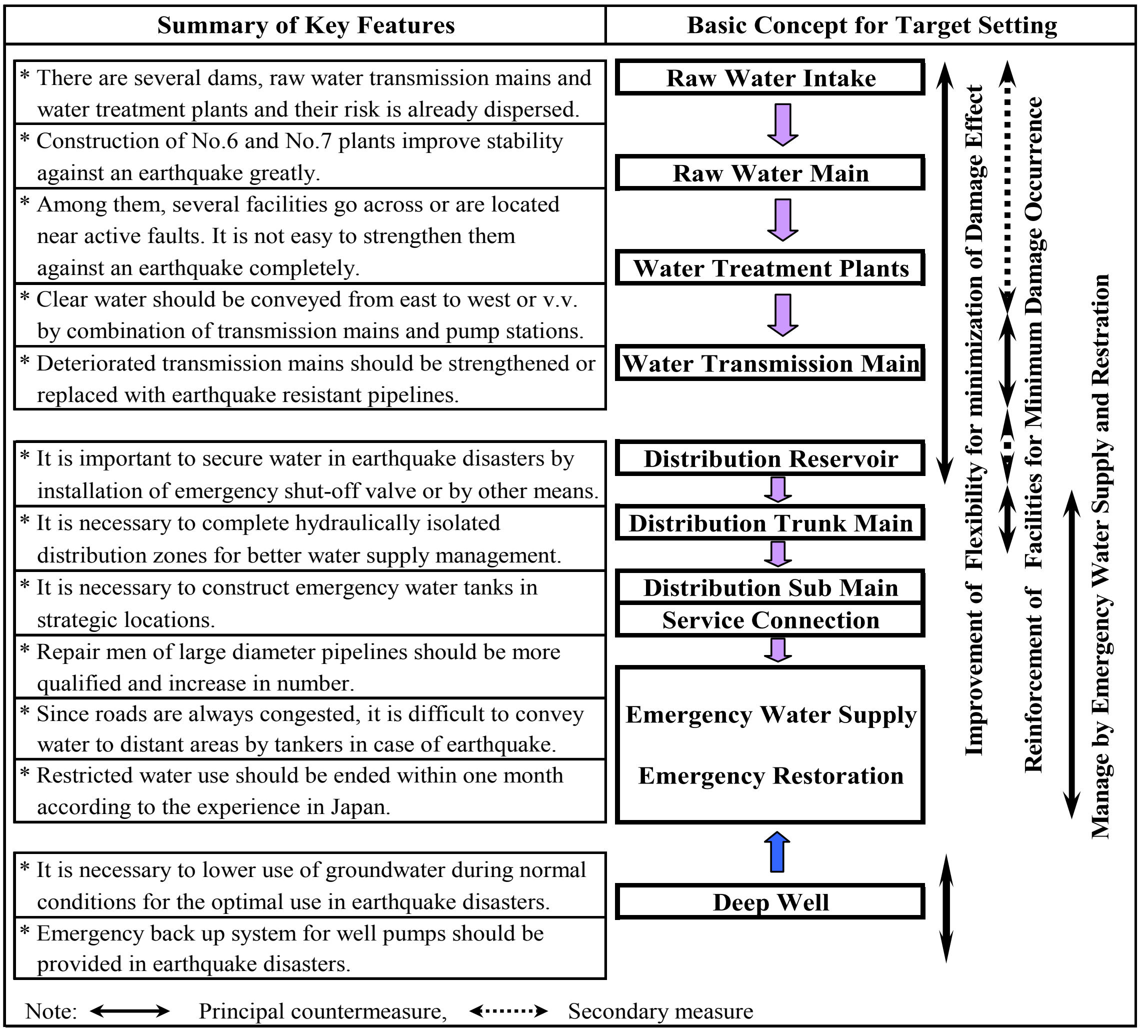


Figure 5.2.1 Basic Concept for the Target Setting

5.3 Target Setting for Earthquake Resistant Plan

According to the basic concept set in the preceding section, target for the earthquake resistant plan will be established in two ways as (1) target for earthquake resistant facilities, *Table 5.3.1*, and (2) target for emergency supply and restoration, *Table 5.3.2* and *Table 5.3.3* respectively.

Table 5.3.1 Target for Earthquake Resistant Facilities

Category of Aseismicity	Principal Measures	Object Facilities
Minimization of Damage Occurrence	Reinforcement of Each Facility	Transmission Main Distribution Trunk Main
Minimization of Damage Effect	Improvement of System Flexibility	Raw Water Main Water Treatment Plant Transmission Main Distribution Reservoir
Preparedness for Emergency (Before Earthquake)	Securing emergency Water	Securing Reservoir Water Preparation of Emergency Water Supply Bases
Emergency Countermeasure (After Earthquake)	Emergency Supply and Restoration	Distribution Network Service Connection

Table 5.3.2 Target for Emergency Water Supply

Days after earthquake	Supply amount	Water use purposes	Access to water	Supply measures
Day	Lpcd		M	
Up to 3day	3	- Drinking: keeping human life	1,000	- Water Tank - Water Tanker
4d to 2week	20	- Drinking, - Toilet - Face washing: minimum daily life	250	- Water Tank - Temporary taps connected to distribution mains
2w to 3week	100	- Drinking - Toilet, - Bathing - Cooking	100	-Temporary taps connected to distribution sub-mains
Approximately 4 week	200 – 250	-Normal daily life	10	-House connections from temporary service pipes - Public taps

Table 5.3.3 Target for Emergency Restoration

Category	Number of Damage	Target Period
Trunk Main	70	0.5 Month
Sub-main	700	1.0 Month
Service Connection	3,850	

S 6 IDENTIFICATION AND STUDY OF EARTHQUAKE RESISTANT MEASURES

6.1 Identification of Prospective Earthquake-resistant Measures

Based on results of the damage estimation, previous study reports, past experience of earthquake disasters, site surveys and discussion with TWWC counterpart team, prospective measures for an earthquake-resistant plan are identified in this section. As shown in *Figure 6.1.1*, prospective measures are classified into two categories, namely measures necessary before an earthquake occurrence or afterward of the earthquake.

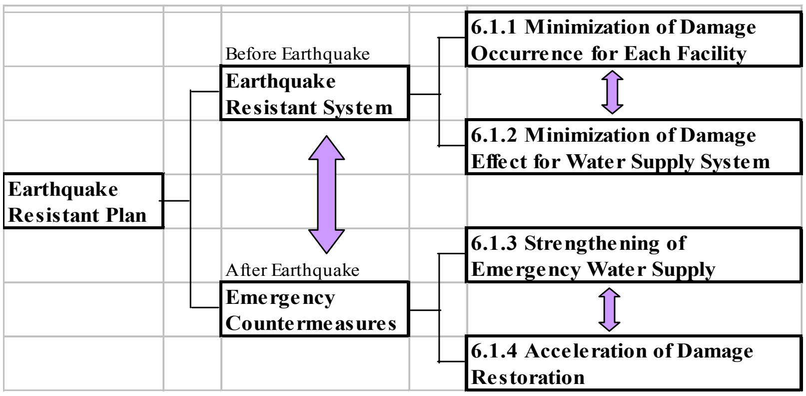


Figure 6.1.1 Scope of Earthquake Resistant Plan

The former one aims to improve the earthquake resistant system and the latter is employed as emergency countermeasures for disaster recovery. The earthquake resistant systems would be achieved by minimization of damage occurrence for each facility and minimization/ mitigation of damage effect for a water supply system. The emergency countermeasures would include strengthening of emergency water supply and acceleration of damage restoration.

Among these measures, those intended for minimization of damage occurrence in each water supply facility in an earthquake disaster and for minimization or mitigation of damage effect on water supply systems are figured out and listed as shown in section 6.2 and 6.3 respectively. Measures for strengthening emergency water supply which should be performed soon after an earthquake disaster occurred are described in chapter 7. Measures for acceleration of emergency restoration of damaged facilities are also mentioned in chapter 7.

6.2 Examination of Earthquake-resistant Measures for Pipeline System

Reliability of water pipeline system after earthquake is influenced by both pipe soundness and system redundancy. Therefore to increase seismic resistant capability of the system, both pipe improvement and increase of pipeline system redundancy are required. The former is reinforcing pipes or replacing them with highly reliable ones and the latter is achieved by building redundant network system.

6.2.1 Pipe Material and Earthquake

(1) Steel Pipe

Steel pipes have enough strength and ductility for pipeline material. Furthermore welded joints have same quality to pipe body. Therefore welded steel pipes are ideal material for high pressure pipeline, especially with butt welding joints.

(2) Ductile Iron Pipe

Ductile Iron Pipe has strong body and used widely in the water field. The joints have simple structures and easy to detach in case of outer forces acts. By using detach-resistant joints, these damage can be avoided.

(3) Reinforced Concrete Pipe

Reinforced Concrete Pipe body is brittle compared to steel or DIP, especially against impact forces. Furthermore joint section is weak and cause water leakage from connection points.

(4) Cast Iron Pipe

Cast Iron Pipe has been used as main pipe material. However neither pipe body nor joint is strong enough against outer force, especially seismic impact force.

(5) Polyethylene Pipe

Pipe body has enough strength and flexibility. High performance polyethylene pipes (HPPE/PE100) are also recommended for water supply system just like gas pipeline.

Steel pipe with welded joint and Ductile iron pipe with detach-resistant joint are suitable for large and medium size diameter pipeline. Polyethylene pipe with electric fusion bond joint has a good quality and is cost effective for small diameter pipe.

6.2.2 Earthquake Effects on Pipeline and Pipe Upgrade Options

(1) Possible Damage Location

Causes of pipeline damage are roughly classified to below major categories.

- Fault crossing points
- Connection to massive structure
- Ordinary buried area

These causes are combined in actual conditions. Fault crossings are considered as major damage reason in Tehran. On the other hand small diameter pipes have complex connectivity conditions and ground strain might cause some damage. North Tehran fault has a offset along fault line is estimated about ±75cm which are derived from seismic motion analysis. After dislocation due to active fault movement, ground is transferred to permanent displacement location. Strains caused by these permanent displacements are small except near active fault. Options against seismic damage are described below.

(2) Use of Casing Pipe or Concrete Box Culvert

Offset at fault crossings are absorbed by these casings or culvert. Main pipes are installed inside these structures and abrupt deformation of pipeline is avoided. Welded steel pipes are used for casing purpose. Concrete box culvert is also used to avoid the pipe damage at fault crossing similar to casing pipe. *Figure 6.2.1* shows schematic illustration of box culvert.

(3) Concrete Encasement around Buried Pipe

Instead of using concrete box culvert, the method is to reinforce the pipe body with reinforced concrete which is considered as resistant beam.

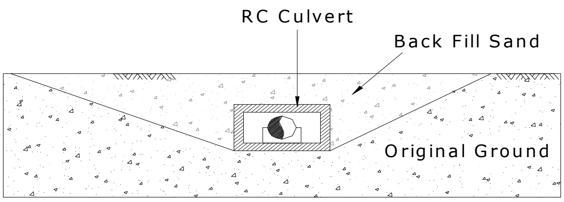


Figure 6.2.1 Concrete Box Culvert

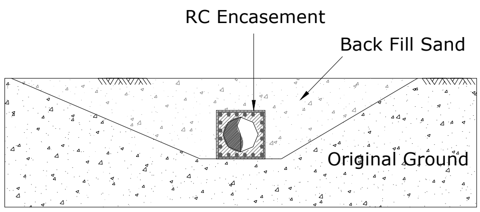


Figure 6.2.2 Concrete Encasement

(4) Use of Flexible/Expansion Joints at Fault Crossing

Both longitudinal and lateral deflections are absorbed by flexible/expansion joints. However since absorbing capacity is limited to certain range, it is necessary to use several joints to absorb large deformation. In some cases, special measures are required such as replacement of surrounding soil to loose sands.

(5) Sacrificial Casing or Box Culvert

The other option allows the structure's breakage as long as main pipeline remains safe. *Figure 6.2.4* shows schematic illustration of such condition. Even if culvert is broken along fault line pipes inside the culvert remain safe because of enough space around the pipe. Another option is combination of such sacrificial culvert and flexible joints. In this condition flexible joints mean both ball joints and axial expansion joint. *Figure 6.2.5* shows example of the method. In this measure offset of fault movement is absorbed by these flexible joints. Box culvert should have enough inner space after fault movement.

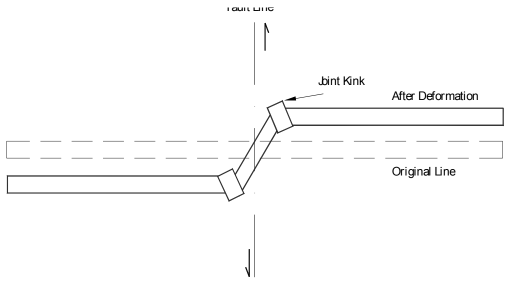


Figure 6.2.3 Use of Flexible joints

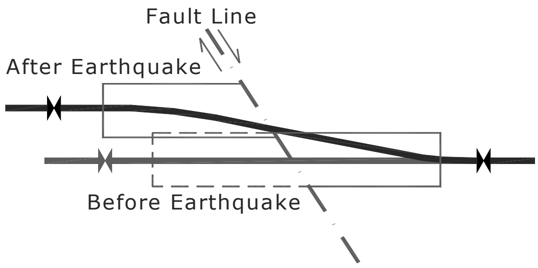


Figure 6.2.4 Breakage of Culvert

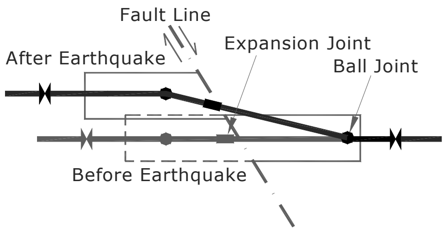


Figure 6.2.5 Culvert with Ball Joint

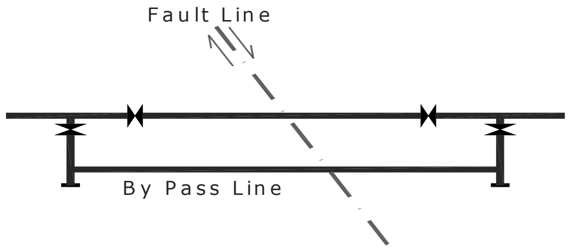


Figure 6.2.6 By-pass Option

(6) By-pass Pipe Option

Figure 6.2.6 shows concept of the option. Permanent by-pass pipe is used for emergency case. In case both main pipe and by-pass pipe are out of use, temporal pipe or hose is connected to these tees to compensate for broken lines.

(7) Connection Measures to Massive Structures

Relative displacement might occur at connections where vibration characteristics of structure are different. However these values are small compared to those of fault offsets. Similar options at fault crossing can be taken, though absorbing displacement is far small. Therefore dimensions of reinforcing become small and damage might be reduced only with strong joints pipes.

(8) Measures against Seismic Motion

Strain caused during earthquake motion is small and possibility of joint slip-out is small even if concentration of these strains accumulates in the neighboring joints. However soil in Tehran is stiff enough, therefore it is not necessary to consider such effects. Even at places with possibility of danger, use of pipe with reliable joints can mitigate the damage.

(9) Concluding Remarks of Measure Options

Several options are described in previous paragraphs. Some damages or breakages can be allowed under the condition of suitable responses derived after the earthquake. These concepts are necessary especially considering the case with low probability of earthquake.

6.2.3 Enhancement of Raw Water Transmission Main

Major damage prone places are considered at active fault crossings. It is difficult to satisfy the condition of large offset along North Tehran fault. Therefore by-pass option is considered practical in these conditions especially for RC pipelines.

6.2.4 Enhancement of Transmission Main

(1) Outline

Transmission main has length of 400 km pipeline. The transmission line is one of the most important lines in water system. There are many fault crossings including active North Tehran fault. Number of locations where pipelines cross faults is 8 regarding active fault and 39 places regarding secondary faults. Most of these crossings locate north region of the city.

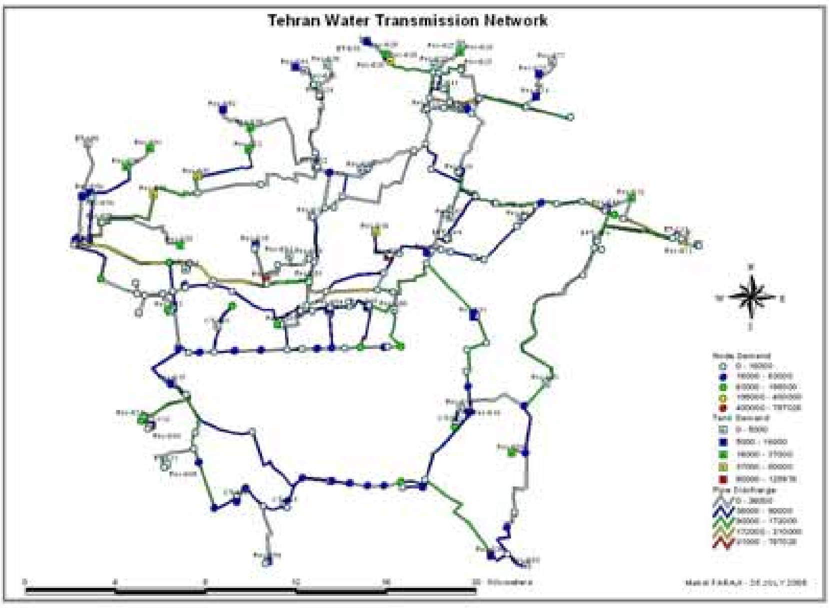


Figure 6.2.7 General Layout of Transmission Main

(2) Pipeline Upgrade Options

There are several active fault crossings in northern region of the city. In those areas transmission pipe diameter is small and box culvert with enough inner space can be possible and main pipe inside the box remains safe even if breakage of such culvert occurs. RC pipeline with 1850 mm diameter crosses secondary fault. By pass option or replacement with steel pipes are considered practical at the point.

(3) Analysis results

Detailed analysis method is described in the main report. Effects of water shortage are derived in each reservoir zones. After North Tehran fault earthquake, zones in northern region have high potentiality of damage, for these zones are close to North Tehran fault.

6.2.5 Enhancement of Distribution Trunk Main

(1) Outline

Distribution trunk main consists of approximately 770km in length and ductile iron pipe has length of approximately 500 km. Pipes with diameter of 300 mm and more are included. There are about 95 fault crossings. Mainly there are secondary faults.

(2) Pipeline Upgrade Options

Since distribution trunk main consists of water supply networks, it is possible to supply water by using other routes after damage of some segments. The pipeline has essentially redundancy. Considering enhancing method, both box culvert and by-pass option are practical. In case of renewal plan is applied to the pipeline, possible hazard can be avoided by using either ductile iron pipe with detach-resistant joint or welded joint steel pipes.

(3) Analysis results

Figure .6.2.20 in the main report shows results of North Tehran fault case. Even under present condition, only limited zones will suffer from water suspension. Most of the zones are below 20 % interruption possibility. Result shows suspension possibilities are small and water interrupted area is limited because of water network.

6.2.6 Enhancement of Distribution Sub Main

(1) Outline

Pipe diameter size is 250mm and less and total length is approximately 6500km. It is good to use quake-resistant pipes according to long term replacement plan.

(2) Pipeline Upgrade Options

Replacement plan should be done based on old pipe renewal plan. Use of reliable joint pipe is necessary to cope with several circumstances not only earthquake.

(3) Analysis results

Damage points were analyzed based on statistical data together with fault crossing numbers. There are many possibilities of damaged points especially in case of North Tehran fault earthquake. About 700 damage points are assumed after the earthquake. About 500 of them are at fault crossing points.

6.2.7 Combined Effects of Water Networks Improvement

Combined effects of the final stage are as follows. In this sub section raw water transmission line is assumed to be in good condition.

1) Present Condition

Figure 6.2.30 in the main report shows results of combined effects of North Tehran Fault earthquake. There are many high potential water suspension zones in north area. Those come from relatively low reliability of transmission mains.

2) Next stage

Following conditions are assumed in next stage.

- All RC pipes are replaced.
- Pipes at fault crossings are measured and cast iron pipes are replaced in distribution trunk main.
- Low reliability pipes with less than 200mm diameter are replaced in next stage of distribution sub main

Combined reliability becomes better then present condition. However influence of existing pipe condition of both trunk and sub mains are large, therefore increase of reliability is small.

3) Future Plan

Following conditions are assumed in a future.

- All RC pipes are replaced.
- All distribution trunk main pipes are replaced.
- All distribution sub main pipes except existing PE pipes are replaced.

This assumes almost no damage occurs in distribution mains

Figure 6.2.32 in the main report shows results of combined effects of North Tehran Fault earthquake. Improvement in northern area is remarkable.

6.2.8 Conclusion of the Section

To enhance water distribution system, both strengthening of pipes and increasing redundancy of pipeline system are required. Steel pipes with welded joints and ductile iron pipe with detach-resistant joints are suitable to increase such reliability. Polyethylene pipe with electric fusion bond is also reliable for small diameter pipes.

There are many options to be applied at fault crossings. Clear water transmission main has important role in distribution system. Water can be transferred to most of the city if transmission mains are in good condition. Even if one of the water treatment plants is out of operation, only limited area will suffer from water shortage. Therefore measures to enhance the transmission main should be done in earlier stage. Especially there are several active fault crossings in northern area of the city. These pipes are relatively small and it is not difficult to strengthen these pipes. Several options can be selected such as installing main pipes in concrete box culvert.

Distribution trunk main is also important. To reinforce or replace pipe with a reliable one is preferable especially at fault crossings. Replacement is considered to be carried out with regular renewal plan. Use of pipe with reliable joints should be included in the plan. Instead of reinforcing all the distribution pipes to maintain 100% safety, it is practical to accept some damages and prepare for quick restoration.

6.3 Earthquake Resistant Plan for Facilities Structure and Equipment

The relation of this section and previous section 4.2 is shown in *Figure 6.3.1*.

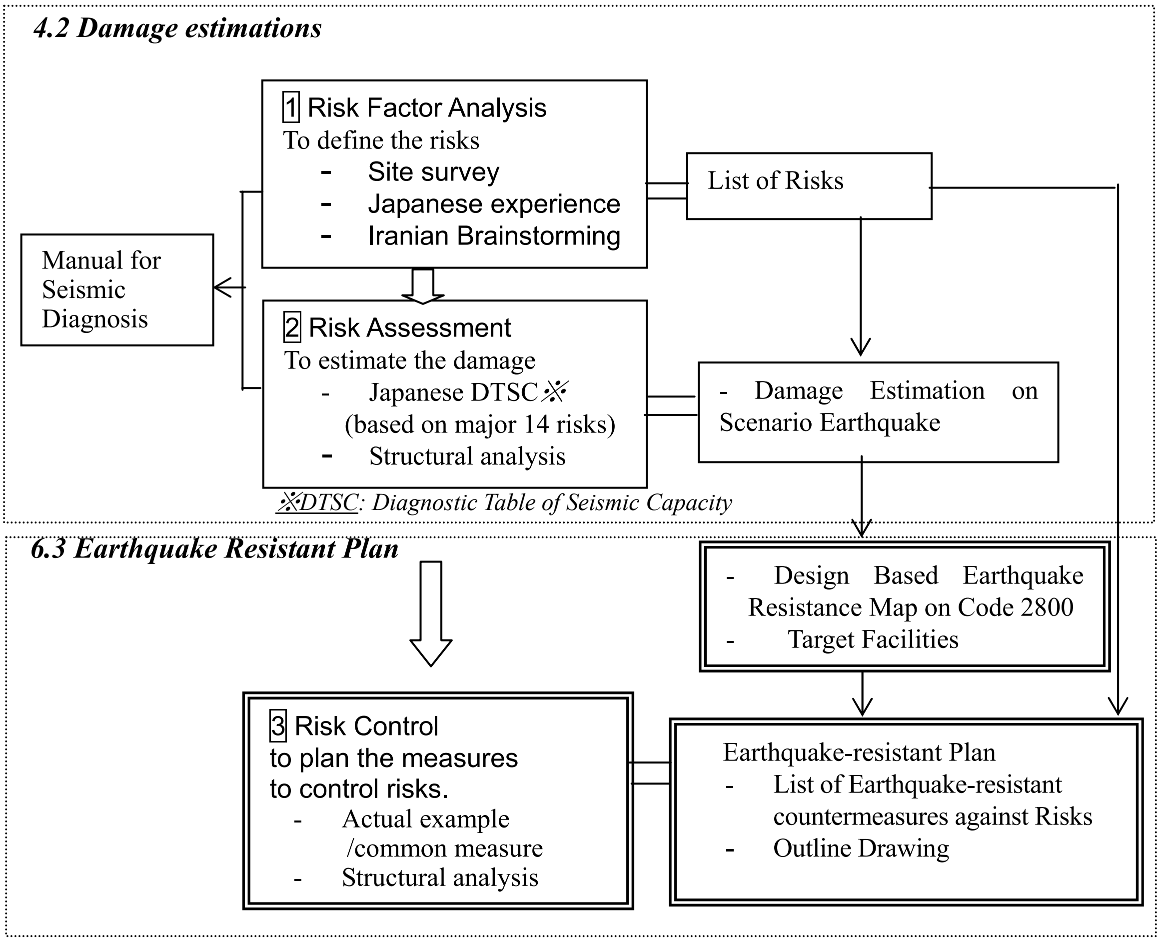


Figure 6.3.1 Flowchart of Related Tasks in This Section

6.3.1 Principle of Measure for Target Facilities

Three of obvious facts are declared so far: The first is that damage of the facilities on fault will be most serious after North Tehran earthquake. The second is that the seismic design has been applied to many building and facilities for these ten years after enforcement of Code 2800. The third is that TWWC intends to carry out seismic reinforcement of existing facilities. Therefore target facilities in study should be selected considering smooth implementation of TWWC transform. The target facilities are categorized as follows.

- Category A: The facilities on fault and other fragile facilities based on disastrous North Tehran scenario earthquake
- Category B: The fragile facilities evaluated by code 2800 on Design-Based Earthquake Resistance Map (Fig.6.3.2 in the main report) without condition of fault

a) Principle of the Measure for Facilities of Category A

Countermeasures for building / tank on fault require huge cost and are not practical at the moment. Therefore, the measures for minimization of damage effects such as back up with pipe / other neighboring facilities are applied in the short term, and in the future they should be relocated or re-constructed properly after the service period is fulfilled.

b) Principle of the Measure on Facilities of Category B

After checking whether the structures satisfy seismic design following Code 2800 or not, the methods for strengthening methods each structure and for minimizing the damage have been studied. Prevention of secondary disaster is also considered as shown in *Figure 6.3.3* in the main report.

6.3.2 Study on Facilities and Priority of Countermeasures

As there are a large number of facilities, implementation program should be prepared considering priorities on the basis of the site survey, damage estimations and earthquake resistance map. The target facilities and their seismic resistance are summarized in *Figure 6.3.4* in the main report.

Considerations /strategy for deciding priority summarized as follows:

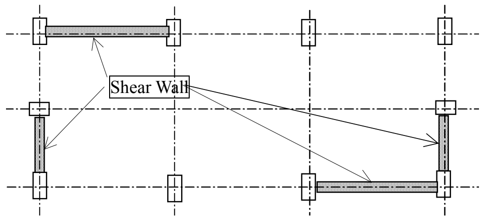
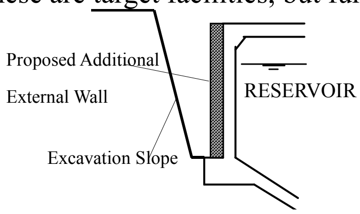
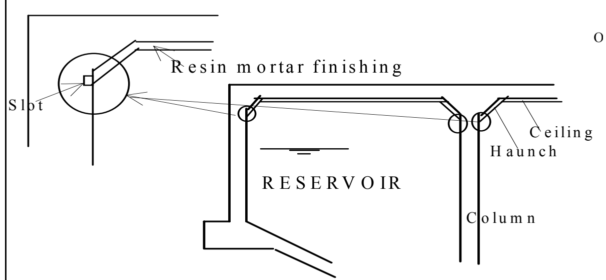
- The countermeasures on facilities which have highest-priority are assumed as follows:
  - Sustaining human life: Buildings where staffs stay for routine work
  - Fragility: Structural members and equipment which fragility were pointed out by visual investigations and structural analysis
  - Easy/simple countermeasures: Fixation of equipment, which is highly economical.
- Since the effect of the damage of large pump stations on water supply system is significant and widespread, important and large pump houses should be reinforced on a priority basis.
- Reinforcement of the reservoirs ought to be carried out one by one, starting from an old facility. Since reservoirs might be high seismic resistance, soil survey around the walls and checking of as-built drawing, especially bar arrangement, should be carried out before the reinforcement.
- The stabilization of a cliff or a slope is very important and of high priority. However soil data of slope is not available. In future geological survey must be carried out.

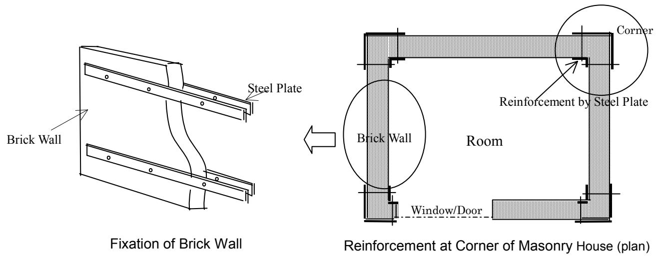
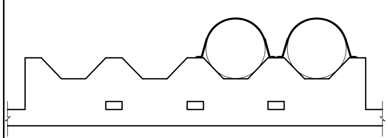
6.3.3 Proposed Countermeasures and Task for the Future

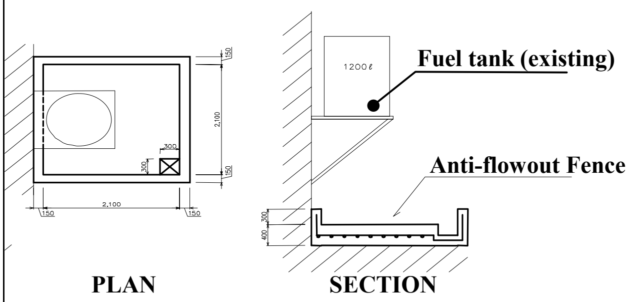
Countermeasures corresponding to risks are summarized in *Table 6.3.5* in the main report, which sorts out implementation plan, Future Plan, pending issues and Non-application measures. *Table 6.3.1* below summarizes the measures which should be implemented.

Table 6.3.1 Risk Control Chart (check sheet of measures)

Risk	Check of the Countermeasures
S-1 Risk on Ground conditions	
S-1-1-1 Fault shifts causes great damage to structures and subsequently accidents resulting in injury or death	S-1-1-1-b Back up by other function Reservoir No.11, 14, 20, 26, 75, 77, 82, Chlorine house, chemical house and Pulsator at WTP No.5, Pulsator and Filter at WTP No.4, Reservoir No.71,95,97 at WTP No.3&4

S-1-1-4 A cliff collapses and damages the building.	S-1-1-4-f Construction of defensive wall on building Bileghan Shelter
S-2 Risk on Structural members	
S-2-1-1 Column collapses, and beam and roof deform or fall.	S-2-1-1-b Frame reinforcement by RC shear wall Generator house at WTP No.1, Generator house at WTP No.2, Pumping houses No.1, 2, 15, 16, 17, 19, 20, 22, 24, 36,40, 52, 57, 58, 73, 27, 28, 38  Arrangement of shear wall
S-2-1-2 Crack occurs at the tank, causes water leakage and water is contaminated.	S-2-1-2-a Reinforcement of partial member Pulsator on WTP No.2 Oldest Reservoir No.1, 2, 3, 4, 5, 6 Old Reservoir No.9, 10, 11, 13, 15, 16, 20, 23, 25, 29, 30, 32 (These are target facilities, but further soil survey is required)  Section of wall reinforcement
S-2-1-3 When whole structure deforms, a deformation becomes the maximum by Expansion Joint, so water stop is cut and water leaks.	S-2-1-3-b Abolishment of the effectiveness of Expansion Joint and unification of a part of structure Filer at WTP No.4
S-2-2-1 As the structure is complicated, when structural model is not optimal, the inestimable force acts, which causes the increase of load on some members, and deformation.	S-2-2-1-b Fixation of Breezeway WTP No.4 chemical house
S-2-3-1 When there is large degradation which the bar has exposed, as the structural function is lost and earthquake resistance cannot be expected, buckling, deformation, crack, leakage of water, etc. occur.	S-2-3-1-a Repair (Refurbishment) Reservoir No.6, 66  Section of Repair

S-3 Risk on Non-structural members	
S-3-1-1 The trough of Pulsator gets separated or breaks down and water quality deteriorates.	S-3-1-1-b Stopper Pulsator's trough in WTP No.2 is reinforced together with the wall
S-3-2-1 The brick wall collapses and causes an accident resulting in injury or death, or equipment is damaged.	S-3-2-1-a Reinforcement of brick wall Building of WTP, Pump House and Emergency Post  Reinforcement of brick wall
S-3-3-1 Windowpane breaks because of caulking material degradation which can cause an accident resulting in injury or death.	S-3-3-1-a Replacement with the degraded window and frame. (common countermeasure) S-3-3-1-b Shatter-resistant film should be pasted on windowpane (common countermeasure)
S-3-3 –2 Broken door prevents a man to escape	S-3-3 –2-a Replacement with the degraded door and frame. (common countermeasure)
S-3-4-1 The outer Marble Veneer falls, which causes an accident resulting in injury or death.	S-3-4 -1-a Fixation with anchor bolt The outer Marble Veneer of chlorine house of WTP No.5
S-3-7-1 A man may fall over handrail resulting in injury or death.	S-2-7-1-a Fixation of handrail post (common countermeasure) S-2-7-1-b Replacement of the high handrail (common countermeasure)
E-1 Risk on Main Equipments	
E-1-1-1 Overturn of surge tank leads to failure of pumping.	E-1-1-1-a Fixation with foundation bolt E-1-1-1-b Installation of additional support Pump station No.2, 22, 96 Before and after of measure
E-1-1-2 Gas leakage from chlorine cylinder causes an accident resulting in injury or death.	E-1-1-2-a Installation of stable pedestal Bileghan, WTP No.1 to No.3, and Stations No. 1, 2, 13, 14, 15, 16, 17, 19, 20, 21, 22, 24, 25, 26, 40, 52, 56, 57, 58, 65, 68, 73, 114  Stable pedestal E-1-1-2-b Installation of neutralization equipment and emergency shutoff valve Bileghan Intake, WTP No.1 to 5, Stations No.52, 73, 4, 5, 7, 13, 19, 21, 31, 36, 40, 65, 66, 68, 69, 89, Southern Tarasht, Said Abad

E-1-1-3 Overturn or sideslip of transformer causes failure of the water supply and fire.	E-1-1-3-a Fixation with foundation bolt in addition to stopper All transformers
E-1-1-4 Overturn of electrical panel causes operating failure of the water supply.	E-1-1-4-a Fixation with foundation bolt pump station No.8, 12, 13, 27, 28, 32, 34, 36, 37, 38, 43, 59, 65, 66, 68, 69, 71, 72, 74, 75, 80, 81, 90, 91, 93, 95, 96, 101, 102, 105, Well Pump
	E-1-1-4-b Reinforcing of stage Reinforcement of steel stage at Pump station No.72, would include the countermeasure of fixation of panel.
E-1-2-1 Damage to pipe causes leakage of water, failure of water supply, and failure of emergency water supply.	E-1-2-1-a Installation of flexible pipe WTP No.1 to No.5, Bileghan Intake
	E-1-2-1-b Installation of emergency shut-off valve at outlet of reservoir All Reservoir (Section 6.1)
E-1-2-3 Leakage of fuel for emergency generator causes secondary disaster like fire	E-1-2-3-a Construction of anti-flowout fence Generator in Bileghan Intake GeneratorWTP No.1 to No.5  Anti-flowout fence
E-1-2-4 Toppling of electric post causes power failure.	E-1-2-4-a Installation of stay. Reservoir No.22
E-1-3-1 (Blackout) Failure of water supply, or deterioration of water quality	E-1-3-1-b Duplicate Incoming Cable Pump Station No.16, 52, 68, 114
E-2 Risk on Sub Equipments	
E-2-1-1 Overturn or sideslip of battery causes failure in operation of radio equipment, monitoring equipment, display lamp of electrical panel , and operation of circuit breaker	E-2-1-1-a Fixation with foundation bolt WTP No.1 to No.5 Pump Stations No.1, 2, 13, 14, 15, 16, 17, 19, 20, 21, 22, 24, 25, 26, 40, 52, 56, 57, 58, 65, 68, 73, 114
E-2-2-1 Overturn of UPS causes operating failure of monitoring equipment until emergency generator starts when blackout takes place.	E-2-2-1-a Fixation with foundation bolt WTP No.1 to No.5
P-1 Risk on Connecting piping	
P-1-1-1 Piping gets separated from the tank which leads to water leakage, so emergency water supply becomes impossible.	P-1-1-1-a Installation of flexible joint (at least one line) Section 6.2
	P-1-1-1-b Installation of back-up pipe with flexible joint Section 6.2

6.4 Facilities and Measures for Emergency Water Supply Bases

6.4.1 Selection of Emergency Water Supply Methods

Existing facilities should be used as much as possible for emergency water supply bases in order to save investment. Therefore following places are listed up for emergency water supply bases:

- Existing reservoirs
- Existing transmission pipes connected to existing reservoir
- Existing deep wells

The first and the second measures are high priority since treated and safe surface water can be used with simple arrangement. Groundwater will be used when the area is not covered by these two measures. When these three measures are not available, water tankers and emergency water tanks will be used. These measures can be further divided according to their practical application. Following measures are selected for emergency water supply methods and order of listing below shows priority of application:

- Supply from existing reservoir with the arrangement of siphon at outlet pipe
- Supply from existing reservoir with the installation of emergency shut-off valve
- Supply from gravity transmission main of Enqelab and Southern Ring Main
- Supply from deep well owned by TWWC and/or in park
- Supply by water tanker to make up for uncovered area by the existing reservoirs or wells
- Supply by emergency water tank to make up for the area, which cannot be accessed by water tanker, or some wells where water quality is poor for drinking purpose

Figure 6.4.1 shows the methods of the first priority, which do not use expensive equipment and are originally proposed by the study team.

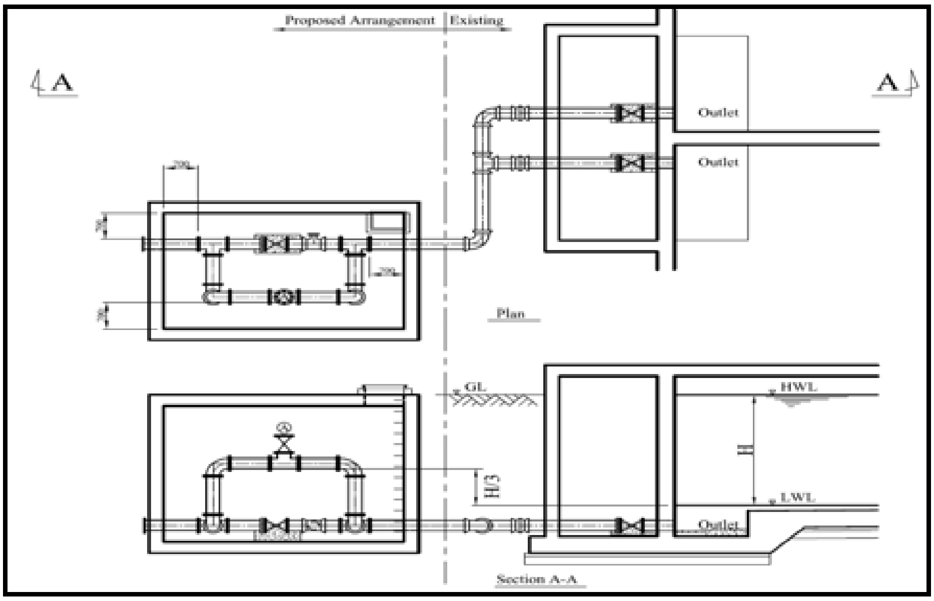


Figure 6.4.1 The Siphon Arrangement of Existing Reservoir Outlet

Among the measures, deep wells are required to equip with chlorination equipment and generator for usage after earthquake. Emergency water tanks have been tested by TWWC. While the capacity of the tank is 10 m^3 or 20 m^3, the small capacity is useful for drinking purpose at poor water quality area and at important places. *Figure 6.4.2* shows emergency water tanks with proposed modification.

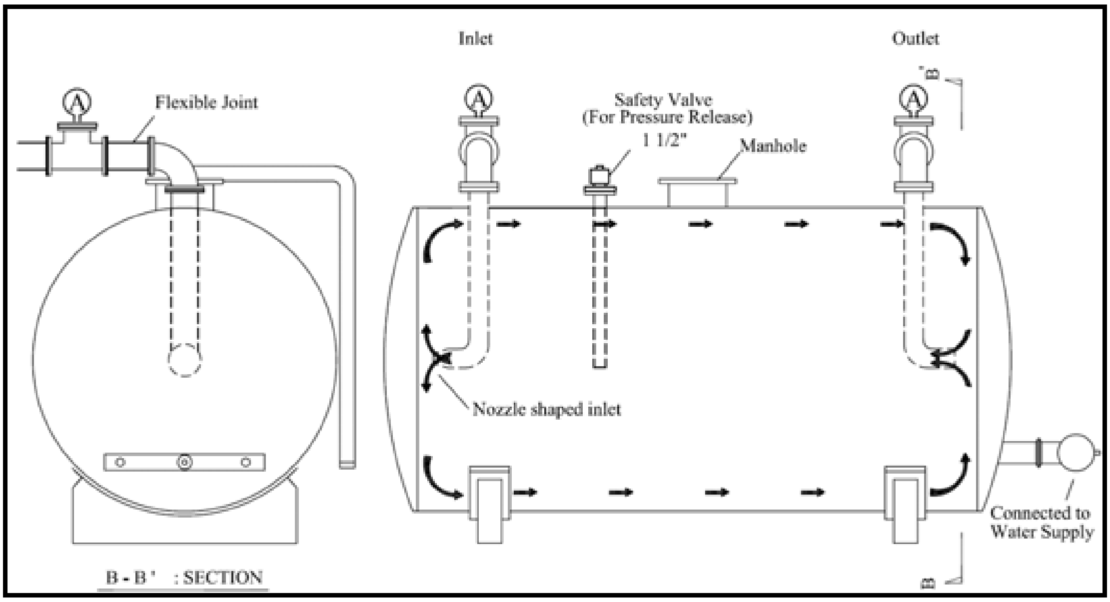


Figure 6.4.2 Emergency Water Tanks

6.4.2 Allocation of Emergency Water Supply Bases

In this Study, emergency water supply bases should be allocated so that anybody can access within 1 km distance after the earthquake, considering steep geographical feature here. At first, emergency supply bases should be allocated so that people can access to the base within 2 km distance in short-term planning. Then, additional bases should be gradually allocated so that maximum access distance to the bases can be reduced to within 1 km in the medium and long-term planning.

Following table outlines the numbers of required emergency supply bases to be allocated.

Table 6.41 Required Number of Emergency Supply Bases by Type and Planning Phase

	Type of supply points	*Number*		
		Short-term	*Mid & long-term*	*Total*
1	Existing reservoir (Outlet arrangement)	30	18	48
2	Existing reservoir (Emergency shut-off valve)	0	3	3
3	Gravity transmission (Southern Ring Main & Enqelab St.)	11	7	18
4	Deep well (owned by TWWC)	0	27	27
5	Deep well (in Park)	22	37	59
6	Emergency water tank	32	169	201

Figure 6.4.3 shows the locations of emergency water tanks within 2 km distance and Figure 6.4.4 shows these locations within 1 km distance. In the short term, measures of easy and low cost arrangement are selected.

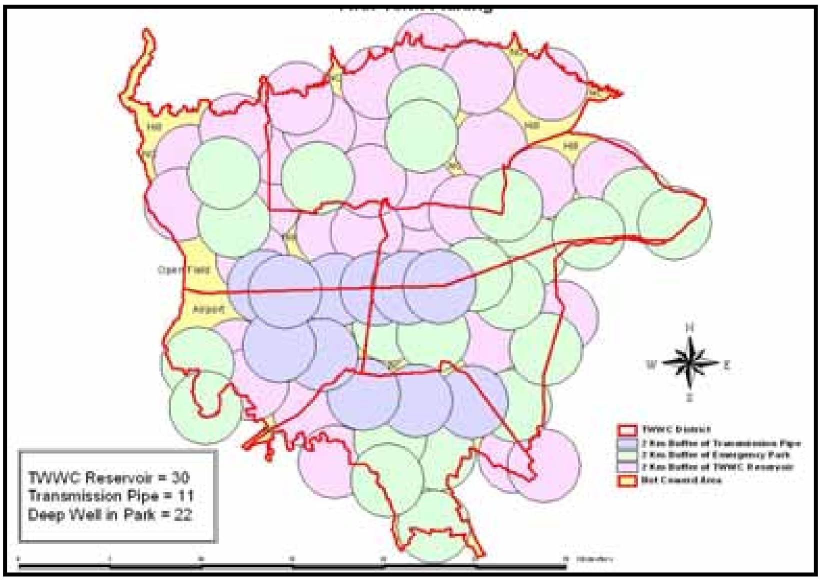


Figure 6.4.3 Emergency Water Supply Points within 2 km

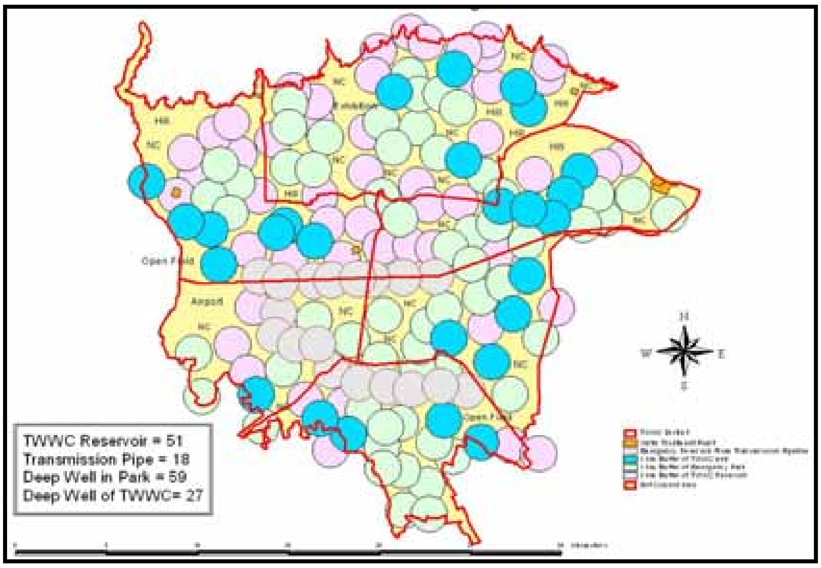


Figure 6.4.4 Emergency Water Supply Points within 1 km

In addition, this Study gives recommendation for consideration of prioritization for the sequence of construction of the emergency water supply bases in the short-term planning as well. In the course of determination of priority, following items should be considered:

- The area where number of supply interrupted population would be greater.
- The area where destruction of houses would be severer.
- The area where power supply suspension would be prolonged.
- The area where water tanker cannot access because the road does not have enough space.

S 7 DEVELOPMENT OF DRAFT EMERGENCY PLAN

Emergency plan is required for getting prepared to overcome disaster, for facilitating rapid rehabilitation of water supply system, and for providing drinking water to consumers immediately after an earthquake. It is important to take adequate anti-earthquake measures, which consider the balance of facility reinforcement and the emergency measures.

7.1 Supply Interrupted Population and Restoration Period

The restoration simulation is done to examine the effects of several anti-earthquake measures by using the indicator of total interrupted population for influence level.

7.1.1 Definition of Estimation of Supply Interrupted Population and the Restoration Period

(1) Precondition of Restoration Simulation

It is required to understand the quantitative influence on the residents by the earthquake. *Table 7.1.1* shows the precondition concerning the restoration simulation.

Table 7.1.1 Precondition of emergency restoration simulation

Item	Content considered by restoration simulation		Content that can be considered outside of restoration simulation
	Before measures	After measures	
a) Power plant	Off the subject	Off the subject	The power plant stops for about one week because of the influence due to the earthquake.
b) Installation of disaster headquarters	For about one week immediately after the earthquake (Period that requires it to establish the first moving system)	For about three days immediately after the earthquake(Because the first moving system is maintained, the period is shortened.)	
c) Well	It is possible to use it.	It is possible to use it.	
d) Raw water transmission main	Off the subject	Off the subject	Water treatment plant in the down-stream stops for a certain period.
e) Water treatment plant	Off the subject	Off the subject	The targeted Water treatment plant stops for a certain period.
f) Transmission main	In each water supply system, reserv-oir in the downstream of the damage part is assumed to be interrupted the water supply.	It is thought that an earthquake-proof pipe doesn't cause damage.	
g) Distribution trunk main	Every the reservoir zone and distri-bution trunk main damage rate are assumed.	It is thought that an earthquake-proof pipe doesn't cause damage.	
h) Distribution sub main Serivce connection	Every the reservoir zone and distri-bution sub main damage rate are assumed.	It is thought that an earthquake-proof pipe doesn't cause damage.	

This simulation is done for scenario earthquake of North Tehran, which will cause the most serious damage.

(2) Calculation procedure of restoration simulation

While the flow chart for the calculation procedure of the restoration simulation is shown in *Figure 7.1.4* in the main report, the method of the simulation is described below.

a) Setting of population of each reservoir zone

The population of 6,938,734 persons in Tehran City in 2005 (Information of Iran Statistics data, District 21-22 were excluded) is allocated to each reservoir zone for the analysis.

b) Setting of transmission main network system

The condition of daily maximum water supply (as of July 19th 2005) is used for the base system.

c) Setting of system of recovery efforts

The organization for pipe repair works is set as *Table 7.1.2* based on the hearing results from TWWC. The hearing revealed that transmission mains are repaired by TWWC head office and Water District offices are responsible for distribution trunk mains, distribution sub mains, and service connections.

Table 7.1.2 Organization of pipe repair works

Type of pipe	Manager	Number	Grounds
Transmission main	TWWC head office	3 teams	System of recovery of transmission main One team is composed of 12 persons
Distribution trunk-main	Water Districts	18 teams	6districts×3 post One team is composed of 12 persons
Distribution Sub-main	Water Districts	54 teams	6 districts×3 post×3team One team is composed of 12 persons
Service connection	Water Districts	108 groups	6 districts×3 post×3team×2group One team is composed of 3-4 persons

d) Calculation of restoration process

The basic idea of the restoration simulation is described below.

Basic idea to simulate restoration

- The period for calling staffs, gathering damage information, and establishment of restoration organization "before taking countermeasures" is assumed as one week. It is set as three days "after taking countermeasures", such as preparation of manual and improvement of staff wills.

- Pipe restoration team distributes each transmission main network system at rates of the number of damage.

- The pipes are considered to be repaired from upstream to downstream (i.e., transmission main→distribution trunk main→distribution sub main→service connection). It is assumed that two teams cannot work at one time on the same pipeline since restoration work of transmission line and distribution mains shall be done from upstream to downstream.

- The restoration period of pipe repair at one place is set as twice of the usual restoration period, which information is obtained by hearing of TWWC, in consideration of difficulties in a traffic condition after earthquake due to building collapse, interruption of the road and others.

Table 7.1.3 Required Period for Pipe Restoration

Type of pipe	Diameter of pipe	Required period for restoration
Transmission main	X≧ϕ600mm ϕ600mm>X≧ϕ300mm	0.33 Part/day/team 0.5 Part/day/team
Distribution trunk main	X≧ϕ300mm	0.5 Part/day/team
Distribution Sub main	X<ϕ300mm	1.0 Part/day/team
Service connection		2.0 Part/day/team

e) Calculation of the water supply interrupted population

Water supply interrupted population is calculated from "the population of each reservoir zone" and "damage rate of pipes". The basic idea for the calculation is described below.

Basic Idea for Calculation of Water Supply Interrupted Population

- Water supply interrupted population is calculated based on the damage rate of pipe of transmission mains, distribution trunk mains, distribution sub-mains, and service connections.

- The damage of power plant, raw water transmission main, water treatment plants, reservoirs, and pumps house are excluded from the restoration simulation.

- When transmission main is damaged, water supply in all downstream reservoir zones is assumed to be interrupted.

- When transmission main is not damaged, the damage rate of reservoir zone is calculated by using the damage rate of distribution trunk main and the damage rate of distribution sub-main.

The water supply rate of interrupted reservoir zone
= 1 − (1−damage rate of distribution trunk main) × (1−damage rate of distribution sub main)

The water supply interrupted population in reservoir zone
= population of reservoir zone × the water supply rate of interrupted reservoir zone

7.1.2 The Analysis Results

(1) Case study

In order to achieve the target restoration period of one month, suitable countermeasures, which consider balance of reinforcement and emergency measures, are examined by restoration simulation. Conditions of the simulation of each case for the case study are summarized in *Table 7.1.4.*

Table 7.1.4 Conditions of Simulation for Each Case

CASE-1	Without Any Countermeasures
CASE-2	When transmission main is earthquake-proof
CASE-3	When transmission main is earthquake-proof and the number of restoration team is increased.
CASE-4	When transmission mains are earthquake-proof and active fault measures are adopted in distribution trunk mains
CASE-5	When transmission mains are earthquake-proof and active fault measures are adopted in distribution trunk mains and distribution sub mains.

(2) The water supply interrupted population and required period for restoration

The water supply interrupted population and required period (days) for restoration in each case study are shown in *Table 7.1.5.*

Table 7.1.5 The water supply interrupted population and required days for restoration

No	the water supply interrupted population			required days for restoration
	Initial (1000 person)	Initial rate (%)	total (1000 person)	(day)
CASE-1	3,995	57.6	125,770	82
CASE-2	1,739	25.0	64,483	73
CASE-3	1,739	25.0	29,728	30
CASE-4	1,640	23.6	48,382	65
CASE-5	1,591	22.9	45,015	60

※Initial rate＝initial water supply interrupted population ÷6,938,734 people（Information of Iran Statistics data）×100

The transition of the water supply interrupted population in each reservoir zone is shown in *Figure e 7.1.1* (CASE-1 and CASE-3).

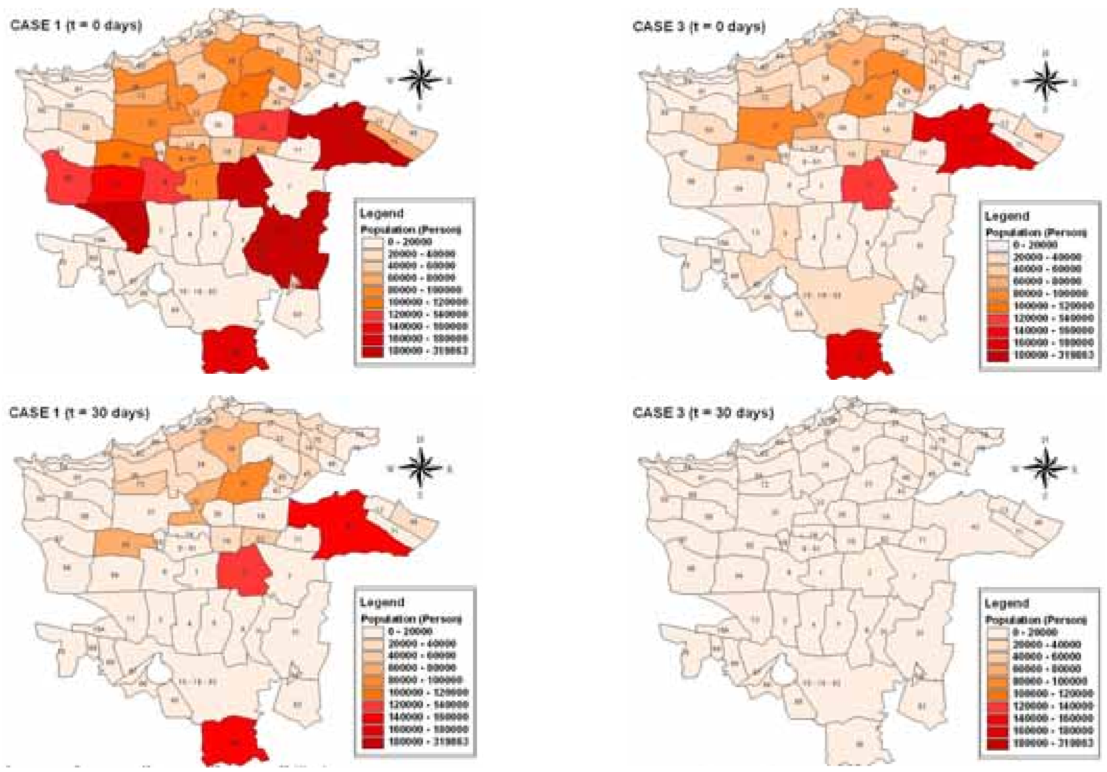


Figure 7.1.1 Water supply interrupted population（t=0 and t=30）

7.1.3 Analysis on Effect of Anti-Earthquake Measures

Figure 7.1.2 shows the water supply interrupted population and the restoration period in each case. The difference of the initial water supply interruption population in CASE-1 and CASE-2-CASE-5 is mainly due to effects of restoration of transmission mains. The difference of restoration period in CASE-2 and CASE-3 is due to an effect of the increase of emergency restoration team. In CASE-3, the target for the restoration period of one month can be achieved.

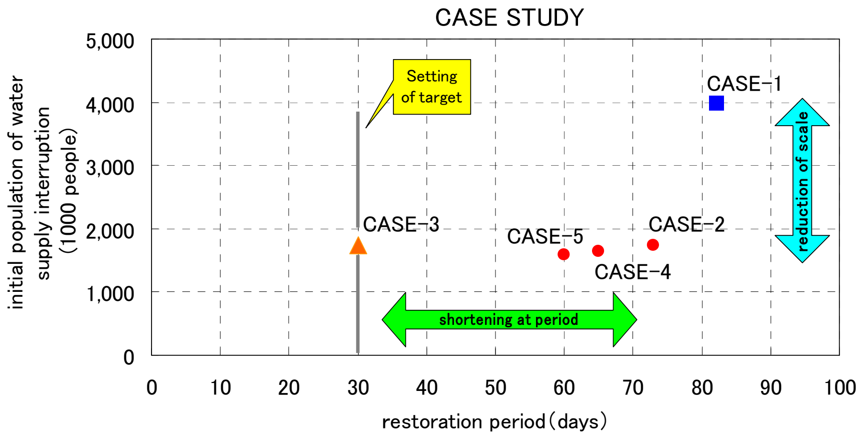


Figure 7.1.2 Water Supply Interrupted Population and Restoration Period in each Case

The results of CASE-2, CASE-4, and CASE-5 show that the target cannot be achieved only by reinforcement of pipelines. It is necessary to consider reinforcement of transmission mains and increase of restoration teams just like CASE-3 for achieving the target. It is required to examine the priority and the balance of "the amount of facility reinforcement works" and "the number of recovery teams" in consideration of budget.

The simulation considers damage in pipeline only. When damages on power plants and raw water, water treatment plants and its upstream are considered, each restoration period and the water supply interrupted population should be added to the result of the above simulation.

7.2 Common Countermeasures for Emergency Water Supply and Restoration

(1) Organization and Initial Activities of Emergency Countermeasures

TWWC has prepared a organization chart for commanding of crisis management and duty description of divisions' head. Based on the above, crisis management organization is summarized in *Figure 7.2.1*.

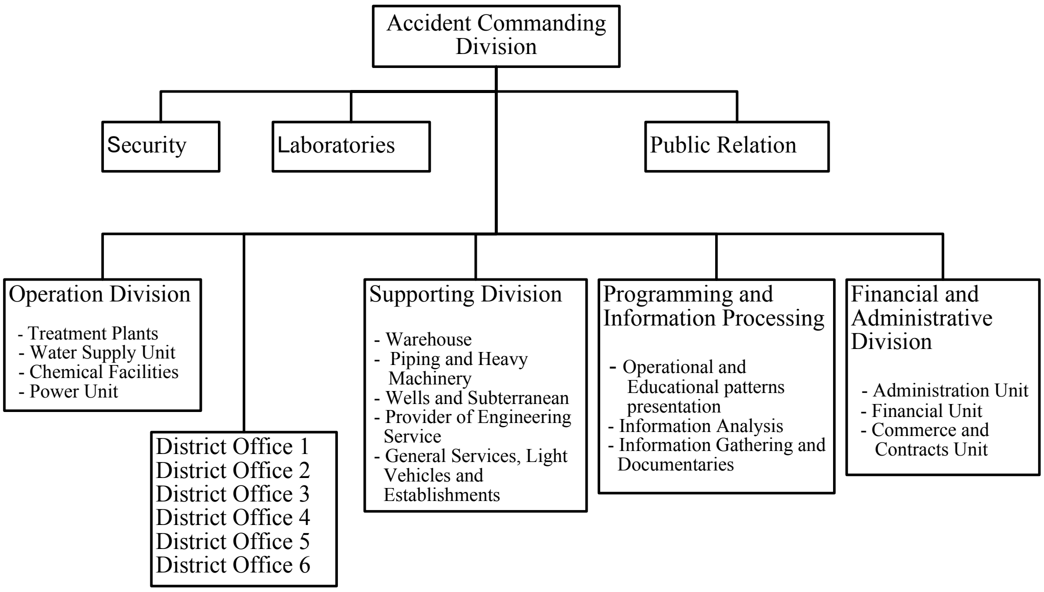


Figure 7.2.1 Organization for Crisis Management in TWWC

It is necessary to make clear the duties of each division and all staffs understand their duties beforehand. Accident Commanding Division should be set up just after earthquake disaster to start control of the emergency activities without delay. The major items of the initial activities are listed below.

- To set up organization of crisis management
- To collect information and check the level of damage of the water supply system
- To communicate / coordinate with related organization
- To request supports from other organizations and private companies
- To start emergency water supply
- To prepare restoration plan by deciding priority and to start leak detection & repair works

Quick mobilization of staffs is indispensable for stating emergency activities without delay. TWWC is required to prepare rules for staff gathering such as obligation of the staff, gathering locations, staff list at each location, and notes. Following methods are recommended for expedition of staff mobilization.

- Preparation and rental of accommodations to key staffs of restoration in the same water district. These key staffs should work for the initial activities.
- Re-arrangement of repair staffs' work assignment to the nearest water district from their resident.
- Providing motorbikes to key staffs for quick mobilization after earthquake. These key staffs should collect information of damage at the sites by using the motorbikes and report to the leader.

Periodical maneuvers for improvement of the skills and conscious mind of staffs are recommended.

(2) Assistance from other Organizations (Relation with other Organizations)

Figure 7.2.2 shows the methods of calling assistance from other organizations to TWWC.

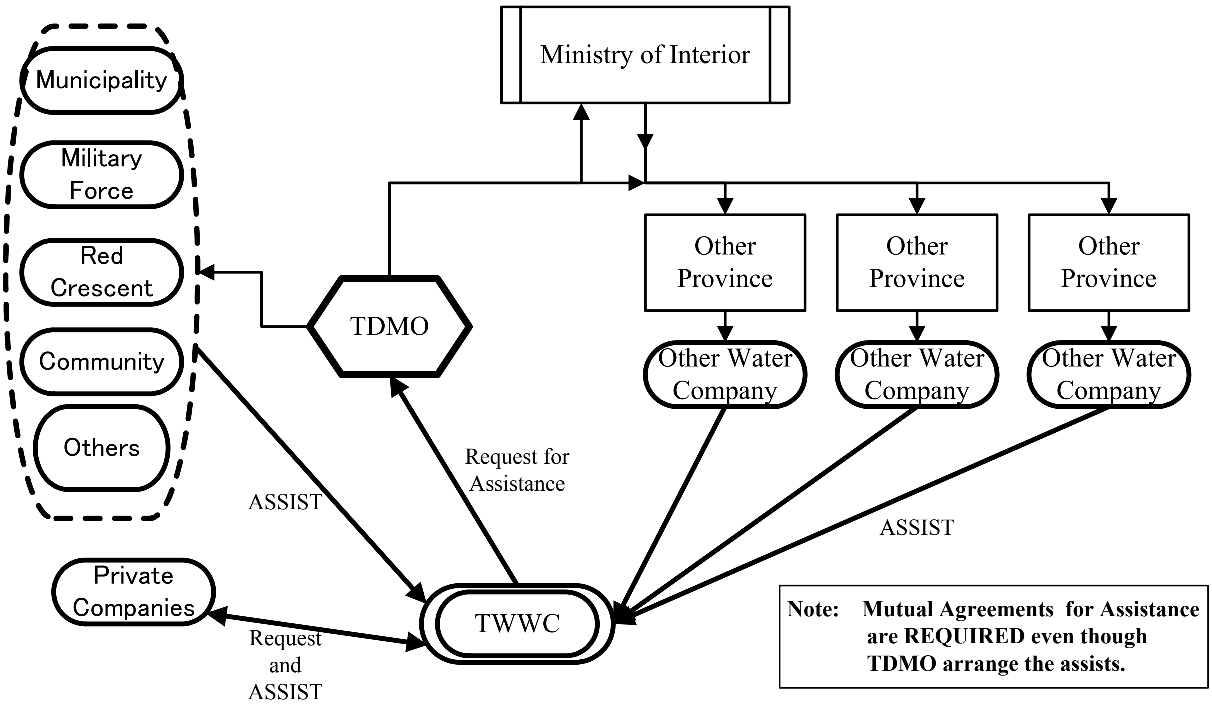


Figure 7.2.2 Assistance from Other Organizations

Tehran Disaster Management Organization (TDMO) is responsible for the arrangement of important organizations, such as military, Red Crescent, fire fighting organization, police, electricity company, and TWWC, after disaster. While TDMO arranges support from water companies in other provinces, it is required for TWWC to discuss and make mutual agreements with them. The discussion should include the number of assistant team, available materials & equipment, duration of assistance and responsibility of cost. It is important to have periodical discussions for reviewing the agreement, and for exchanging information of activities such as improvement of stocked materials, pipeline drawings, and manuals. In addition, private companies will also become a great help after earthquake. It is required to have discussions with them and make arrangement, which includes following supports:

- Supply of pipe and other materials
- Emergency restoration of pipes
- Rental of heavy vehicles with operators
- Rental of water tankers

It is necessary to prepare manuals beforehand in order for assistants to execute smooth and adequate emergency activities. Preparation of general maps and pipe drawings, which show emergency water supply bases and important facilities, is a must. They should be kept in several locations.

(3) Preparation of Manual

The manuals should explain initial activities, organization, communication system after disaster, list of other water companies & private companies with the explanation of support contents, TWWC's responsibility to assistant teams, and commanding system. It is important to make all the staffs of TWWC understand the manuals and to revise them periodically.

(4) Communication System

Collection and analysis of information is indispensable for planning of emergency activities. It is required to decide rules for communication and to secure several communication systems. Telemetry system should be used efficiently after earthquake. It is also necessary to review the number of several communication systems, such as such as telephone and mobile phone, telemetry system, fixed type wireless communication system, mobile type wireless communication system, and internet. The necessity is found, during the study, to make communication facilities as earthquake resistant by fixing the bolts and to provide sufficient generators and batteries for the communication system.

7.3 Emergency Water Supply Plan

As shown in the *Figure 7.3.1*, existing reservoirs and existing wells should be used as water supply bases. The number of the base will be increased by setting emergency water supply taps at distribution lines.

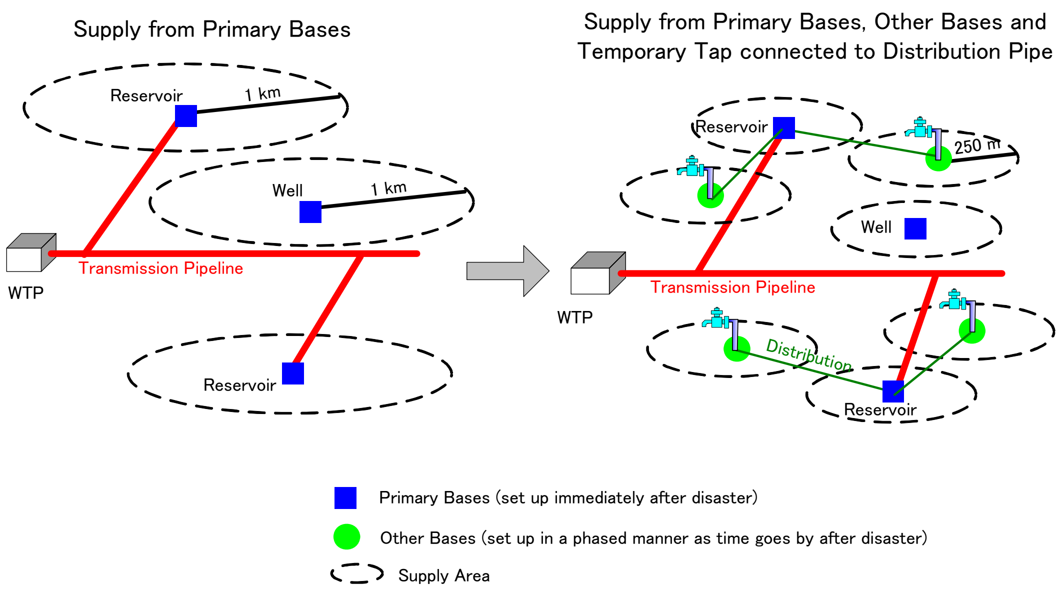


Figure 7.3.1 Image of Emergency Water Supply

(1) Methods of Emergency Water Supply

It is important to prepare emergency water supply plan beforehand for smooth execution of emergency water supply. The emergency water supply bases will feed water to emergency cars, such as water tankers and fire fighting, in addition to supply water to consumers. When traffic of road is secured after earthquake, water tanker is very useful to transmit water to temporary tanks and to important facilities, such as general hospitals and evacuation places. It is required to prepare a list of private companies, which are now watering the greens by water tankers, and then to discuss with municipality for emergency usage of these water tankers after earthquake. Since emergency distribution of bottled water will be useful to supplement the emergency water supply activities, it is recommended to consider introduction of water packing machine for water bag at water treatment plants.

(2) Proposed Duty Description for Emergency Water Supply

The major candidates of assistants for emergency water supply will be municipality, other water companies and volunteers. Volunteers can assist water supply activities after short training, while water tanker can be supplied by TWWC, private companies, other water companies, and military service. Since it is better for technical staffs in TWWC to put efforts on emergency restoration, other staffs should perform the key roles of emergency water supply. In addition, the division of public relation (PR) is necessary to give sufficient information to the consumers, while laboratories should have responsibility of checking water quality, considering the possibility of contamination from damaged facilities. It is also important for Supporting Division to take responsibility of storage of materials and equipment.

(3) Emergency Water Supply to Important Facilities

Since it takes time to strengthen distribution pipe routes up to important facilities despite the high priority, several methods should be considered to secure water. Evacuation places should be basically selected as emergency water supply bases. Water supply to the hospitals should be done by water tankers when it is necessary and practical. It is also required to guide general hospitals to secure water by themselves by preparing deep wells and generator or large reservoirs. Water in the reservoirs can be used for fire fighting through distribution pipes and fire fighting cars can get water from emergency water supply bases when distribution pipelines are damaged. TWWC is also necessary to discuss Fire Fighting Organization on water securing methods, such as usage of qanat water and groundwater from wells, and to recommend the Organization to prepare generators for usage of well pumps during power suspension.

7.4 Emergency Restoration Plan

Preparation of emergency restoration plan, especially increase of work teams and properly organized restoration, is indispensable for quick recovery of water supply system.

(1) Procedure and Methods of Emergency Restoration

Information of damage should be collected just after earthquake for preparation of restoration. Observation of abnormality in telemetry system or other meters will give information for initial judgment of damage level, which is required for preparation of countermeasures. And then, checking of pipe condition at sites should be started from transmission mains and distribution main pipes, which are important pipes, and then continued to sub-mains. High risk locations of damage along the main pipe should be listed up beforehand for quick patrol. The emergency restoration plan should be revised after progress of the activities. The damage states and restoration results should be recorded in the format as shown in the main report and used as the data for permanent restoration, which should be done considering future plans.

(2) Proposed Duty Description on Emergency Restoration

Duty description of each division should be prepared and all of the staffs should clearly understand it. Operation Division is required to prepare restoration plan and coordinate six water districts for execution of restoration works. District Offices and Emergency Posts are responsible for actual emergency restoration at sites. Supporting Division is responsible for storage and supply of pipe material, heavy machinery, tools and equipment. Adequate tools and equipment should be prepared for restoration teams and especially for assistants. When the stock of pipe materials and other tools are insufficient, they should be brought from supplier / manufacturer as soon as possible. It is important to keep good relation with private companies during ordinary times.

S 8 FORMULATION OF EARTHQUAKE RESISTANT PLAN

8.1 Selection of Earthquake Resistant Measures

The earthquake resistant plan to be formulated hereunder is aiming at realization of measures for Tehran water supply system resistant to earthquake. When essential measures such as relocation of a water treatment plant are taken, the earthquake resistant plan becomes very costly, and it does not generate any increase of water sales income. These measures are excluded from the plan to be formulated 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 is included in the earthquake resistant plan.

8.1.1 Measures for Upstream Facilities

Earthquake resistant measures for raw water transmission mains and water treatment plants are described hereunder. Analysis of raw water main has not been done due to insufficient data and the scope of this work. Since these are so fundamental and important facilities to convey water to Tehran city, comments are made regarding the countermeasures against seismic forces.

As shown in *Table 8.1.1*, fault crossing points of raw water transmission mains or tunnels will be damaged in case of a great scenario earthquake. Water treatment plants No.3&4 and No.5 which are located on the faults will also be damaged. It is difficult to reinforce them completely against the earthquake or to relocate them to a safety location due to their size and necessary cost. Minimization or mitigation of the damage effect will be realistic measures. Considering location of these facilities or distance from the scenario faults, it is hardly considered for two or more systems to be damaged simultaneously by an earthquake occurrence. Therefore, countermeasures are studied on the assumption that one of the WTP systems will be damage by a scenario earthquake.

Interruption of No.1 or No.5 WTP system will not affect much to its service area because water can be transmission to the area by other live systems, as analyzed by hydraulic simulation in section 4.3 in the main report. However, No.2 or No.3&4 systems could not be covered by others. Therefore, water transmission from the future WTP No.6 to WTP No.2, interconnection of WTP No.3 and No.4, or water transmission from WTP No.5 to No.3&4 will become necessary. Water supply by tankers should also be taken into account.

As for smaller earthquakes, structural analysis based on Code 2800 was made for water treatment facility structures. The bearing capacity of structural members of several facilities was found to be insufficient by the analysis. There are a lot of mechanical and electrical equipment which are not fixed firmly to walls or floors. These facilities or equipment should be reinforced to earthquake resistant. Installation of shear walls, reinforcement of clarifier walls or retrofitting of brick walls will be major work items for facility reinforcement, and fixation of the equipment to walls or floors or installation of Chlorine neutralization equipment should be included in the countermeasures as studied in chapter 6 of the main report.

8.1.2 Measures for Downstream Facility

Measures for downstream facilities from clear water transmission mains to distribution networks as shown in *Table 8.1.2*, are employed in the earthquake resistant plan.

As for transmission mains, their reinforcement is employed as a principal measure for minimization of damage occurrence. Estimated damage points, reliability of 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 with reliability of 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 upper section of distribution trunk mains shall be reinforced for minimization of damage occurrence although principle measure for water distribution mains is emergency water supply and restoration. Trunk mains at fault crossing and connection to structures in northern part are planned to be reinforced. Damages on other trunk mains and sub mains will be covered by emergency countermeasures.

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

There are facilities and structures which are partially insufficient in bearing capacity for Code 2800 similar to the case of WTP. There are also mechanical and electrical equipment with unstable installing conditions and with possibility of second disaster occurrence. These facilities and equipment are planned to be reinforced properly.

Table 8.1.1 Countermeasures for Raw Water Main and Water Treatment Plant

	System	No.1 (Jalaliyeh)	No.2 (Kan)	No.3&4 (Tehranpars)	No.5 (Panjom)
Facilities Water Source	Main Dam	Karaj Dam Tareghan Dam (Sapplemental Source of Karaj Dam)	Karaj Dam	Latiyan Dam	Lar Dam
Raw Water Main	Type and Dimensions	D1,000mm x L73km x 2sets Steel Pipelines	D2,000mm x 67km x 2sets Reinforced Concrete Pipes	D2,700mm x L9km +D3,000 x L20km Tunnel	D3,600mm x 11.3km + d2,000 x L7.2km x 2sets
	Fault Crossing	1 point near Bileghan	8 points between Bileghan and WTP No.2	2 poins between Dam and WTP No.2	
	Fault Related	North Tehran Fault	North Tehran Fault	North Tehran/Mosha	North Tehran/Mosha
	Fault Dislocation	40 - 50cm	30 - 40cm	30 - 40cm	
WTP	Capacity	$2.7m^3$/day	$8.0m^3$/day	$8.0m^3$/day	$7.5m^3$/day
	Fault Location	remote from fault	remote from fault	on the fault	on the fault
Fragility of the System	For Scenario Earthquake: Pipes	Damage estimation of raw water mains was not executed, because they are located out of the study area. However, it is considered that raw water mains and raw water tunnels would be damaged by fault dislocation.			
	WTP	Not much damage on whole WTP	Not much damage on whole WTP	WTP would be damaged by fault dislocation	
	For Historical Earthquake: Pipes	Damage estimation of raw water mains was not executed, because they are located out of the study area.			
	Code 2800: WTP	Damages on some parts of facilities and equipment	Damages on some parts of facilities and equipment	Damages on some parts of facilities and equipment	Damages on some parts of facilities and equipment
Possibility of Reinforcement or Mitigation	Coverage by Other WTP or Transmission Main When Interrupted	Water transmission from WTP No.2 and No.3&4 could almost cover WTP No.1 area.	Several zones around WTP No.2 would suffer water shortage, bacause of its capacity and higher elevation	Several zones around WTP No.3 &4 would suffer water shortage, bacause of its large capacity and insuffficien transmission capacity of No.5 to	Water transmission from WTP No.3&4 and No.2 could almost cover No.5 area. Because No.3 &4 supplied No.5 area until recent years.
	Possibility of Prior Reinforcement	Not much difficult because of only one fault crossing and moderate pipe diameter	Difficult because of big diameter pipelines and many fault locations	Difficult of reinforcement for both of tunnel and WTP	Difficult of reinforcement for both of tunnel and WTP
	Other Measures for Mitigation	Not necessary	Possibility of transmission of Tareghan water, WTP No.5 and future WTP No.6 water	Large scale water transmission from WTP No.5. Interconnection of No.3 and 4	Interconnection of No.5 and future WTP No.6
Measures to be Adopted for Raw Water Main and WTP	For Scenario Earthquake: Pipes	Necessary to study in detail of reinforcement at fault crossing	Necessary to study above measures especially for minimization or mitigation of damage effects		
	WTP	No measure at present other than coverage by others.	Cover by others and emergency wate supply by tankers.	Cover by others and emergency wate supply by tankers.	No measure at present other than coverage by others.
	For Historical Earthquake: Pipes	Same study as for scenario earthquakes is considered necessary.			
	Code 2800: WTP	Parts or members of facility stuructures and equipment should be reinforced			

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Table 8.1.2 Countermeasures for Water Transmission and Distribution Facilities

Facilities and Their Conditions	Numbers	Description and Inclusion in the Project
1) Clear Water Transmission Main	Target	Reinforcement for minimization of damage
General		
Dimensions		Diameter: 2000-150mm, Length: 399km
Number of fault crossing	39	Twin pipes are counted as one pipeline
Connection to structures	150	
Damage by scenario earthquake		Reliability smaller than 70% (R<70%)
Fault crossing	60%	To be implemented in the project
Connection to structures	20%	To be implemented in the project
Damage by scenario earthquake		R>70%
Fault crossing	40%	To be implemented in future stage
Connection to structures	80%	Included: larger reliability but cheap/easy implementation
2) Distribution Trunk Main	Target	Basically treated by emergency countermeasures
General		
Dimensions		Diameter: 1600-300mm, Length: 768km
Number of fault crossing	95	
Connection to structure	190	
Damage by scenario earthquake		R<70%
Fault crossing	30%	To be implemented in the project considering high priority
Connection to structures	20%	To be implemented in the project considering high priority
Damage by scenario earthquake		R<70%
Fault crossing	70%	To be implemented in future stage
Connection to structures	80%	To be implemented in future stage
3) Distribution Sub Main	Target	Treated by emergency water supply and restoration
General		
Dimensions		Diameter: 250-50mm, Length: 6385km
Number of fault crossing	552	
Damage by scenario earthquake	868	Not included in the project
4) Distribution Reservoirs	Target	Minimization of damage effect
General		
Numbers	70	Including contact tanks and clear water tanks
Numbers located on fault	9	
Damage by Scenario Fault		
Reservoir on Fault	9	By-pass installation or supply by other facilities
Insufficien Capacity by Code 2800		
Aged/Deteriorated Reservoirs	15	Reinforcement of structure members or refurbishment
5) Pump stations	Target	Minimization of damage effect
General		
Numbers	40	
Numbers located on fault	3	
Damage by Scenario Fault		
Reservoir on Fault	3	Water supply by other facilities or supply by tankers
Insufficient Capacity by Code 2800		
Aged/Deteriorated Pump House	21	Installation of share walls & reinforcement of brick walls are included in the project
6) Mechanical and Electrical Equipment		
Damage Judged by Site Survey and Foundation Bolt Strength		
Unstable and unsafety Equipment	Many	Fixation/support of equipment, installation of chlorine neutralization equipment, etc. are included in the project.

8.2 Setting of Project Period and Target Year

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 short term stage for the first three years, middle term stage for next four years and long term stage for the last five years. TWWC places 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.

Thus, the project period is set as 12 years after one year preparation and the target year of the project is et 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 for five years from 2015 to 2019 as shown in *Table 8.2.1*.

Table 8.2.1 Proposed Project Period

Year	2007	2010	2014	2019	
Period	Preparation	Short Term	Middle Term	Long Term	Future
	1 year	3 years	4 years	5 years	

8.3 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 but some of them would be imported from foreign countries. So, the costs are estimated dividing into local cost and foreign cost.

Thus, construction cost is preliminarily estimated as approximately US$22Million and the total project cost is estimated as US$28.5million as described in *Table 8.3.1*. The project cost estimated corresponds to US$2.5Million/year which is 3.5% of the annual water sales income in the last year.

Table 8.3.1 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	

8.4 Implementation Program

8.4.1 Stepwise Implementation Program

Priority of implementation for each work item is studied considering emergency, importance, social condition, cost and benefit. Evaluation items for the priority are summarized in *Table 8.4.1*.

Table 8.4.1 Evaluation Items for Priority of Implementation

➢ Fragile Facility - located on the fault - not fixed appropriately - already deteriorated - made of fragile material ➢ If damaged, facility operation stops ➢ If damaged, suffers casualties ➢ If damaged, bigger loss occurs ➢ If damaged, secondary disaster occurs	➢ Damage of upper facility causes bigger loss ➢ Facility easily retrofitted ➢ Large benefit gains from small cost ➢ Improvement order among similar facilities - from aged or deteriorated items - from items affecting largely ➢ Facility for securing emergency water ➢ Facility for emergency water supply

Other than considering the above evaluation items, there is the most important item for considering implementation of the earthquake resistant plan and that is investigation of fault locations which is considered to take three to four years to complete. Thus, cost for short term program is set small, while cost for long term is estimated bigger as shown in *Table 8.3.1*.

S9 ECONOMIC ANALYSIS FOR PROJECT EVALUATION AND FINANCIAL PLANNING

9.1 Objectives of Economic Analysis

The earthquake resistant project which aims at strengthening functions of critical lifelines is based on the assessment of the scale of avoiding losses and damages caused by the occurrence of the scenario earthquake. Furthermore, the following factors should be taken into account in evaluating the specific earthquake resistant project.

a) The earthquake resistant project itself does not substantially increase the amount of water supply, and, as a result, it also does not generate any additional cash revenues from users.

b) The benefits of the earthquake resistant project are uncertain due to the fact that it depends on the frequency and scale of the occurrence probability of the scenario earthquake.

c) The earthquake resistant project significantly contributes to the national interest through the protection of the lifelines of the capital.

Generally, benefits of an earthquake resistant project derive from the reduction in the number of days required for the restoration from the scenario earthquake. More concretely, these benefits will be quantified in the form of the monetary value of avoiding i) the loss of the value added in the damaged area by the water supply interruption, ii) the additional cost of workers required for the restoration, and iii) the additional cost of workers required for the emergency water supply.

9.2 Project Benefits

In accordance with the execution of the project, the number of the service population affected by the water supply interruption will be significantly decreased, thereby leading to approximately 2.2 million reduction in the number of the affected population. It should be noticed that while the initial interruption ratio for the water supply before the earthquake resistant investment is estimated at 44.2%, the ratio after the investment will be considerably decreased to 25.0%. In addition, the number of the required workers for the restoration works will be also decreased to a large extent. It is estimated that the number of worker-days required will be decreased from 44,268 to 18,468 after the project, leading to the massive down-sizing by 25,800 worker-days. Furthermore, the number of the required workers for the emergency water supply will be also decreased to a large extent. It is estimated that the total number of worker-days required for the emergency water supply will be decreased from 13,083 to 5,412 after the project, leading to the significant reduction by 7,671 worker-days.

9.3 Cases for Economic Analysis

These economic benefits are converted to the annual economic values based on the earthquake occurrence probabilities in accordance with the following 7 cases under 4 approaches, as *Table 9.3.1* shows.

Table 9.3.1 Cases for Economic Analysis and Earthquake Occurrence Probabilities

Case	Analytic Approach	Earthquake Probability	Level of Risk
Case A	Basic Scenario Approach *1)	Scenario Earthquake (Once per 500 years)	Risk of Basic Scenario Earthquake
Case B	Risk Premium Based Approach	Once per 400 years	Between Case A and Case D
Case C	Risk Premium Based Approach	Once per 300 years	Between Case A and Case D
Case D	Risk Premium Based Approach	Once per 200 years	Lower Limit of Actually Traded Risk
Case E	Risk Premium Based Approach	Once per 100 years	Upper Limit of Actually Traded Risk
Case F	Service Life Based Approach	Once per 50 years	One Earthquake Occurrence during Service Life
Case G	Catastrophic Risk Based Approach	-	No Consideration of Earthquake Probability

Source: Categorized by JICA Study Team

By applying the above earthquake occurrence probabilities as well as the relevant conversion factors, the annual benefits on financial price basis are calculated and converted to the annual benefits on economic price basis, as *Table 9.3.2* shows.

Table 9.3.2 Annual Benefits on Financial and Economic Price Basis

Case	Earthquake Probability	Annual Financial Benefits (USD)	Conversion Factor	Annual Economic Benefits (USD)
Case A	Once per 500 years)	811,725	0.970	787,374
Case B	Once per 400 years	1,014,657	0.970	984,217
Case C	Once per 300 years	1,339,347	0.970	1,229,167
Case D	Once per 200 years	2,029,314	0.970	1,968,434
Case E	Once per 100 years	4,058,627	0.970	3,936,868
Case F	Once per 50 years	8,117,254	0.970	7,873,737

Source: Calculated by JICA Study Team

9.4 Project Costs

The total project cost is estimated at USD 28,500 thousand, which will be invested in 12 years from the financial year 2008 to 2019. The financial investment costs are converted to the economic costs by using the respective conversion factors. The replacement costs as well as the operation and maintenance costs for facilities and equipment are also included in addition to the investment cost.

9.5 Results of Economic Analysis

Although the seismic risk of the scenario earthquake is relatively low and uncertain, the following 4 approaches for the economic analysis will lead to the justification of the economic feasibility of the earthquake resistant investment. The results of the sensitivity analysis considering risk factors such as the cost increase by 10 percent as well as the benefit decrease by 10 percent are also computed, as *Table 9.5.1* shows.

a) In accordance with ***"Basic Scenario Approach"****1), the results reveal that the economic indicators such as EIRR is far less than the cut-off rate of 5 percent, implying that the project does not seems to be economically feasible based on the basic scenario basis.

NOTE – Basic Scenario Approach*1) : Occurrence probability of earthquake, which has the same intensity level of scenario earthquake, can be assumed as around 2,000 years by observing *Figure 3.4.1*, which is obtained from "Research Project for Strengthening and Control of Tehran Gas Network Against Earthquake Phase 2". Since there are four scenario earthquakes, the occurrence probability for one of them is tentatively assumed as one-forth of 2,000, i.e.500 years for the economic analysis purpose in the Study.

b) In accordance with ***"Risk Premium Based Approach"*** which is based on the assumption that the earthquake occurrence probability ranges from 0.005 (once per 200 years) to 0.01 (once per 100 years) referring to the actual earthquake risk market, the results prove that the economic indicators such as EIRR exceeds the cut-off rate of 5 percent even in case of the lower limit of the actually-traded earthquake occurrence probability of 0.005 (once per 200 years), implying that the project seems to be economically feasible based on this approach.

c) In accordance with ***"Service Life Based Approach"*** which is based on the assumption that, regardless of the risk of the scenario earthqauke, the earthquake occurrence probability is fixed at the level that the scenario earthquake might occur once during the project life of 50 years, the results show that the economic indicators such as EIRR are much higher than the cut-off rate of 5 percent to prove the ample economic viability of the project.

d) Furthermore, even though the probability of the scenario earthquake occurrence is extremely low, the results of ***"Catastrophic Risk Based Approach"*** suggest that the project is justifiable regardless of the risk probability, implying that the probable maximum loss by the scenario earthquake is catastrophically devastating enough once the earthquake happens. According to the estimate of damages by the scenario earthquake, the probable maximum loss is estimated at USD 407,723 thousand which is 0.247 percent and 0.665 percent of the current GDP and the gross capital formation of the country, respectively.

Table 9.5.1 Calculations of EIRRs

Case	Earthquake Occurrence Probability	Base Case	Risk 1 (Cost=10%up)	Risk 2 (Benefit=10%up)	Risk 3 (Both Risks)
Case A	Scenario Earthquake (once per 500 years)	0.62%	0.03%	0.02%	-0.51%
Case B	Once per 400 years	1.93%	1.36%	1.30%	0.75%
Case C	Once per 300 years	3.69%	3.07%	3.00%	2.40%
Case D	Once per 200 years	6.73%	5.98%	5.90%	5.19%
Case E	Once per 100 years	13.53%	12.43%	12.32%	11.28%
Case F	Once per 50 years	23.37%	21.82%	21.66%	20.18%
Case G	Probability Not Considered	n.a.	n.a.	n.a.	n.a.

Source: Calculated by JICA Study Team

In conclusion, the economic analysis based on the occurrence probability of the scenario earthquake cannot justify the massive investment on the earthquake resistant project with the lower economic indicator below the cut-off rate due to the fact that the occurrence probability of the scenario earthquake is extremely low. However, the results of the economic analysis, taking into account the economically-traded probability as well as the service-life based probability of the scenario earthquake, suggests that the earthquake resistant project is economically justifiable with the relatively higher economic indicators above the cut-off rate. Furthermore, the project could be economically viable, since the devastating scale of the maximum probable loss is considered regardless of the occurrence probability of the scenario earthquake.

In addition to the economic viability of the earthquake resistant project, there are a wide range of unquantifiable social benefits accrued from the project, thereby making the results of the economic analysis more justifiable. In conclusion, the central government as well as TWWC is fully responsible for implementing this earthquake resistant project which is economically worthwhile for the large-scale investment in the capital city of the country.

9.6 Objectives of Financial Analysis

The main objectives of the financial analysis are to assess a wide range of the following financial aspects of TWWC and to propose the optimum financial arrangement for funding the earthquake resistant project.

a) The impacts on a wide range of TWWC's financial sustainability indicators will be estimated.

b) The impacts on the TWWC's financial statements such as the profit and loss statement as well as the balance sheet will be estimated.

c) The impacts on the TWWC's avoidance of a huge amount of the revenue loss in case of the actual earthquake occurrence will be estimated.

d) The required amount of the subsidies as well as the tariff increase will be calculated to estimate the financial burden share between TWWC and users.

9.7 Cases for Financial Analysis

In an attempt to set up the basis for the financial analysis, 12 cases with the following financial variations are set up for the financial analysis as *Table 9.7.1* shows.

Table 9.7.1 Cases for Financial Analysis

Scope of Subsidy and Financing	Very Highly Concessional Loan (Repayment Period 40 Years, Grace Period 10 Years, Interest Rate 0.75%)	Highly Concessional Loan (Repayment Period 30 Years, Grace Period 10 Years, Interest Rate 2.00%)	Semi-Commercial Loan (Repayment Period 20 Years, Grace Period 5 Years, Interest Rate 5.00%)
No Subsidy	A-1	A-2	A-3
Subsidized for Only Pipelines	B-1	B-2	B-3
Subsidized for Pipelines + Facilities/Equipment	C-1	C-2	C-3
Subsidized for All Project Components	D-1	D-2	D-3

Source: Categorized by JICA Study Team

9.8 Results of Financial Analysis

The results of the financial analysis are summarized as below.

a) It is envisaged that the massive investment on the earthquake resistant project might worsen the financial sustainability indicators such as the working ratio and the operating ratio. The large-scale investment on the project will further deteriorate the alarming working ratio of 125.7 and the operating ratio of 129.2 which are both worse than the minimum requirements of the working ratio of 100.0 and the operating ratio of 120.0, respectively, even if the non-subsidized portion is financed by a lower-interest rate loan.

b) It is also concluded that the redemption of the loan for the earthquake resistant investment to cover the non-subsidized portion might also have considerable negative impacts on TWWC's financial statements such as the profit/loss statement as well as the balance sheet. As the worst scenario, Case A-3 under no tariff increase to cover the non-subsidized portion suggests that the gross profit and the net profit based on the financial statement 2005 of TWWC will be decreased by 5.83 percent and 2.12 percent, respectively.

c) Although the massive investment on the earthquake resistant project might cause a wide range of negative impacts on the financial status of TWWC, the project will be able to avoid a huge amount of the revenue loss of TWWC when the earthquake actually happens. The loss of the gross revenue to be avoided in case of the actual occurrence of the scenario earthquake is estimated at USD 2,596 thousand, which is 3.89 percent of the gross water sales of the financial year 2005.

d) Based on the required amount of subsides by the central government, the total amount of the loan for the non-subsidized portion by TWWC is fixed, thereby computing the maximum and average annual repayment in accordance with the variations of the financial cases. *Table 9.8.1* indicates the amount of required subsidies and the annual maximum/average loan repayment by TWWC.

Table 9.8.1 Amount of Required Subsidies and Annual Loan Repayment by TWWC

Case	Amount of Subsidies (Thousand USD)	Subsidies Ratio against Total Investment (%)	Total Amount of Loan by TWWC (Thousand USD)	Maximum Annual Repayment by TWWC (Thousand USD)	Average Annual Repayment (Thousand USD)
A-1	0	0.0	28,530	1,139	680
A-2	0	0.0	28,530	1,892	805
A-3	0	0.0	28,530	2,979	941
B-1	9,138	32.0	19,391	771	462
B-2	9,138	32.0	19,391	1,273	547
B-3	9,138	32.0	19,391	1,980	640
C-1	18,829	66.0	9,700	385	231
C-2	18,829	66.0	9,700	487	201
C-3	18,829	66.0	9,700	791	236
D-1	28,530	100.0	0	0	0
D-2	28,530	100.0	0	0	0
D-3	28,530	100.0	0	0	0

Source: Calculated by JICA Study Team

e) Apart from recommendations on the financial planning for this specific earthquake resistant project, the following financial arrangements should be separately adopted to achieve the financial soundness of TWWC in providing water supply services.

- The current tariff scheme does not support the full cost recovery for the total operating expenses of TWWC to provide city-wide quality water supply services. The tariff table should be comprehensively reviewed to cover at least the regular operational expenses as well as the non-subsidized portion of the investment cost. A wide range of counter-measures to reduce the NRW as well as to increase the current charge collection rate should be also taken to avoid the loss of tariff revenues.

- Operational efficiency should be significantly improved to achieve the full cost recovery for the operation of TWWC. The relatively lower number of staff per thousand connections (SWC), which is an indicator to measure operational efficiency, should be attained to avoid inefficient use of staff. Efficiency for the staff utilization should be improved so as to satisfy the minimum requirement for the number of SWC which is 5.00 per thousand staff.

- Other indicators to gauge operational efficiency should be also enhanced to achieve the full cost recovery. Those indicators include Working Ratio (WR) which is the ratio of total annual operational expenses, excluding depreciation and debt services, to total tariff revenues, and the Operating Ratio (OR) which is the ratio of the operational expenses, including depreciation and debt services, to the same total tariff revenues. Especially, a wide range of overhead costs including personnel expenses for the indirect divisions of TWWC should be downsized.

9.9 Recommendations for Financial Planning

The following 4 steps are recommended to establish the realistic and sound financial plan for the earthquake resistant project.

a) ***To explore an acceptable level of the tariff increase for the earthquake resistant improvement based on WtP through CVM***: In order to appropriately fix the optimum level of the mixture of the tariff increase and the injection of subsidies to service the repayment of the non-subsidized portion of the project, ***the first step*** for the proper financial planning is to explore an acceptable level of the tariff increase that is consistent with users' WtP (Willingness to Pay) for the additional improvement of the earthquake resistant function through this specific project. CVM (Contingent Valuation Method) should be employed to scientifically estimate the WtP.

b) ***To appropriately streamline the current tariff scheme as a precondition for the tariff increase***: As a key precondition for the tariff increase to demand the additional burden of users, ***the second step*** for the financial planning is to streamline the present complicated tariff structure. The current tariff structure is too much complicated, and the rate structure should be simplified to properly recover the costs of services for different user groups by an appropriate design of tariff blocks.

c) ***To fix the optimum level of the mixture of the tariff increase and the amount of subsidies***: After exploring an acceptable level of the additional tariff increase for the earthquake resistant improvement as well as streamlining the tariff, ***the third step*** is required to fix the optimum level of the mixture of the tariff increase and the amount of subsidies to be injected. Within the optimum level of the users' WtP for the earthquake resistant improvement based on the results of the CVM which is proposed in the first step, an optimum level of the tariff increase should be fixed.

d) ***To establish the modernized accounting system in line with the global accounting standards and to monitor the financial sustainability indicators***: ***The fourth step*** is that the accounting method for TWWC should be reformed in line with the global standard for accounting procedures for a public utility entity which is similar to that for the private sector. This final step is absolutely necessary for TWWC to monitor the sound and sustainable financial operation after the large-scale investment on the earthquake resistant project. Under the improved and modernized accounting system, TWWC will be able to properly monitor the financial sustainability indicators such as staff per thousand water connections (SWC), working ratio (WR) and operating ratio (OR) under the planned optimum financial arrangement.

S 10 SOCIAL AND ENVIRONMENTAL CONSIDERATION

According to the Iranian local regulation, the proposed project would not require full scale EIA. Further, this project does not need involuntary relocation caused by large-scale land acquisition or exploitation of new water resource. Nevertheless, there are several items which should be taken into account to meet JICA's Social & Environmental Guidelines such as:

- Traffic jam during construction stage
- Waste water during construction stage
- Noise, dust and vibration during construction stage

Above predicted negative impacts are not prolonged and limited in construction stage therefore they can be avoided or mitigated as long as proper consideration would be given and incorporated in design and construction stage.

By means of implementing the proposed project, following positive impacts are expected:

- Initial water supply suspended population could be decreased.
- Required time for restoration work for water supply system can be cut down.
- Necessary amount of drinking water can be reserved after the earthquake disaster.
- Secondary disaster such as gas leak from chlorine facility or fire caused by oil leak can be prevented.

Accordingly, it is concluded that implementation of proposed project does not have adverse impact on the existing environment in the Study Area.

S 11 EVALUATION OF EARTHQUAKE-RESISTANT PLAN AND RECOMMENDATIONS

A water supply project is normally planned to satisfy increase of water demand and to increase water sales income. On the other hand, the benefit of an earthquake resistant project, which aims at strengthening functions of lifelines, is avoidance of losses and damages caused by the occurrence of the earthquake. Therefore, in evaluation of the earthquake resistant plan, the following factors should be taken into account:

- The earthquake resistant project itself does not increase the amount of water supply, and, as a result, it does not generate any additional cash revenues from consumers.
- The benefits of the earthquake resistant project are uncertain due to the fact that it depends on the occurrence probability of the earthquake.
- The earthquake resistant project contributes to the national interest through the protection of the capital's lifelines.

The earthquake resistant project hereunder includes not only an earthquake resistant plan for facilities but also emergency water supply and restoration plans.

11.1 Socio-economic Evaluation

Socio-economic effects to be generated by the execution of the earthquake resistant project are as follows:

- Initial water supply interrupted population would decrease by 2.2 million, and emergency restoration period would decrease by approximately 50 days.
- Tehran citizens could have emergency water supply of 3 lpcd right after an earthquake and the amount increases as time goes on,
- Citizen could access drinking water with maximum distance of 1 km and it decreases as time elapses,
- Citizens could have normal water supply conditions within one month after an earthquake,
- Tehran citizens of 98 million man-days could be relieved from water shortage by execution of the earthquake resistant project, and
- Benefit of the project is preliminarily estimated as US$407million.

Economic indicators are analyzed on the basis of benefit described above. These are EIRR of 0.5%, B/C of 0.491 and NPV of US$-11,456, all of the values are far below feasibility, reflecting the nature of the project for the scenario earthquake employed with the returen period of about 500 years. When the return period is assumed to be 200 or 100 years for the purpose of analysis, EIRR increases to 6.67% or 14.57% respectively. In this case, B/C obtained will be 1.138 or 2.457 respectively. These figures are in a feasible range.

11.2 Technical Evaluation

Most of the activities can be done with the local technology. Some technology shall be imported from other countries but they can be maintained with local skills. Therefore, the proposed project can be considered as technically sound. Basic effects of the earthquake resistant project are:

- great decrease of initial water supply interrupted population from 4 million to 1.7 million after the project, and
- great reduction of restoration period of damaged water supply facilities from 82 days to 30 days after the project.

Some deteriorated distribution reservoirs are refurbished and some CIP distribution pipelines will be replaced with DIP with earthquake proof joints. These activities contribute to increased stability of the water supply system, which includes reduction of water leaks and decrease of pipe breakage by high water pressure or water hammer, etc.

11.3 Financial Evaluation

Since investment would not generate an increase of water sales, it is difficult for an earthquake resistant project to be financially feasible. Therefore, it is intended that cost of this earthquake resistant project be small and the project be realistic. As a result, when the earthquake resistant project is implemented by the TWWC expenditure only, increase of water tariff would not be bigger by, approximately 5.5%. When the return period is assumed to be 200 or 100 as mentioned in previous section of Socio-economic Evaluation, the water tariff increase will become less. However even with this level of the tariff increase, it is considered not easy to be agreed by the citizens.

In Japan, central government subsidy of 1/4 to 1/3 of the project cost is given to non profit program such as the earthquake resistant project. It is expected that a governmental subsidy should be given to the project for successful implementation. If so the rate of increase of tariff will be lower than the above.

11.4 Environmental Evaluation

The earthquake resistant project is to reinforce or retrofit the existing water supply system and does not include a new facility construction or expansion of the existing facilities. This is why the project would not require acquisition of a new water source or an additional land area. In addition, reinforcement or retrofitting works for facility structures and equipment are executed within buildings or premises of the facility and the outgoing noise and vibration would be the minimum.

According to the Iranian local regulation, the proposed project would not require full scale EIA. However, there are several items which are better to be considered during implementation stage such as; 1) Traffic jam during construction stage, and 2) Noise, dust and vibration during construction stage. They should not be forgotten.

11.5 Comprehensive Evaluation

The project formulated by this study can be judged as adequate for execution because of following: Big benefits can be obtained by decrease of water supply interrupted population and restoration period. Effects on environment are small. Since the total project cost is not huge, economic and financial feasibility can satisfy thee cut-off level when the return period is considered as 200 years, even though the project does not increase water sales.

It is of vital importance to protect the citizens from an earthquake disaster although the probability of its occurrence would be very low. In case of Teheran and its vicinity, 150 years period, which is thought as a return period of large scale earthquakes as described in "Seismic Microzonation Study" report, has already passed after the earthquake with second largest acceleration occurred in 1830.

It is expected for TWWC to be given a considerable portion of governmental subsidy in order to implement the earthquake resistant project satisfactorily.

11.6 Recommendation

Recommendation on the earthquake resistant plan including the plan of emergency countermeasures is summarized as in the followings.

(1) General

- Review , further study in detail and design of the project by local consultants.
- Collection of data and information: reinforcement steel bar arrangement of facility structures or buildings, Drawings and design data of connecting points between pipelines and facility structures for identification of their reinforcement means, sizes and locations of old "Qanat" or other structures, etc.
- Preparation of a master plan of the waters supply system
- Hydraulic Isolation of Reservoir Zones

(2) Seismic Data

- Investigation of fault location with its upper depth and probabilities of movement including secondary faults.
- Land slide or collapse in northern area.

(3) Materials and Installation

- Use of weld steel pipes for large diameter line, ductile iron pipe with detach-resistant joints for medium size pipes and polyethylene pipe with electro fusion bond joint for small diameter pipes are recommended.
- Good joining procedures should be prepared. Corrosion control and installation procedures are also important.

(4) Emergency Countermeasures

- Formulate future stepwise construction plan of distribution reservoirs and implementation plan for emergency water supply basis.

- Selection of deep wells in the parks for emergency use.
- Monitoring of water quality of every deep well, which is used as emergency supply bases.

(5) Emergency Water Supply and Restoration Activity

- Cooperation with TDMO and execution of periodical meetings.
- Establishment of mutual cooperation with other nearby water agencies
- Coordination for emergency assistance with private sector who has necessary material and equipment. Training shall be given to private companies on pipe restoration.
- Decision on the detailed roles / duties of each division in crisis management organization of TWWC. After the decision of duties is made, it is important to make all the staff understood.
- Preparation of rules for emergency gathering of staff.
- Training on usage of emergency water supply bases including checking water quality, chlorination, and cooperating with assistants from other organizations or residents.

S12 TECHNICAL ASSISTANCE FOR REDUCTION OF NON REVENUE WATER (NRW)

12.1 Definition of NRW and Related Technical Terms

It is observed that TWWC does not necessarily have clear definitions of the terms relevant to NRW at the moment. The figure of NRW shown by TWWC sometimes includes water losses from raw water transmission and water treatment facilities in addition to clear water transmission and distribution facilities. Different usage or different understanding of the terminology will lead to misunderstanding of the current situation and failure in finding tactics for reduction of NRW. It is recommended to define the terminology clearly and make it understood by all the staff. The terminology defined by IWA, as shown in *Table 12.1.1*, is recommended for TWWC since it is internationally accepted and it becomes easier to compare the figures/conditions with other various cities in the world.

Table 12.1.1 Definition of Non Revenue Water Components by IWA

<table>
<tr><td rowspan="9">System Input Volume (Production/ Distribution Volume)</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Non-metered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption (water used for fire fighting, etc)</td><td rowspan="7">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Non-metered Consumption (free water distributed at standpipes)</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent Losses (Non-technical or Commercial Losses)</td><td>Unauthorized Consumption (illegal use and connections)</td></tr>
<tr><td>Metering Inaccuracies
- No meters
- Meters not working
- Meters not recording accurately
- Meters misread</td></tr>
<tr><td rowspan="3">Real Losses (Technical Losses)</td><td>Leakage from Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakagefrom Service Connecting pipes up to Customers' Meters</td></tr>
</table>

Source: IWA (International Water Association)

When the above definition is applied, the NRW of TWWC can be said to be lowered from 44.5% to 23.7% in the past ten tears.

12.2 Composition of Water Losses and Their Measurement

(1) Raw Water Transmission Loss

Raw water transmission loss is assumed but not measured at present. In order to know the raw water transmission loss, water flow should be measured at raw water intake and groundwater pumping and then they should be compared with measurement of the raw water flow at inlet of water treatment plant and chlorine contact tank or reservoirs.

(2) Water Treatment Loss

Water treatment loss is also estimated but not measured at present due to insufficient meters at the outlet of treatment plants. Water loss in each water treatment plant needs to be confirmed by measurement and if treatment loss is large, it will be required to review filter backwash methods and/or drainage of pre-sedimentation basin and clarifiers. It will also be required to consider return of waste water to inlet canal.

(3) Non Revenue Water (NRW)

NRW cannot be measured at present because of insufficient installation of meters for treated water and ground water. The current situation of each component of NRW is summarized below.

- Unbilled Authorized Consumption: Consumer meters are not installed at unbilled authorized consumers. Water volume should be measured by installation of meters after listing up the major unbilled authorized consumers. Water volume for pipe flushing and other works should be estimated if it is difficult to measure by flow meters.
- Unauthorized consumption: Unauthorized connections have been identified through public reports, meter readers as well as repeated auditing of consumers' properties. It is important to keep records for estimation of unauthorized consumption even though it is not big.
- Metering inaccuracy: TWWC has started periodical replacement of consumer meters of Class C in 2000 and 673,000 meters were replaced between 2000 and 2004. TWWC has a plan to replace all the consumer meters every 6 to 7 years for decreasing NRW.
- Leakage: It is found from the repair records that a large number of 433 accidents were attended by TWWC every day in 2004. Majority of leakages (about 89.8%) were found in House Connections. In order to understand the seriousness of problem clearly, leakage volume should be measured or estimated when leaks are found and recorded after repair.

12.3 Activities of TWWC for NRW Reduction

(1) Leak Detection and Repair Works

JICA study team has found that the equipment is manipulated appropriately and leak detection and repair works are executed in an adequate way. However, it takes time to calibrate or repair tools & equipment and to get new tools. In addition, operation and maintenance staffs pointed out that quality of materials and tools are not always appropriate due to insufficient quality control for procurement. It will be required to review procurement procedure together with specification and standard periodically.

(2) NRW Reduction Efforts

Non Revenue Water (NRW) has been significantly decreased in these 10 years in Tehran water supply system. The approach of NRW reduction taken by TWWC is considered as appropriate and should be appreciated, while reliability of the data/ figure might not be so high. The major efforts taken by TWWC are summarized as follows:

- Replacement of Consumer meters: TWWC has replaced about 80 % of the total consumer meters in Tehran and is executing periodical replacement.
- Control of Water Pressure: TWWC put great efforts on controlling water supply pressure. The major activity is installation of pressure reducing valves.
- Replacement of old pipes: TWWC is replacing old pipes and problematic pipes. About 505 km of pipes are replaced in the last 9 years.
- Leak Detection and Quick repair: About 3.2 km of distribution pipes were detected in fiscal year 2004. In the recent five years (from FY 1999 to FY 2004), leakage detection has bee conducted along 1,2810 meters, which is more than 1.5 times of total distribution mains length. Repair teams in each emergency post are in service for 24 hours a day to repair leakage without delay.

12.4 Recommendation on Methods for Further Reduction of NRW and Other Losses

Since NRW and other water losses have been drastically decreased, it will become difficult to reduce NRW at the same pace and it will require much more efforts and costs for further reduction. “Selection of Priority” becomes much important to reduce NRW in effective ways. Priority includes priority activities, priority area to be surveyed, and priority pipes to be replaced. Recommended methods for further reduction of NRW and other water losses are summarized below.

(1) Measurement and Monitoring of Flow Rate

Flow rates should be measured and recorded to know the amount of water losses after installation or repair of required meters. Meter reading will contribute to finding the priority facilities to be repaired or improved. Monitoring of each flow rate is very useful to find problems in each system and occurrence of accidents, and then to select priority zones for leak detection.

(2) Analysis of factors / causes of NRW and Other Losses

It is required to measure or estimate the amount of water loss of each factor of NRW It will contribute to finding the priority factors to be improved and priority measures to be taken. Periodical analysis of the amount or ratio of each loss will also give the idea on the effectiveness of efforts.

(3) Hydraulic Isolation of each Zone

TWWC is preparing a plan to divide distribution areas into several supply zones and isolate them in order to control water pressure. However the areas are not hydraulically isolated in a proper manner at present. Since hydraulic isolation by zones is the most appropriate method to control water pressure in distribution area in Tehran, it is strongly recommended to isolate all the zones hydraulically.

(4) Data Collection and Usage

It is useful to report accidents and compile data for studying causes of NRW and its reduction methods. The required data for reduction of water losses, collection methods, and data usage are discussed below.

- Introduction of uniform data base system: Department of Water Production & Distribution Affairs in the head office should take initiative to prepare uniform data system, taking into account the purpose of data collection and the methods of usage.
- Leakage data to be colleted /assumed: Time for attending, repair period, detailed conditions of leakage, attribution of accidents (natural or artificial) and assumption of leak volume should be recorded for finding priority works and then for preparation of leakage reduction plan.
- Preparation of leakage maps: Repair teams should prepare leakage maps by marking the leakage on pipe network drawings (Scale 1/2,000). The leakage maps will become useful to find problematic pipelines and areas.
- Updating of distribution pipe network drawings: It is required to update information of distribution pipe network whenever it is changed or found.
- Data compiling and usage: Each district office should collect and transfer the data to the head office periodically and then the head office should compile them for analysis and finding priorities. The results of analysis should be announced periodically. The usage of data, in other words the purpose of data collection, should be discussed and understood by all the staffs.

(5) Discussion for Improvement

The staffs' knowledge on the problems in operation & maintenance for reduction of water losses and the improvement methods should be collected through discussion for further reduction of NRW.

(6) Improvement of Motivation

Since the activities for NRW reduction are very tough jobs, it is necessary to seek the methods for keeping highly motivation of the staffs. Realizing the staffs' idea for improvement is one of the methods. Several methods for improvement of motivation should be discussed.

(7) Public Relation

About 99.1% of accidents was informed by consumers in fiscal year 2004. It is important to encourage consumers' information through public relation activities.

(8) Others

Other recommended methods are listed below.

- Improvement of relation with Meter Readers: The strategy for improvement of meter reading and encouragement of problem reporting from meter readers should be discussed and applied.
- Quality Control of Material: Specification and standard of materials, together with the procurement procedure, should be reviewed with consideration of ideas from the operation staffs.
- Continuation of good repair works: It is always necessary to keep clean the repair site and prevent both poor quality repair and quick reoccurrence of leaks.
- Allocation of Budget to District Offices: This will contribute the improvement of repair methods, such as quick repair of tools and introduction of motorcycle for quick attendance of simple leakage,

S 13 ADVISORY SERVICE FOR PUBLIC RELATIONS

13.1 Evaluation on Current State of Public Relations

The Tehran Province Water and Wastewater Corporation (TPWWC) shifted to a private enterprise along with the government deregulation policy in 1970. Tehran Water and Wastewater Corporation (TWWC) was separated from TPWWC in January, 2004 and became an independent enterprise.

Public relations section was shared by both companies at first, and then was separated like other sections in September, 2005. The public relations section of TWWC, the public communication center (Call122), shifted to customer service section of TWWC, while PR & public education office changed the name and reduced into small organization of 17 staff. The activity range is not wide for the time being.

13.2 Suggestion for Better Activities of Public Relations

For the future activities of PR & public education office, following advices are suggested.

- Balance of information releasing and hearing from citizens is important for the success of public relations activities.
- Publicity about earthquake disaster occurrence is important.
- It is important to nominate monitors to executer hearing of customers' opinion for the measurement of public relations activity effects.
- All the staff are required to have consciousness that they are PR people for TWWC and behave accordingly.
- Since it is important to make the citizen visit the institution of TWWC easily, it is desirable to establish a museum.

A copy of pamphlet published by Tokyo metropolitan government titled "Ten lessons in an earthquake" was translated in Persian as a means of publicity for disaster management measures for the benefit of citizens. Practical use is expected.

13.3 Suggestions for Exhibition of Water Museum Establishment

(1) Movement for a museum establishment

Five high ranking officials of Iran visited a science museum of water in Kobe in May, 2002 and were impressed with excellent exhibition and good relations between water bureau and citizen. And they thought it is necessary for Tehran to have a water museum like Kobe.

There are two candidates for location of a museum, one is old telemetry system building and the other is inside the building of No 3 distribution reservoir, near Laleh Park. The former is situated near the TWWC headquarters and No 1 water treatment plant, and the latter is in neighborhood of carpet museum / jewel museum. Both seem convenient for the citizens to visit several museums at a time. It is desirable to decide the location through deliberate study by establishing the water museum construction committee.

(2) The basic policy for establishment of water museum

The following 3 items are shown as a basic policy

- Recognition of necessity of water museum construction as a part of public relations activities
- Promotion of a construction plan / enforcement by establishment of the museum construction committee
- Selection of exhibition items and exhibition method

(3) Some samples of exhibition items and exhibition methods in Japan

Among many water museums in Japan, three big cities are selected as models, which are Water Historical Museum / Water Science Museum in Tokyo, Water Memorial Museum / Water Engineering Museum in Yokohama, and Water Science Museum in Kobe. Among exhibition items and exhibition methods of these cities, several models, which are thought to be desirable to be referred, are introduced. The layout of exhibition of Water Historical Museum is shown in *Figure 13.3.1* in the next page.

(4) Administration of water museum

1) Administration method

Desirable administration method of water museum is summarized in *Table 13.3.1*.

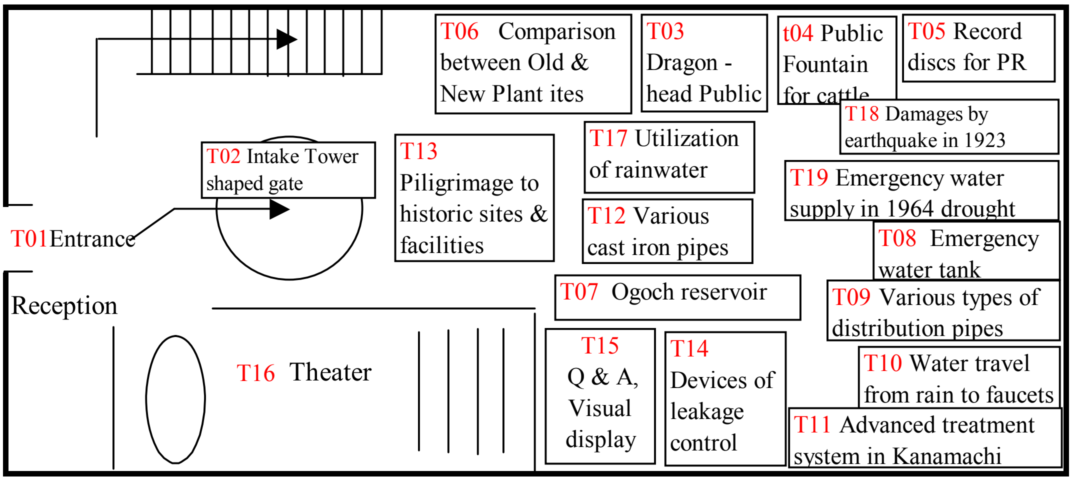
Table 13.3.1 An administration method of a museum

An administration body: TWWC
Fund: Expenditure of Tehran city
Management: Trust
Term of a contract: Five years
Opening time: From 9:00 a.m. to 5:00 p.m.
Entrance charges: 1,000 Rial/person

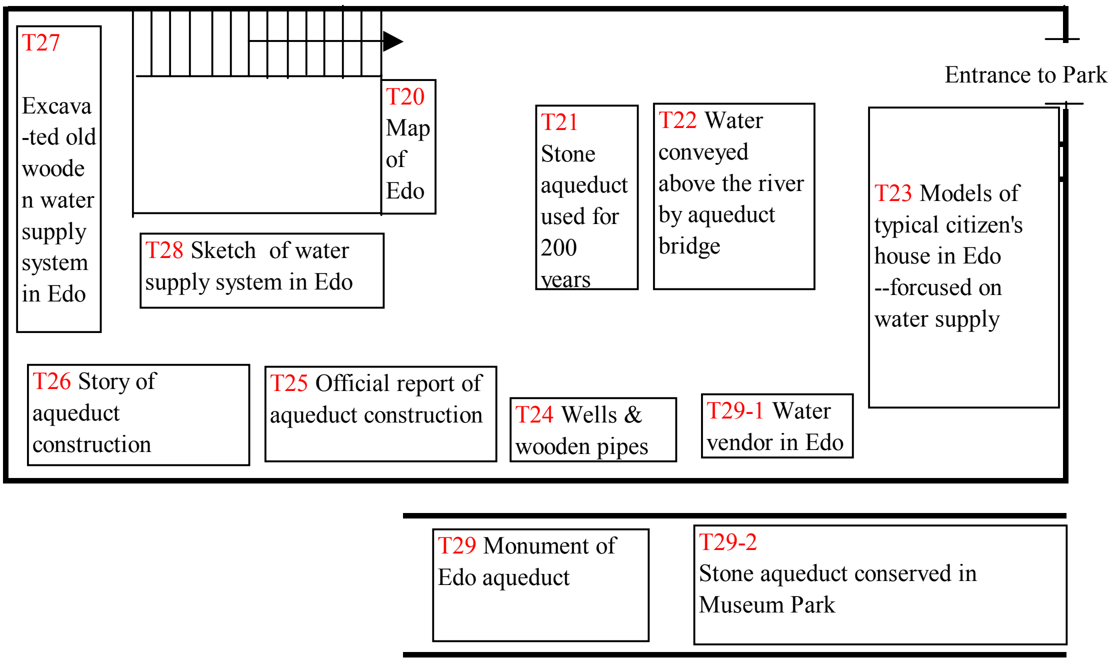
2) Suggestions for administration

Some suggestions for sustainable administration of water museum are shown as follows.

- Mass media should be used for publicity of the opening of water museum to citizen. One useful method is printing the photograph of water museum building on the back of water bills.
- Water museum is positioned as an important part of publicity work of TWWC.
- Efforts should be continued to increase the number of visitors.
- Originality for exhibition items and methods is necessary to attract visitors.
- Cooperation with various groups such as community, schools, citizens and environment is necessary.
- others



・Ground Floor： Modern Water Supply Section (After 1868)



・1st Floor & Park : Premodern Water Supply Section (Before 1868)

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Figure 13.3.1 Tokyo Historical Water Museum