# CHAPTER 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.

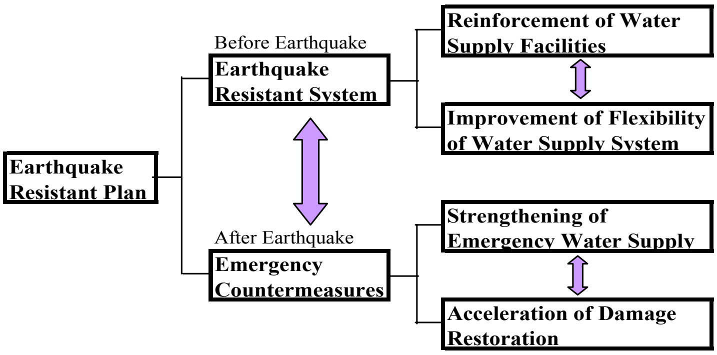


**Figure 5.1.1 Earthquake Resistant Plan**

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 contrary, 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. The target is also to be set taking the results of the damage estimation of the system studied in the preceding chapter and examples of the past earthquake countermeasures into account.

## 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 obtained as mentioned in the above. 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. Thus, outlines of these items are firstly mentioned and summarized into a basic concept for the target setting.

### 5.2.1 Outcomes of the Damage Estimation of Facilities and Pipelines

Outcomes of the analysis of damage estimation of the water supply system made in the preceding chapter ie., Chapter 4 are summarized in *Table 5.2.1*. Outlines of the estimated damage are presented in the following.

#### (1) Facilities and Equipment

Among facilities and equipment of Tehran water supply system, some components of water treatment plants No.3 and No.5 are expected to have a probable damage by an earthquake which may interrupt their operation. plant No.4 would also have a possible damage because the plant is located near plant No.3.

Since these treatment plants are located on or near the secondary faults, they would undergo a probable damage in case the fault dislocation occurs. The worst scenario for the case would be operation interruption of each of plants No3&4 and No.5.

Three pump stations out of the 40 stations listed in the table are estimated to suffer a prospective damage and nine distribution reservoirs out of 70 reservoirs are also threatened by possible damage.

**Table 5.2.1 Summary of Estimated Damage of the Water Supply System**

**Possible Damage of Facilities (North Tehran Fault)**

| Name of Facilities | Number of Damages | Total Quantity | Remarks |
|---|---|---|---|
| Water Treatment Plants | 3 | 5 | Chlorine & chemical houses of No.5.<br>Treatment facilities of No.3,No.4 |
| Pump Stations | 3 | 40 | No.14,26,75 |
| Reservoirs, etc. | 9 | 70 | No.11,14,26,71,75,77,82,95,97 |

**Possible Damage of Pipelines (North Tehran Fault)**

| Name of Facilities | Number of Damages | Total Quantity | Remarks |
|---|---|---|---|
| Transmission Main | 22 | 399,346 m | Fault:10, Structure:12 |
| Distribution Trunk Main | 66 | 768,179 m | |
| Distribution Sub Main | 707 | 7,553,452 m | |
| Total | 795 | 7,951,705 m | |
| Service Connection | 3,865 | | Connections under Public Roads |

**(2) Pipelines**

As to pipelines including transmission mains, distribution trunk mains and sub-mains, the damage will be affected not only by materials and joint types but also by their size. The damage of diameters of smaller size occurs in a remarkable number of cases.

As seen in the above table, the water transmission mains with the total length of 514 km might get damaged at 22 locations, of which 10 locations might be on the faults and the remaining 12 locations at the connection points with massive structures.

Trunk distribution mains with the total length of 842 km might get damaged at 71 locations. Distribution sub-mains might get damaged at as many as 695 locations which is about 10 times the quantity of the trunk mains with a total length of 6,600 km.

**(3) Service Connection**

Service connections are classified into two categories- the connections under public roads and the ones in the consumer premises respectively. Damage of buildings in the city is estimated to be high, and the quantity of defective connections inside the consumer premises would be somewhat in proportion to the rate of building damage. These defective connections are to be repaired along with the restoration of the buildings by the consumers and are not included among emergency countermeasures in the present study.

Instead, number of the connections under public roads to be damaged by an earthquake is approximately 5 times as many as that of the distribution sub-mains experienced in Japan. In this study, value 3,500 is applied as the number of damage cases in the service connections as shown in *Table 5.2.1*.

### 5.2.2 Comprehensive Features of Tehran Water Supply System

Problems and countermeasures of Tehran water supply system in earthquake disasters quoted from the previous study reports are summarized in *Table 2.4.6* of the preceding subsection 2.4.3. Comprehensive features of the system in an earthquake disaster are detailed in *Table 5.2.2* summarizing the above problems and countermeasures and items found by the study team during the course of the study. As many as 35 items of the problems and countermeasures from reinforcement measures to emergency water supply items and from large to small items are summarized as comprehensive features in the table.

## Table 5.2.2 Comprehensive Features of Tehran Water Supply System in Earthquake Disasters

| Items | Overall Problems and Counter Measures of the System |
|---|---|
| 1) Earthquake resistant system | |
| Dam & Water Intake | Since the Latiyan dam is evaluated to get damaged by an earthquake, an earthquake-resistant plan for the Tehran water supply system should be prepared considering a long-term water intake suspension. |
| | The operation of Mamloo dam will be started in 2007. The Tehran water supply system will have five dams as surface water sources in total. In addition, the system has plentiful groundwater source. Possession of variety water sources could decrease the risk of water supply insufficiency in an earthquake disaster. |
| Raw Water Transmission Main | Pipelines installed in slopes including siphons and those crossing faults should be strengthened by taking necessary earthquake-resistant measures. |
| | The western part and eastern part of the pipelines are interconnected with each other as a back-up raw water supply. |
| Deep Wells | It was identified that liquefaction in the southern part of the city does not occur according to Research Project for Strengthening and Control of Tehran Gas Network Against Earthquake. Probability of wells damage in this area will be low. |
| | In case of power failure due to an earthquake, diesel generators should be provided. |
| | Provision of portable units of generator is mandatory for functioning despite a disaster. |
| Water Treatment Plant | It is necessary for the water treatment plant located across the fault to take necessary measures by detailed survey. |
| | It is preferable to install interconnecting mains between clear water tanks of the plants. |
| | Liquefied chlorine gas is used for chlorination in the intake station and pump station. To prevent second disasters by leakage of chlorine gas, cylinders should be fixed firmly and neutralization system of chlorine gas should be introduced. Otherwise, similar to the Japanese trend, a change from the chlorination system to sodium hypochlorite system is proposed. |
| Pump Station | The pump houses not included in earthquake-resistant design shall need some reinforcement. |
| | Some electrical panels and equipment not firmly fixed shall need improvement. |
| Transmission Main | The important main should be replaced with earthquake-resistant pipes to secure transmission of water to reservoirs as water bases. Reliable and common earthquake-resistant pipes should be used. |
| | Improvement of the present complicated transmission network is necessary for enhancement of water transmission capacity by providing additional pipelines and valves. |
| | Transmission mains crossing faults and connections at structures should be strengthened. |
| Distribution Reservoir | Only one tank of reservoir should, if possible, be partitioned into two tanks. |
| | Expansion joints without elasticity should be strengthened. |
| | Structurally unbalanced tanks should be strengthened by additional shear wall. |
| | To store water for emergency water supply, modification of outlet pipes is recommended. |
| | Reliable emergency shut-off valves should be installed at outlet pipes. |
| Distribution Pipelines (Network) | Replacement of such vulnerable PVC pipes with earthquake-resistant pipes. |
| | Distribution network should be hydraulically isolated in other words water supply zoning should be done by providing valves and pipelines. |
| | The large-sized supply zones at the southern part of the city should have sub zones for easy operation and maintenance. |
| Service Connections | Replacement of such vulnerable PVC pipes with earthquake-resistant pipes. |
| | According to the damage estimation by JICA's Comprehensive MP, the damage of buildings is extensive. Accordingly, house connections will be damaged. Provision of stop valves on secondary distribution mains is indispensable in order to isolate the damaged area or building. |
| Old Tehran & Bazaar Area | It was identified that liquefaction in the southern part of the city does not occur. Possibility of damage of wells in this area will be low. |
| | Flow meters should be provided on the pipeline directly distributed to the supply zone. |
| 2)Preparedness for emergency response | |
| Cooperation | Mutual aid agreement among other cities/provinces shall be important for emergency response and restoration of water supply facilities. |
| | Training the skills for pipeline repairing works is an urgent matter even if staff belongs to other cities/provinces that have agreed on mutual aid. |
| | Provision of maps or drawings showing transmission and distribution network to other cities/ provinces should be considered. |
| Man-power | To formulate restoration work parties in advance. |
| | Training of skills related to large-sized pipeline repairing is also needed. |
| Emergency Bases | The traffic jams can be observed throughout the Tehran city. The emergency water supply by water wagon or water tankers would be difficult. A number of emergency tanks should be provided. |
| | Publicity for the locations of emergency bases and points of emergency water supply. |

### 5.2.3 Lessons from the Past Earthquake Disasters

#### (1) Lessons learned in Iranian Case

Iran is an earthquake-prone country, located in the Alps-Himalayan Orogenic Zone.

If a devastating earthquake disaster occurs in the city of Tehran, serious traffic confusion will occur. Therefore it is important to fully gain the regional characteristics for securing emergency water supply bases during earthquake disaster and for preparing an emergency restoration plan.

The study team collected and reviewed information and data on 1) the public awareness of the earthquake disaster and 2) the damage and restoration situation, etc. of the water supply system in the two devastating earthquakes of Bam and Manjil.

The following table summarizes the two earthquakes:

**Table 5.2.3 Outlines of Past Earthquakes**

| | Bam Earthquake | Manjil Earthquake |
|---|---|---|
| Location | Near the city of Bam, Kerman Province, Southeast of Iran | About 100 km southwest of the Caspian Sea, Gilan Province, North of Iran |
| Date | December 23, 2003 | June 21, 1990 |
| Local Time | 05:26 | 00:30 |
| Moment Magnitude (Mw) | 6.5 | 7.3 |
| Maximum Acceleration | 1.01g | - |

#### 1) The Manjil Earthquake

As for the Manjil earthquake, collection of data is hard because this earthquake occurred 15 years ago. However, the following reports are valuable sources of knowledge for the key issues regarding the Manjil earthquake.

- Report-1:
  Rescue operation and reconstruction of recent earthquakes in Iran, Disaster Prevention Management Volume 8 Number 1 1999 pp5 - 20 M. Ghafory-Ashtiany, IIEES, Tehran, I.R. Iran
- Report-2:
  Reasons of Extraordinary Higher Damage in 1990 Manjil Earthquake Y.SATTARAZADEH-GHADIM, University of Tarbriz, I.R. Iran

Report-1 described seismological and structural view points, evaluation of the rescue and relief operation and reconstruction program of three devastating earthquakes which occurred in 1997, which are Bojnoord, Ardebil and Ardekul (Ghaen-Birjand) earthquakes based on the lessons learned during the Manjil earthquake.

Key issues of Report-1 are quoted as follows:

Based on 1991 law, the Natural Disaster Headquarter (NDH) under the Ministry of Interior with the full authority is responsible for policy, guidance, supervision, coordination of the disaster management or post disaster activities including rescue and relief operations, temporary settlement and reconstruction with the cooperation of all the respected government agencies.

The direct executive responsibilities under NDH are:

- Rescue and relief: Red Crescent of Iran and Armed forces;
- Temporary settlement: Red Crescent of Iran and Ministry of Interior;
- Reconstruction: Housing Foundation of Iran and Ministry of Housing and Urban Development

Rescue and relief:

For 72 hours after the occurrence of a disaster, all the related government agencies, Red Crescent, some divisions of armed forces, transportation, etc. will be under the command of the NDH manager.

Temporary settlement:

After the end of rescue and the relief operation of Manjil earthquake, prefabricated shelters with an area of 12 to 20 $m^2$ were provided by government to each family during the reconstruction period.

Overall evaluation showed that the temporary settlement not only created social and economic problems, but also prolonged the reconstruction period and thus it was not a very successful experience. Temporary shelter can be a good idea for urban living and in a camp form with appropriate infrastructure but not for rural areas.

Reconstruction experiences:

The reconstruction of Manjil-Rudbar also requires detailed discussion due to its vast coverage as well as great variations. Totally 200,000 units in Gilan and Zanjan provinces (mainly in Rudbar, Manjil and Loshan) were reconstructed or repaired under the supervision and guidance of the Housing Foundation with people's cooperation and with subsidized construction material and free interest loans. Most of the structures which used steel frames with bracing and good foundations were designed and constructed according to the Iranian seismic code (2800).

The major lifeline systems were repaired, restored and upgraded in less than a year and completed within two years; see Ghafory-Astiany (1998) for performance and restoration of lifeline and industrial facilities in Manjil-Rudbar area. It took almost three years for the reconstruction to be completed.

And the key issues of Report-2 are referred to as follows:

The results of field studies carried out immediately after the event in different parts of the earthquake area revealed that in addition to the higher magnitude of the earthquake and its inappropriate occurrence time, several other reasons such as

the presence of very bad weather condition during and after the earthquake,

the presence of dense population settled in several cities and numerous villages,

the lack of good quality access roads to the scattered villages in a mountainous area,
the presence of numerous weak buildings, mostly constructed in the areas of unstable soil and rock condition or constructed by using inappropriate design, low-quality construction techniques, low-quality construction materials and low-quality workmanship, as well as the occurrence of liquefaction phenomena in parts of the earthquake area,
the lack of preparedness for a rapid, efficient and well-organized rescue operation,
and the lack of public awareness about what they should do before, during and after the earthquake event
were the main reasons of extraordinary higher loss due to Manjil earthquake.

### 2) The Bam Earthquake

Lessons learned from Bam earthquake are reported in Final Report, The Study on Reconstruction Plan for Bam Water Supply System, The Comprehensive Master Plan Study on Urban Seismic Disaster Prevention and Management for the Greater Tehran Area in the Islamic Republic of Iran, March 2005, JICA, where lessons cover not only the water supply but all related matters to cope with the earthquake disaster.

In this report, the damage of the water supply facilities observed after the earthquake is summarized as follows:

- The water supply system has a total length of 9.3 km of conveyance pipe between wells and reservoirs and a total of 420 km of distribution pipe network. The network was heavily damaged.
- 22,000 house connections were almost all destroyed and rendered malfunctioning due mainly to the collapse of residential building.
- Distribution reservoirs in Bam (R1 and R2) had little damage. On the other hand, the reservoir (1,600 m3) in Baravat was seriously damaged.
- The pump houses around R1 and R2 are made of brick and suffered quite big damage, especially, the pump houses of No. 1 and No. 2 wells, totally collapsed. The drawn quantity of two wells of No. 13 and No. 14 decreased to some extent.

There was a detailed report on the water supply conditions made in March 2004 after three months of the Bam earthquake.

In Bam city, the damage of distribution pipe network was very serious and it was extremely hard to repair these pipes. Temporary public water taps were installed in various locations in the city after separating seriously damaged network from the distribution main which were relatively less damaged. After the separation of damaged pipes conducted by closing gate valves, polyethylene pipes (PEP) were branched from the upstream points of the closed valves for temporary water supply.

Ground-surface piping and temporary water taps in Bam City

The PEP were mainly supplied with the help of other provinces (the aid from foreign countries were relatively small). As seen in the pictures above, temporary ground-surface pipes (running on the ground surface for emergent water supply) were installed by the local water supply authority itself.

Temporary water supply tanks in Bam City

In addition to these temporary pipes, temporary water supply tanks with taps were installed in various locations in the city with help of other Iranian provinces (partially from international organizations as well). Approximately three months after the earthquake, 18 tankers were operated to supply water to these tanks.

**(2) Lessons learned in Japanese Case**

The following tables show damage of water supply facilities by the past major earthquakes occurred in Japan. The Japanese earthquake-resistant plan of water supply system are executing based on the evaluation on the past experienced damage to the water supply facilities.

In Japan, a massive metropolitan earthquake disaster (so-called the Great Hanshin and Awaji Earthquake) occurred in the cities of Kobe, Ashiya, Nishinomiya, the southern part of Hyogo Prefecture in 1995. In terms of water supply facilities, 650,000 houses were affected by the earthquake, and the amount of damage was estimated as much as 54 billion Yens. It took 3 months to complete the emergency rehabilitation. In this disaster, the whole water supply system was damaged including the destruction of the Water Supply Bureau's main office and water distribution tanks, the submergence of transmission pumps, the crushing of transmission lines, etc. Despite severe damage to the water supply system, most of reservoirs, which introduced emergency shut-off valves, survived damage and consequent malfunctioning to continue water supply in the post-disaster period. This fact suggests that emergency water supply during a post-disaster period can be secured by appropriate installation of emergency shut-off valve to the reservoirs in advance. The Study team will use the experiences obtained in this disaster regarding fast organizational mobilization, emergency water supply, monitoring and control of water quality, emergency rehabilitation, public communication and response to inquiries, etc.

Especially for disasters in metropolitan areas, it is very important to facilitate rapid rehabilitation for continuous supply of water in any situations for living use including tap water. On the other hand, it is also important to develop earthquake-resistant water supply system which has flexibility to cope with disasters. The water distribution system of Tehran city is of gravity flow type from the distribution reservoirs which is the same as that of Kobe city destructed in the Great Earthquake in 1995. Based on the experience in Kobe City, the Team believes that appropriate flow controlling mechanism should be installed at the outlets of water distribution reservoirs in order to avoid rapid and massive outflow from the reservoirs at the initial stage of a disaster.

Especially in the districts where an earthquake may cause many building destructions, restoration work of damaged pipelines would be restricted. Therefore the Team believes that pipes should be installed and modified in earthquake-resistant manner although the initial construction cost becomes higher. In addition, aging pipes subject to breakage should also be replaced in the course of routine operation and maintenance work.

Tehran City has several active earthquake faults. The Team believes it is important to examine the geographical relation between main water supply facilities and the existing faults to take preventive measures against earthquake such as installation of flexible joints, etc. for transmission and distribution mains. Corresponding to the progress of rehabilitation, the water demand during disaster usually increases day by day from potable water to toilet and bath uses. Therefore, the augmentation of emergency water reservoirs, water tankers, etc. is also important to reduce the damage caused by earthquakes.

## Table 5.2.4 Outline of Damage to Water Supply Facilities by the Past Major Earthquakes in Japan

*Note:*
*M: Moment Magnitude, JMI: Japan Meteorological Seismic Intensit)*

<table>
<tr><th>Earthquake</th><th>Damage</th><th>Lessons Learned</th></tr>
<tr><td rowspan="2">1. Nihon-kai Chubu Earthquake<br>(1)Year of occurrence<br>May 26, 1983<br>(2)Magnitude<br>M=7.7, JMI=5</td>
<td>a. Damage to Facility<br>- No major damage to reservoir, water treatment plant and distribution tank.<br>- Such light damage as crack occurrence, surface mortar peeling from concrete structures, settlement of the structure and collapse of the surrounding embankment due to ground settlement.<br>- Drying-up of wells, damage to inclined plate in clarifier, disturbance of filter sand, burnt damage to motor of sludge pump due to overheat, breakdown of machineries.</td>
<td>- Necessity to confirm bearing capacity of foundation soil<br>- Emergency shutdown Valve was well functioned.</td></tr>
<tr><td>b. Damage to Pipeline<br>- Damage number and percentile of transmission and distribution pipe in Akita & Aomori prefecture
<table>
<tr><td>Material</td><td>ACP</td><td>PVC</td><td>CIP</td><td>DIP</td><td>SP</td><td>Others</td><td>Total</td></tr>
<tr><td>Number</td><td>776</td><td>784</td><td>46</td><td>40</td><td>64</td><td>102</td><td>1,812</td></tr>
<tr><td>%</td><td>42.9</td><td>43.3</td><td>2.5</td><td>2.2</td><td>3.5</td><td>5.6</td><td>100</td></tr>
</table>
- Damage number/km of transmission and distribution pipe in major three city in Akita & Aomori prefecture
<table>
<tr><td>Material</td><td>ACP</td><td>PVC</td><td>CIP</td><td>DIP</td><td>SP</td><td>PE</td></tr>
<tr><td>Total Length</td><td>377,784</td><td>100,586</td><td>188,940</td><td>289,557</td><td>40,538</td><td>51,682</td></tr>
<tr><td>Damage nos./km</td><td>0.96</td><td>2.34</td><td>0.22</td><td>0.07</td><td>0.64</td><td>0</td></tr>
</table>
- Damage number of supply pipe in Akita & Aomori prefecture
<table>
<tr><td>Material</td><td>SP</td><td>PVC</td><td>LP</td><td>PE</td><td>Total</td></tr>
<tr><td>Number</td><td>74</td><td>1,615</td><td>66</td><td>30</td><td>1,785</td></tr>
<tr><td>%</td><td>4.1</td><td>90.5</td><td>3.7</td><td>1.7</td><td>100</td></tr>
</table></td>
<td>- Feature of damage in Akita and Aomori prefecture is different.<br>Damage to PVC joints prevail in Akita due to ground deformation during liquefaction, but damage to straight and bent pipe laid in gravelly soil due to stress concentration by strong ground motion in Aomori.<br><br>- Damage portion is between branch to stop valve (47%), between stop valve and meter (30%), and between meter and riser pipe (20%).</td></tr>
<tr><td>2. Chiba Toho-Oki Earthquake<br>(1)Year of occurrence<br>Dec. 17, 1987<br>(2)Magnitude<br>M=7.7, JMI=5</td>
<td>a. Damage to Facility<br>- Breakage of well riser pipe, damage to protection block at intake, breakage of outlet of surge tank, surface mortar peeling from the outer wall of distribution tank, breakage of intake pump, inclination of retaining wall(maybe due to liquefaction), cut of cables.</td>
<td>- Evaluation of liquefaction potential.<br>- Identification of such incidental structure and equipment as riser pipe, protection block, connection pipe prone to have damage Clarification<br>- Confirmation of redundancy of the cable length.</td></tr>
</table>

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(2)Magnitude
M=7.7, JMI=5

b. Damage to Pipeline

- Damage to transmission and distribution pipeline amounts to 296. Almost all damage is in distribution pipe.
- Damage number and Percentile transmission and distribution pipe in 17 water supply bodies in Chiba prefecture

| Material | ACP | PVC | CIP | DIP | SP | Others | Total |
|---|---|---|---|---|---|---|---|
| Number | 118 | 116 | 1 | 23 | 37 | 1 | 296 |
| % | 39.9 | 39.2 | 0.3 | 7.8 | 12.5 | 0.3 | 100 |

- Damage number and percentile service pipe in 17 water supply bodies in Chiba prefecture

| Material | PVC | SP(thread joint) | LP | Others | Total |
|---|---|---|---|---|---|
| Number | 4,316 | 574 | 47 | 141 | 5,078 |
| | 85.0 | 11.3 | 0.9 | 2.8 | 100 |

- Average damage numbers

| Material | ACP | PVC | CIP | DIP | SP* |
|---|---|---|---|---|---|
| Number/km | 0.036 | 0.039 | - | 0.014 | 0.129 |

* all thread joints

- Damaged portion is 60% at joints, 30% in straight pipe, 10% at bents and branches.

3.Kushiro-Oki Earthquake

a. Damage to facility

- Fall down of the inclined plate, damage to the additional part of the extended building, damage to canal joint and to culvert joint.
- Surface mortar peeling, wooden structure within building
- Crack occurrence at the bottom slab of PC distribution tank

- Clarification between expansion joint and the other joints.
- Identification of the dangerous part of surface mortar peeling.
- Confirmation of stability of foundation

(1)Year of occurrence
Jan. 15, 1993

(2)Magnitude
M=7.1, JMI=6

b. Damage to Pipeline

- Transmission pipe has a few damage
- Distribution pipe

Damage in three cities and three towns.

| Material | ACP | PVC | CIP | DIP | SP | PE | Total |
|---|---|---|---|---|---|---|---|
| Damage number | 12 | 16 | 18 | 18 | 8 | 11 | 83 |
| Damage number/km | 0.1 to 0.47 | 0.02 to0.89 | 0.08 to2.22 | 0.02 to0.54 | 0.3 to 8.0 | 0.01 | |

<table>
<tr><td>4.Hokkaido Nansei-Oki Earthquake<br>(1)Year of occurrence<br>July. 12, 1993</td><td>a. Damage to facility<br>- Fall down of the inclined plate, Overturn of remote [illegible] el.</td><td>- Confirmation of suitable fixing.</td></tr>
<tr><td>(2)Magnitude<br>M=7.1, JMI=6</td><td>b. Damage to Pipeline<br>- Damage in three cities and three towns.<br><table><tr><td>Material</td><td>ACP</td><td>PVC</td><td>CIP</td><td>DIP</td><td>SP</td><td>Others</td><td>Total</td></tr><tr><td>Damage number</td><td>52</td><td>18</td><td>15</td><td>12</td><td>8</td><td>33</td><td>138</td></tr></table>- Service pipe<br>Damage number of the service pipe is 445. PE pipe has no damage.</td><td></td></tr>
<tr><td>5.Sanriku Haruka-Oki Earthquake<br>(1)Year of occurrence<br>Dec. 28, 1994</td><td>a. Damage to facility<br>-Slight damage to the structure and equipment<br>-Slight overturn damage to equipment due to unsuitable fixing<br>-Crack occurrence in elevated water tank, crack occurrence at connection pipe</td><td>-Importance of suitable fixing.<br>-Construction of earthquake resistant elevated water tank</td></tr>
<tr><td>(2)Magnitude<br>M=7.5, JMI=6</td><td>b. Damage to Pipeline<br>- Transmission and distribution pipeline<br><table><tr><td>Material</td><td>ACP</td><td>PVC</td><td>CIP</td><td>DIP</td><td>SP</td><td>SGP</td><td>PE</td><td>Others</td><td>Total</td></tr><tr><td>Damage number</td><td>14</td><td>246</td><td>14</td><td>18</td><td>1</td><td>20</td><td>3</td><td>16</td><td>332</td></tr><tr><td>Damage number/km</td><td>0.06</td><td>0.12</td><td>0.24</td><td>0.02</td><td>-</td><td>0.29</td><td>-</td><td>-</td><td>Average 0.05</td></tr></table>- Service pipe<br>44.5% of total damage of service pipe is PVC, 55.3 %, PE and 0.2 %, SGP.</td><td>- Earthquake-resistant pipes are employed for the first time prior to any other municipal water supply pipeline and have not any damage. But other pipeline than the earthquake-resistant pipeline was damaged.<br>- Damage at branch and joints is remarkable.</td></tr>
<tr><td>6.Hyougo-ken Nanbu Jisin (Great Hanshin Earthquake)<br>(1)Year of occurrence<br>Jan. 17, 1995<br>(2)Magnitude<br>M=7.2, JMI=7</td><td>a. Damage to facility<br>- Damage to the structure and equipment due to rock fall from around the facility<br>- Breakage of riser pipe of wells and damage to well pumps<br>- Leakage due to excess expansion at expansion joints and crack of concrete structure<br>- Deformation of structure and the displacement of pile foundation due to lateral spread by liquefaction<br>- Breakage of water cooling pipe for emergency generator<br>- Fall down, damage of such submersible equipment as mixer, sludge scraper, inclined plate, equipment in rapid sand filter the inclined plate, Overturn of remote control panel.</td><td>- Such topographical hazard as high embankment and steep slope around the facility<br>- Impossible operation of emergency generator owing to the lack of fuel<br>- low expansible joint<br>- soil stability especially that of liquefaction<br>- hazardous embankment having</td></tr>
</table>


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- Buckling of the members of steel radio tower for radio
- Overturn of the CRT
- Crack occurrence at the columns of overhead crane
- Crack of the building accommodating heavy equipment

possibility of occurring lateral movement of foundation soil
- fixing of equipment and machinery
- Columns and beams supporting heavy weight

b. Damage to Pipeline

- Transmission pipe and distribution pipe, damage ratio = number /km

| Material | ACP | PVC | CIP | DIP | SP | Others | Total |
|---|---|---|---|---|---|---|---|
| Kobe city | - | 24 | 394 | 710 | 13 | 123 | 1,264 |
| Asiya city | - | 116 | 88 | 90 | 2 | 1 | 297 |
| Nishinomiya | 43 | 216 | 176 | 256 | 1 | 5 | 697 |
| Takaraduka | 44 | 30 | 20 | 104 | 0 | 5 | 203 |
| Amagasaki | 8 | 4 | 57 | 39 | 4 | - | 112 |
| Osaka | - | 1 | 197 | 19 | 1 | 1 | 218 |
| Hokutan | 9 | 47 | - | 15 | 1 | 22 | 94 |
| Total | 104 | 437 | 932 | 1,233 | 22 | 157 | 2,885 |
| Damage ratio | 2.57 | 1.01 | 0.44 | 0.14 | 0.08 | - | 0.24 |

- Almost two third of total damage are at joints.

- Service pipe, faucet etc.

| Damage location | Under road | Within residence | Total damage | Total service pipe | Damage ratio % |
|---|---|---|---|---|---|
| Kobe city | 11,823 | 50,695 | 62,518 | 364,464 | 17.2 |
| Asiya city | 382 | 2,846 | 3.,228 | 22,791 | 14.2 |
| Nishinomiya | 4,820 | 36,417 | 41,237 | 82,208 | 50.2 |
| Takaraduka | 670 | 10,200 | 10,870 | 61,531 | 17.7 |
| Amagasaki | 1,330 | 4,778 | 6,108 | 194,510 | 3.1 |
| Osaka | 939 | 2,903 | 3,842 | 637,825 | 0.6 |
| Hokutan | 50 | - | 50 | 3,420 | 1.5 |
| Other 17 cities | 1,624 | 29,394 | 30,792 | 915,664 | 3.4 |
| Total | 21,638 | 137,233 | 158,645 | 2,282,413 | 7.0 |

- Damage of riser pipe in residence area is remarkable.

### 5.2.4 Examples of Target Setting in Japan

Examples of target setting for an earthquake resistant plan performed in Japan are described in the following.

During a few days just after an earthquake disaster, first cry of the suffering citizens to the water agency is “need for drinking water” and “need to know the present condition of the surroundings”. One or two weeks after the disaster, people are getting irritated and are demanding more water. Then, approximately one month after the disaster, these people would get off the limits of patience regarding the insufficient water supply condition. This phenomena in Japan is considered to be similar to citizens of Teheran.

Demand of emergency water supply in terms of quantity, use category and period after the disaster is summarized based on the problems and complaints brought by Kobe city office in the great Hanshin earthquake disaster and listed in *Table 5.2.5*.

**Table 5.2.5 Emergency Water Demand in Kobe City**

| Period (days) | 1～3 | 4～7 | 8～14 | 15～21 | 22～28 | 29 & after |
|---|---|---|---|---|---|---|
| Use category | | | | | | Limit of patient<br><br>Normal water supply |
| Drinking | Minimum | | | Private or Temporally house | | |
| Cocking | | Evacuation place | | Same as above | | |
| Toilet | | Same as above | | Same as above | | |
| Washing | | | Evacuation place | Same as above | | |
| Shower/ Bath | | | Same as above | Same as above | | |
| Water amount | 3 lpcd | 20 | 100 | 100 ～250 | | |

Water supply agencies of Osaka prefecture and Nishinomiya city both of which are adjacent to Kobe city established similar criteria on the emergency water supply in earthquake disasters as shown in *Table 5.2.6*. The criteria include an access distance to the emergency water supply points.

**Table 5.2.6 Emergency Water Supply Criteria of Osaka and Nishinomiya**

| Steps | First | Second | Third |
|---|---|---|---|
| Target amount | 3 lpcd | 20 – 30 lpcd | 30 – 40 lpcd |
| Water use category | Drinking water:<br>keeping human life | Minimum domestic uses:<br>Left + cook, wash hands | Domestic use: |
| Supply methods | Water supply tank<br>Water tanker | Left<br>+ Tentative supply bases | Increase of tentative supply bases |
| Access distance | Less than 500m | Less than 500m | Less than 250m |

*Table 5.2.7* shows criteria for the emergency water supply in earthquake disasters of Tokyo water supply system.

**Table 5.2.7 Criteria of Tokyo Metropolitan Water Supply System**

| Period | 1～4days | 5～10days | 11～20days | 21days～1month |
|---|---|---|---|---|
| Supply amount | 3 lpcd | 3 – 20 | 20 – 100 | 100 – 250 |
| Use category | | | | Normal water use |
| Drinking | Yes | Yes | Yes | |
| Washing hands | | Yes | yes | |
| Laundry | | Yes | yes | |
| Toilet flushing | | yes | Yes | |
| Shower, bath | | | Yes | |
| Access distance | 2 km | 2km - 250m | 250m – 100m | 100m - |

### 5.2.5 Basic Concept for Target Setting

Key factors affecting largely to the earthquake resistant plan are extracted from the above four kinds of study results or considerations of sections 5.2.1 to 5.2.4 and summarized in *Figure 5.2.1*. Based on these key features, basic concept for the target setting is figured out as shown in the same figure.

Since some 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. Considering dispersion of treatment plants and their upper stream facilities, the following three measures are speculated;

- To connect the east side treatment plants with the west side ones in order to transmit clear water to the side which is in need of water,
- To supply service area of the interrupted plant through the existing transmission mains and pump stations which receive clear water from the other plants in operation,
- To install a by-pass pipeline.

Thus, improvement of the system flexibility is employed as the principal countermeasure.

Role of transmission mains is to convey clear water to distribution reservoirs which are the most important water bases for Teheran citizens. If the transmission mains get damaged in earthquake disasters, produced water at or transmitted water to a plant could not be conveyed to the reservoirs. Most of the weak positions of the main are the pipes on the fault and connecting points of pipes to massive structures which could be strengthened by installation of an appropriate flexible joint or by other means. Hence, the principal measure to apply is set to strengthen the mains.

Since probable damage on distribution sub-mains and service connections was analyzed far more extensively than the other water mains, it is difficult to strengthen all the lengthy pipelines. Principal emphasis for these pipelines is placed on emergency water supply and emergency restoration of damaged pipelines. However, such improvement of the system as completion of hydraulically isolated distribution zones and establishment of sub-zones in larger size zones should be realized as earlier as possible. Increase of emergency water supply bases are also indispensable.

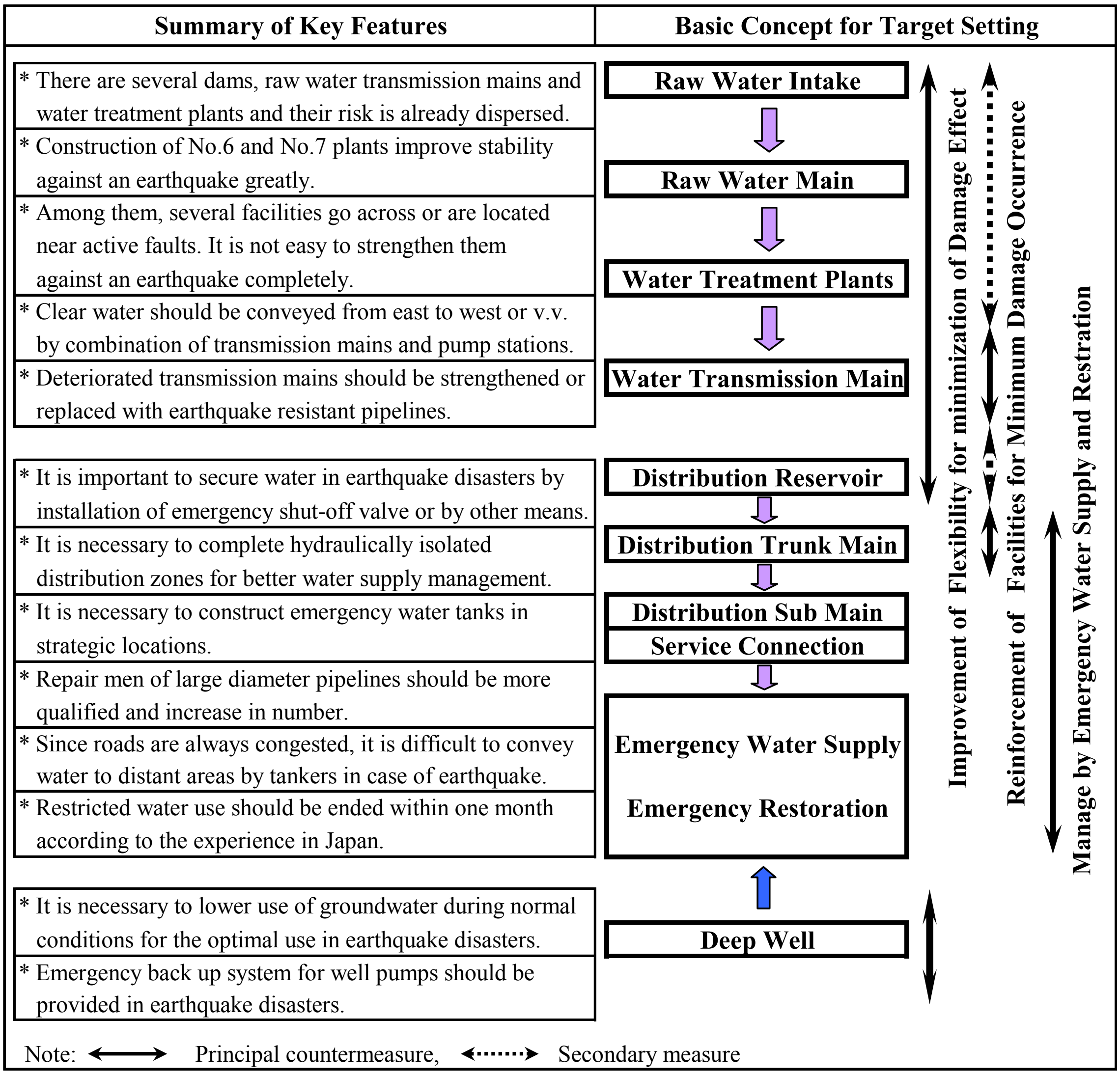


**Figure 5.2.1 Basic Concept for the Target Setting**

## 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, and (2) target for emergency supply and restoration.

### 5.3.1 Target for Earthquake Resistant Facilities

Target for Earthquake Resistant Facilities for minimization of damage occurrence and damage effect is set as shown in *Table 5.3.1*. However, the measures shown in the table are the principle ones only and some secondary measures shall also be taken into account for an appropriate plan for earthquake resistant facilities. Preparedness for emergency water supply is also included in the target for earthquake resistant facilities.

**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<br>Distribution Trunk Main |
| Minimization of Damage Effect | Improvement of System Flexibility | Raw Water Main<br>Water Treatment Plant<br>Transmission Main<br>Distribution Reservoir |
| Preparedness for Emergency (Before Earthquake) | Securing emergency Water | Securing Reservoir Water<br>Preparation of Emergency Water Supply Bases |
| Emergency Countermeasure (After Earthquake) | Emergency Supply and Restoration | Distribution Network<br>Service Connection |

### 5.3.2 Target for Emergency Supply and Restoration

As there are no guidelines for emergency water supply and restoration in Iran, Japanese guideline is applied for setting the target after proper modifications to fit the guideline with conditions of Tehran City.

As for the access to water by the citizens just after an earthquake disaster,

- it would be difficult for the citizen to get access to a distant water base considering geographical features of the city, and,
- it would also be difficult for a water tanker to move to distant locations inferring from the normal congestion of the city roads.

To set 1.0km as a maximum access distance to a water base is thought reasonable.

As mentioned in the preceding section 5.2.4, a patience period of Japanese citizens for insufficient water supply is reported to be approximately one month. Considering the plentiful water use of Tehran citizens in the normal condition, it is appropriate to determine the maximum insufficient period of water supply as one month which is the same period as in Japan.

Thus, target for the emergency water supply is set as shown in *Table 5.3.2*.

**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<br>- Water Tanker |
| 4d to 2week | 20 | - Drinking,<br>- Toilet<br>- Face washing: minimum daily life | 250 | - Water Tank<br>- Temporary taps connected to distribution mains |
| 2w to 3week | 100 | - Drinking<br>- Toilet,<br>- Bathing<br>- Cooking | 100 | -Temporary taps connected to distribution sub-mains |
| Approximately 4 week | 200 – 250 | -Normal daily life | 10 | -House connections from temporary service pipes<br>- Public taps |

As described in the above section, countermeasures for damages of distribution network and service connections are emergency restoration. The target period for restoration of major portion of the damaged facilities is set as one month considering the above patient period as shown in *Table 5.3.3*.

It should not be forgotten that restoration work of water supply pipelines has to be executed from upstream to downstream along the flow direction. Restoration of distribution trunk mains should be made earlier.

**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 | |

# CHAPTER 6 IDENTIFICATION AND STUDY OF EARTHQUAKE RESISTANT MEASURES

## 6.1 Identification of Prospective Earthquake-resistant Measures

Based on results of the damage estimates, 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.

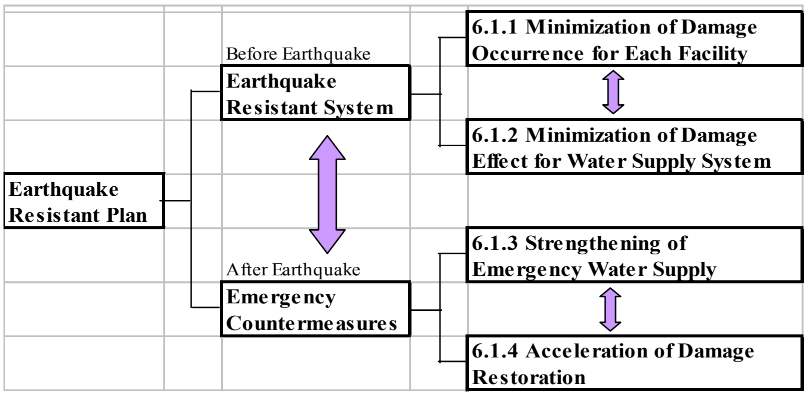


**Figure 6.1.1 Scope of Earthquake Resistant Plan**

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.

### (1) Measures for Minimization of Damage Occurrence

Measures for minimization of damage occurrence in each water supply facility in an earthquake disaster, that is measures for reinforcement of each facility to earthquake resistant, are brought out hereunder. *Table 6.1.1* shows prospective measures for minimization of damage occurrence.

### (2) Measures for Minimization/Mitigatio of Damage Effect for the System

Measures for minimization of damage effect on water supply systems, that is to increase the flexibility of the system, is also figured out and listed as shown in *Table 6.1.2*.

### (3) Measures for Emergency Water Supply

Measures for strengthening emergency water supply which should be performed soon after an earthquake disaster occurred are described in *Table 6.1.3*.

### (4) Emergency Restoration Measures

Measures for acceleration of emergency restoration of damaged facilities are listed in *Table 6.1.4*. Organization items as listed in the table show necessary organization structure for both of emergency water supply to the citizens and emergency restoration of damaged facilities.

### Table 6.1.1 Identification of Measures for Minimization of Damage Occurrence

| Category | Name of Water Supply Facilities | Possibility of Minimization of Damage and its Measures |
|---|---|---|
| Earthquake Resistant Pipelines | Raw Water Transmission Main | Strengthening of the existing raw water mains is difficult due to pipe sizes, etc. |
| | Treated Water Transmission Main | Installation of appropriate expansion joints on the pipes crossing a fault.<br>Installation of appropriate expansion joints on the effluent pipes from concrete structures.<br>Replacement of the existing pipes to earthquake resistant ones, in case where,<br>- transmission mains are considered most important among the system component,<br>- restoration of the main is not easy because, for instance, it is laid beneath a trunk road,<br>- deteriorated concrete pipes still exist. |
| | Trunk Distribution Main | Installation of appropriate expansion joints on the principle trunk pipes crossing a fault. |
| | Distribution Newwork | Installation of appropriate expansion joints on the large pipes in the distribution net-work crossing a fault. |
| | Service Connection | Replacement of the existing PVC service mains to PE pipes of high quality.<br>Improvement of polyethylene pipe material.<br>Backfilling of service main trench by sand or other appropriate materials.<br>Damaged service mains in the premises are to be restored along with the building restoration. |
| Earthquake Resistant Facilities | Water Source/ Water Intake | It is difficult to upgrade Latian dam to earthquake-resistant structure although it is considered unstable against an earthquake. |
| | Water Treatment Plant | There is no appropriate measure to strengthen No.4 and No.5 treatment plants against an earthquake although they are located on or very close to a fault.<br>Reinforcement of pulsator clarifiers in No.2 or No.4 Plant<br>Reinforcement of the generator house in No.1 treatment plant.<br>Reinforcement of the chemical house in No.4 treatment plant. |
| | Pumping station | Reinforcement of No.2 pumping station |
| | Distribution Reservoir | Reinforcement of deteriorated No.6 distribution reservoir |
| Earthquake Resistant equipment | Surge tank | Reinforcement of surge tanks at No.2 and No.22 distribution reservoirs |
| | Electrical Equipment | Reinforcement of electric panels at No.15 distribution reservoir<br>Fixing portable type transformers by foundation bolts as an earthquake resistant measure<br>Improvement of piping and cabling around a structural expansion joint<br>Securing enough spare length of electric cables, the present state of which is not sufficient<br>Batteries and UPS, many of them are not fixed, shall be fixed with appropriate stoppers |
| | Chlorine Dosing Equipment | Fixing chlorine cylinders in treatment plants other than No.5 plant |

**Table 6.1.2 Identification of Measures for Minimization/Mitigation of Damage Effect**

| Category | Name of Water Supply Facilities | Possibility of Minimization of Damage Effect and its Measures |
|---|---|---|
| Earthquake Resistant Pipelines | Raw water Transmission Main | Same measure as mentioned in water treatment plant |
| | Water treatment Plant | Installation of a large scale interconnecting pipeline between east side treatment plants and west side ones including pumping stations |
| | Treated water Transmission Main | Installation of additional transmission mains<br>Enhancing the function of the existing transmission network |
| | Distribution Network | Establishment of hydraulically isolated distribution zones<br>Establishment of necessary sub-zones in a distribution zone of excessive scale<br>Commissioning of the new telemetry system |
| Earthquake Resistant Facilities | Water Source/Water Intake | Same measure as mentioned in water treatment plant |
| | Deep Wells | Selection of deep wells to be used in earthquake disasters |
| | Water Treatment Plant | Installation of a by-pass pipeline in No.4 and No.5 treatment plants |
| | Pumping Station | Installation of a by-pass pipeline in necessary pumping stations |
| | Distribution Reservoir | Installation of a by-pass pipeline in necessary distribution reservoirs |
| Earthquake Resistant Equipment | Deep Wells | Provision of mobile or fixed type generators for well pumps |
| | Transmission Pump | Installation of stand-by set of pumps |
| | Chlorine Dosing Equipment | Installation of neutralization equipment<br>Future introduction of sodium hypochlorite system for safety |
| | Electric Equipment | Installation of emergency generators to strategic pumping stations |
| | Fuel for generators | Installation of anti-outflow fences or walls for the oil tank of the existing generators |

**Table 6.1.3 Identification of Prospective Measures for Strengthening of Emergency Water Supply**

| Items | Category of Measures | Prospective Measures for Strengthening of Emergency Water Supply |
|---|---|---|
| Securing of Drinking Water | Securing Water in Distribution Reservoir | Early construction of planned distribution reservoirs<br>Construction of emergency water tanks where no reservoirs exist<br>Installation of emergency branches on water transmission pipelines<br>Remodeling of outlet pipes of distribution reservoir to secure a half of interior water<br>Installation of an emergency shut-off valve in the reservoirs |
| | Emergency Use of Groundwater | Installation of emergency branches on an effluent pipeline of deep wells<br>Temporary alteration of deep wells for trees or irrigation to supply drinking water<br>Arrangement of disinfectant or disinfection equipment for the water use change |
| Practice of Emergency Water Supply | Preparation for Implementation | Preparation of an emergency water supply manual<br>Training and maneuver of emergency water supply according to the above manual |
| | Water Supply by Carriers | Acquisition of necessary carriers from other cities, bottled water shops, etc.<br>Preparation of temporary water tanks, PET bottles, Polyethylene tanks, etc.<br>Preparation of emergency water taps |
| | Water Supply at Bases | Emergency water supply to evacuation places or temporary housing<br>Quick installation of additional emergency water supply points<br>Stockpiling of pipes and fittings for emergency installation<br>Preparation of emergency water taps |

**Table 6.1.4 Identification of Prospective Measures for Acceleration of Damage Restoration (1/2)**

| Items | Category of Measures | Prospective Measures for Acceleration of Damage Restoration |
|---|---|---|
| Organization for emergency water supply and restoration | TWWC Organization | Review and strengthening of the present crisis management organization structure<br>Training of initial mobilization of the organization structure especially on holidays<br>Improvement of motivation of officials of the organization |
| | Cooperation and Collaboration with Related Organization | Review of cooperation among the central government, Tehran city and TWWC for crisis management<br>Review of cooperation with supporting organization including surrounding cities, water supply contractors and other infrastructure organization including gas, electricity, etc.<br>Review of cooperation with supporting organization such as army, red crescent, etc. |

**Table 6.1.4 Identification of Prospective Measures for Acceleration of Damage Restoration (2/2)**

| Items | Category of Measures | Prospective Measures for Acceleration of Damage Restoration |
|---|---|---|
| Organization for emergency water supply and restoration | Collection of Information | Identification of damage points and their states by cooperation with Tehran city government<br>Identification of damage points and their states by TWWC emergency patrol<br>Identification of damage points and their states by citizen reports<br>Collection of information of emergency supply and emergency restoration states |
| | Communication and PR | Prior training of citizens with emergency measures in an earthquake disaster<br>Securing of emergency communication devices<br>Establishment of emergency communication structure including command chain<br>Direction of quick implementation of emergency water supply<br>Direction of quick implementation of restoration work<br>Public information on damage, emergency supply and emergency restoration states |
| Implementation of emergency restoration | Preparation for Implementation | Preparation of restoration manuals including selection of restoration items and magnitudes, prioritization for restoration, organizing and distribution of work parties, etc.<br>Execution of training and maneuver according to the manual<br>Prior arrangement of necessary data including maps or GIS database of facilities |
| | Securing Water for Restoration | Securing water for restoration by allocation of emergency water supply<br>Hydraulic analysis and supplying water from undamaged or already restored facilities |
| | Securing Man Power | Assessment of structures of necessary man power for restoration including necessary equipment<br>Assessment of necessary work parties for restoration<br>Augmentation of restoration parties of large diameter pipelines |
| | Preparation of Equipment for Restoration | Preparation of heavy equipment for restoration<br>Preparation of necessary tools and equipment<br>Stockpiling pipe materials including straight pipes, bends, flanges, couplings, valve boxes<br>Prior study of sales offices of pipe materials including their price and period for supplies |
| | Management of Related Record | Appropriate recording of restoration process<br>Communication of restoration record to related organization |
| Others | Sharing of Facility Data | Prior submission of maps or drawings of Tehran water supply system to neighborhood cities to share information |
| | Unification of Material Standard | Unification of material standard of water supply facilities among neighborhood cities |

## 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.

Existing pipeline system has class structure, i.e., shape of cascade. Water transferred from intake to final users through the system. *Figure 6.2.1* shows schematic layout of the system.

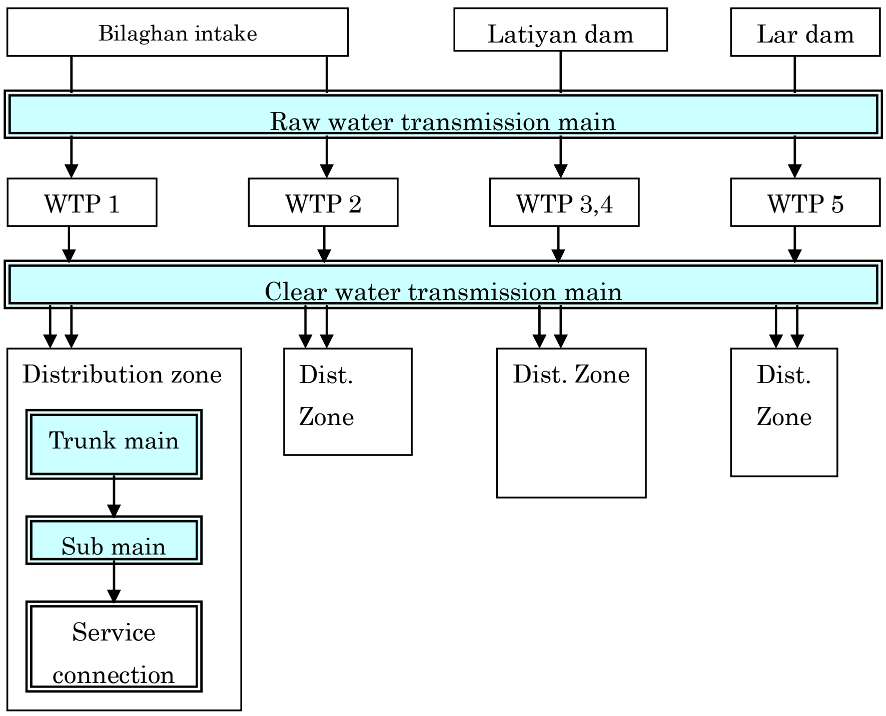


**Figure 6.2.1 Water Supply Cascade Structure**

In this section, suitable options for measures against earthquake are studied considering practical conditions. This section consists of the following subjects.

- Characteristics of pipe material and damage caused by earthquake
- Measure options to improve pipes
- Measures for each category of pipelines and evaluation results

### 6.2.1 Pipe Material and Earthquake

In this sub section characteristics of pipe material in the water field are described. Especially seismic resistance features are mentioned. Asbestos cement pipe and vinyl chloride pipe (PVC) are not included, for these materials are not considered to be used in future.

**(1) Steel Pipe**

Steel pipes are commonly used for large diameter trunk mains. Raw mild steel material is ductile and endures more than 30 % elongation. Even formed in shape of pipe, around 20 % of elongation can be expected. On the other hand, they can not resist against compressive force because of low stability property. There are several pipe forming methods from steel plate. Spiral welded seam pipe has large variety of manufacturing dimensions. However there is a case that size accuracy is not in good condition. On the other hand, pipes formed with plate bending method, dimension accuracy is kept in good condition. This product is called as straight welded seem pipe. However pipe length is limited by steel plate dimensions and therefore long size pipes can not be produced.

Both weld joints and mechanical ones are applied to field joints. Mechanical joints called "Viking Johnson" were commonly used in Tehran. Some sliding can be allowed at these joints. These joints are kept stable in ordinary conditions. Nevertheless should an outer disturbance due to earthquake occur they are weak. Welded joints are used to avoid such damage of slip-out. There are two types of joint shape regarding welding method. One is butt weld and the other is bell and spigot shape. Butt weld is most reliable method, therefore they are used for high pressure oil and gas pipelines. Butt weld is also applied to water pipelines which require high quality welding. However more skills are required to maintain certain quality levels. Another type of bell and spigot is welded by fillet weld and high skill is not required compared to butt weld and joining speed is faster.

Welded joint quality has same strength as pipe body. However to satisfy this condition, quality control including corrosion protection is indispensable. Quality control at field welding is one of the most important issues.

These welded pipes show good resistance against earthquake. Even without any particular measures these pipes are regarded as seismic resistant material. Therefore use of steel pipe is one of the options to satisfy safety condition at fault crossings.

**(2) Ductile Iron Pipe**

Ductile Iron Pipe (hereinafter referred to as DIP) has strong body and is used widely in the water field. Mechanical joints are commonly used and rubber gaskets are attached as seal material at joints. "Tyton" joints are recently used in TWWC. Such mechanical joints have simple structures and are easy to join the pipes. On the other hand joints are easy to detach in case of outer forces acts. To avoid these damages, detach-resistant (also called as anti-detachment or quake-resistant etc.) joints are developed and widely used in Japan to decrease joint breakage due to earthquake. Even with these detach-resistant joints, strength of joints are far below that of pipe bodies, therefore joints can not afford to resist in case of excess force or displacement applied to them locally. Use of such detach-resistant joint contributes to reduce joint slip out during earthquake. Therefore use of these joints is recommended to increase joint resistance during earthquake.

**(3) Reinforced Concrete Pipe**

Reinforced Concrete Pipe (hereinafter referred to as RC) is mainly used as sewage pipe. Pre-stressed concrete pipes are used recently with their improved strength. Nevertheless pipe body is still brittle compared to steel or DIP, especially against impact forces. Furthermore joint section is weak and causes water leakage from connection points. On the other hand cost is low and special corrosion control is not necessary. That is the reason these RC pipes are used as pipes under low pressure conditions. TWWC uses large diameter RC pipes for raw water transmission main and clear water transmission main. At present, hydraulic pressures of these lines are relatively low and no problem seems to exist, however once earthquake strikes Tehran there might be a large trouble considering the importance of these lines.

**(4) Cast Iron Pipe**

Cast Iron Pipe (hereinafter referred to as CIP or CI) has a long production history and has been used as main pipe material in the field of waterworks. However neither pipe body nor joint is strong enough against outer force, especially seismic impact force. These pipes are recommended to be replaced by stronger pipes like DIP with detach-resistant joints or polyethylene pipes with electric fusion bond joints.

**(5) Polyethylene Pipe**

Polyethylene Pipe (hereinafter referred to as PE) is widely used for gas pipeline recently. Pipe body has enough strength and flexibility. The reason why PE pipes were not used as water pipe is that there are several material problems under long duration of exposure to chloride contained water. However these problems were already solved and use of PE pipes are expanded as water pipes, especially for small diameter pipes. High performance polyethylene pipes (HPPE/PE100) are mainly used and these type of pipes can be used in Tehran. On the other hand, quality control is quite important to maintain joint strength. Most reliable method of joining is to use electrical fusion bond and the other methods such as butt joint is not adequate to keep joint strength. PE pipes are considered seismic resistant pipes in nature and can be used even at fault crossing.

As a conclusion, strong pipe against earthquake should have strong joints. Therefore steel pipe with welded joint and DIP with detach-resistant joint are suitable for large diameter pipeline. PE 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. The results of damage estimations were described in section 4.1. On the other hand, small diameter pipes have complex connectivity conditions and ground strain might cause some damage. This is one of the reasons why we adopted statistically method for analyzing small diameter pipe damages.

North Tehran fault is one of the most dangerous faults near Tehran. North Tehran fault is a thrust fault and offset along fault line is estimated about ±75cm which are derived from seismic motion analysis. In case of other thrust faults of North Ray and South Ray, ±20cm is assumed offset, therefore maximum 40cm offset is applied both horizontally and vertically for these faults.

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. Nevertheless secondary faults might be affected by such ground displacement. Soil conditions near secondary fault are not stiff enough because of historical fault behavior. Therefore there are some possibilities of secondary fault movement induced by outer forces. Permanent ground displacement value was adopted as offset value at secondary fault in damage analysis.

Permanent ground displacements after North Tehran fault earthquake do not exceed 40cm in northern region of Tehran and 20 cm in southern region respectively. In case of North Ray and South Ray fault earthquake, maximum displacements of 10cm in northern region and 20cm in southern region are estimated. Therefore values of 40cm in northern region and 20cm in southern region are considered maximum offsets at secondary fault crossings.

Detail of fault modeling is attached in Appendix-3 together with structure modeling.

Options for earthquake measures are described in below paragraphs below.

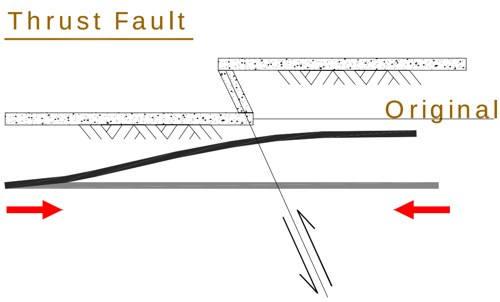


**Figure 6.2.2 Fault Move Offset**

#### (2) Bridge Option

Strains induced in pipeline depend on locations of points chosen in each side of fault line. (Refer to appendix-3 about details.) Pipeline longitudinal strains can be absorbed by having enough length between these two points. Also deflection angle varies gradually under these conditions. Bridge type option is one of the methods to avoid damage caused by fault movement. Some special countermeasures for piping are only necessary near bridge supports, i.e., some expansion or flexible joints are required at those points. No outer restraint acts on pipeline, therefore damage possibilities are relatively low.

On the contrary, construction cost is high, especially in case of long span bridge. The span of bridge for the purpose of the fault tends to become longer considering uncertainty of fault location. This option can be taken for only limited cases.

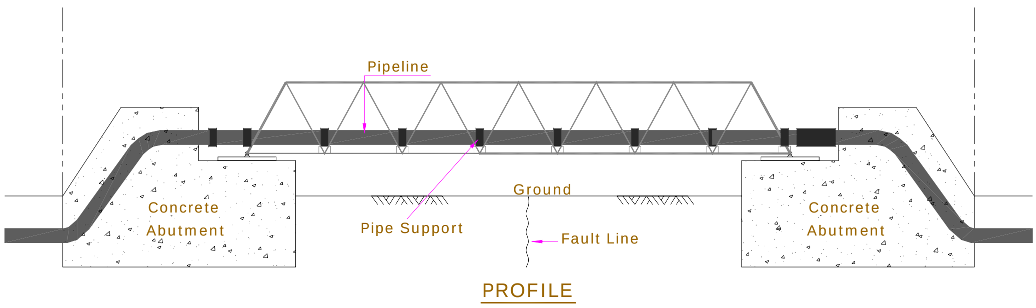


**Figure 6.2.3 Sample of Bridge Option**

#### (3) Above Ground Piping

Above ground piping is similar to bridge option. Supports are set more densely than bridge option. This type piping is commonly used in case of absorbing expansion effects caused by temperature change in the field of oil and gas pipeline. These methods are suitable for piping inside plants, however it is difficult to apply ordinary pipeline areas considering maintenance conditions and protection from outer disturbance.

#### (4) Use of Casing Pipe

Pipe materials commonly used for casings are steel and concrete pipes. Purpose of usage of these casing is to protect main pipes from outer force. Furthermore these casings are also used when "jacking method" is applied. To satisfy the safety during jacking, pipe material should have enough strength against thrust force applied by jack. Concrete pipes are strong enough for compression and that is why concrete pipes are widely used. However considering resistance against earthquake, satisfying only these requirements is not sufficient. Purpose of casing pipes as seismic hazard protection should prevent main pipes from deformation defined as "kink" which means abrupt angle change along pipe axis. Therefore uniform pipe flexual rigidity is necessary, i.e., joints should have same strength and rigidity as pipe body so that behavior of the casing can be regarded as "beam" structure.

The above described behavior is regarding lateral displacement from fault offset and longitudinal displacement is absorbed by main pipes. This condition is satisfied by using DIP with detach-resistant joints. In case of steel pipes are used, certain length is necessary to absorb the displacement to reduce strains to low level.

As a result only welded steel pipes can be used for casing purpose. However flexural rigidity of steel pipe wall is small due to thin thickness and therefore easily getting flattened, therefore special attention should be paid in case of concentrated shearing force is applied to them like near fault line.

Modeling method of underground casing and culvert is described in Appendix-3.

**(5) Reinforced Concrete Box Culvert Option**

Concrete box culvert is used to avoid the pipe damage at fault crossing similar to casing pipe. *Figure 6.2.4* shows illustration of box culvert. Box culvert is modeled as beam. Main pipes are installed inside the culvert and outer force doesn't act directory to the main pipes. Only slight displacement changes or angle changes are transferred to main pipes.

As described before, longitudinal displacement can be absorbed by main pipes and culvert resists against lateral displacement. In case of longitudinal displacement absorption is expected by the culvert, combined shaping is necessary to satisfy. *Figure 6.2.5* shows these conditions. Each side of fault line moves and combined both longitudinal and lateral force act on the pipeline. *Figure 6.2.6* shows mechanism of displacement absorption with piping layout. Components perpendicular to pipeline axis can absorb longitudinal displacement and those parallel to axis connected to the perpendicular components can absorb lateral displacement. As a result

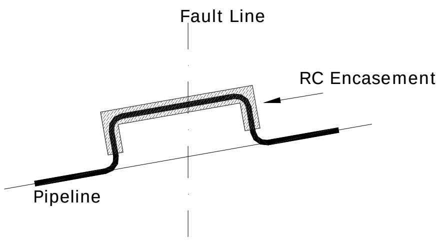


**Figure 6.2.5 Layout in Plan**

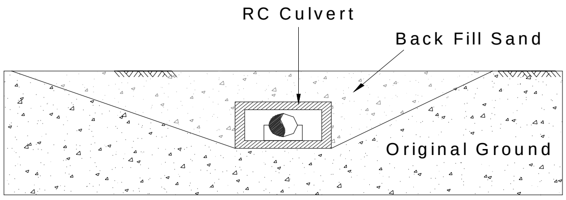


**Figure 6.2.4 Concrete Box Culvert**

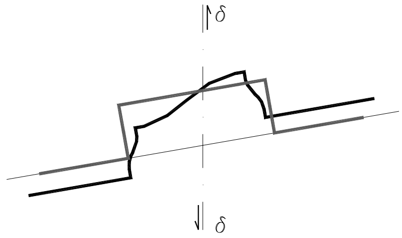


**Figure 6.2.6 Deformation caused by Longitudinal and Lateral Force**

pipelines are deformed with the shape as shown in *Figure 6.2.6*. In this figure, right side of fault line moves upward and as a result pipeline issubjected to tensile and bending deformation. Such layout piping is applied when pipeline crosses fault with some intersect angles.

This method can apply to new installation or replacement of pipeline, especially small diameter pipes. Detail of underground beam model was described in Appendix-3. However if the offsets become large, both huge length of culvert and large cross-section are required because of the increase in resultant stress.

**(6) Concrete Encasement around Buried Pipe**

Instead of using concrete box culvert, reinforcing the pipe body with reinforced concrete which is considered as resistant beam. Mechanism of avoiding the damage is similar to that of concrete culvert. i.e., beam modeling is the same. Longitudinal displacement is absorbed by joints of DIP in case of using box culvert.

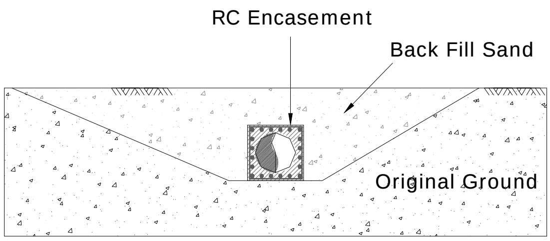


**Figure 6.2.7 Concrete Encasement**

On the other hand, in case of concrete pipes, main pipes can't move freely inside the encasement and longitudinal displacement shall be absorbed out of encasement. Structural analysis can be done with similar method applied to culvert.

**(7) Use of Flexible/Expansion Joints at Fault Crossing**

Both longitudinal and lateral deflections are absorbed by flexible/expansion joints. Therefore occurrence of excessive stress or strain in pipe is avoided by using these joints. However absorbing capacity is limited to certain range, it is necessary to use several joints to absorb large

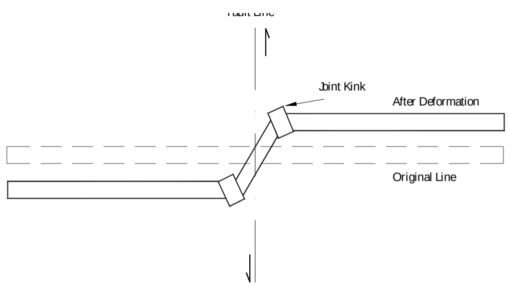


**Figure 6.2.8 Use of Flexible joints**

deformation. Nevertheless in case pipes are installed in stiff soil conditions, deformation might be concentrated to only limited joints and other joints do not act properly. In this case, special measures are required such as replacement of surrounding soil to loose sands.

Original purpose of the flexible joint is to release stress of pipe connected to massive structure whose settlement is different from surrounding soil where pipes are buried. Under these conditions, it is easy to specify exact location. On the other hand, it is natural that location of fault has some uncertainty and it is necessary to use several joints to satisfy these conditions.

Therefore in case of use of these flexible joints in buried condition, precautions are required that such joints act properly. Furthermore cost of flexible joints is high especially for large diameter pipes.

### (8) Sacrificial Casing or Box Culvert

In previous options, measures described are considered safe even after earthquake. Other option allows the structure's breakage as long as main pipeline remains safe. *Figure 6.2.9* shows schematic illustration of such condition. Even culvert is broken along fault line, pipes inside the culvert remain safe because of enough space coverage around the pipe.

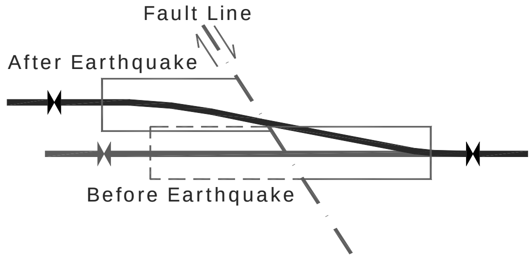


**Figure 6.2.9 Breakage of Culvert**

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 6.2.10* shows an example of the method. In this measure offset of fault movement is absorbed by these flexible joints. Box culvert should keep enough inner space after fault movement. *Figure 6.2.11* shows illustration of mechanism and picture of ball joints.

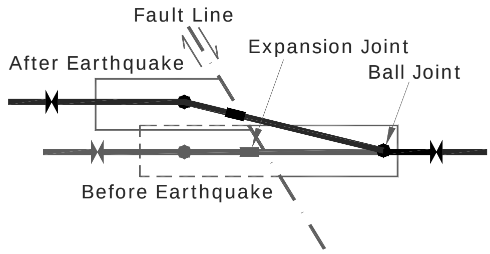


**Figure 6.2.10 Culvert with Ball Joint**

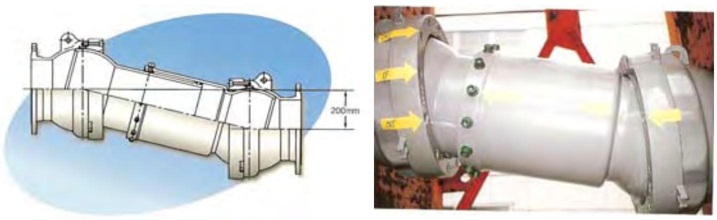

**Figure 6.2.11 Ball Joints**

### (9) By-pass Pipe Option

*Figure 6.2.12* shows concept of option. Permanent by-pass pipe is used for emergency case. By-pass pipe is connected to existing main pipe with tees and valves. Usually all valves are in open states. In case of breakage of main line at fault line, neighboring valves are operated so that water can flow through only by-pass line. By-pass line is designed to supply minimum required quantity in case of emergency. Such tees attached to main existing line are also used as water outlet or tap in case of necessity. Therefore 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.

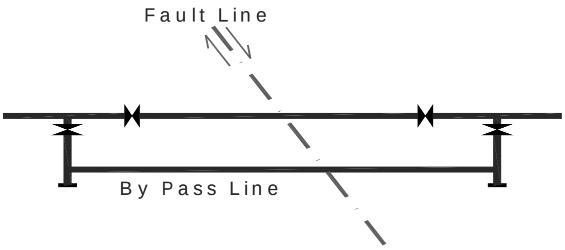


**Figure 6.2.12 By-pass Option**

**(10) 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. Flexible joints can be used to avoid the damage caused at such connections. However main purpose of using the flexible joints is to absorb displacement caused by unequal settlement as described before. These settlements mainly occur as a result of soft clay consolidation.

Similar options at fault crossing can be taken, though absorbing displacement is far smaller. Therefore dimensions of reinforcing become small and damage might be reduced only with detach-resistant joints in case of ductile iron pipes. In addition use of steel pipes with welded joint can also avoid such damage even if slight damages might exist.

**(11) Measures against Seismic Motion**

Strain caused during earthquake motion is small and possibility of joint slip-out is small even when concentration of these strains accumulates in the neighboring joints. Motion effects become large when pipes are installed in thick piled surface layer. Bed rock motion is amplified through the surface layer and resultant near surface ground strain becomes large. However soil in Tehran is stiff enough, therefore it is not necessary to consider such effects. These strains can be roughly calculated using surface ground motion velocity and shear velocity of seismic wave. For instance in case when shear wave velocity is 300m/sec and surface of ground motion velocity is 50 $cm/sec^2$, ground strain near ground surface becomes 0.16%. Considering the strain accumulation to adjacent joint with 5.5 m length pipe, slippage becomes only 9mm. Steel pipes are also quite safe under such low strain levels. Nevertheless use of detach-resistant joints is recommended to secure against unexpected phenomenon in case ductile iron pipes are used. Needless to say that use of welded steel pipe reaches the same results.

For smaller diameter pipes, polyethylene pipe with electric fusion bond joints is one of the ways to keep high reliability. Use of pipes with reliable joints is the only way to secure pipeline reliability. Even at places with possibility of danger, use of pipe with reliable joints can mitigate the damage.

**(12) Concluding Remarks of Measure Options**

Several options are described in previous paragraphs. There is a case which offset of fault is quite large and to keep reinforcing structures in safe condition is quite difficult for the reasons of economical circumstances. Therefore 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

#### (1) Outline

Parallel lines of 1000mm diameter steel pipe are used from Bileghan intake to water treatment plant (herein after referred to as WTP) 1（Jalaliye）and parallel lines of 2000mm diameter RC pipe are used from Bileghan intake to WTP2（Kan）in west of Tehran. Therefore there are two pipeline routes from Bileghan to water treatment plants. On the contrary, mountain tunnels are used to transport water from Lar dam to WTP5(Sohanak) and from Latiyan dam to WTP3,4(Tehran Pars) respectively.

Steel pipeline route is approximately 43 km including 8 km of concrete channel /culvert sections. Therefore total length of steel pipelines is about 70 km. In some places like invert siphon, steel pipes are reinforced with concrete encasement. RC pipeline route is about 33 km and total pipeline length is 66 km.

Major damage prone places are considered at active fault crossings. Steel pipelines cross with fault near Bileghan intake. On the other hand, RC line crosses faults at 8 places including near Bileghan intake.

Considering reinforcing method for these lines, bridge type, concrete culvert and concrete encasements are to be considered. However the crossing points are many, therefore bridge type is not practical in consideration of space restrictions and construction cost. Furthermore concrete box culvert structure becomes also huge.

Except for rectangular cross of fault and pipeline, axial/longitudinal deformation occurs in pipeline. These deformations have to be absorbed by pipes besides the concrete encasement. Therefore some special consideration is necessary. Even though 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 RC pipeline.

#### (2) Pipeline Upgrade Options

One of the measures to reinforce mountain tunnel at fault crossings is to increase concrete lining thickness. These measures are expected to inducwe same effects as a beam model described in previous sub-section. However this method is only possible under suspension of water transport. Therefore taking measures to mountain water tunnel is almost impossible. Both of raw water transmission tunnels to WTP3,4 and WTP5 have similar conditions of fault crossings, however the situation of WTP5 tunnel is more serious, for fault crossing places are much more than the other one.

On the other hand, several options can be chosen for raw water transmission lines from

Bileghan to Tehran. North Tehran fault crossings are considered the most hazardous points. North Tehran fault is a thrust and lateral strike slip and fault offsets come up to the order of 1.5 meter. Therefore it is almost impossible to prevent damages completely. Besides return period of the strong earthquake is quite long and too much investment for earthquake measures seem far from being cost effective. Considering these conditions practical options can be adopted as countermeasures. Considering concrete material and diameter of 2000mm, it is hard to apply measures to concrete lines. Therefore application of by-pass line option is one of the best selections. In this option if breakage of main lines occurs, substantial quantity of water is secured through by-pass line. In case neither line is functioning, temporal pipes are connected to branch tees. This method is possible considering low flow rate, i.e., hydraulic gradient is small and flow rate can be controlled.

For steel lines, some additional options can be selected. North Tehran fault crossing is considered at one location, i.e., 2 points as pipeline, in addition to the above described by-pass option, use of concrete box culvert can be chosen. There are some places with concrete encasements, although the purpose of these encasements was not for earthquake. Even though these encasement might be effective as seismic resistance as well.

Assuming these damages of tunnels and raw water transmission pipelines, hydraulic analysis was carried out to ensure the possibility of water supply interruption in case one of the water treatment plant is shutdown. Details of these case studies are described in section 4.3. As a result, water interrupted area is limited even enough water can not be delivered. This means TWWC's clear water transmission network constitutes a redundant system. Therefore maintaining the redundancy of transmission line is indispensable for water supply.

However state of having one of the water treatment plants out of operation causes water shortage even if some volume is supplied by well water. Therefore connection lines between water treatment plants are to be considered to increase raw water system redundancy. Those are connection lines from water treatment plant 2 and junction point of steel pipeline and channel and line between WTP3,4 and WTP5. Length of the former is about 1.5 kilometers and that of the latter is about 7 kilometers. WTP 2 and WTP3,4 are important and interruption of raw water to these plants affects supply capacity. Nevertheless to satisfy the former connection line, pump facility at junction of steel line and channel is required. Still enough water supply to WTP2 is impossible considering dimensions of steel pipelines. As a result the main purpose of this connection line becomes as supply of water to WTP 1 in case of steel pipeline shut-down. About the latter connection line between WTP3,4 and WTP5, difference of altitude of about 180 meters exists. To install booster pump to transport water from WTP3,4 to WTP 5 is less cost effective. This line can be used by gravity flow, i.e., from

WTP 5 to WTP3,4. It is effective considering the importance of WTP 3,4, however damage possibility of tunnels is higher in case of WTP 5, for tunnel length is large and there are many intersections with faults.

Therefore these connection lines' necessity is considered together with condition of WTP 6 and 7 which are planned to be in future operation.

### 6.2.4 Enhancement of Transmission Main

#### (1) Outline

Transmission main has length of 400 km pipeline. They consist of connection lines from WTP to reservoirs and discharge lines to distribution trunk mains. The transmission line is one of the most important lines in water system. Pipe material, diameter and length are listed in Appendix-2.

Results of damage are described in section 4.1 “Damage Estimation of the Pipeline System”.

As mentioned before main damages are caused at fault crossings. Secondary fault crossings are also included for the fault crossing. There is a possibility of secondary fault dislocation after movement of active fault such as North Tehran fault. However the possibility of the secondary fault dislocation after scenario earthquake can not be specified. Therefore worst case is considered in this study and actual damage might be less than estimated.

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.

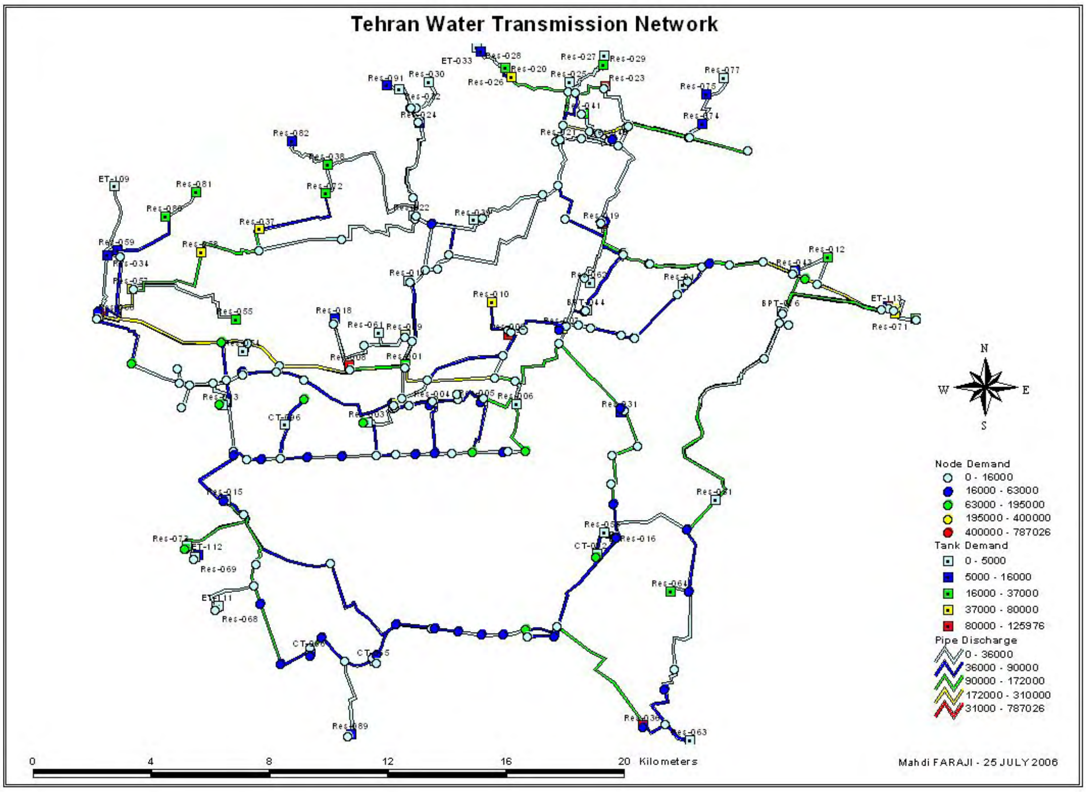


**Figure 6.2.13 General Layout of Transmission Main**

Transmission lines are quite important for their function locate at most upstream of clear water distribution system. As described before most of water transportation can be managed even if one of the treatment plants stops. This is entirely relied on soundness of transmission line system. Therefore it is desirable that pipelines should be stable even after strong earthquake. Measures for fault crossings are the main concern and several options can be taken for. Most of fault crossings are with secondary fault and dislocation offsets are relatively small.

**(2) Pipeline Upgrade Options**

To apply bridge type option is almost impossible considering location of pipeline. Therefore installation of pipes inside concrete culvert is considered as one of the best measures selection. 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. Inner space where pipe can move with some allowance is decided by assuming fault offsets. In the culvert, use of ductile iron pipes with detach-resistant joints is preferable considering absorption of longitudinal displacement. Lateral displacement is absorbed with concrete culvert as described before.

Concrete encasement measures are also possible. However longitudinal displacements of pipes are restrained with surrounding concrete encasement, therefore similar consideration to raw water transmission pipeline is necessary to absorb longitudinal displacement. Reinforcing concrete pipes have some difficulty to absorb the displacement. RC pipeline with 1850 mm diameter crosses secondary fault. Considering the above conditions, replacement of this section to be steel pipes is one of the options. Even though, considering uncertainty of secondary fault movement, temporal piping is practical for such large diameter pipes.

Except active fault crossing such as North Tehran fault, secondary faults are considered as side slip and offsets caused by secondary fault movement are relatively small. Therefore in case of steel pipes with weld joints as pipeline are considered safe even without any special measures. Furthermore application of butt weld is preferable to maintain strength of joints to be equivalent to the pipe body.

As a conclusion, practical measures for transmission line are listed below.

| Pipe Size | Active fault crossing | Secondary fault crossing |
|---|---|---|
| Large | N.A. | Temporary connection |
| Medium | Use of detach-resistant joint | Use of detach-resistant joint |
| Small | Use of casing/culvert | |

### (3) Summary of Analysis Method

Hydraulic analysis was carried out and results were described in section 4.3. Case studies with suspension of one of the main water treatment plants were also included. In such cases, water shortage might occur, however only limited areas will suffer from water stoppage. This means TWWC's transmission network has topologically good shape. Therefore keeping transmission main reliability is quite important and if pipelines are safe, serious condition can be avoided.

Hereinafter analysis method is briefly described. Water starts from water treatment plant and reaches to reservoirs or junctions connected to distribution mains through transmission main system.

Water in the reservoirs is distributed to corresponding reservoir zones together with direct injected water to distribution mains. Therefore transported water is allocated to specified reservoir zones. These quantities are given as demand quantities. Considering these conditions, each demand has corresponding reservoir zone. If any damage occurs in pipeline and demand quantities become less than required or even zero, such influences can be considered as effects to certain reservoir zone. Magnitude of effects is summarized for every reservoir zone. Worst case for the zone is the case of water supply stops completely. Possibility of such water stoppage situation is calculated in the analysis. Sometimes term "reliability" is used instead of damage possibility. This reliability indicates possible rate of "any" water to the zone. 100% reliability means any water arrives to the zone even though quantity is quite small. This doesn't mean percentage of water shortage area nor water

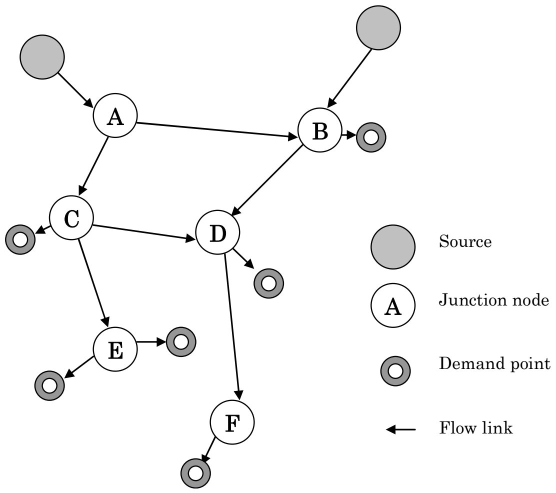


Figure 6.2.14 Reliability Analysis

quantity.

Each element of flow link shown in *Figure 6.2.14* has own reliability. Each source has also reliability value. Reliability of downward stream junction node is derived from multiplying upstream node reliability with link reliability. In such manner reliability of all nodes can be calculated. Node A in *Figure 6.2.14* has a relative high reliability value because the node is near the source. Node B and D have also high reliability values, for these nodes have more than one upstream paths. Even if one of the upstream paths is in trouble, water can reach through other paths. Such redundancy is essential considering reliability. Nevertheless acquired quantity is less than required one. Each demand is allocated to certain reservoir zone. After calculating reliability of each junction nodes, such reliability is weighted by quantity of demand so that effect of shortage is influenced by importance of nodes. These are kind of index to show the magnitude of influence. After summing up the index of junction in each zone, reliability of reservoir zone is derived.

Flow link reliability is based on damage calculation, however some modification was done. *Table 6.2.1* shows assumed reliability of flow link. Reliability of flow links with steel or DIP in northern area is reduced to 0.5 at active fault crossing and to 0.75 at secondary fault crossings. On the contrary RC pipes reliability is less than these values considering weakness of material. Reliability values of each length are also shown in the table. Reliabilities for steel pipe and DIP are set higher than that of RC pipe.

**Table 6.2.1 Flow Link Reliability**

| Reliability at fault Earthquake:North Tehran fault | | | | |
|---|---|---|---|---|
| | Pipe Matrial | Active fault | Secondary fault | No fault |
| Northern area | Steel,DIP | 0.5 | 0.75 | 0.95 |
| | RC | 0.25 | 0.5 | 0.85 |
| | Measured pipe | 1 | 1 | 1 |
| Southern area | Steel,DIP | 1 | 1 | 1 |
| | RC | 1 | 1 | 1 |
| | Measured pipe | 1 | 1 | 1 |
| Reliability at fault Earthquake:North Ray fault / South Ray fault | | | | |
| | Pipe Matrial | Active fault | Secondary fault | No fault |
| Northern area | Steel,DIP | 1 | 1 | 1 |
| | RC | 1 | 1 | 1 |
| | Measured pipe | 1 | 1 | 1 |
| Southern area | Steel,DIP | 0.5 | 0.75 | 0.95 |
| | RC | 0.25 | 0.5 | 0.85 |
| | Measured pipe | 1 | 1 | 1 |

| Reliability per unit length | | |
|---|---|---|
| | Pipe Matrial | 1/Km |
| Whole area | Steel,DIP | 0.95 |
| | RC | 0.85 |
| | Measured pipe | 1 |

DIP:Ductile iron pipe
RC*Reinforced Concrete pipe

Water demand quantities which are used in hydraulic analysis are allocated to appropriate reservoir zones. Possibility of water supply to a zone is calculated summing up the multiplied results of node junction reliability and demands which is used as weight factor. In such manner possibility of water supply interruption is derived. Possibility of water supply interruption indicates expectation value of no water supply to specified reservoir zone. Value of 100% means no water arrives to the zone, on the contrary 0 % means water can be received in reservoir zone even though quantity is not enough. Note that 0 % doesn't mean that water demand in zone is satisfied.

Three stages are assumed in the analysis.

- Present condition
- Next stage which means necessary measures are applied at fault crossings.
- Final stage which means RC pipes are replaced with more reliable pipes.

Steel pipes and ductile iron pipes which are considered in good conditions and have enough strength remain same as present condition. These pipes might be replaced in far future, however network shape will be changed and analysis can not be carried out considering such condition.

Results are shown from next paragraph. In present condition, results from North Tehran case and North Ray case are different, therefore both cases are shown. In the next and future stage both results are same. The other cases, i.e., scenario earthquake of South Ray fault or Mosha are attached in appendix-2 as table.

**(4) Analysis results**

Figures below show results of water supply interruption possibility in each reservoir zones. In this sub-section, only effect of transmission line is considered. Combined effects for total water distribution system are described later.

**1) Present Condition**

*Figure 6.2.15* shows possibility of water supply interruption after North Tehran fault earthquake. Zones in northern region have high potentiality of damage, for these zones are close to North Tehran fault. In these areas transmission pipes which have relatively small diameter have several fault crossings and there is no other alternative supply route. High interruption rate in other zones is caused by assumed damage of large diameter concrete pipeline which starts from WTP 2. *Figure 6.2.16* shows results of North Ray fault case. Possibility becomes small compared to those results of North Tehran fault. Even though some zones have still high interruption possibility.

**2) After Some Countermeasures are Applied**

After countermeasures for all fault crossings are applied, north region interruption possibilities become small. *Figure.6.2.17* shows the result of next stage. From this stage North Tehran case and North Ray case are considered same, for main damages are caused at fault intersections which are already measured. Although high interruption prone areas still remain. This can be explained that increase in ength from water treatment plants decreases the reliability.

### 3) Final stage

Figure 6.2.18 shows results of final stage. In this stage all RC pipes are replaced. However steel pipes and ductile iron pipes which are considered as strong material pipes are remains. With same reason as next stage, some zones far from water treatment plant have relatively high interruption possibility.

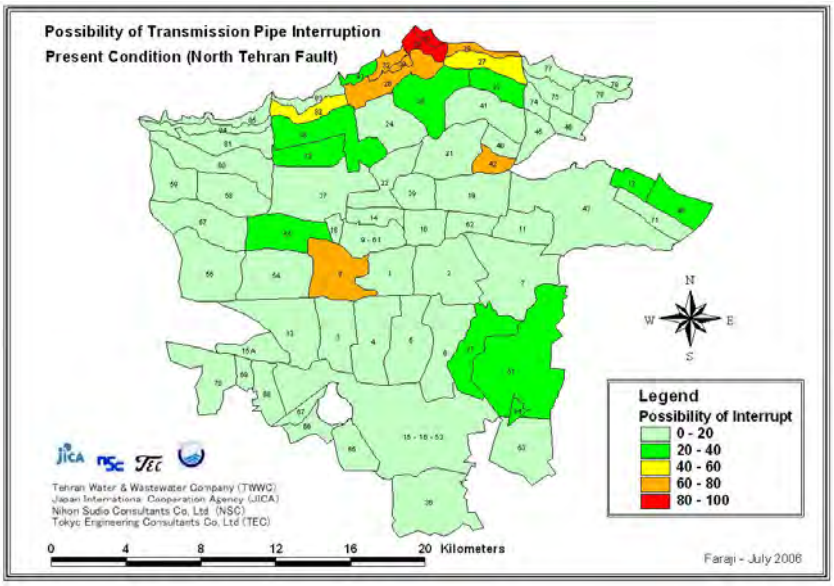


**Figure 6.2.15 Effects of Transmission Main**

**(Present condition, North Tehran fault)**

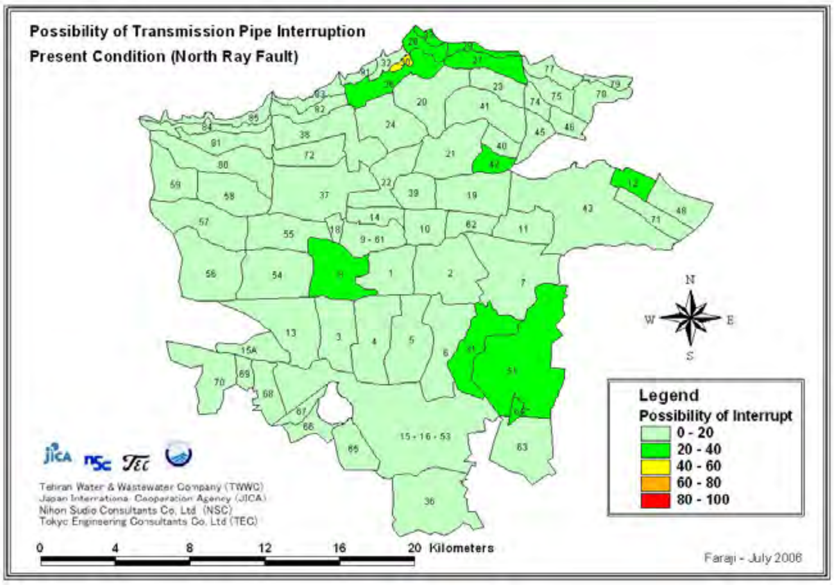


**Figure 6.2.16 Effects of Transmission Main**

**(Present condition, North Ray fault)**

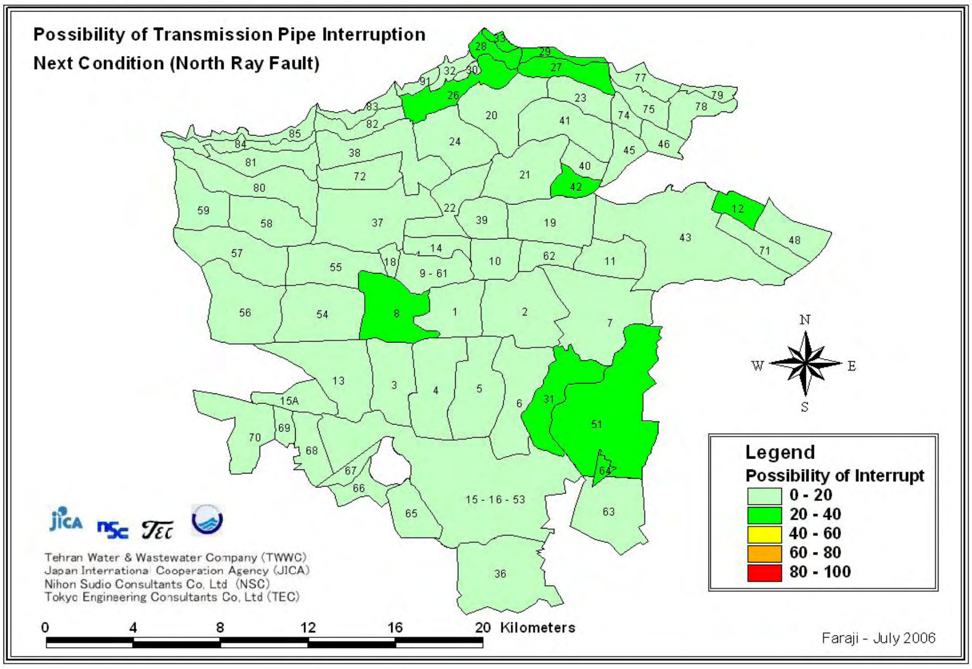


**Figure 6.2.17 Effects of Transmission Main (Next Stage)**

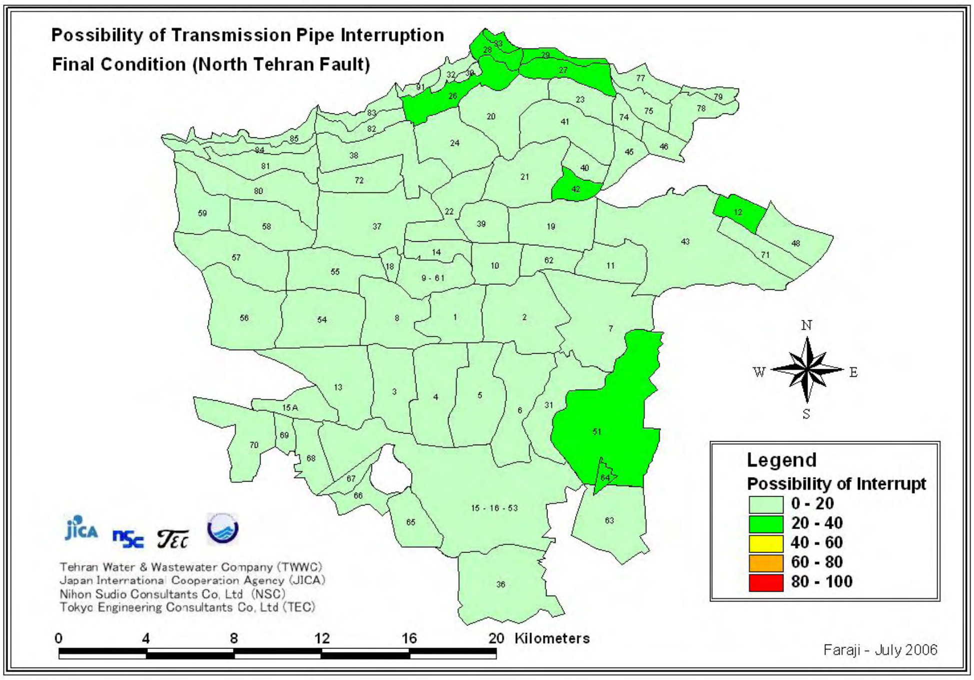


**Figure 6.2.18 Effects of Transmission Main (Final Stage)**

### 6.2.5 Enhancement of Distribution Trunk Main

#### (1) Outline

Distribution trunk main consists of approximately 770km in length and DIP has length of approximately 500 km. Function of the main is to deliver water from reservoirs to distribution sub mains. Pipes with diameter of 300 mm and more are included except those which are considered as transmission mains.

There are 95 estimated fault crossings. Mainly there are secondary faults. Damage analysis results are shown in section 4.1. Damage tendency is similar to the case of transmission main, i.e., major damage is caused by fault dislocation. Furthermore there are possibilities of joint detachment at places where pipes are connected to massive structure such as concrete reservoirs because of difference of motion characteristics.

#### (2) Pipeline Upgrade Options

Similar method to transmission pipeline can be applied. However distribution trunk main consist water supply networks and even though some segments are damaged, it is possible to supply water using other routes. The pipeline has essentially redundancy.

Considering enhancing method, both box culvert and by-pass option are practical. In case 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 method

Countermeasures are similar to those of transmission case. Installing box culvert or concrete encasement at fault crossing is one of the selections. Use of detach-resistant joints is also effective.

Analysis method is described below. Distribution trunk main receives water from transmission main and deliver them to distribution sub mains through piping system. In case of some damage points break up in the network, water might not be delivered to sub mains properly. There are many connections to sub mains and there are many valves in the network. Pipeline is divided to pipe segment by the valves. Considering valve numbers and pipe length, pipe segment length is considered approximately 350m. For total length of distribution trunk main is approximately 770 km and numbers of valves are 2300. Water supply is interrupted in case of such segments become inactive because of shutdown of upstream valves. Ratio of total length of interrupted pipeline to total length in the zone is assumed to be the ratio of water supply suspended area.

Number of damaged points in the zone is derived from damage estimate. Model of network topology is shown in *Figure 6.1.19*. Distribution trunk main network in the zone is assumed to be connected to the transmission line outlet with two points. All pipes divided to several lines and ends of these lines are connected to above mentioned outlets. The term lines means group of pipe segments.

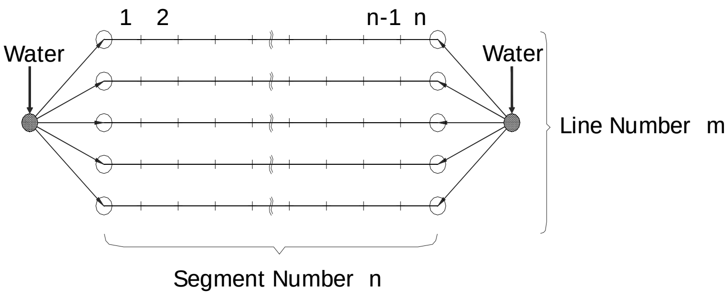


**Figure 6.2.19 Network Model**

Therefore if two segments in the line are blocked with valve operation, pipe segments isolated by these segments are out of operation. In case one segment is stopped in the line,it renders only that segment out of operation, for water reaches other segments through active route. Assuming such topology in each reservoir zone the number of damage points are allocated using Monte Carlo simulation. In this model, one line consists of approximately 100 pipe segments.

Considering improvement by pipe reinforcing, pipe reliability is being increased after some countermeasures or replacements are performed. Total effects of these measures are included and water interrupted areas are reduced based on the effects. Cast iron pipe reliability is assumed to be zero at present stage which means if there is possibility of damage, damage will happen in the rate of 100%. On the other hand in case reliability equals 1.0, even if possibility of damage at the point exists, pipe damage possibility is lowered to zero. Therefore all pipes in the zone are replaced and reliability become 100%, water interrupted area becomes zero.

Three stages are considered as developing steps. First stage is present condition with no specified measures. Second stage is the next step plan with both all countermeasures are done at fault crossings and all cast iron pipes are replaced. In this analysis reliabilities are defined by material. Assumed reliability values are listed below.

- Present condition
  Reliability of CI=0
  Reliability of Steel & DIP=0.25 (better than CI)
- Next stage means measures are applied at fault crossings.
  Reliability of CI with measured=0.75
  Reliability of Steel & DIP with measured=0.95
- Final stage means CI pipes are replaced with steel or DIP and pipes are measured completely.
  Reliability of all pipe=0.99

By using these values, analysis was carried out.

### (4) Analysis results

In this paragraph, only effect of distribution trunk main is in consideration. Combined effect of water interruption is described later. Detailed data tables are attached in appendix-2.

#### 1) Present Condition

*Figure .6.2.20* 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.

*Fig.6.2.21* shows results of North Ray fault case. All of the reservoir zones are below 20 % interruption possibility.

Both results show suspension possibilities are small and water interrupted area is limited because of water network.

#### 2) Next Stage and Final stage

*Figure 6.2.22* shows the results of next stage and *Figure 6.2.23* shows results of future stage. Water supply interruption is small and almost 0 % in the final stage.

Therefore measures to fault crossings are necessary to reduce water interruption zones. Replacement of pipes is enough to follow old pipe replacement plan. In those cases, use of strong joint pipes is recommended.

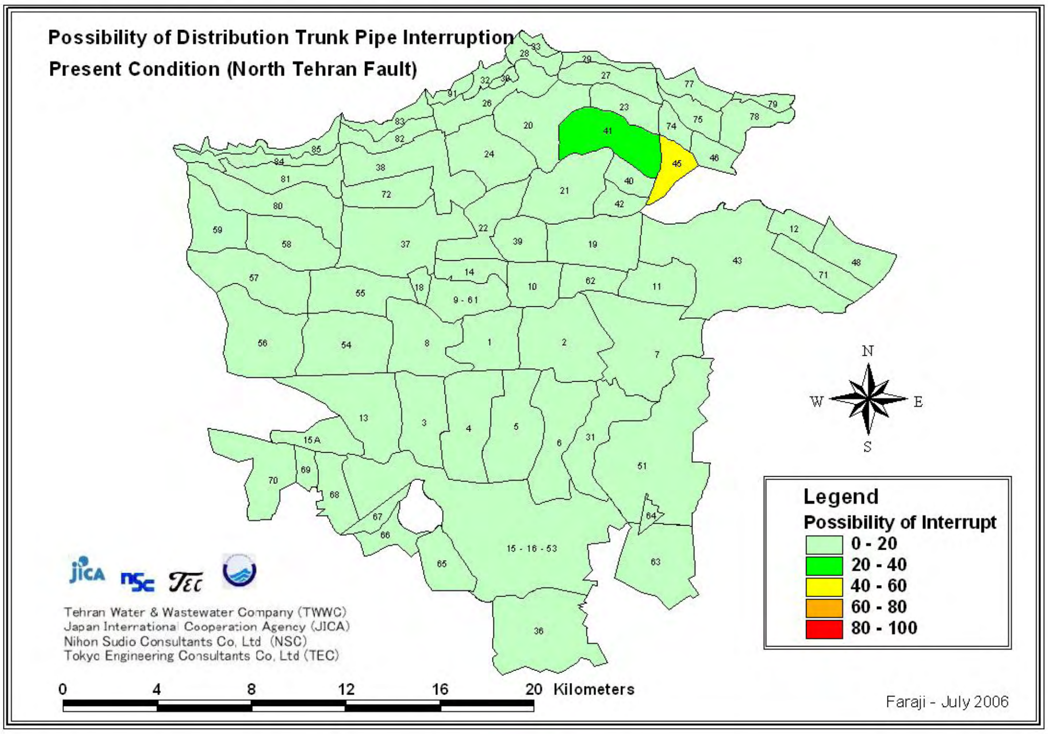


**Figure 6.2.20 Effects of Distribution Trunk Main**

**(Present Condition, North Tehran fault)**

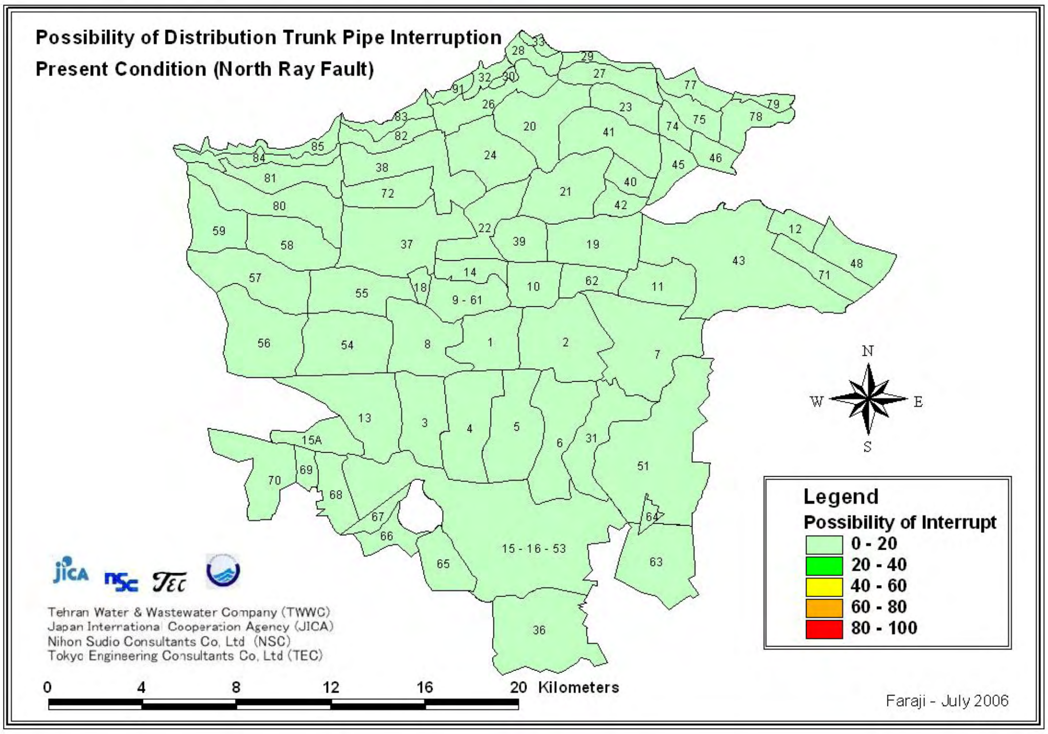


**Figure 6.2.21 Effects of Distribution Trunk Main**

**(Present Condition, North Ray fault)**

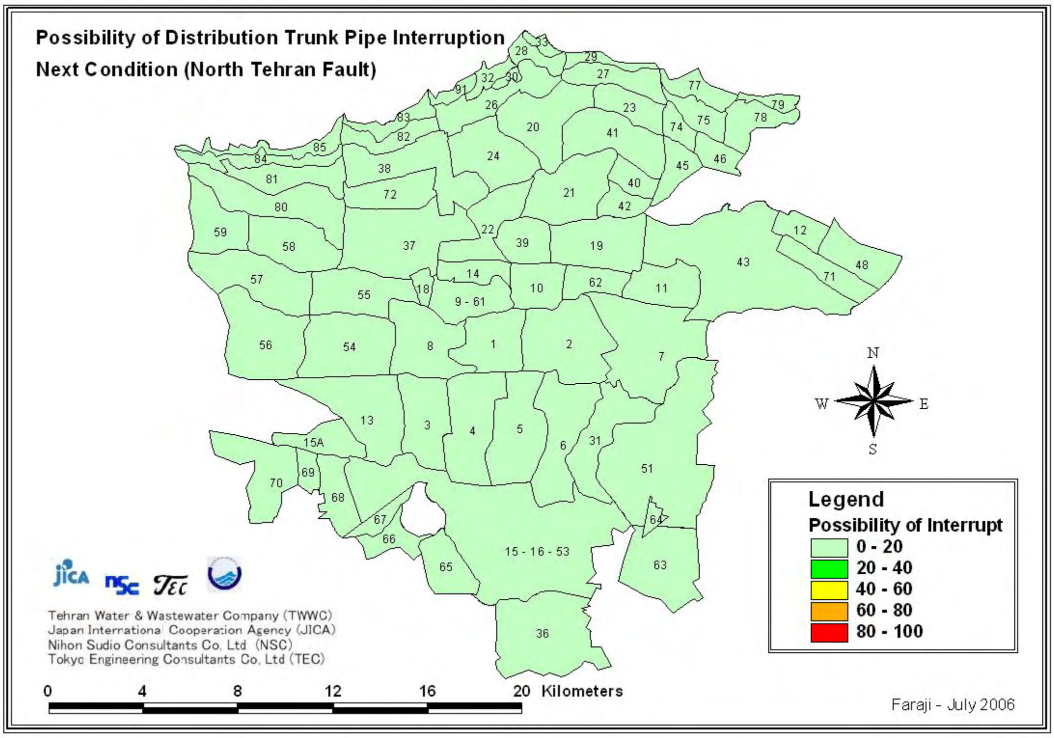


**Figure 6.2.22 Effects of Distribution Trunk Main (Next Stage)**

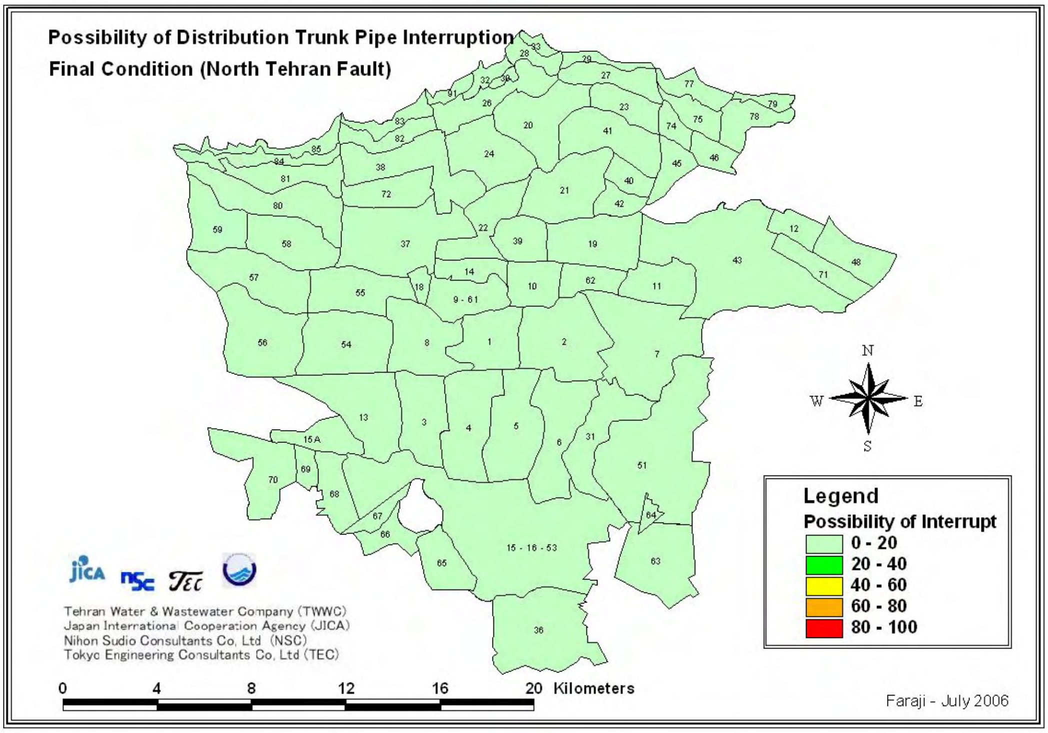


**Figure 6.2.23 Effects of Distribution Trunk Main (Final Stage)**

### 6.2.6 Enhancement of Distribution Sub Main

#### (1) Outline

Distribution sub main has a function of connecting trunk main to service connections. Pipe size is 250mm and less and total length is approximately 6500km. Cast iron pipe is used for old laid ones and ductile iron pipes and polyethylene pipes are commonly used recently. There are several reasons for pipe damage including poor quality control of piping, neglect of surrounding conditions etc. Therefore analysis of damage estimation was executed based on combination of statistical record and fault location information. Acceleration or velocity at ground surface is applied as independent variable for damage calculation and such rate is modified with pipe material and diameter. There is possibility of about 700 damage points, however condition of damage varies from slight to severe, in case of North Tehran fault earth quake.

Total length of distribution sub main is about 6,500 km. Therefore applying countermeasures only for earthquake is difficult when considering practical condition including economic reason. However it is possible to use quake-resistant pipes according to long term replacement plan. All pipes will be replaced considering life period. Taking such tactics it might take long time though after completion damage possibility become drastically small. Unfortunately if an earth quake occurs before completion, damage shall be restored.

Replacement of old pipes is carried out according to TWWC's replacement plan. Old cast iron pipes were replaced in early developed area. After the replacement of very old pipes, approximately 70km pipes are replaced yearly at the moment. Cast iron pipe is not strong enough even in normal conditions. Therefore replacement of cast iron pipes is considered to have a priority. Replacement with PE has been done recently, however pipe joining method is not electric fusion bond and accident of water leakages were reported even when there was no earthquake. PE is reliable as described before if electric fusion bond is applied during piping.

Simulation method is similar to that of distribution trunk main. In this case water is delivered through trunk main. In this paragraph, effect of measures only accounts for sub main lines.

#### (2) Pipeline Upgrade Options

No special care might be necessary for these pipelines. Total length is huge and furthermore specifying damage possibility places are rather difficult. Therefore replacement plan shall 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 method

Similar analysis method to distribution trunk main is applied. In each reservoir zone, line elements have about ten segments. Each segment is approximately 100 meter considering numbers on isolation valves. Details of conditions are tabulated in appendix-2 together with length of pipe material classification. Damage assumed places are much more compared to trunk main, especially in case of North Tehran fault earthquake. Three stages are considered similar to those of trunk mains. Assumed reliability values are listed below.

- Present condition
  Reliability of PE& DIP=0.25
  Reliability of other material=0 (No steel pipes exist )
- Next stage means old CI pipe replacement is completed.
  Reliability of DIP with measured or PE=0.95 (old DIP pipes are regarded as same )
- Final stage means small DIP is also replaced with DIP with detach-resistant joints or PE
  Reliability of all pipe=0.99 except old PE with value of 0.25

By using these conditions, analysis was carried out.

### (4) Analysis results

Water supply interrupted rate in each reservoir zone is calculated. This procedure is similar to that of trunk main. These are only effect of distribution sub main damage.

#### 1) Present Condition

*Figure 6.2.24* shows results of North Tehran Fault case and *Figure 6.2.25* shows results of North Ray. 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. Even water distribution main has a network configuration, water supply interrupted areas become wide in case of many damage points. Northern region in the city has high interruption possibility in case on north Tehran fault. This comes from high value of ground acceleration during earthquake. Such possibilities results less than 20 % in every reservoir zone in case of North Ray fault case. Intensity of ground acceleration or velocity is smaller than those of North Tehran case. Detailed results are shown in appendix-2.

#### 2) Next Stage

*Figure .6.2.26* shows results of North Tehran Fault earthquake and *Figure 6.2.27* shows results of North Ray Fault earthquake. Percentage of water interrupted area become small in both cases. Refer to appendix-2 for details.

#### 3) Final Stage

*Figure 6.2.28* shows results of North Tehran Fault earthquake and *Figure 6.2.29* shows results of North Ray Fault earthquake. Results show great improvement condition. However these conditions might be completed in far future, even though progress is going on by using detach-resistant joints.

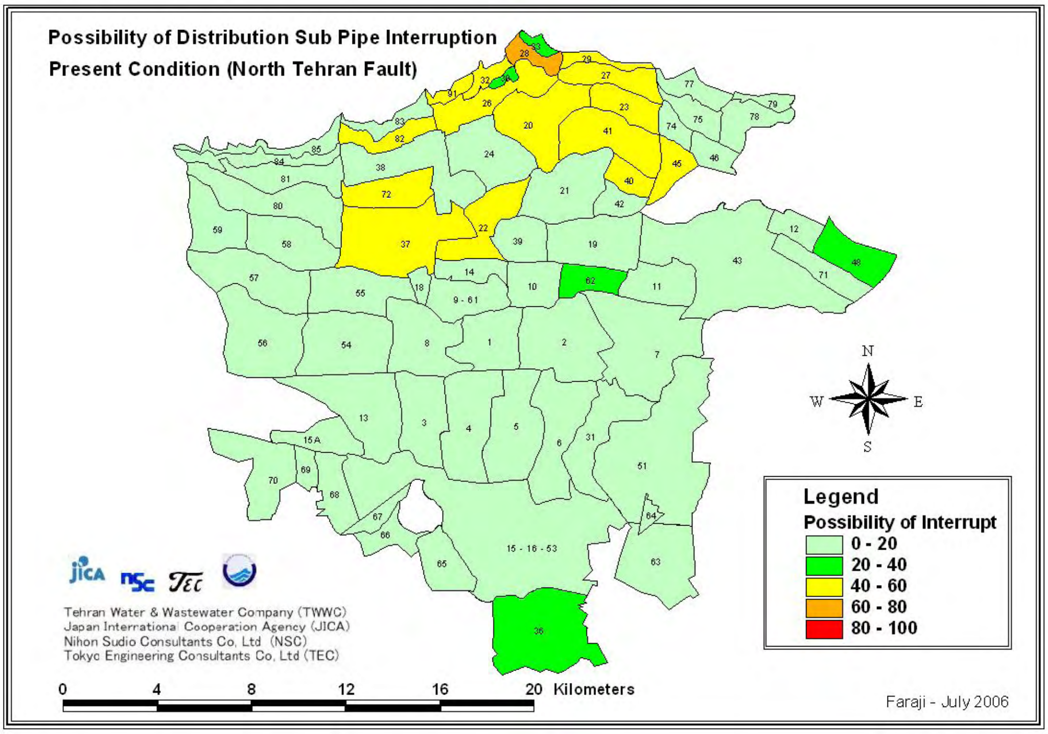


**Figure 6.2.24 Effects of Distribution Sub Main**

**(Present Condition, North Tehran fault)**

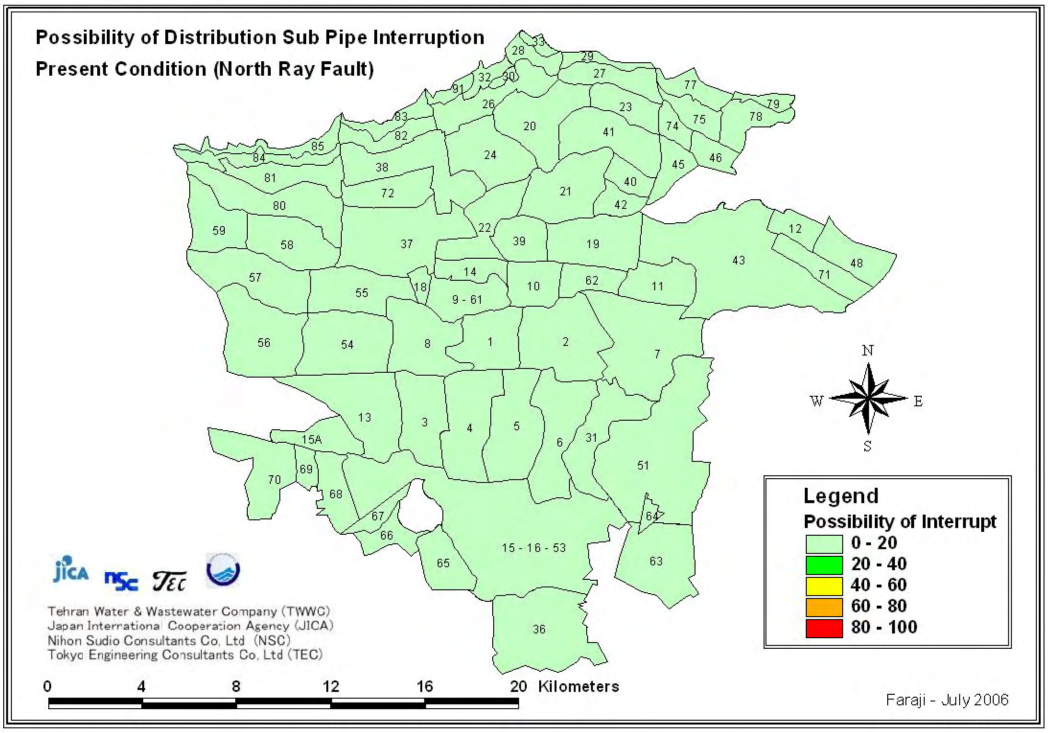


**Figure 6.2.25 Effects of Distribution Sub Main**

**(Present Condition, North Ray fault)**

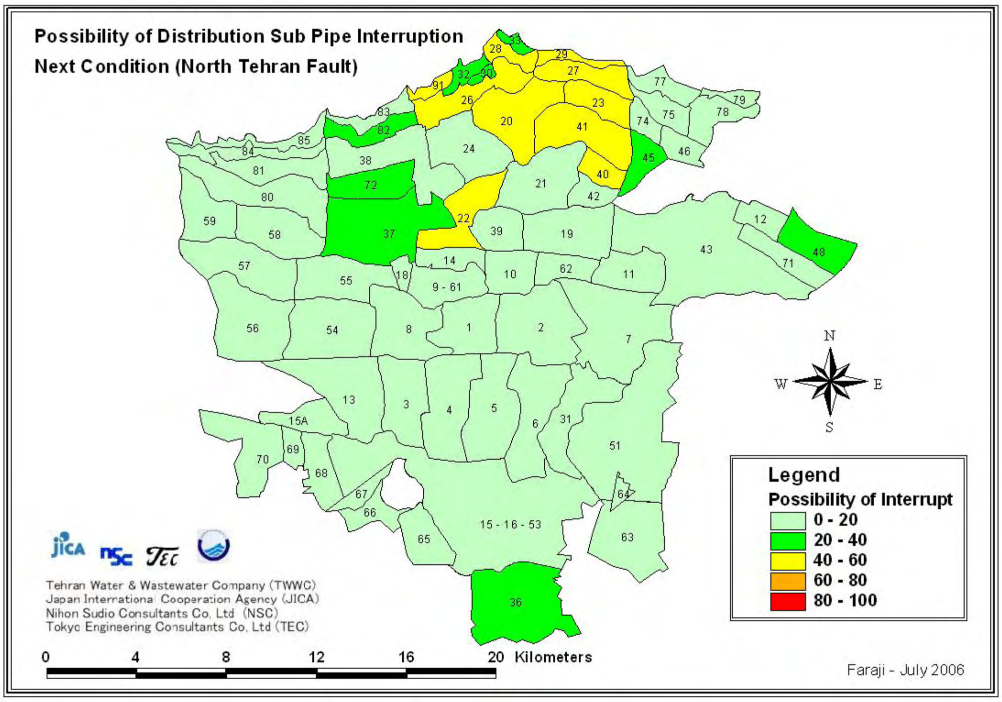


**Figure 6.2.26 Effects of Distribution Sub Main**

**(Next Stage, North Tehran fault)**

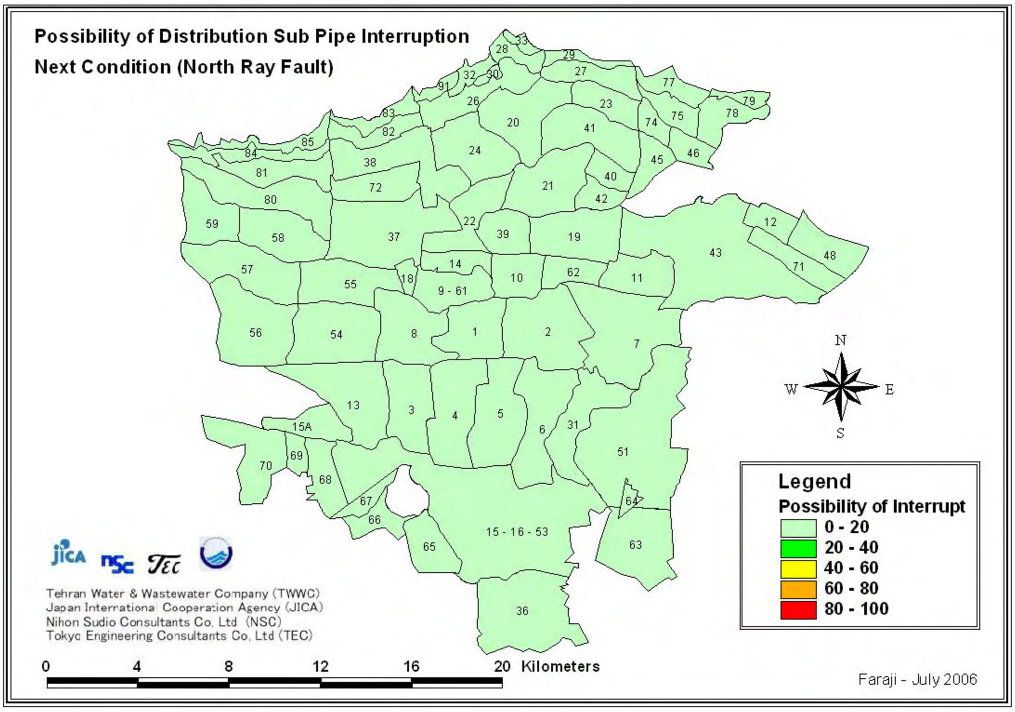


**Figure 6.2.27 Effects of Distribution Sub Main**

**(Next Stage, North Ray fault)**

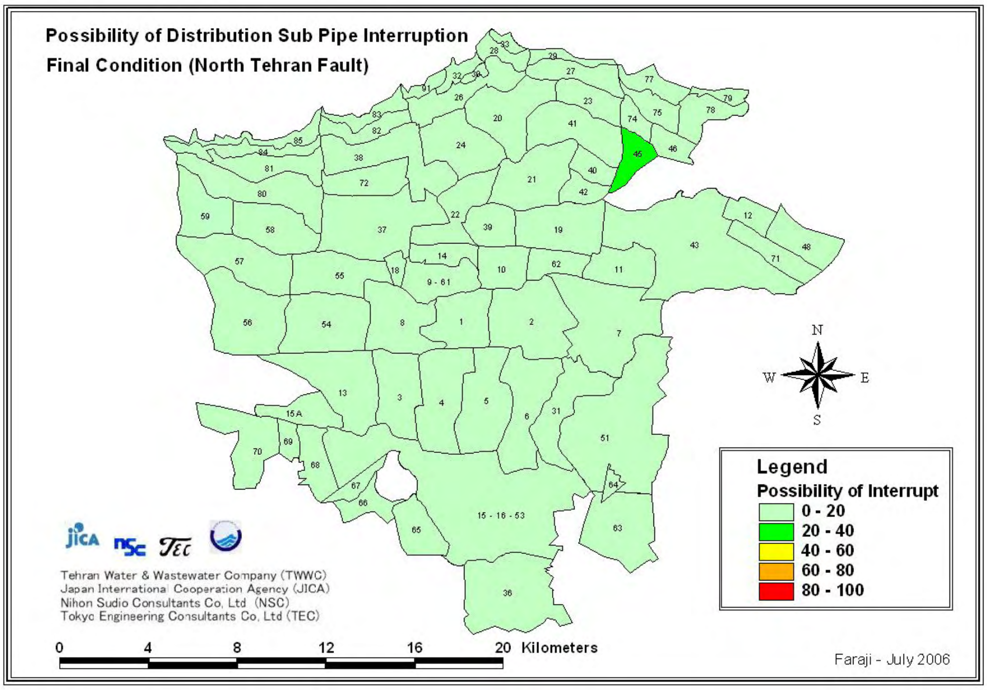


**Figure 6.2.28 Effects of Distribution Sub Main**

**(Final Stage, North Tehran fault)**

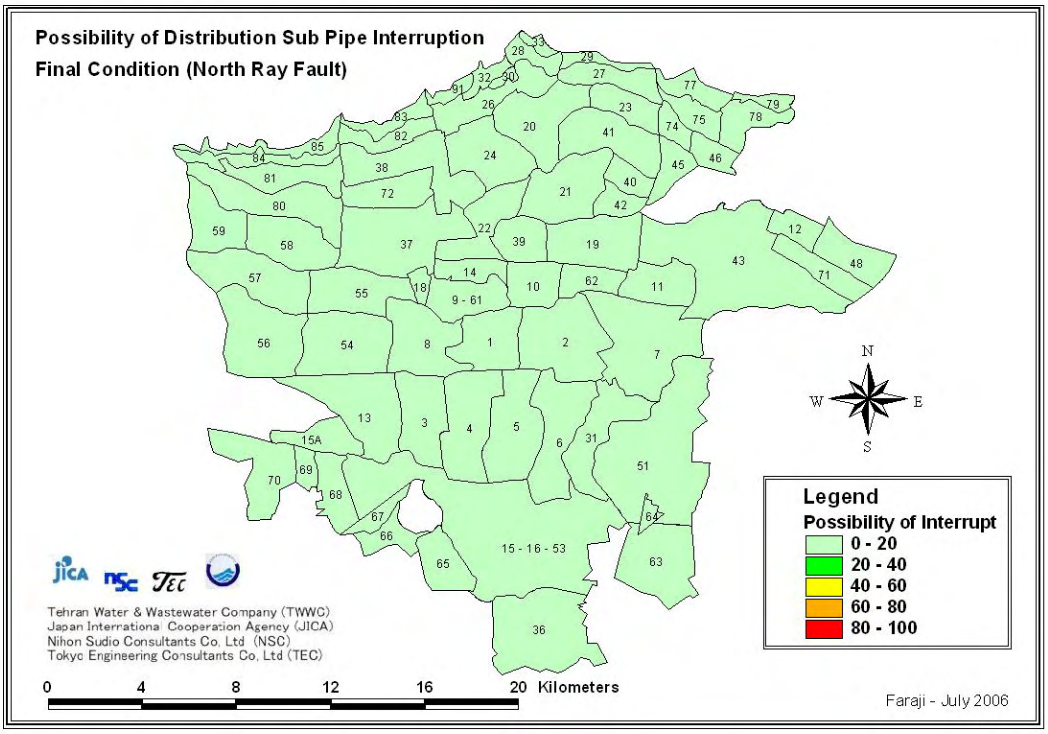


**Figure 6.2.29 Effects of Distribution Sub Main**

**(Final Stage, North Ray fault)**

### 6.2.7 Combined Effects of Water Networks Improvement

Combined effect means damage index of water supply system. Therefore effects of measures are evaluated based on the index. This means each classified sub system such as transmission main or distribution sub system should be improved in consideration of total reliability increase.

In this sub section raw water transmission line is assumed to be in good condition.

**1) Present Condition**

*Figure 6.2.30* shows results of combined effects of North Tehran Fault earthquake and *Figure 6.2.31* shows combined results of North Ray 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

*Figure 6.2.32* shows results of combined effects of North Tehran Fault earthquake and *Figure 6.2.33* shows combined results of North Ray Fault earthquake.

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 future stage.

- Transmission main is in final stage. All RC pipes are replaced.
- All pipes are replaced in final stage of distribution trunk main.
- All pipes except existing PE pipes are replaced in final stage of distribution sub main

This assumes almost no damage occurs in distribution mains including both trunk main and sub mains. Therefore combination effects are influenced by transmission main reliability. Nevertheless this stage is considered for far future, especially considering assumptions of distribution sub mains.

*Figure 6.2.34* shows results of combined effects of North Tehran Fault earthquake and *Figure 6.2.35*shows combined results of North Ray Fault earthquake.

Improvement in northern area is remarkable, though there still remains high possibility of water suspension zones. Even in the future, some of Combined effect means damage index of water supply system. Therefore effects of measures are evaluated based on the index. This means each classified sub system such as transmission main or distribution sub system should be improved in consideration of total reliability increase.

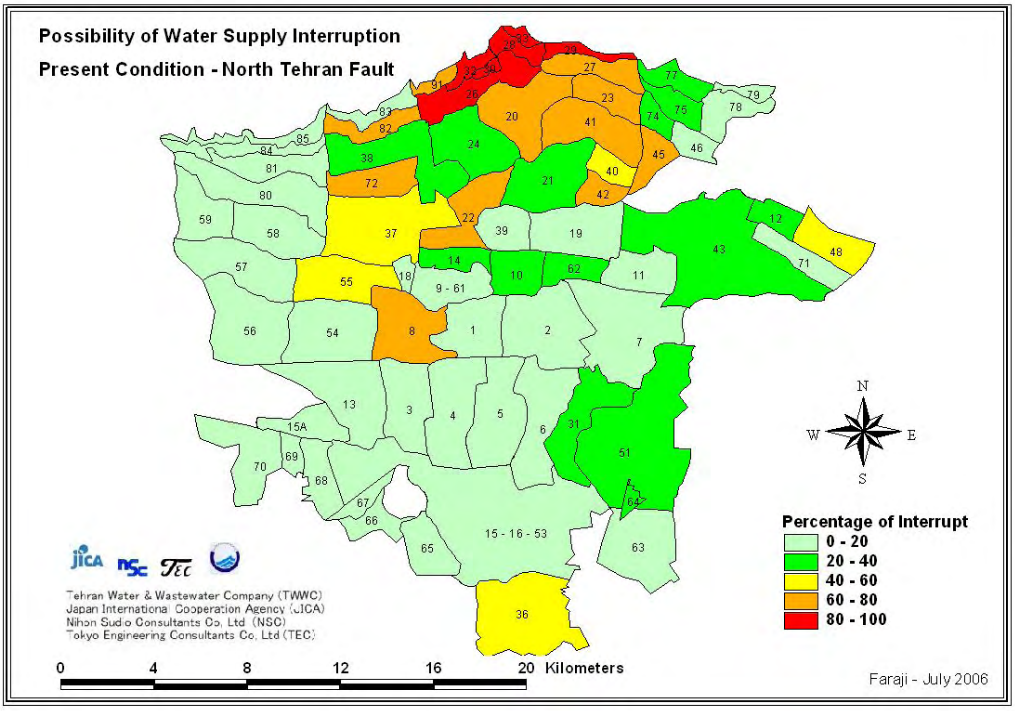


**Figure 6.2.30 Combined Effects to Water System (Present Condition, North Tehran fault)**

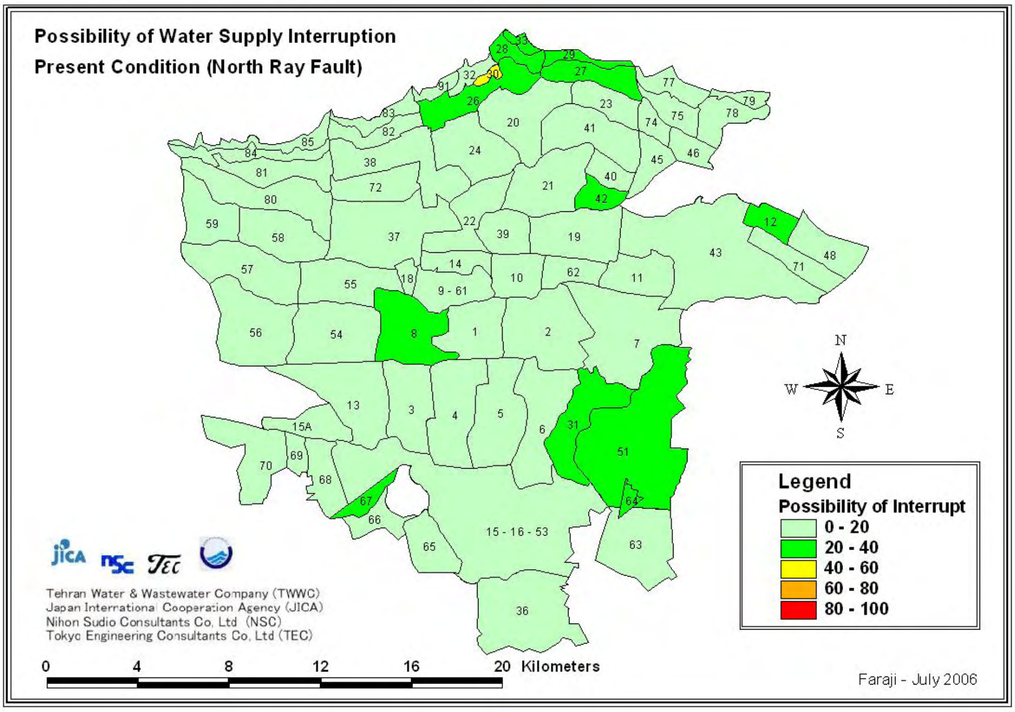


**Figure 6.2.31 Combined Effects to Water System (Present Condition, North Ray fault)**

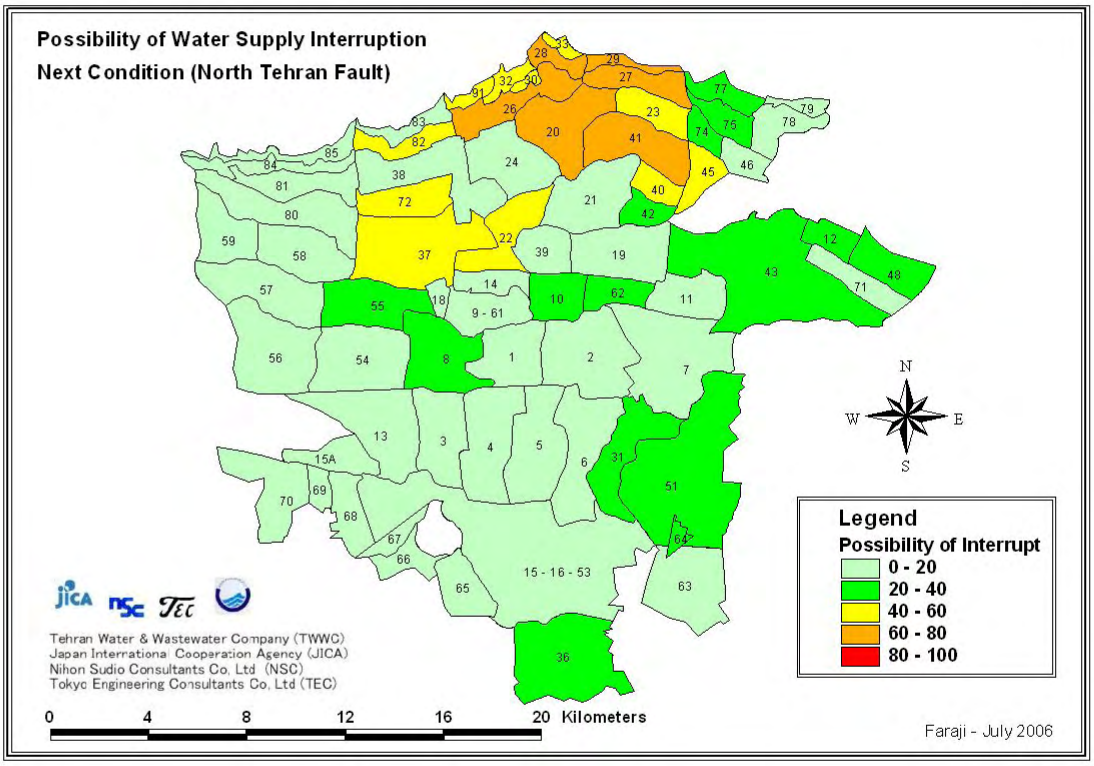


**Figure 6.2.32 Combined Effects to Water System**

**(Next Stage, North Tehran fault)**

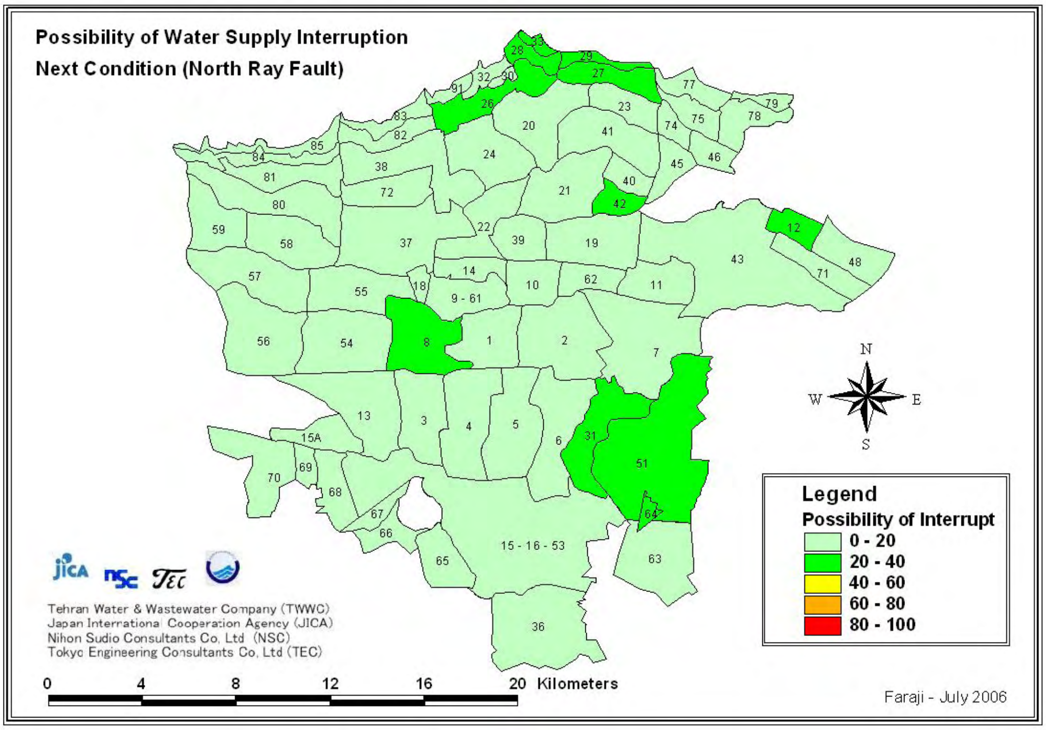


**Figure 6.2.33 Combined Effects to Water System**

**(Next Stage, North Ray fault)**

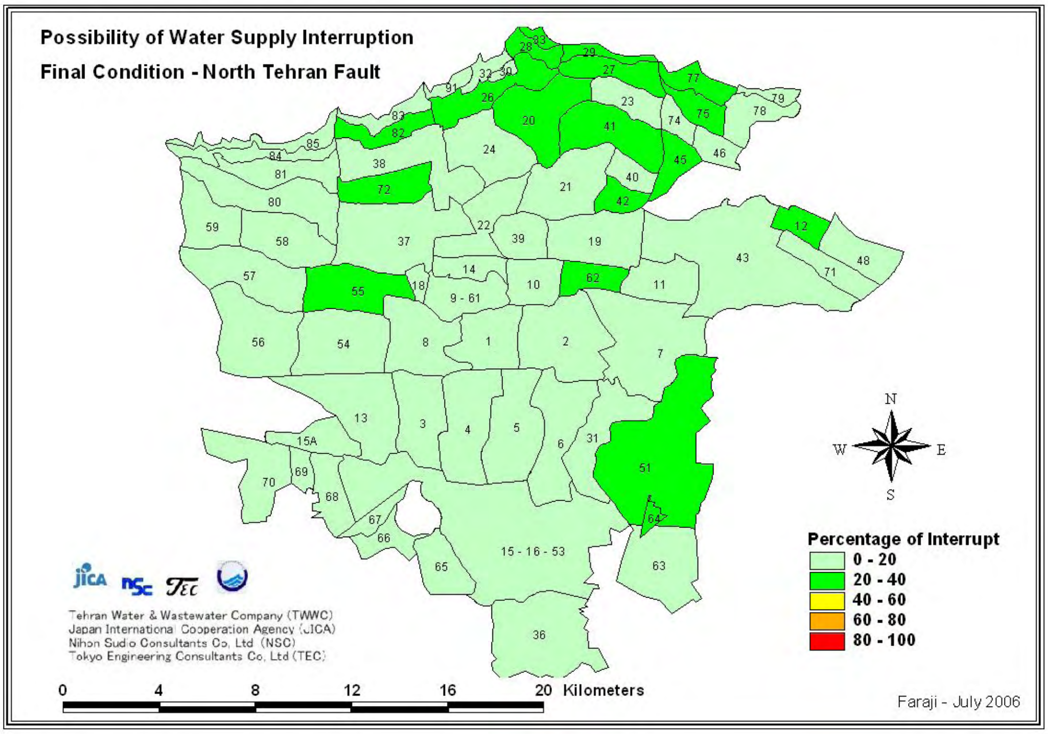


**Figure 6.2.34 Combined Effects to Water System**

**(Final Stage, North Tehran fault)**

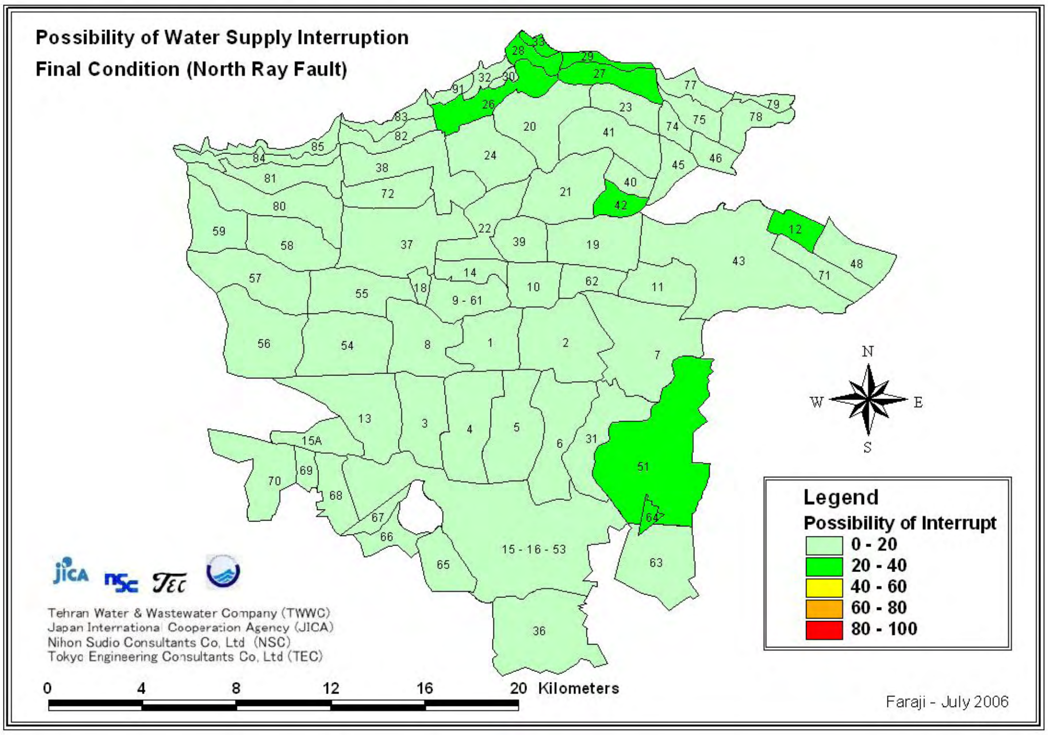


**Figure 6.2.35 Combined Effects to Water System**

**(Final Stage, North Ray fault)**

### 6.2.8 Conclusion of the Section

Upgrade options for pipelines and effects of measures are described in this section. To enhance water distribution system, both strengthening of pipes and increasing redundancy of pipeline system are required. Measures to strengthen pipe are mainly including the increase of joint reliability. Most of the damages are considered to be at joint position, i.e., slip-out of joint caused by large offsets. Large offset is mainly caused by fault dislocation. Therefore measures for fault crossing are the most important ones.

Steel pipes with welded joints and ductile iron pipe with detach-resistant joints are suitable to increase such reliability. Use of these pipes without any special measure might be possible to reduce damages caused by dislocation along fault line. Polyethylene pipe with electric fusion bond is also reliable for small diameter pipes.

Several other measures are also mentioned. There are many options to be applied at fault crossings. However offsets caused in case of North Tehran fault movement is quite large and it is not practical to take any measures even if not impossible. To adopt proper preparation of response after earthquake is one of the selections. Furthermore, instead of reinforcing pipes with huge structures to maintain 100% safety, it is practical to accept some damages which can be repaired without difficulty. Raw water transmission main is one of the examples.

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. This implies transmission main is a redundant system. 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. However this main has a network shape and water can be supplied through several paths. Even though, 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.

No special measures are needed for distribution sub main. For these pipelines are quite long and influence of damage is limited. Repair after breakage is one of the practical methods. Pipe replacement will be executed with renewal plan similar to trunk mains, use of ductile iron pipe with detach-resistant joint or polyethylene pipe with electric fusion bond joint are most important to ensure pipeline safety.

To increase reliability to water treatment plants, new raw water pipeline can be proposed. Connection of WTP2 and steel pipeline has a problem that enough water can not be supplied to WTP2 under the condition of steel transmission line capacity. Connection line between WTP3,4 and 5 is not cost effective because of altitude difference. These are already described before.

It is clear that main damages are caused by fault dislocation. However there is a possibility of faults which have not become clear of their existence. Also there is possibility of ground collapse even if they are thought to be small. Such damages might be caused by wall collapse of “qanats” which is used as underground canal in old time. The location map of these “qanat” is being prepared by TDMO. Nevertheless only part of their locations has been clarified. Therefore it is necessary to prepare for these uncertainties. To ensure pipeline reliability, use of pipes with strong joints is indispensable under uncertain circumstances including such “qanats” existence.