### 4.2 Damage Estimation for Facilities and Equipment

This section for seismic diagnosis of facilities and equipment consists of preliminary seismic diagnosis and detailed diagnosis. Main findings of preliminary seismic diagnosis are pointing of defects based on the visual investigation. In detail diagnosis, earthquake-resistant evaluation and damage estimation is carried out for surveyed structures and equipment on the basis of using a diagnostic table and some structure analysis.

#### 4.2.1 Preliminary Seismic Diagnosis

This section of preliminary seismic diagnosis for facilities and equipment consists of the following items.

- Review of the existing report of earthquake resistant design prepared by TWWC
- Description of preliminary seismic diagnosis method
  Arrangement of whole study works including data collection, classification of facilities based on their importance, key points to visual investigation, consideration of design year, etc. Diagnosis method will be described based on the existing structural analysis and diagnostic reports.
- Results of preliminary seismic diagnosis
  Summary of seismic diagnosis results is based on visual investigation.

**(1) Review of Related Study Report**

The review of "The Study on Water Supply System Resistant to Earthquake in Tehran municipality" (hereinafter referred to as "Earthquake-resistant study by TWWC") has been carried out. Mainly, diagnosis related to facilities has been made, and some points of issue became clear from the reports.

Since no structural calculation documents were available for an old structure, TWWC carried out structural analysis again and confirmed earthquake resistant capabilities.

Vulnerability models of the Reservoir and the Pump House are based on the structural calculation, and therefore these results can be used in this Study. These vulnerability models are targeted to construction year of 1970’s. However, additional models are necessary to represent the old structures before these periods. These old structures are constructed based on English standards in 1950’s.

**(2) Preliminary Seismic Diagnosis**

The preliminary diagnosis for facilities consists of data collection including construction year, classification of facilities importance, the visual inspection and plan of the whole diagnosis work which is followed by safety assessment. The outlines of the study are described below.

**1) Whole Plan of Facility Diagnostic Work**

Definition of work range is important in the preliminary stages. Work range is divided into work items (work package), and attention shall be paid so that those items cover all necessary points related to Seismic Diagnosis. This is called Work Breakdown Structure (hereafter referred as WBS)

Technical management and follow-up are performed as described in the following table.

**Table 4.2.1 WBS of Seismic Diagnosis**

| Upper Object Category Ⅰ | Direct Object Category Ⅱ | Work Package |
|---|---|---|
| Confirmation of common matter | Arrangement of general matter | Confirmation of design year and construction year |
| | Importance and ambient environment of facilities | Selection of the matter with regard to the importance of facilities |
| | | Environment condition and geographical features of the site surroundings |
| | | Hysteresis of land |
| | Checking of the Past disaster events | The date of occurrence, a disaster situation, the details on repairs carried out |
| | Existing status of maintenance | Visual investigation of function |
| | Earthquake resistance of a water supply system | Availability of network planning |
| | | Availability of alternative channel or alternative facility |
| Diagnosis of Ground conditions | Collection and Compilation of data | Geographical feature data |
| | | Soil investigation data |
| | | Availability of insufficient data |
| | Soil values | Sorting out of soil characteristic values |
| | Sorting out of ground analysis | Liquefaction |
| | | Consolidation calculation |
| | Visual investigation | Investigation of excavation work |
| | | Investigation of a differential settlement |
| | Review of results of investigation | Reduction of soil characteristic value on account of liquefaction |
| | | Calculation of the amount of cavities which sank |
| | | Study of ground lateral shift probability accompanying liquefaction |
| Earthquake resistance of Structure | Collection and compilation of data | Collection and sorting out of As-built drawing and design calculation |
| | | Availability of insufficient data |
| | Visual investigation | The information on arrangement of buildings |
| | | The settlement situation of building |
| | | The degradation situation of structure, set up of the reduction coefficient of material strength |
| | | Location and specification of Expansion Joint |
| | Confirmation of original design condition | Design year |
| | | The list of design-criteria at the time of design |
| | | Ground condition |
| | | The situation of pile |
| | | Conditions of Foundation calculation |
| | Qualitative seismic resistance evaluation | Existence of aseismatic design |
| | | Aseismatic-design criteria considered at the time of design |
| | | Existence of load increase |
| | | Condition of Pile crown |
| | Evaluation of the existing data | Evaluation of existing structural calculation |
| | | The review of the existing diagnostic data |
| | Evaluation by simple calculation | Calculation and evaluation of extension of shear wall |
| | Evaluation by Detailed seismic diagnosis | The necessity for detailed diagnosis |
| | | Physical test |

| | | |
|---|---|---|
| | | Structural analysis |
| | | Seismic resistance Evaluation of joint piping or connecting pipes with tank |
| | | Assessment of damage |
| | | Emergency repair plan |
| | Study of earthquake-resistant countermeasure | Study of the reinforcement |
| | | Creation of design drawing |
| | Preparation of Earthquake-resistant plan | Determination of the priority of construction |
| | | The confirmation of the annual budget of TWWC |
| | | Rough estimation of construction cost |
| | | The construction plan proposed |
| | | The structural detail for aseismatic design proposed |
| Earthquake resistance of Non-Structural Member | Visual investigation | Confirmation of fixed situations, such as finishing material and handrail |
| | Study of earthquake-resistant countermeasure | Study of the reinforcement |
| | Preparation of Earthquake-resistant plan | Calculation of approximate construction cost |
| | | The construction plan proposed |
| | | The structural detail for aseismatic design proposed |
| Earthquake resistance of Mechanical and Electrical Equipment | Collection and sorting out of data | Collection and sorting out of As-built drawing |
| | | Collection and sorting out of structural calculation for foundation-bolt |
| | | Confirmation of alternative equipment |
| | Visual investigation | Installation situation of pumps |
| | | Installation situation of surge tanks |
| | | Chlorine dosing equipments |
| | | Existence of Emergency shut-off valve |
| | | Installation situation of Self-standing panel |
| | | Installation situation of Battery |
| | | Installation situation of UPS |
| | | Installation situation of Flexible pipe |
| | | Sufficient or insufficient length of spare cable |
| | | Existence of Emergency generator |
| | | Existence of Anti-flowout fence under the oil tank |
| | | Installation situation of Electric post |
| | Evaluation by Serious seismic Diagnosis | The necessity for detailed diagnosis |
| | | Calculation of toppling and sideslip risk |
| | Study of earthquake-resistant countermeasure | Study of the reinforcement |
| | | The outline of proposed design |
| | Preparation of Earthquake-resistant plan | Calculation of approximate construction cost |
| | | The construction plan proposed |
| | | The aseismatic design guideline proposed |

**2) Data Collection**

Data collection including drawings is one of the main purposes of the preliminary work. Collected data are arranged and adjusted so that they can be used properly in the detailed diagnosis. Some of the seismic diagnosis in the preliminary stage is limited to qualitative analysis but quantitative analysis is indispensable in the stage of detailed diagnosis, therefore these basic data are quite necessary and should be well arranged to get a better outcome from collected information.

However, volume of such facilities data is large. Therefore, very important and relevant data are selected and considered to represent the structure type.

**3) Facilities Classification by Importance**

In order to attain the final objective, namely Earthquake-resistant plan, and to determine the priority of each facility in Earthquake-resistant plan, classification of importance of these facilities is essential.

It is the master plan of extensive earthquake-resistant plan, the implementation of which has not been experienced even in Japan and it is desired to determine the priority of the structures to be supplied with necessary countermeasures including enough consideration and site investigation.

In case of earthquake-resistant project, the final plan includes both proposed method for earthquake-resistant procedures such as rehabilitation of existing structures and/or construction of alternative facilities, if necessary.

Therefore, knowledge or consideration from section 2.3 is integrated. They are listed for emergency repair convenience, allowance of supply capacities, location of facilities in the upstream of system, necessity of information office such as disaster control office, etc.

Considering these matters, a level of importance is assigned to each facility.

a) Water intake and WTP are important infrastructures which do not have alternatives. Once disaster occurs, these facilities are considered as the most important ones, for these facilities have functions of both emergency water supply bases during water supply suspension and they serve as the most important points to resume daily water supply service to people after recovery. Therefore, detailed investigations of those structures are quite necessary.

b) Reservoirs and pump stations which are located in the upstream in supply system and large water supply facilities (with distribution capacity of more than 1.0$m^3$/seconds of average water supply) should be considered important.

c) Locations of information centers at the time of emergency.

d) Buildings or tanks where emergency repair is difficult and possibility of secondary disaster caused by structural collapse is high.

e) Reservoir and pump stations located in the areas with the following geomorphologic conditions have the high risk of earthquake damage.

- On the fault and near the fault, the earthquake acceleration in these areas is considered to be quite large, once these faults move.
- In the areas where liquefaction may occur.

- Structures on the cliff.
- Structures on the artificial embankment.

The importance classification of the facilities considered in presenting this Study is shown in *Table 4.2.2*.

In addition, it was observed that the ground water level is low and that the ground mainly consists of adhesive soil and sandy gravel at the location of water supply facilities, therefore the possibility of liquefaction is considered to be low. Ground condition is stiff and no location with loose soil was found during the survey. Furthermore, there is no building or tank located on the artificial landfill.

## Table 4.2.2 Importance classification by social / natural environmental condition on which the facility is arranged (the existing operation facility)

| Rank of importance / Geographical feature conditions where an earthquake damage risk is high | Facility of the high priority of countermeasure | | | | Facility of the low priority of countermeasure | |
|---|---|---|---|---|---|---|
| | ① Facility which is important infrastructure and does not have an alternative one | ② Reservoir and Pumping station located in upstream and the amount of water supply is large (more than amount of average water supply 1.0m3/s) which also could supply other water-supply districts at the time of emergency water supply | ③ Facility which collects information at the time of a disaster | ④ Institution where emergency repair is difficult and there is fear of a secondary disaster by structural collapse | other reservoir | Well where earthquake resistance is high |
| On fault | WTP No3-4<br>WTP No5 | No.14, No.71, No.95, No.97 | WTP No1 | | No.11,No.26,No.75, No.77, No.82 | W21002,24002 |
| Near fault | | No.20,No.32,No.72,No.54, No.51 | | | No.23,No.25,No.27,No.30, No.46, No.41, Estakhr, No.74, No.12, No.10, | W21001,21003,22001,22002,22003,22004,22005,22006, 22007,24001,24003,41001, 40701,40702,11001,11002 |
| liquefaction may | None | | | | | |
| cliff | Bilaghan Intake,<br>Lar Dam Intake,<br>LatianDam | | | Bilaghan Intake,<br>Lar Dam Intake,<br>LatianDam | | |
| near Slope | | No.38 | | | No.25, No.55, No.23 | |
| On landfill | None | | | | | |
| On soft ground | None | | | | | |
| others | WTP No1<br>WTP No2 | No.1,No.2,No.7,No.62,No.22,No.93,No.57,No.58,No.37,No.59,No.80,No.43, No.19,No.40, No.21,No.99, No.3, No.4, No.5,No.6, No.96, No.13, No.15, No.31,No.53,No.16,No.36,No.39,No.92,Yaft Aabad Pumping Station,No.65,No.89, No.73 | | | No.66,No.67, No.68,No.69 etc | |

### 4) Visual Investigation

The diagnosis by Visual investigation is the main approach for the preliminary seismic diagnosis. Earthquake resistance is evaluated from past experience. Damage examples are classified by category of facilities, structural or non-structural members, mechanical and/or electrical equipments. Followings are the list of structural members/equipments which are easy to be damaged in general.

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

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

c) Pipes in the soil with high liquefaction tendency

d) The equipments whose support conditions change

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

e) The bolts used for equipments anchoring to their base

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

g) Fixtures
Cupboards, chemicals, tools etc.

Furthermore degree of deterioration for every structure shall be considered.

### 5) Diagnosis with Design Year

Structures are classified into two categories, constructions undertaken after the year of earthquake resistant criteria code application and the constructions implemented before it.

Code of Practice (Standard 2800) was issued in 1987, and a duty of observance was legally implemented by Roodbar-Manjil earthquake in 1990. The code was revised in 1999 and this revised code is the latest one available. ("BHRC Publication No.S 374, 2003" is used for the study.)

Therefore, the year 1990 is the year when earthquake-resistant criteria were applied. Considering the time lag of design and construction, it is expected that the earthquake-resistance code was commonly applied for buildings with its operation year after 1995. The relatively new structures which were built around 1970 are designed on the basis of Iranian code, even though cross sections of structural members are large compared to those of 1950's designed by English code. Both of these codes did not include seismic criteria. TWWC carried out the structural calculation of existing relatively new buildings, and confirmed that the earthquake resistance of the structure is high.

The following points could be considered in the priority on implementation program.

For the relatively new structure constructed during the year from around 1970 to 1995, earthquake resistance ranking is assumed as average. The earthquake resistance of new structure constructed in 1995 and afterwards is ranked high.

### 6) Diagnosis with Existing Structural Calculation Results and Data

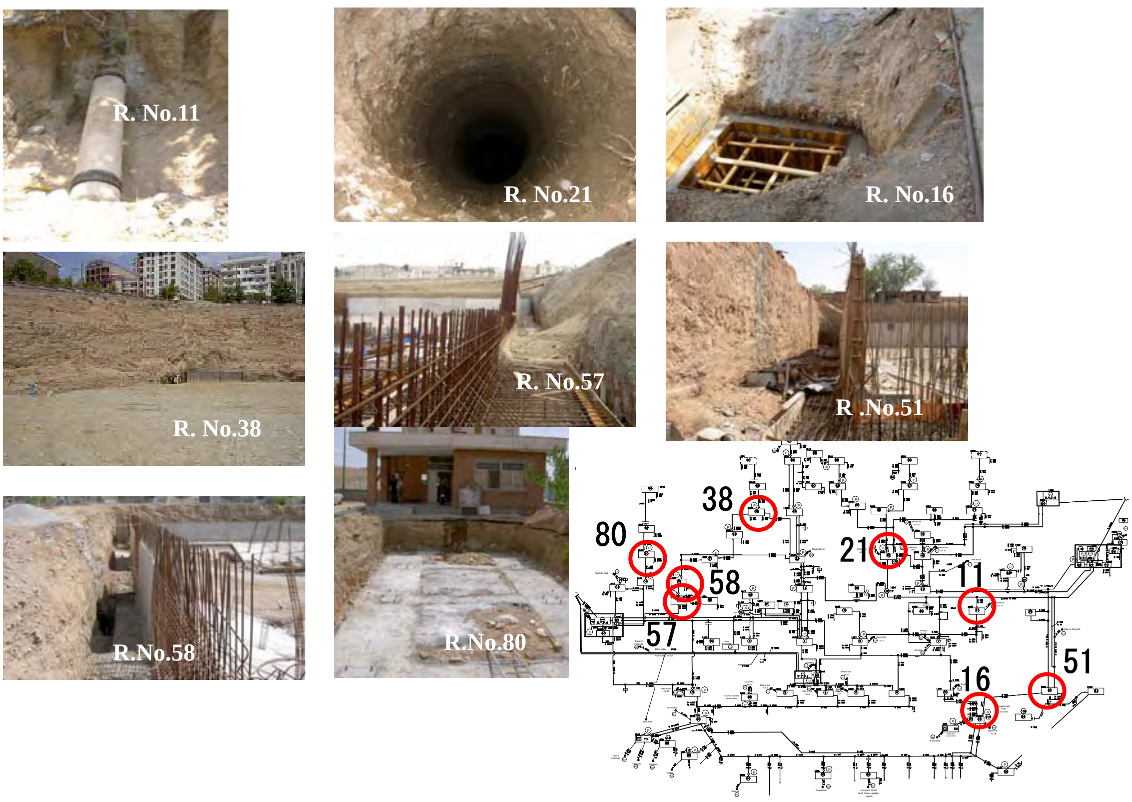
Diagnosis based on structural calculation will be done both as preliminary and as detailed seismic diagnosis. In preliminary seismic diagnosis, earthquake resistance is surveyed/ observed in terms of allowable on existing structural calculation documents and past experience. In case where structural calculation documents are not available, necessary structural calculation is performed in the detailed seismic diagnosis stage.

Simultaneously, the existing diagnostic data are reviewed and checked to see whether they include any useful information for the Study. And the study might be changed based on the results.

## (3) Summary of Visual Investigation

### 1) Ground Condition

When we carried out visual investigation of facilities, we could observe the soil condition on extension field of Reservoir, Construction site of manhole, excavation for piping and so on. Ground showed us vertical excavated face, and all that, we understood was that the earthquake resistance propensity of facilities in Tehran would be really goood because of little active earth pressure during earthquakes. Picture 4.2.1 shows the good ground conditions. Ground condition looks like symbol of earthquake resistant plan in Tehran.




**Picture 4.2.1 Ground Condition on Reservoir Sites**

- Reservoir No.11 in northeast: Exposure of inlet pipe
- Reservoir No.21 in north: Underground-pipe works and construction of chamber and sewage pit
- Reservoir No.16 in southeast: Construction site of manhole
- Reservoir No.38 in northwest: Ground wall
- Reservoir No.51 in west: Extension field of Reservoir
- Reservoir No.57 in northwest: Extension field of Reservoir
- Reservoir No.58 in northwest: Extension field of Reservoir
- Reservoir No.80 in northwest: Foundation works of telemetry house

Moreover, it is observed that soil is cohesive and that there is no ground water from the construction situations of reservoir No.16 in southern alluvial fan. RC manhole was made without formwork, concreting using excavated ground face, only by inside formwork. Probability of liquefaction is low.

Beyond the foundation of facilities, we have to mention the circumference risks. Since the surface soil of northern cliff/slope has weathered, it tends to collapse. For risk avoidance, we propose to study renovation method of building on cliff/slope where collapse might occur in the future.

## 2) Structure

a) Well

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

b) Water Treatment Plant (WTP)

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

WTP No.1

Since the slab burden area supported by each column is large in the generator house, the seismic resistance capacity would be very small, so structural calculation should be performed, and the frame of generator house has to be reinforced by the seismic resistant wall such as shear wall.

WTP No.2

Concreting work, which is under the condition of month-long average temperature exceeding 20 degrees, is so called “Hot weather concrete” in Japan. Considering concreting condition, aggregates are protected from direct sunshine and water cement ratio is reduced and admixtures are added. During summer, the temperature in Tehran is high and construction becomes more difficult compared to that in Japan. Nevertheless, works performed in Tehran are in good condition, generally. However, shrinkage (cracks by shrinkage of concrete on construction) is observed. Compared to the degradation with cracks existing in Japan, that in Tehran must be slow because of dry conditions. On the other hand seasonal temperature difference is large and stress caused by temperature change occurs on a concrete surface and degradation continues gradually and slowly, therefore in present conditions, repair and finish work is required on the beam of Lime & Iron chloride Dosing device house, Generator & Transformer house, and Pulsator.

WTP No.3

The conditions of principal structure of water tanks and buildings look good, which is because of good ground, so they are highly resistant to earthquake. But as the cracks on Pulsator's piping duct are observed, repair of the cracks is needed.

WTP No.4

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


**Picture 4-2-2 chemical House**

WTP No.5

- Earthquake design was applied to this WTP; therefore the principal structure has high earthquake resistance. But what the structures is located on the fault, had to be considered.
- Settlement of the backfilling around Chemical House was observed (Picture 4-1-3). The influence was indicated by the existence of crack at external staircase or retaining wall, the cave-in of the ground, etc. But the settlement has not affected beams or columns. It is thought that there is no problem in a frame because the deformation was small or negligible. Since the backfilling ground is not stable yet, there is high possibility of affecting the surrounding retaining wall. Therefore,


**Picture 4-2-3 Chemical House**

a certain countermeasure is possibly required in the future.

- This WTP has used new construction material which is not used in other WTP(s). This might cause new issues for earthquake-resistant design. There is the possibility of curtain wall falling or detaching marble veneer used for the wall outer finishing or columns of the building. The probability is high that these non-structural members including windowpane might get broken in case of earthquake, or might get separated, and fall off and may harm the human being present nearby.

c) Pump House

The cross section of the design by subsequent Iranians is larger than the early design by the English. Old structure is classified into two categories (early design and subsequent Iranian design), and detailed earthquake-resistant diagnosis shall be performed based on structural analysis.

TWWC has not analyzed the early design. Structural analysis is performed for pump house No.2 as a typical model of early design in this Study.

**Picture 4-2-4 Early design of No.2 Pump House Designed by English (1955)**

**Picture 4-2-5 Subsequent design of No.16 Pump House Designed by Iranian (1970)**

d) Reservoir

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

We could not observe the inside of the tank in many cases, but inside deterioration becomes apparent at ventilations. Therefore, the level of degradation was observed through concrete of manhole or the ventilation opening of the manhole cover.

When manhole cover was opened at Reservoir No.6, humid steam came out from inside. Further, when the inside wall of the manhole was inspected, sign of deterioration was observed. Finally, when the inside tank was inspected, the concrete cover of wall, column and ceiling was observed to be coming off. It became clear that degradation at No.6 and No.66 was remarkable. As for these reservoirs, it was evident that they had an inadequate ventilation opening. Therefore setting of adequate ventilation opening is proposed.

Much dew condensation was seen on the inner surface of the manhole cover at Reservoir No.30. Though, no internal corrosion was observed, there may be internal corrosion in the future, so setting of adequate ventilation opening is proposed.

e) Administration House

The janitor always resides inside the area of reservoir and pump station. This means safety of administration house might be an issue of human life protection. Since many houses are small, their loads are also small. If structure has not decayed, it is considered that there will be few earthquake damages concluded from the earthquake experience in BAM earthquake.

f) The Reduction Coefficient of Material Strength

Since a structure deteriorates, it takes into consideration the reduction coefficient of the material strength to structural analysis. The reduction coefficient was estimated in *Table 2.5.3* as a result of visual observation.

**Table 4.2.3 The Reduction Coefficient**

| | | The reduction coefficient of material strength |
|---|---|---|
| Intake | All facilities | 1.0 |
| WTP | Pulsator of WTP No.2 and No.3<br>Filter of WTP No.4 | 0.9 |
| | Others | 1.0 |
| Pump House | All facilities | 1.0 |
| Reservoir | Reservoir No.6 and No.66 | 0.8 |
| | Others | 1.0 |

**3) Nonstructural Member of House and Tank**

Nonstructural member such as mortar finish, a windowpane or marble veneer with heavy finish could produce earthquake damages. Therefore, reinforcement should be applied to the parts with the degraded member or poor workmanship, immediately.

a) Entrance（WTP No.5）

The danger of curtain wall has come to be pointed out according to the earthquake damages in Japan in recent years. Nevertheless curtain wall is used as the outer wall of the entrance, the condition of attachment and allowance for deformation should be checked.

b) Chlorine House（WTP No.5）

Installation of large marble veneer to columns is not stable in chlorine house. Since marble veneer has already fallen down, and installation position is high, it is dangerous in case of earthquake. It is recommended to strip off all of them and re-install or fix them by anchor bolts. In the case of stone-finish, metal strap anchor is used for the slates to fix them to the wall. Being attached only with mortar without metal strap anchor as observed in Tehran, slate panels may easily detach in case of an earthquake.

Since a slate is heavy and easy to fall from concrete in case of occurrence of earthquake, there is a fear of accident that might cause injury or death as a result of falling down as it is attached at relative heights. Needless to say even though the height of buildings is low, there is the necessity for reinforcement of this building.

Fixation of marble veneer finish of chlorine house at WTP No.5 is proposed.


**Picture 4.2.6 Chlorine House**

### 4) Mechanical and Electrical Equipment

Based on the observation of site survey, the following issues should be considered in earthquake-resistant plan. In addition, strength calculations of the foundation bolt of typical pump, surge tank, and electrical panel are shown in the Appendix-.

- Pump: Fixation of pump
- Surge tank: Fixation of surge tank
- Chlorine dosing equipment: Fortification of pedestal of chlorine cylinder
- Chlorine dosing equipment: Introduction of sodium hypochlorite system
- Piping: Installation of emergency shut-off Valve
- Self-standing panel: Fixation of self-standing panel
- Transformer: Fixation of the transformer wheel
- Battery: Fixation of battery
- UPS: Fixation of UPS (Uninterruptible Power Supply)
- Piping: Installation of flexible pipe around the expansion joints
- Cable: Length allowance of cable
- Oil tank: Construction of anti-flowout fence under oil tank
- Electric post: Installation of stay of electric post
- Others: Equipment fixed on brick wall

a) Pump: Fixation of Pump

Almost all the pumps are fixed to the foundation with foundation bolt firmly and seem to be in good condition. To confirm whether pump is earthquake-resistant or not, strength calculations of the foundation bolt were carried out using some as-built drawings. The result of calculation turned out to be “earthquake resistant”. (See Appendix)

b) Surge Tank: Fixation of Surge tank

Except for pump station No.2, 22, 96, many surge tanks are fixed firmly to the foundation with foundation bolts and seem to be in good condition.

Surge tank at pump station No.2 was not installed in the in-between stage of the support of tanks based on the design. Therefore, supports should be installed immediately.

Foundation of surge tank at pump station No.22 has cracks. It should be reinforced immediately.

As for the RC foundation of the installing tanks at pump station No.96, since the size of foundation is smaller than the leg of tank, this means legs are not on the concrete. Improvement is required in thismatter.

c) Chlorine Dosing Equipment: Improvement of Pedestal of Chlorine Cylinder

Some cylinders seem to be in danger of movement or sideslip by earthquake and neutralization equipment is not prepared in that respect. Construction of chlorine cylinder storage like WTP No.5 and installation of neutralization equipment will be proposed.

d) Chlorine Dosing Equipment: Introduction of Sodium Hypochlorite System

Study team will propose the countermeasure, which changes the chlorine dosing system into safer sodium hypo-chlorite system.

e) Piping: Installation of Emergency Shut-off Valve

Emergency shut-off valve is necessary for the reservoirs to prevent secondary disaster and wasting water through leakages. Therefore installation of emergency shut-off valve at the outlet of reservoir is proposed.

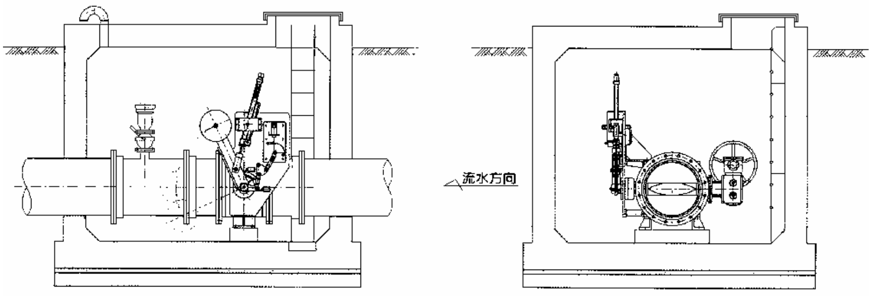



**Figure 4.2.1 Emergency Shut-off Valve**

f) Self-standing Panel: Fixation of Self-standing panel

In Tehran, mainly 3 types of electrical self-standing panels are used. The summary of information on each panel is as follows:

**Table 4.2.4 Self-standing Panel**

| Type A<br>High Tension Cubicle | Type B<br>Low Tension Cubicle | Type C<br>Other type |
|---|---|---|
|  |  | <br> |
| Fixed with foundation bolt | Fixed with foundation bolt | Fixed with welding, or not fixed at all |

To confirm whether those panels are earthquake resistant or not, strength calculations of the foundation bolt were carried out. The result of calculations of Type A and Type B turned out to be “earthquake resistant”. (See Appendix-) As to Type C, it is difficult to consider them as earthquake resistant, because they are not fixed with foundation bolt.

g) Transformer: Fixation of the Transformer Wheels

The wheels of transformer are on the rail and restrained by a stopper, but it does not seem to be earthquake resistant, Because they are not fixed with foundation bolt. Therefore fixing of the transformer with foundation bolts is proposed.

h) Battery: Fixation of Batteries

Except for the battery at Reservoir No.1, the stopper or foundation bolts are not installed in most of the facilities. Therefore, stoppers for battery restraint should be installed.

i) UPS: Fixation of UPS (Uninterruptible Power Supply)

UPS is not fixed with stopper or foundation in any of the facilities. Installation of foundation bolts for UPS is required.

j) Piping: Installation of Flexible Pipe around the Expansion Joints

Except for No.5 WTP, flexible pipe is not installed around the expansion joint in most of WTPs. Installation of a flexible pipe and dividing the cable tray around the expansion joint are proposed.

k) Cable: Length Allowance of Cable

It seems that there is not enough spare length of cable at most of the facilities. If possible, rewiring with enough spare length of the cable would be proposed for the important equipments. Otherwise right-angled trench might be changed as shown in the following figure, and length of cable needs to have enough allowance.

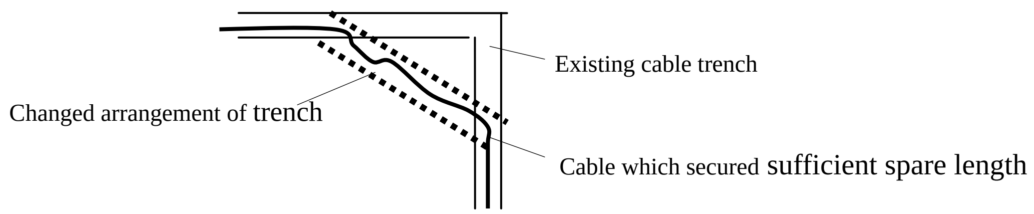



**Figure 4.2.2 Plan of Cable Trench**

l) Oil tank: Construction of Anti-Flowout Fence under Oil Tank

Construction of the anti-flowout fence under the oil tank is necessary to prevent a secondary disaster. Therefore, construction of anti-flowout fence is proposed

n) Electric Post: Installation of Stay of Electric post

The electric post at Reservoir No.22 (Vanak) is inclined a little; thereby it is in danger of toppling by an earthquake. That may cause failure of facility. Hence, installment of stay is proposed.

m) Others: Equipment fixed on Brick Wall

Since the large oil tanks or equipments are supported by weak brick wall, additional supports are required for these walls.

### 4.2.2 Selection of Detailed Diagnosis Method

#### (1) Benchmark and Selection of Detailed Diagnosis Method

Various information, related to earthquake analysis including soil data have also been collected and compiled to carry out detailed diagnosis. Detail diagnosis includes damage estimation, and the earthquake-resistant countermeasures. In this section, damage estimations, which is one of the highlights of detailed diagnosis has been performed.

Since there are several complicated factors involved in the damages threatening facilities and equipments, there is no definition of the damage and no proper, appropriate approach to damage estimation in Iran.

In addition to diversity of damage factors, there are also individual perception gaps in facilities and equipments. Individual perception is subject to great change with each experience, and alteration of position and their technical background.

The approach to Risk Management is appropriate to evaluate the risks and formulate measures systematically for such cases of complicated conditions. Risk Management aims risk control as the ultimate goal. The procedure comprises <u>three steps</u> as follows.

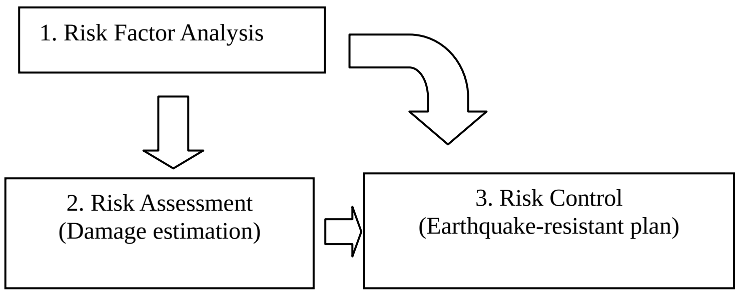



**Figure 4.2.3 Flowchart of Risk Management**

1. To start with, the Risk Factor Analysis is performed. It is the most important step and it clarifies what and where the possible risks are. It is resolved through fact finding survey, Japanese experience and brainstorming to be performed to find out risks Iranians might have to face when the earthquake occurs.

2. Risk Assessment viz. damage estimation is performed with a concern for major damage risk factors. Evaluation of major damage risks can be performed by Japanese Diagnostic Table for Seismic Capacity (hereafter refers to as DTSC). Although Damage estimation uses DTSC, it could be modified according to situation and needs. The DTSC categorizes the risk factor into 14 items consisting of Ground, Liquefaction, Land features, Elevation, Material, RC Wall area, Water depth, Structural formation, Soil cover, Construction year, Flexible pipe, Expansion Joint, and Seismic intensity scale, and it is required to set up Fragility point for all aspects of each factor, being described in details later.

3. Risk Control viz. earthquake-resistant plan will be proposed for every damage risk, and the risk control which must be carried out as high-priority measures, is determined.

Risk Assessment on this section is directly related to Risk Control, so it is necessary to know the idea of Risk Control, anticipated goal beforehand. Generally Risk Control is categorized based on the following five viewpoints.

1. Avoidance of risk
2. Mitigation of loss
3. Diversification of risk
4. Emergency-repair response
5. Transfer of a risk to insurance

For example, these are applied corresponding to the above number 1 to 5 as follows.

1. From the viewpoint of Avoidance of risk: The risk with serious damage should be avoided beforehand. For example, the facility on a fault should be moved according to a relocating plan. (There is also another method, which could be applied as countermeasure for the facility on the fault, like the back up by the water supply system which is the viewpoint of the Diversification of risk)

2. From the viewpoint of Mitigation of loss: Though it is difficult to mitigate all risks completely, it shall be done to reinforce the fragile main structure members and an economical/effective measures such as fixation of nonstructural members and equipments.

3. From the viewpoint of Diversification of a risk: If the anticipated damage of the Tehran water supply facilities were dispersed sufficiently, the correspondence by the back up of the water supply system would be possible for anticipated damage, or the physical measures against the anticipated damages could be postponed/ carried out one by one, so public investment must be implemented on Long-term planning as follows.

**Table 4.2.5 Phased Project Planning**

| Planning | Program |
|---|---|
| Short-term | The programs for protection of human life from disaster |
| | The programs for maintaining the water supply system, prior to the important facilities and equipment |
| | The programs for maintaining the water supply system |
| | Reinforcement of the old structures constructed before 1970. |
| | (The programs for maintaining the water supply system) |
| Long-term | Reinforcement of the old structures constructed before 1995. |
| Future Plan | Relocation of the facilities on fault |

4. From the viewpoint of Emergency-repair correspondence: to get to know the risks appropriately, and to make a plan of the emergency-repair correspondence is also one of the proper earthquake-resistant countermeasures to the earthquake that rarely happens. For

example, in the case of a 500-year probability earthquake, exceeding conditions of code 2800 viz. the acceleration 350G of a 100-year probability.

5. From the viewpoint of Transfer of a risk to insurance: For the accomplishment of the public service responsibility against the situations of such disastrous risks, the Transfer of a risk to insurance could not be mentioned.

As mentioned above if we look through the whole considerations, evaluation viewpoint would be:

- to confirm the facility on fault precisely: the damage of this kind of facility should be evaluated as they have a very low seismic resistance.
- to evaluate the fragility: as the code for building has been enforced for years, structural analysis should be performed in accordance with a 100-year earthquake occurrence probability condition on Code 2800, and the obtained fragile tendency could be used as feedback to the DTSC for damage estimations.
- to judge the situation of fixation of non-structural members and equipments: these are carried out through survey on site, and also the damage estimations of the involved conditions of DTSC(ground, land features, elevation, material, RC wall area, structural formation, construction year, seismic intensity)
- to mention the emergency-repair correspondence on the situation of damaged facilities dispersion in the case of the various earthquakes scenarios of rare earthquake occurrence probability: Though the earthquake occurrence probability is not certain and well defined, damage estimations could be performed considering four scenarios.

Detailed Diagnosis Method is summarized as follows.

**Step1: Risk Factor Analysis**
Method is to select from;
1 Site Survey
2 Japanese Experience
3 Iranian concerns extracted through brainstorming

**Step2: Risk Assessment (Damage Estimation)**
Method is to estimate by;
1. Japanese DTSC
2. Structural analysis

**Step3: Risk Control（Earthquake-resistant Plan）**
Method is from the viewpoint of;
1.Avoidance of risk: to execute special programs for protection of human life.
2.Mitigation of loss: to execute the reinforcement of facilities and equipments for maintaining the water supply system
3.Diversification of risks: to have correspondence with the back up of the water supply system, and wide-range correspondence of phased project planning
4.Emergency-repair correspondence: to have correspondence after earthquake in the case of the occurrence of the least probable earthquake.

**Figure 4.2.4 Flowchart of Detailed Diagnosis Method based on the idea of Risk Management**

Considerations about the conditions of the structural analysis and the benchmark for structural study are outlined as follows:

## 1) Criteria of structure analysis

A seismic design Level 1 of Japan makes the structural designs according to the condition of an earthquake of approx. 50 years return, the middle ranked earthquake in which the structure encounters the earthquake once or twice in the life-time. This is the design by the elastic range of a structural material. The standard seismic acceleration is set to 0.2g in Japan. Tehran city sets a standard seismic acceleration of 0.35g, and is designing in the elastic range the same as in Japan.

Level 2 design includes plastic deformation in Japan, considering approx. a 100-year return earthquake which exceeds the life-time of the structure with 50-years, and it aims at protection of a) human life, and b) the maintaining of minimum functions. In this case, after an earthquake, if a foundation inclines, it might be rebuilt.

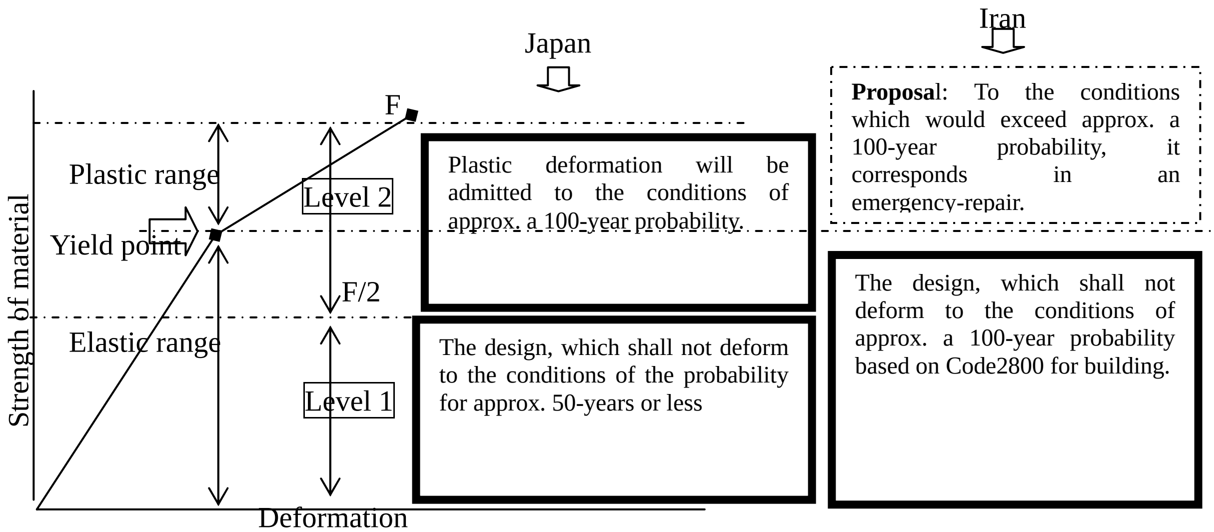
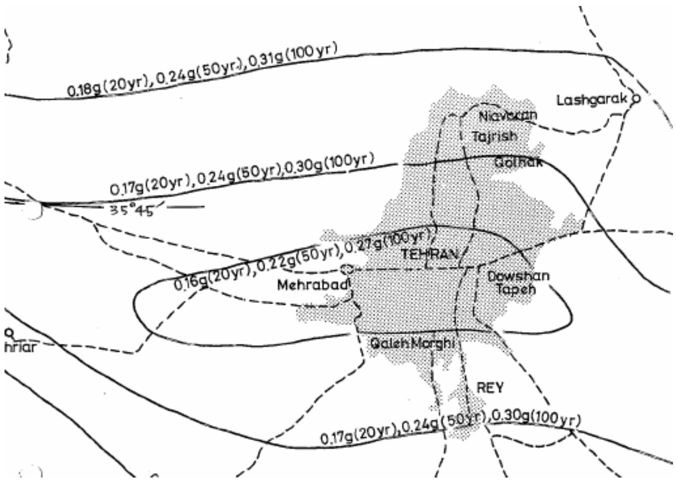



**Figure 4.2.5 Structural Criteria Paralleled between Japan and Iran, and Proposal**

According to acceleration map (*Figure 4.2.6*) of "Geological Survey of Iran" (1983 Ministry of Mine & Metal), which is the original idea of Code2800, acceleration of a probability is set to 0.31g, the value of 100-year probability in the northern area of Tehran. In addition, this value must be referred to the condition of Code 2800 for building on the basis of 0.35g acceleration.

From the above viewpoint, the acceleration of Code 2800 is approx. a 100-year probability and is designed in the elastic range. In fact, as this earthquake occurrence probability benchmark in Iran was set as a rare situation, design criteria have sufficient allowances.




*Source: "Geological Survey of Iran" (1983 Ministry of Mine & Metal)*

**Figure 4.2.6 Acceleration Map**

**2) Benchmark for structural study**

When the above Japanese design criteria is applied to this study, the probability of earthquake occurrence is important.

At first, as we have to confirm the seismic resistance by the condition of code 2800 for building, then we would perform some structural calculations.

Next, we consider the earthquake scenario for performing damage estimation, in the case of biggest North Tehran Fault scenario, the acceleration is calculated with 746gals on a north slope, which is more than twice energy considered in Code2800, so the probability of a scenario earthquake is obviously more than 100 years. If probability of occurrence was presumed to be 500 years, the idea that a risk might happen without the structural reinforcement at such low probability, would be accepted.

Consequently, the reinforcement of a structure might be based on Code2800. And it is appropriate that the assessment of damage by scenario earthquake is for study of the measure of backup/bypass, and for the determination of priority on implementation program.

**3) The situation of concrete**

We surveyed the situation of concrete neutralization, and confirmed that the tank's concrete was in a very good condition. It was a very good watertight concrete, which reduced the water cement ratio.

Usually, concrete presents alkalinity (pH 12-13) due to presence of calcium hydroxide.

Therefore, under this alkaline environment in concrete, a protection barrier is formed around a reinforcing bar and this is protecting iron from corrosion. The calcium hydroxide changes to carbonic acid calcium with passage of time through the action of the carbon dioxide in the air, which is called neutralization. Although Carbonic acid calcium formed on concrete is rigid but fragile, it has no strength. Therefore if neutralization is advancing, the non-destructive test by a Schmidt rebound hammer couldn't be applied.


**Picture 4.2.7 Phenol-Phthalein Test on the wall of utility conduit of Pulsator at WTP No.2**

If neutralization advances, a protection barrier for iron would no longer be formed around a reinforcing bar and iron corrosion will start.

Neutralization would be measured chemically using the nature in which the face of alkaline (pH 9-10 or more) concrete changes into purplish red color if phenol-phthalein liquid is sprayed upon the concrete.

As a result of survey, neutralization is not advancing, it is concluded that advance of neutralization is slow in Tehran, because of the weather and good construction technology /workmanship of concreting.

Though there were some cracks in the tanks, they are not serious because the rust of a reinforcing bar was not observed. There were two serious examples of Reservoir No.6 and No.66 in which concrete came off and fell owing to the insufficient concrete cover.

As neutralization is not advancing, compressive strength of concrete by non-destructive test might be applied to the confirmation of design conditions, viz. 300 $kg/cm^2$ for water tank and 250 $kg/cm^2$ for building on the ground.

We performed the non-destructive test by a Schmidt rebound hammer, and confirmed the compressive strength of several concretes on the site and the result is presented in the following table. It shows that if deterioration was considered, the design conditions would be applied.

**Table 4.2.6 Result of the Non-destructive Test by a Schmidt Rebound Hammer**

| Testing member | Compressive strength ($kg/cm^2$) |
|---|---:|
| A Column of Lime storage at WTP No2 | 380 |
| Top Slab of Pulsator at WTP No2 | 462 |
| Wall of Duct of Filter at WTP No2 | 506 |
| Wall of Duct of Pulsator at WTP No2 | 503 |
| Wall of Duct of Pulsator at WTP No3 | 481 |
| Column of Duct of Pulsator at WTP No4 | 343 |
| Wall of Duct of Pulsator at WTP No4 | 497 |
| Wall of substructure at Generator of WTP No.1 | 362 |
| Pump Chamber at Pump house No.2 | 369 |
| Column of Ground Floor at Pump house No.2 | 312 |
| Pump Chamber at Pump house No.1 | 335 |
| Manhole Wall at Reservoir No.1 | 460 |
| Wall of substructure at Latiyan Intake | 475 |

**(2) Method of Damage Estimation**

**1) Risk Factor Analysis**

This procedure is important to perform the assessment of damages and to plan the earthquake-resistant measure. The background of the importance of this procedure is shown below.

When we consider the earthquake-resistant measures for facilities and equipments, we should know the reasons and effects of each measure.

We have to extract the earthquake-resistant measures for next steps. As for the reason and effect of measure, it is based on the risk of anticipated earthquake damages. That risk is the same as our fear. The risk factors of the earthquake damages can be defined from Japanese experience and Iranian concerns- the fears disclosed through Brainstorming. As the anticipated risk and the reason behind proposing a countermeasure would be needed for implementation of the earthquake-resistant plan, it is clear that Risk Factor Analysis is important.

We extracted the risk factors that are required for planning the measures for the facilities and equipments to make it earthquake-resistant, the risk factors are set up on *Table 4.2.7* from the Japanese experience and the result of Brainstorming.

**Table4.2.7 Designated Risk Factors and Risks**

| Genre | Breakdown | Risk Factor | Risk |
|---|---|---|---|
| S Structure | S-1 Ground | S-1-1 Ground condition | S-1-1-1 Fault shifts cause great damage to structures and subsequently accidents resulting in injury or death |
| | | | S-1-1-2 A soft-ground soil slides and differential settlement occurs and the structure inclines, or crack in concrete leading to water leakage |
| | | | S-1-1-3 Liquefaction occurs and differential settlement occurs and structure inclines, or crack of concrete causes water leakage |
| | | | S-1-1-4 A cliff collapses and damages the building. |
| | | | S-1-1-5 Landfill collapses or exposed foundation causes differential settlement. |
| | | | S-1-1-6 A slope collapses and damages the facilities, private residence, or road |
| | S-2 Structure Member | S-2-1 Capacity of Member | S-2-1-1 Column collapses, and beam and roof deform or fall. |
| | | | S-2-1-2 Crack occurs at the tank, causes water leakage. |
| | | | S-2-1-3 When whole structure deforms, a deformation becomes the maximum by Expansion Joint, so water stop is cut and water leaks. |
| | | S-2-2 Structural System | S-2-2-1 As the structure is complicated, when structural model is not optimal, the inestimable force acts, which causes the increase of load on some members, and deformation. |
| | | | S-2-2-2 If the foundation is bad; toppling of Over Head Reservoir causes a second disaster on the outskirts. |
| | | S-2-3 Deterioration | S-2-3-1 When there is large degradation which the bar has exposed, as the structural function is lost and earthquake resistance cannot be expected, buckling, deformation, crack, leakage of water, etc. occur. |
| | S-3 Non-structural | S-3-1 Accessories for treatment | S-3-1-1 The trough of Pulsator gets separated or breaks down and water quality deteriorates. |
| | | S-3-2 | S-3-2-1 The brick wall collapses and causes an accident |

| | | | |
|---|---|---|---|
| | Member | Brick wall | resulting in injury or death, or damaged equipment. |
| | | S-3-3 Windowpane /door | S-3-3 -1 Windowpane breaks because of caulking material degradation which can cause an accident resulting in injury or death. |
| | | | S-3-3 –2 Broken door prevents a man to escape |
| | | S-3-4 Wall material | S-3-4 -1 The outer Marble Veneer falls, which cause an accident resulting in injury or death. |
| | | S-3-5 Water stop | S-3-5-1 same as S-2-1-3 |
| | | S-3-6 Retaining wall | S-3-6-1 A Retaining Wall topples and a building slides, and this causes an accident resulting in injury or death. |
| | | S-3-7 Handrail | S-3-7-1 A man may fall over handrail resulting in injury or death. |
| E Equipment | E-1 Main Equipment | E-1-1 Fixation of Main Equipment | E-1-1-1 Overturn of surge tank leads to failure of pumping. |
| | | | E-1-1-2 Gas leakage from chlorine cylinder causes an accident resulting in injury or death. |
| | | | E-1-1-3 Overturn or sideslip of transformer causes failure of the water supply. |
| | | | E-1-1-4 Overturn of electrical panel causes operating failure of the water supply. |
| | | | E-1-1-5 Overturn of pump causes operating failure of the water supply. |
| | | E-1-2 Piping and Cabling | E-1-2-1 Damage to pipe causes leakage of water, failure of water supply, and failure of emergency water supply. |
| | | | E-1-2-2 Damage to cable causes operating failure of the water supply. |
| | | | E-1-2-3 Leakage of fuel from emergency generator causes secondary disaster like fire |
| | | | E-1-2-4 Toppling of electric post causes power failure. |
| | | | E-1-2-5 A man between huge piping would not be able to escape and fall a victim in the pump room. |
| | | E-1-3 Blackout | E-1-3-1 Failure of water supply system, or deterioration of water quality |
| | | E-1-4 Reliability of equipment | E-1-4-1 Equipment breaks down and does not work or a glitch occurs. |
| | | E-1-5 Information | E-1-5-1 As broadcast does not inform the earthquake intensity for every area, workers cannot concentrate on emergency work due to being anxious about their family's safety. |
| | | | E-1-5-2 As the whole damage cannot be grasped, suitable directions cannot be taken from the disaster countermeasure's headquarters. No idea of the action for workers before directions come from headquarters, workers might go home. |
| | E-2 Sub equipment | E-2-1 Battery | E-2-1-1 Overturn or sideslip of battery causes failure in operation of radio equipment, monitoring equipment, display lamp of electrical panel , and operation of circuit breaker |
| | | E-2-2 UPS | E-2-2-1 Overturn of UPS causes operating failure of monitoring equipment until emergency generator starts when blackout takes place. |
| P Piping | | P-1-1 Connecting piping | P-1-1-1 Piping gets separated from the tank which leads to water leakage, so emergency water supply becomes impossible. |
| | | | P-1-1-2 Valve is not working which causes water leakage or failure of the water supply.<br>P-1-1-3 A person well versed of the piping system in the |

| | | | |
|---|---|---|---|
| | | | headquarters might be absent, and instructions of valve operation cannot be executed. |
| EC Emergency correspondence | | EC-1-1 Access | EC-1-1-1 A repair task force does not arrive due to the traffic jam or debris |
| | | | EC-1-1-2 When a repair task force cannot do anything due to no access road |
| | | EC-1-2 Stock of Material | EC-1-2-1 Equipments and material for emergency repair might be insufficient. |
| | | EC-1-3 Organization | EC-1-3-1 Key-persons are absent or suffer a disaster, and appropriate correspondence cannot be performed. |

**2) Risk Assessment (Damage Estimation)**

While carrying out the assessment of earthquake damage on a building or equipment, the individual perception gaps are different depending on individual experience, position, and their technical backgrounds.

So, in order to perform the generalized assessment of damage without prejudice, it is better to evaluate for major risks defined previously, and to give objectivity.

Evaluation in terms of major risk factors can be performed by the Japanese Diagnostic Table for Seismic Capacity (hereafter referred to as DTSC) .

The method of DTSC is the most objective evaluation method for assessment of damage. This DTSC is the method to evaluate the fourteen risk factors by the fragility point. The table was prepared by Health and Welfare Ministry in 1981, and the fragility point has been modified in 2000, based on the latest earthquake damage statistics in Japan, by Japan Water Research Center under a subsidy of Health, Labor and Welfare Ministry.

The DTSC in this report will apply two tables, the tables for non-slab tank and for the tank with slab. Though there is no table for the Pump station, we tentatively made it by arranging the table of the tank with slab, and using it in this Report. In this Study, structural calculation of pump house has been performed. Further, this DTSC would be modified and be given more objectivity.

The fragility value is calculated in the following procedures and seismic resistance is evaluated. We show the sample explanation of the use of DTSC for Reservoir.

a) Sample explanation of a DTSC for Reservoir

The DTSC categorizes risk-factor into 14 items, Ground, Liquefaction, Land features, Elevation, Material, Earthquake-resistance Wall area, Water depth, Structural formation, Soil cover, Construction year, Flexible pipe, Expansion Joint, Seismic intensity, and it is required to set up Fragility point for every scope of each factor.

On each scope of risk factor, higher value of fragility point implies that it is more fragile. For instance, type-3 ground(soft ground) is more fragile than the type-1ground (firm ground), shown in *Table 4.2.8*.

Study team modified construction year of the Japanese scope on the following bases to be applied to the case of Iran. Code 2800 was issued in 1987, and a duty of application went into effect legally after Roodbar-Manjil earthquake in 1990. Therefore, 1990 is the year earthquake-resistant criteria would be applied commonly. Considering 5 years of time lag for design and construction, we assumed that the buildings built after 1995 are highly earthquake resistant.

**Table 4.2.8 Some Modification of the DTSC**

| | Japanese DTSC | | | modified DTSC for Iran | |
|---|---|---|---|---|---|
| | Scope | Fragility point | modification | Scope | Fragility point |
| Construction year | From 1975 onward | 1.0 | ⇨ | from 1995 onward | 1.0 |
| | 1926≦ ≦1974 | 1.2 | | | |
| | Before 1925 | 1.5 | | before 1995 | 1.5 |

**Table 4.2.9 Modified DTSC for the Structure with Slab**

| Risk factor | Scope | Fragility point |
|---|---|---|
| Ground | Type-1 (firm ground) | 0.5 |
| | Type-2 (middle firm ground) | 1.0 |
| | Type-3 (soft ground) | 1.8 |
| Liquefaction | not occur | 1.0 |
| | possible | 2.0 |
| | occur | 3.0 |
| Land features | plane land/terrace | 1.0 |
| | Sloping ground | 1.2 |
| | Top of mountain | 1.3 |
| | Landfill | 1.5 |
| Elevation | On the ground | 1.2 |
| | Semi subterranean | 1.1 |
| | Underground | 1.0 |
| Material | RC | 1.0 |
| | Brick | 3.0 |
| Wall area of X-axis& Y-axis ／tank area | 0.05＜ | 1.0 |
| | 0.05＞ | 1.5 |
| Water depth | 5m≦ | 1.0 |
| | 5m＜ | 1.3 |
| Structural formation | Wall | 1.0 |
| | Column & Beam | 1.2 |
| | Flat slab | 1.4 |

| | | |
|---|---|---|
| Soil cover | 0.4m≧ | 1.0 |
| | 0.4m＜ | 1.2 |
| Construction year | from 1995 onward | 1.0 |
| | before 1995 | 1.5 |
| Flexible pipe | existing | 1.0 |
| | nothing | 2.0 |
| Ex.j | good condition | 1.0 |
| | bad condition | 2.0 |
| Degraded degree | small | 1.0 |
| | middle rank | 1.5 |
| | intense | 2.0 |
| Seismic intensity | 5:(approx.100～250gals) | 1.0 |
| | 6:(approx.250～800gals) | 2.2 |
| | 7:(approx. over 800gals) | 3.6 |

*Note: Shaded part indicates typical condition in Tehran*

Procedure of calculation of total fragility point is as follows.

- Each fragility point, corresponding to the scope of risk factor is selected
- All selected fragility points are multiplied. For example, the point marked blue color in the above table, are multiplied and presented as the total point in the following table. This is the typical case of Reservoir in Tehran,

**Table 4.2.10 Calculation of Total Fragility Point**

| Seismic intensity | Total fragility point |
|---|---|
| 5:(approx.100～250gals) | 0.5*1.0*1.0*1.0*1.0*1.5*1.0*1.4*1.2*1.5*2.0*1.0*1.0*1.0=3.8 |
| 6:(approx.250～800gals) | 0.5*1.0*1.0*1.0*1.0*1.5*1.0*1.4*1.2*1.5*2.0*1.0*1.0*2.2=8.3 |
| 7:(approx. over 800gals) | 0.5*1.0*1.0*1.0*1.0*1.5*1.0*1.4*1.2*1.5*2.0*1.0*1.0*3.6=13.6 |

- Seismic resistance is determined compared with total fragile point and definition of a seismic resistance level in the *Table 4-2-11*.

**Table 4.2.11 Convert of Fragility Point to Seismic Resistance**

| Seismic intensity | Determination of Seismic Resistance | | |
|---|---|---|---|
| 5:(approx.100～250gals) | 3.8<10 | ⇨ | High-level |
| 6:(approx.250～800gals) | 8.3<10 | | Middle -level |
| 7:(approx. over 800gals) | 13.6=10～17 | | Low-level |

- Seismic resistance is evaluated from the relation between total fragility point and a seismic resistance level as shown below.

**Table 4.2.12 Definition of Seismic Resistance and Damage**

| The total fragility point | Seismic resistance | The definition of damage |
|---|---|---|
| ＜10 | High -level | As seismic resistance of structure is of high-level, countermeasure would not be required in advance. Although the bigger force beyond prediction may act and some minor damages may be generated, The remedy could be in the form of emergency repairs. |
| 10～17 | Middle -level | In this case, seismic resistance of structure is of middle-level, therefore some damages may occur therefore countermeasure would be required in advance. It is not urgent. |
| ＞17 | Low -level | As seismic resistance of structure is of low-level, serious damages may occur therefore countermeasure would be required in advance. It is urgent. |

b) Ex) Evaluation of Reservoir No.6

Procedure is as follows;

i. The fragility point appropriate for the conditions of each risk-factor is determined. For example, since advance of degradation is intense, degree of degradation may be 2 points.

ii. Each score is multiplied, and the total point is computed.

iii. It is estimated that Seismic resistance is in high-level for the seismic intensity scale 5, in middle level for the scale 6, and in low-level for the scale 7.

iv. Surface acceleration in the earthquake scenario of North Tehran Fault, is the largest, 309gals. The surface acceleration, 309 gals is equivalent to Seismic intensity scale 6, so it is considered that the structure has middle-level seismic resistance at Seismic intensity scale 6.

v. It was found out that the degradation affects seismic resistance. So degradation repair is needed.

c) Ex.) Evaluation of Reservoir No.25

Similarly, analysis is performed on the reservoir No. 25 (as mentioned above for evaluation of Reservoir No. 6).

i. The point appropriate for the conditions of each risk-factor is determined. In the case of Reservoir No.25, four different points are observed compared with Reservoir No.6 that degradation is not advancing, water is deeper, located at sloping land, and acceleration is bigger of 671 gals in the earthquake scenario of North Tehran Fault.

ii. Surface acceleration 671 gals is equivalent to Seismic intensity scale 6, so according to the table, seismic resistance is middle-level. When evaluated by the code 2800, it would be high-level.

iii. Reservoir No.25 is located in a sloping ground, and seismic resistance is estimated as high-level based on the condition of code 2800, the acceleration condition of a 100-year probability, because of the good foundation. Moreover, in the earthquake scenario of North Tehran Fault, seismic resistance is evaluated as middle-level, but there is no urgency to take the countermeasure of structure because the probability of earthquake occurrence is very small.

**Table 4.2.13 DTSC for Reservoir No.6 and No.25**

| Type of Structure | | | Structure with Slab | |
|---|---|---|---|---|
| Name of Facility | | | Reservoir No.6 | Reservoir No.25 |
| Factor of Risk | Scope | Fragility point | Selected fragility point | Selected fragility point |
| Ground | Type-1 | 0.5 | 0.5 | 0.5 |
| | Type-2 | 1.0 | | |
| | Type-3 | 1.8 | | |
| Liquefaction | not occur | 1.0 | 1.0 | 1.0 |
| | possible | 2.0 | | |
| | occur | 3.0 | | |
| Land features | plane land or terrace | 1.0 | 1.0 | |
| | sloping ground | 1.2 | | 1.2 |
| | Top of mountain | 1.3 | | |
| | landfill | 1.5 | | |
| Elevation | On the ground | 1.2 | | |
| | Semi subterranean | 1.1 | | |
| | Underground | 1.0 | 1.0 | 1.0 |
| Material | RC | 1.0 | 1.0 | 1.0 |
| | Brick | 3.0 | | |
| Wall area of X-axis and Y-axis／tank area | 0.05＜ | 1.0 | | |
| | 0.05＞ | 1.5 | 1.5 | 1.5 |
| Water depth | 5m≧ | 1.0 | 1.0 | |
| | 5m＜ | 1.3 | | 1.3 |
| Structural formation | Wall | 1.0 | | |
| | Column & Beam | 1.2 | | |
| | Flat slab | 1.4 | 1.4 | 1.4 |
| Soil cover | 0.4m≧ | 1.0 | | |
| | 0.4m＜ | 1.2 | 1.2 | 1.2 |
| Construction year | from 1995 onward | 1.0 | | |
| | | 1.2 | | |
| | before 1995 | 1.5 | 1.5 | 1.5 |
| Flexible pipe | existing | 1.0 | | |
| | nothing | 2.0 | 2.0 | 2.0 |
| Ex.j | good condition | 1.0 | 1.0 | 1.0 |
| | bad condition | 2.0 | | |
| Degraded degree | small | 1.0 | | 1.0 |
| | middle rank | 1.5 | | |
| | intense | 2.0 | 2.0 | |
| Seismic intensity | 5(approx. 100 to 250gal) | 1.0 | 7.6 | 5.9 |
| | 6(approx. 250 to 800gal) | 2.2 | 16.6 | 13.0 |
| | 7(approx. over 800gal) | 3.6 | 27.2 | 21.2 |
| Seismic resistance | high-level(Code2800 350gals) | 10＞ | 5 | 5 |
| | middle-level(North Tehran Fault 671gal at No.25) | 10～17 | 6 | 6 |
| | low-level | 17＜ | 7 | 7 |

### 4.2.3 Detailed Diagnosis for Damage Estimation

#### (1) Geological Condition of Structure Foundation

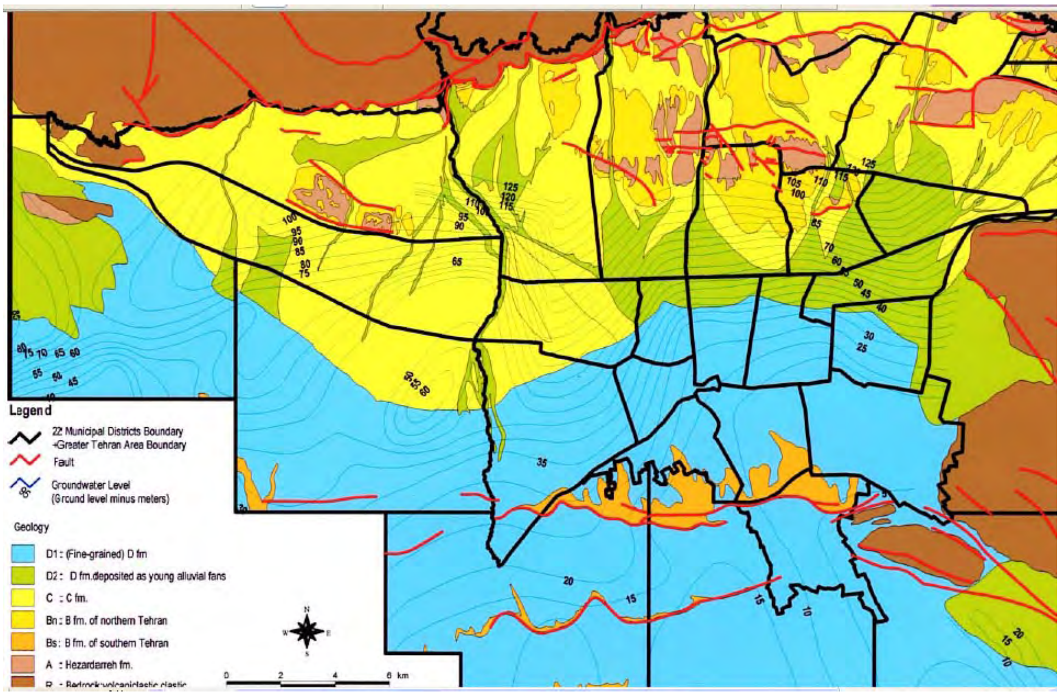
#### 1) Liquefaction

Liquefaction of sand is generated under two conditions, one is the existence of the ground water and the other is the existence of fine sand. Liquefaction is the phenomenon in which the absorption force of the particles of sand is cut off by shaking and it liquefies as a result.

The ground water level of Tehran is deep.

The object area where the water supply facility is located is the northern part from South Ray Fault. The depth of a ground water level increases toward north; it is GL-15m to more than GL-125m.

According to Seismic Microzoning, the possibility of liquefaction is pointed out in the area of a shallow ground water level. However, since the ground water level is deep at the reservoirs or pump stations, possibility of liquefaction is low at the concerned facilities.




*Source: The JICA Study on Seismic Microzoning*

**Figure 4.2.7 Groundwater**

#### 2) Foundation for structure

The foundation of tanks and buildings are shallow- maximum 10m. Ground condition is as follows.

- Boring G-13 (northern area) : sandy gravel / N value= 50
- Boring K-13 (central area): sandy gravel - clayish cohesive soil / N value= 25 - 50
- Boring N-13 (southern part): clayish cohesive soil / average N value=approx.25

It can be observed that it is very hard foundation even at a surface, except the ground of Reservoir No.68 and No.89.

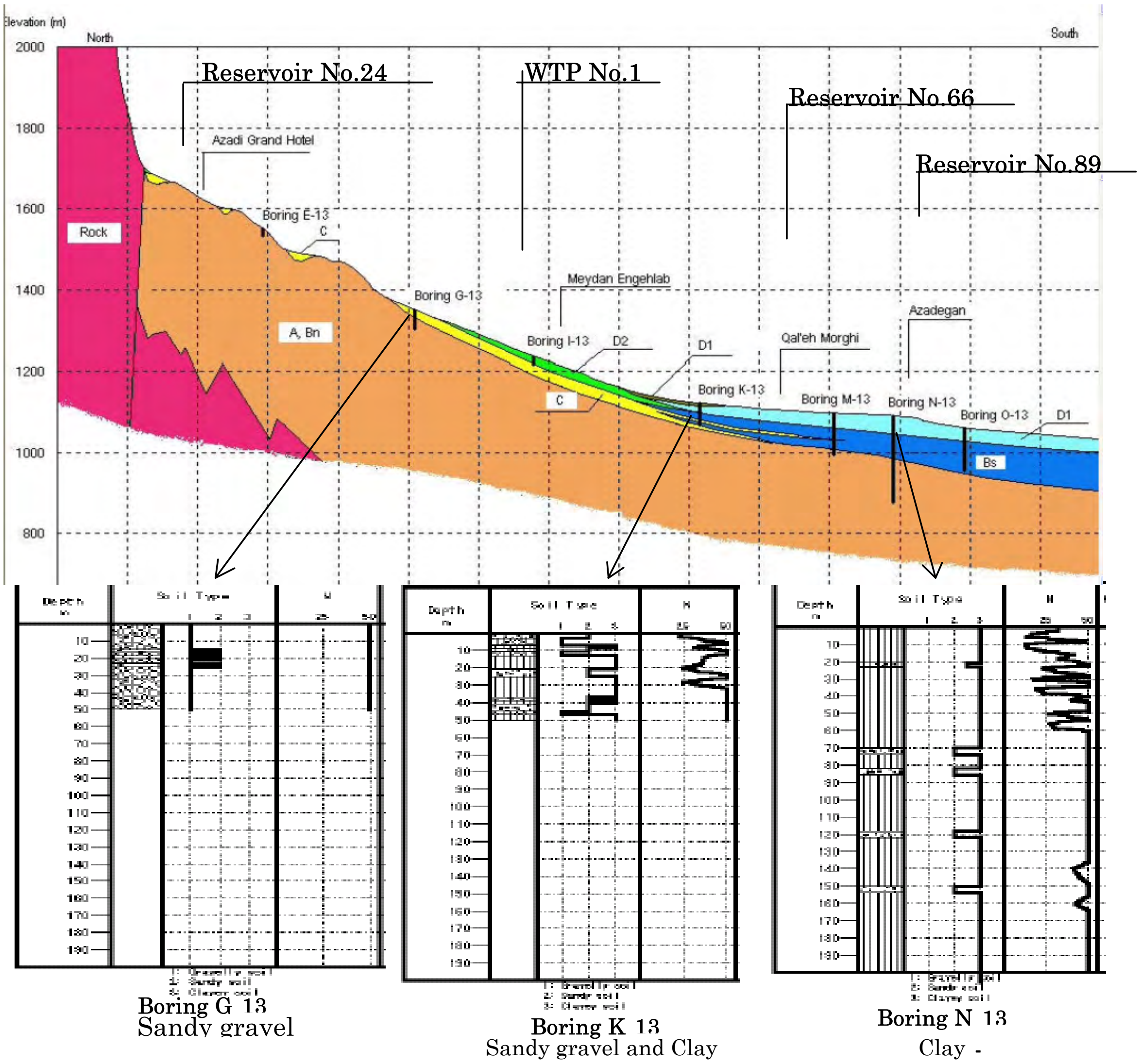
In Japan the good-quality foundation is defined in terms of N values which is 30 for sandy soil and

20 for clayish cohesive soil. So the bearing capacity is satisfied.

Except the structure located on fault and Reservoir No.68 and No.89 assumed to be on soft ground, ground conditions of tanks and buildings are extremely well, so it may be expected that large-scale damages do not occur.

**Table 4.2.14 Scenario Surface Acceleration**

| | Senario Surface Acceleration (Gal) | | | |
|---|---|---|---|---|
| | Reservoir No.24 | WTP No.1 | Reservoir No.66 | Reservoir No.89 |
| North Tehran Fault | 449 | 242 | 140 | 115 |
| Mosha Fault | 126 | 104 | 81 | 82 |
| South Ray Fault | 58 | 134 | 233 | 378 |
| North Ray Fault | 67 | 121 | 256 | 371 |




*(reference from "The JICA Study on Seismic Microzoning")*

**Figure 4.2.8 Soil Property Chart on Geological Cross Section**

## (2) Outcome of Damage Estimation

### 1) Consideration from Structural Analysis

As the structural analysis for several models were accomplished, the Seismic resistance thus obtained are shown below.

- Oldest Reservoir (Reservoir No.6, repaired) is middle.
- Long beam one storey Structure above ground (Generator House of WTP No.1) is low.
- Pumping house (Reservoir No.2) is middle.
- Deep tank with thin wall such Pulsator at WTP No.2 is middle.
- Ordinary tank such Filter at WTP No.2 is high.
- Chemical House at WTP No.4 is high. ( Supporting point of Breezeway should be reinforced though)

### 2) Outcome of Damage Estimations by DTSC

Conditions on damage estimations are described below.

- DTSC is evaluated according to what we have done in the site survey of WTP and sixty seven Reservoirs, only on the surveyed facilities.
- As structural analysis was accomplished, DTSC was modified a little.
- Damage estimation has been carried out considering four earthquake scenarios; North Tehran Fault, Mosha Fault, South Ray Fault, and North Ray Fault, and reflected on Damage Estimation Map.
- Facilities on fault are located only in northern Tehran, and displacement of some faults are approximately 30cm to 100cm on these facilities in the case of North Tehran Fault, but it is small in the case of other scenarios. So, DTSC was considered that the damages of these facilities are estimated seriously on the North Tehran fault scenario.
- The case of DTSC on the condition of Code 2800 would show present potential earthquake resistance. It must be recognized that this case is different with Damage Estimation Map. But we will submit for Earthquake Resistant Map in section 6.3.
- New Structure designed by code 2800 is also evaluated by fragility point and on the basis of construction year, It's seismic resistance must be high-level, but seismic resistance of some new facilities on DTSC are evaluated middle-level contrary to our intention, so evaluations on these facilities were modified making a note on DTSC.
- Seismic resistance of Reservoir No.23 is estimated middle-level by DTSC, but by structure analysis, it is high-level, so DTSC changed.
- Regarding the earthquake resistance of Reservoir No.6; one of the oldest Reservoir, it is evaluated as middle-level on DTSC due to evaluation on degradation of compartment, moreover we carried out the structural analysis, and found out that earthquake resistance was also on middle-level because the bar arrangement of a partial wall of No.6 is abnormally small in number, this was rare case. On the other hand the earthquake resistance of the oldest Reservoirs- No.1 to No.5 are evaluated to be high-level on the basis of DTSC, but these Reservoirs must be of the same design as Reservoir No.6 assumed by the fact that these are of the same construction age. If so earthquake resistance should be middle-level, but since we could not confirm bar arrangement on all reservoirs, therefore we could not modify the DTSC of Reservoir No.1 to No.5 easily, only from the reason of construction age assumed to be the same. But still it's remained suspicious that the reinforcing bar of Reservoir No.1 to No.5 might be insufficient, so it is justified to make clear that these Reservoirs are nominated as candidate for further study issue.

Therefore we modified the evaluation as of middle-level earthquake resistance of Reservoirs No.1 to No.5 on Earthquake resistance Map.

At damage estimations, anticipated damages of four scenario earthquakes have been performed by the DTSC, shown in *Table 4.2.16* to *4.2.18*.

As the result of estimations, the damages are remarkable only in the case of North Tehran Fault shown in Fig.4.2.9.

### Table 4.2.15 Explanatory Note

| | No.42 | No.11 on the fault |
|---|---|---|
| high-level | 5 , 6 | 5 |
| middle-level | 7 | 6 |
| low-level | | 7 |
| North Teheran Fault | 554 | 441 |
| Mosha Fault | 213 | 187 |
| South Ray Fault | 62 | 121 |
| North Ray Fault | 72 | 131 |
| Code 2800 | 350 | 350 |

- Seismic resistance
- Scenario earthquake
- Purple color; Facility on Plan
- Green color; Facility performed survey
- Seismic resistance is the middle level on the condition of seismic intensity 6 viz. approx..250 to 800 gal (surface acceleration)
- Red color; Seismic resistance is low-level because this reservoir is on the fault. Facility on a fault would be evaluated low
- Blue color; Seismic resistance is high-level because of the Surface Acceleration is small.
- Yellow color; Seismic resistance is middle-level because of the Surface Acceleration is equivalent to seismic intensity 6
- Surface acceleration

### Table 4.2.16 Outcome of Damage Estimation of Reservoir

| | No.1 | No.2 | No.3 | No.4 | No.5 | No.6 | No.7 | No.8 | No.9 | No.10 |
|---|---|---|---|---|---|---|---|---|---|---|
| high-level | 5 , 6 | 5 , 6 | 5 , 6 | 5 , 6 | 5 , 6 | 5 | 5 , 6 | 5 , 6 | 5 | 5 |
| middle-level | 7 | 7 | 7 | 7 | 7 | 6 | 7 | 7 | 6 | 6 |
| low-level | | | | | | 7 | | | 7 | 7 |
| North Tehran Fault | 228 | 258 | 226 | 271 | 293 | 306 | 285 | 267 | 245 | 316 |
| Mosha Fault | 94 | 133 | 104 | 113 | 120 | 125 | 149 | 119 | 98 | 119 |
| South Ray Fault | 87 | 124 | 127 | 147 | 154 | 157 | 107 | 125 | 87 | 73 |
| North Ray Fault | 81 | 134 | 134 | 116 | 126 | 142 | 152 | 110 | 77 | 92 |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 |

| | No.11 on Fault | No.12 | No.13 | No.14 on Fault | No.15 | No.16 | No.17 | No.18 | No.19 | No.20 |
|---|---|---|---|---|---|---|---|---|---|---|
| high-level | 5 | | 5 | 5 , 6 | 5 | 5 | | 5 , 6 | 5 , 6 | 5 |
| middle-level | 6 | | 6 | 7 | 6 | 6 | | 7 | 7 | 6 |
| low-level | 7 | | 7 | | 7 | 7 | | | | 7 |
| North Tehran Fault | 441 | 318 | 231 | 331 | 175 | 223 | 621 | 241 | 558 | 511 |
| Mosha Fault | 187 | 136 | 125 | 107 | 111 | 115 | 187 | 96 | 235 | 177 |
| South Ray Fault | 121 | 104 | 127 | 77 | 158 | 212 | 112 | 73 | 100 | 67 |
| North Ray Fault | 131 | 69 | 145 | 88 | 174 | 208 | 99 | 73 | 101 | 63 |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 |

| | No.21 | No.22 | No.23 by calculation | No.24 | No.25 | No.26 on NTF | No.27 | No.28 | No.29 | No.30 |
|---|---|---|---|---|---|---|---|---|---|---|
| high-level | 5 , 6 | 5 , 6 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| middle-level | 7 | 7 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| low-level | | | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| North Tehran Fault | 659 | 408 | 691 | 449 | 671 | 511 | 583 | 483 | 583 | 435 |
| Mosha Fault | 198 | 111 | 216 | 126 | 222 | 177 | 187 | 156 | 187 | 134 |
| South Ray Fault | 108 | 65 | 117 | 58 | 110 | 67 | 72 | 65 | 72 | 59 |
| North Ray Fault | 91 | 85 | 88 | 67 | 88 | 63 | 61 | 58 | 61 | 64 |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 |
| | No.31 | No.32 | No.33 | No.34 | No.35 | No.36 | No.37 | No.38 | No.39 | No.40 |
| high-level | 5 , 6 | 5 | 5 | | | 5 , 6 | 5 | 5 | | 5 |
| middle-level | 7 | 6 | 6 | | | 7 | 6 | 6 | | 6 |
| low-level | | 7 | 7 | | | | 7 | 7 | | 7 |
| North Tehran Fault | 250 | 386 | 462 | | 181 | 112 | 258 | 324 | 441 | 617 |
| Mosha Fault | 150 | 126 | 148 | | 91 | 103 | 85 | 102 | 129 | 203 |
| South Ray Fault | 175 | 53 | 65 | | 158 | 259 | 67 | 63 | 59 | 124 |
| North Ray Fault | 155 | 63 | 58 | | 250 | 296 | 68 | 63 | 93 | 93 |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 |
| | No.41 | No.42 | No.43 | No.44 | No.45 | No.46 | No.47 | No.48 | No.49 | No.50 |
| high-level | 5 | | 5 , 6 | | | | | | | |
| middle-level | 6 | | 7 | | | | | | | |
| low-level | 7 | | | | | | | | | |
| North Tehran Fault | 653 | 554 | 336 | | | 604 | | | | |
| Mosha Fault | 207 | 213 | 131 | | | 203 | | | | |
| South Ray Fault | 115 | 62 | 101 | | | 100 | | | | |
| North Ray Fault | 91 | 72 | 82 | | | 100 | | | | |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 |
| | No.51 | No.52 | No.53 | No.54 | No.55 | No.56 | No.57 | No.58 | No.59 | No.60 |
| high-level | 5 | 5 , 6 | 5 | 5 , 6 | 5 , 6 | | 5 | 5 | 5 , 6 | |
| middle-level | 6 | 7 | 6 | 7 | 7 | | 6 | 6 | 7 | |
| low-level | 7 | | 7 | | | | 7 | 7 | | |
| North Tehran Fault | 174 | 218 | 218 | 262 | 270 | | 288 | 255 | 287 | |
| Mosha Fault | 104 | 117 | 113 | 125 | 177 | | 98 | 78 | 96 | |
| South Ray Fault | 103 | 207 | 205 | 104 | 100 | | 104 | 61 | 110 | |
| North Ray Fault | 155 | 229 | 205 | 112 | 106 | | 129 | 75 | 137 | |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 |
| | No.61 | No.62 | No.63 | No.64 | No.65 | No.66 | No.67 | No.68 | No.69 | No.70 |
| high-level | 5 , 6 | | 5 | 5 , 6 | 5 , 6 , 7 | 5 | | 5 | 5 , 6 | |
| middle-level | 7 | | 6 | 7 | | 6 | | 6 | 7 | |
| low-level | | | 7 | | | 7 | | 7 | | |
| North Tehran Fault | 255 | 435 | 109 | 210 | 128 | 140 | 151 | 240 | 184 | 172 |
| Mosha Fault | 100 | 200 | 85 | 120 | 85 | 81 | 164 | 152 | 96 | 93 |
| South Ray Fault | 85 | 105 | 147 | 206 | 276 | 233 | 303 | 201 | 156 | 151 |
| North Ray Fault | 76 | 131 | 172 | 284 | 292 | 256 | 224 | New 291 | 219 | 244 |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | New 350 | 350 | 350 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No.71 on Fault | No.72 | No.73 | No.74 | No.75 on NTF | No.76 | No.77 on NTF | No.78 | No.79 | No.80 |
| high-level | 5 | 5 | 5 , 6 | 5 , 6 | 5 , 6 | 5 , 6 ,7 | 5 , 6 , 7 | | | 5 , 6 |
| middle-level | 6 | 6 | 7 | 7 | 7 | | | | | 7 |
| low-level | 7 | 7 | | | | | | | | |
| North Tehran Fault | 248 | 399 | 181 | 513 | 522 | | 505 | | | 262 |
| Mosha Fault | 164 | 120 | 91 | 166 | 169 | | 170 | | | 75 |
| South Ray Fault | 82 | 108 | 158 | 60 | 61 | | 56 | | | 59 |
| North Ray Fault | 83 | 96 | 259 | 65 | 62 | | 60 | | | 78 |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 |
| | No.81 | No.82 on NTF | No.83 | No.84 | No.85 | No.86 | No.87 | No.88 | No.89 | No.90 |
| high-level | | 5 , 6 , 7 | | | | | | | 5 | |
| middle-level | | | | | | | | | 6 | |
| low-level | | | | | | | | | 7 | |
| North Tehran Fault | 272 | 299 | | | | | | | 115 | |
| Mosha Fault | 74 | 108 | | | | | | | 82 | |
| South Ray Fault | 49 | 61 | | | | | | | New 378 | |
| North Ray Fault | 69 | 61 | | | | | | | New 371 | |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | New 350 | 350 |
| | No.91 | No.92 | No.93 | No.94 | No.95 on Fault | No.96 | No.97 on Fault | No.98 | No.99 | No.100 |
| high-level | 5 , 6 | | | | 5 | 5 , 6 | 5 | | | |
| middle-level | 7 | | | | 6 | 7 | 6 | | | |
| low-level | | | | | 7 | | 7 | | | |
| North Tehran Fault | 386 | 241 | 281 | 248 | 248 | 253 | 248 | | | |
| Mosha Fault | 126 | 104 | 92 | 164 | 164 | 168 | 164 | | | |
| South Ray Fault | 53 | 134 | 94 | 82 | 82 | 131 | 82 | | | |
| North Ray Fault | 63 | 121 | 127 | 83 | 83 | 130 | 83 | | | |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 |
| | No.101 | No.102 | No.103 | No.104 | No.105 | No.106 | No.107 | No.108 | No.109 | No.110 |
| high-level | | | | 0 | 0 | | | | | |
| middle-level | | | | 0 | 0 | | | | | |
| low-level | | | | | | | | | | |
| North Tehran Fault | | | | 275 | 330 | | | | | |
| Mosha Fault | | | | 121 | 144 | | | | | |
| South Ray Fault | | | | 119 | 103 | | | | | |
| North Ray Fault | | | | 105 | 86 | | | | | |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 |
| | No.111 | No.112 | No.113 | No.114 | | | | | | |
| high-level | | | | | | | | | | |
| middle-level | | | | | | | | | | |
| low-level | | | | | | | | | | |
| North Tehran Fault | | | | | | | | | | |
| Mosha Fault | | | | | | | | | | |
| South Ray Fault | | | | | | | | | | |
| North Ray Fault | | | | | | | | | | |
| Code 2800 | 350 | 350 | 350 | 350 | | | | | | |

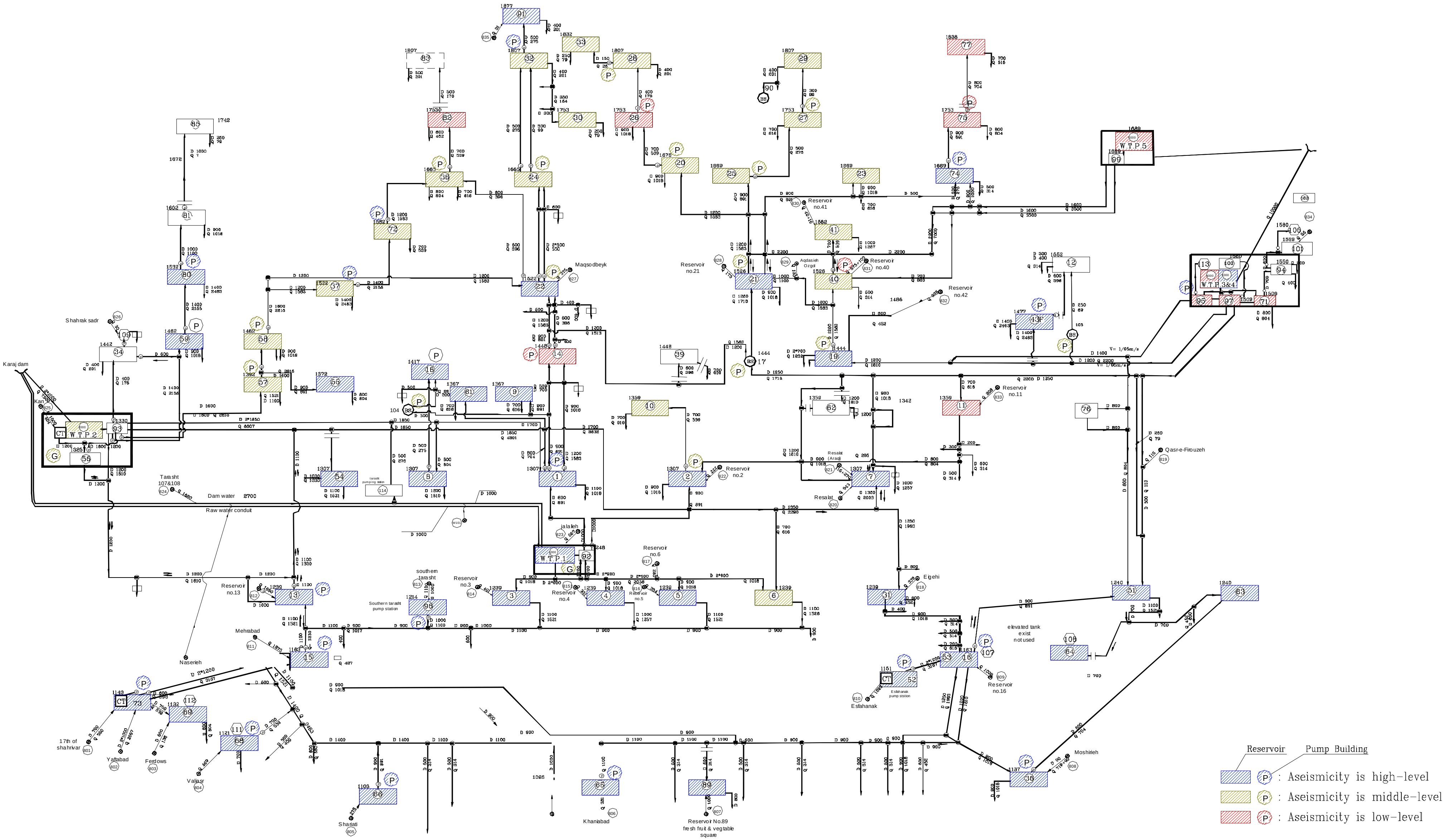
## Table 4.2.17 Outcome of Damage Estimation of Pump House

| | No.1 | No.2 | No.8<br>No Pump | No.12 | No.13<br>No House | No.14<br>on Fault | No.15 | No.16 | No.17 | No.18 |
|---|---|---|---|---|---|---|---|---|---|---|
| high-level | 5 | 5 | | | | 5 | 5 | 5 | 5 | |
| middle-level | 6 | 6 | | | | 6 | 6 | 6 | 6 | |
| low-level | 7 | 7 | | | | 7 | 7 | 7 | 7 | |
| North Tehran Fault | 228 | 258 | 267 | 318 | 231 | 331 | 175 | 223 | 621 | 241 |
| Mosha Fault | 94 | 133 | 119 | 136 | 125 | 107 | 111 | 115 | 187 | 96 |
| South Ray Fault | 87 | 124 | 125 | 104 | 127 | 77 | 158 | 212 | 112 | 73 |
| North Ray Fault | 81 | 134 | 110 | 69 | 145 | 88 | 174 | 208 | 99 | 73 |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 |
| | No.19 | No.20 | No.21 | No.22 | No.24 | No.25 | No.26<br>on NTF | No.27 | No.28 | No.32<br>No House |
| high-level | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | |
| middle-level | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | |
| low-level | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | |
| North Tehran Fault | 558 | 511 | 659 | 408 | 449 | 671 | 511 | 583 | 483 | 386 |
| Mosha Fault | 235 | 177 | 198 | 111 | 126 | 222 | 177 | 187 | 156 | 126 |
| South Ray Fault | 100 | 67 | 108 | 65 | 58 | 110 | 67 | 72 | 65 | 53 |
| North Ray Fault | 101 | 63 | 91 | 85 | 67 | 88 | 63 | 61 | 58 | 63 |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 |
| | No.34 | No.36 | No.37<br>No House | No.38 | No.40 | No.43<br>No House | No.52 | No.56 | No.57 | No.58 |
| high-level | 5 | 5 | | 5 | 5 | | 5 | 5 | 5 | 5 |
| middle-level | 6 | 6 | | 6 | 6 | | 6 | 6 | 6 | 6 |
| low-level | 7 | 7 | | 7 | 7 | | 7 | 7 | 7 | 7 |
| North Tehran Fault | | 112 | 258 | 324 | 617 | 336 | 218 | | 288 | New255 |
| Mosha Fault | | 103 | 85 | 102 | 203 | 131 | 117 | | 98 | 78 |
| South Ray Fault | | 259 | 67 | 63 | 124 | 101 | 207 | | 104 | 61 |
| North Ray Fault | | 296 | 68 | 63 | 93 | 82 | 229 | | 129 | 75 |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | New350 |
| | No.59<br>No House | No.65 | No.66 | No.68<br>No House | No.69<br>No Pump | No.71<br>No Pump | No.72<br>No House | No.73 | No.74 | No.75<br>on NTF |
| high-level | 5,6,7 | 5 , 6 | 5 , 6 | | | | | 5 | 5 , 6 | 5 |
| middle-level | | 7 | 7 | | | | | 6 | 7 | 6 |
| low-level | | | | | | | | 7 | | 7 |
| North Tehran Fault | 287 | 128 | 140 | 240 | 184 | 248 | 399 | 181 | 513 | 522 |
| Mosha Fault | 96 | 85 | 81 | 152 | 96 | 164 | 120 | 91 | 166 | 169 |
| South Ray Fault | 110 | 276 | 233 | 201 | 156 | 82 | 108 | 158 | 60 | 61 |
| North Ray Fault | 137 | 292 | 256 | 291 | 219 | 83 | 96 | 259 | 65 | 62 |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | New350 |

| | No.80 | No.81 | No.82 on NTF /No Pump | No.90 | No.92 | No.93 | No.94 | No.95 No Pump | No.96 Steel | No.97 Under construction |
|---|---|---|---|---|---|---|---|---|---|---|
| high-level | 5 , 6 | | | | | | | | 5 | 5,6,7 |
| middle-level | 7 | | | | | | | | 6 | |
| low-level | | | | | | | | | 7 | |
| North Tehran Fault | 262 | 272 | 299 | | 241 | 281 | 248 | 248 | 253 | 248 |
| Mosha Fault | 75 | 74 | 108 | | 104 | 92 | 164 | 164 | 168 | 164 |
| South Ray Fault | 59 | 49 | 61 | | 134 | 94 | 82 | 82 | 131 | 82 |
| North Ray Fault | 78 | 69 | 61 | | 121 | 127 | 83 | 83 | 130 | 83 |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 |
| | No.99 | No.100 | No.101 | No.102 | No.104 | No.105 | No.114 | | | |
| high-level | | | | | 5 | 5 | | | | |
| middle-level | | | | | 6 | 6 | | | | |
| low-level | | | | | 7 | 7 | | | | |
| North Tehran Fault | | | | | 275 | 330 | | | | |
| Mosha Fault | | | | | 121 | 144 | | | | |
| South Ray Fault | | | | | 119 | 103 | | | | |
| North Ray Fault | | | | | 105 | 86 | | | | |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | | | |

## Table 4.2.18 Outcome of Damage Estimation of WTP

| | WTP No.1 Clarifier | WTP No.1 Filter | WTP No.2 Pulsator | WTP No.2 Filter | WTP No.3 Pulsator | WTP No.3 Filter | WTP No.4 Pulsator on NTF | WTP No.4 Filter on NTF | WTP No.5 Pulsator | WTP No.5 Filter |
|---|---|---|---|---|---|---|---|---|---|---|
| high-level | 5 , 6 , 7 | 5 , 6 , 7 | 5 | 5 , 6 , 7 | 5 , 6 , 7 | 5 , 6 , 7 | 5 , 6 , 7 | 5 | 5 , 6 , 7 | 5 , 6 , 7 |
| middle-level | | | 6 | | | | | 6 , 7 | | |
| low-level | | | 7 | | | | | | | |
| North Tehran Fault | 242 | 242 | 283 | 283 | 224 | 224 | 260 | 260 | 618 | 618 |
| Mosha Fault | 104 | 104 | 92 | 92 | 167 | 167 | 167 | 167 | 208 | 208 |
| South Ray Fault | 134 | 134 | 97 | 97 | 77 | 77 | 81 | 81 | 96 | 96 |
| North Ray Fault | 121 | 121 | 129 | 129 | 78 | 78 | 78 | 78 | 97 | 97 |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 | 350 |
| | WTP No.1 Generator House | WTP No.2 Generator House | WTP No.4 Chemical House | WTP No.5 Chlorine House on the NTF | WTP No.5 Chemical House on the NTF | Chemical Factory | | | | |
| North Tehran Fault | 242 | 283 | 260 | 618 | 618 | 207 | | | | |
| Mosha Fault | 104 | 92 | 167 | 208 | 208 | 162 | | | | |
| South Ray Fault | 134 | 97 | 81 | 96 | 96 | 77 | | | | |
| North Ray Fault | 121 | 129 | 78 | 97 | 97 | 82 | | | | |
| Code 2800 | 350 | 350 | 350 | 350 | 350 | 350 | | | | |




# Figure 4.2.9 Damage Estimation Map ( North Tehran Fault )

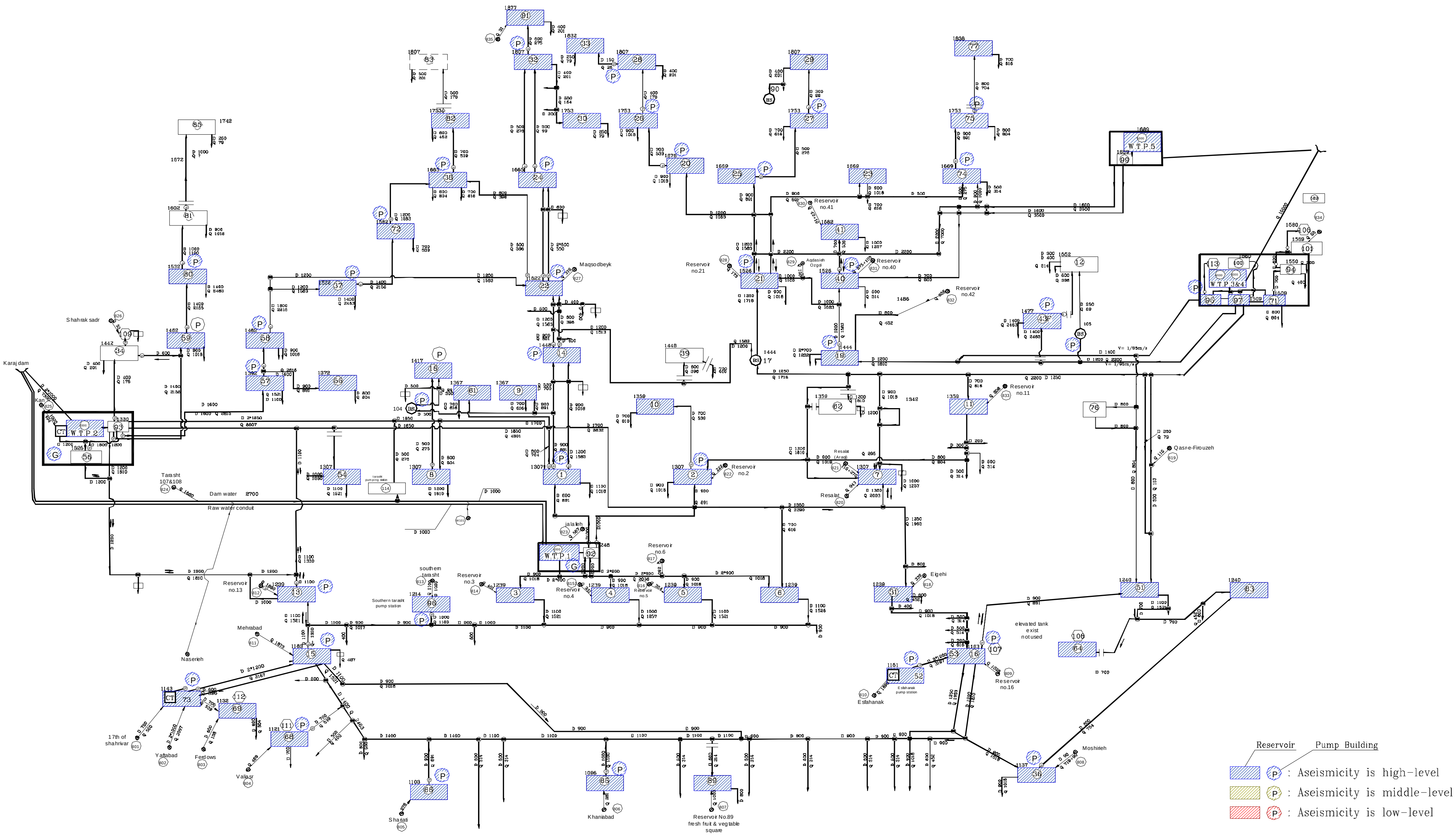



**Figure 4.2.10 Damage Estimation Map ( Mosha Fault )**

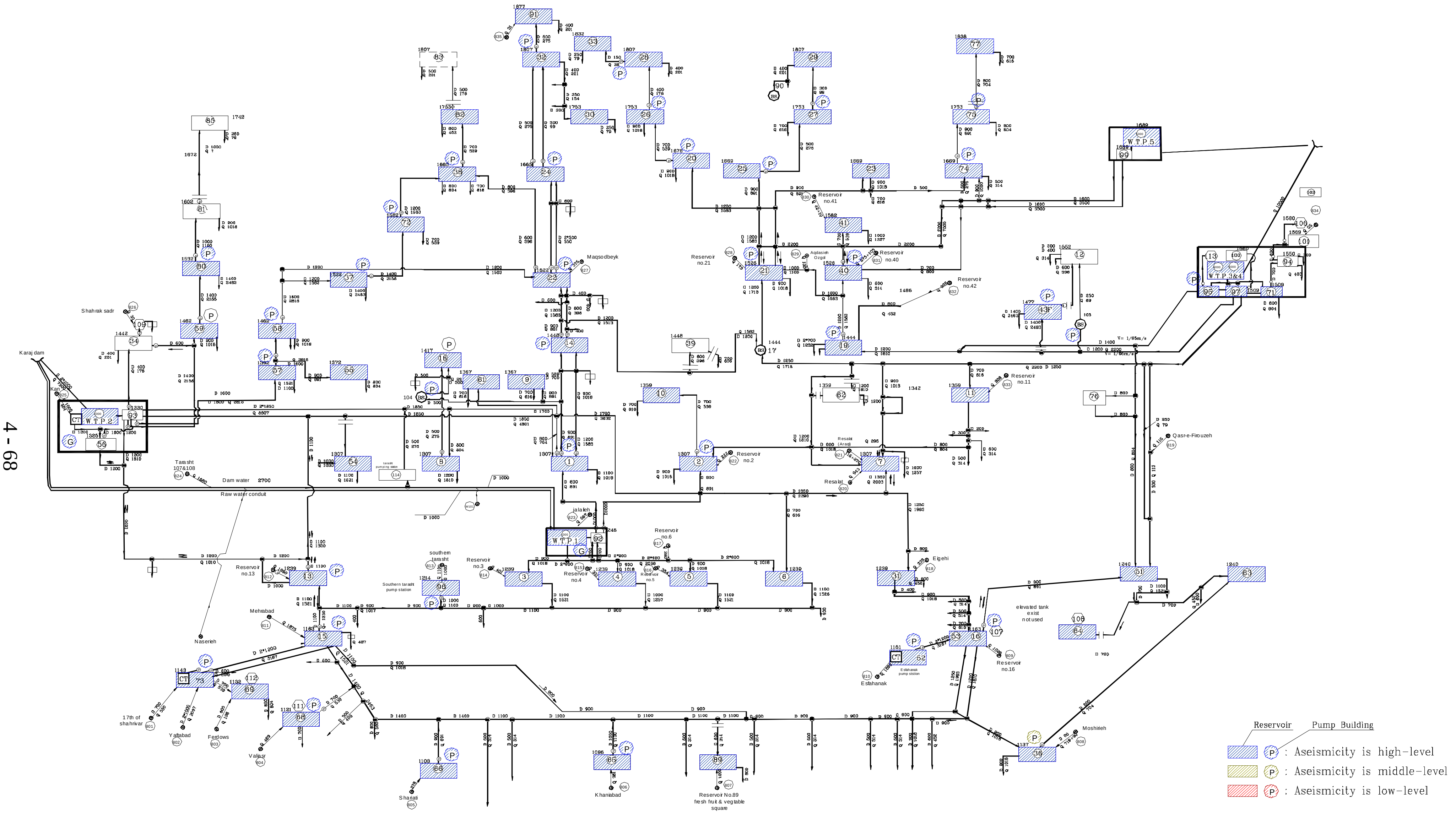



**Figure 4.2.11 Damage Estimation Map ( South Ray Fault )**

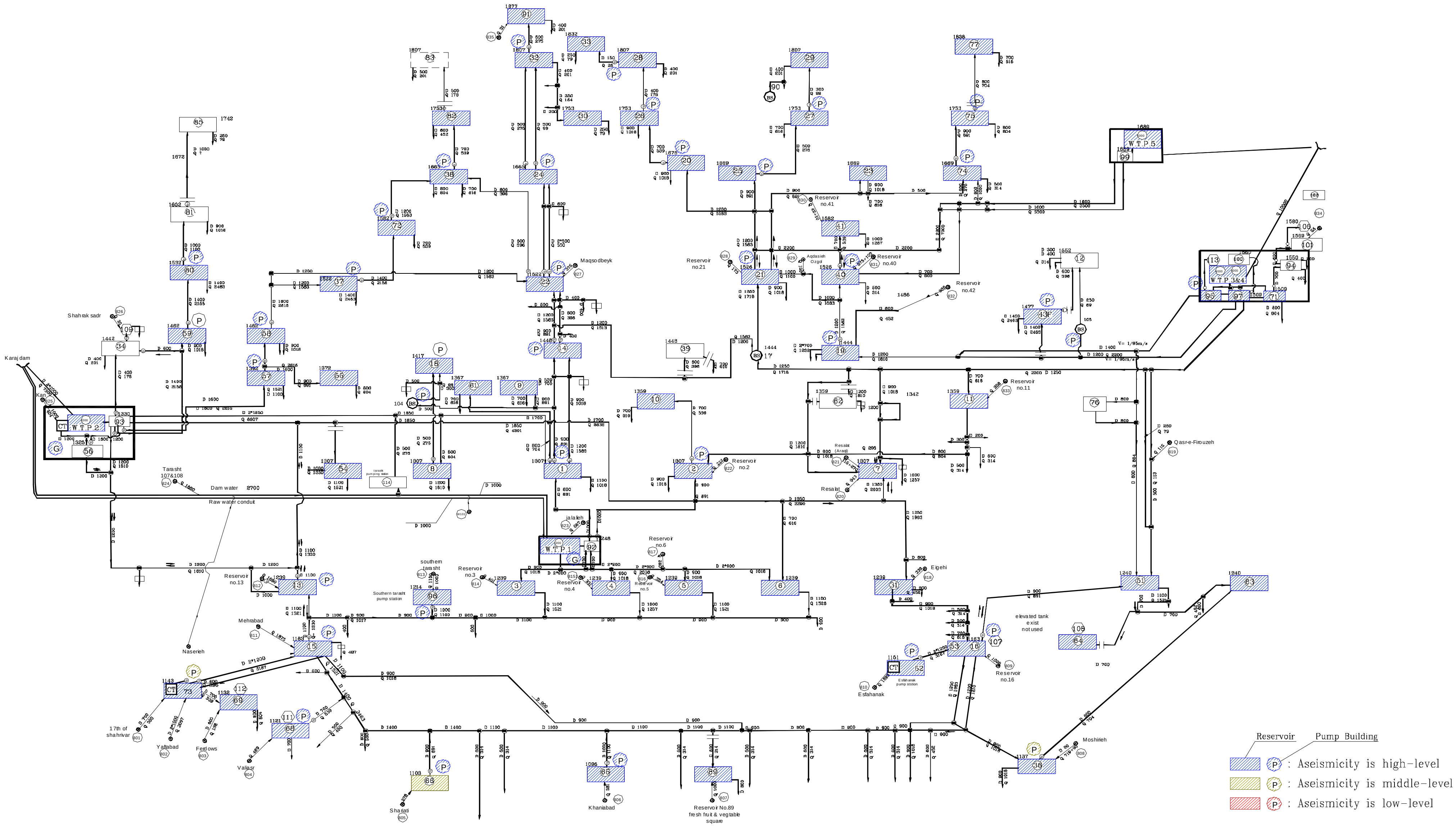



Figure 4.2.12 Damage Estimation Map ( North Ray Fault )

## 4.3 Hydraulic Analysis of Pipe Network of Tehran Water Supply System

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

Water supply from distribution reservoirs to Tehran citizen is principally done by gravity flow. Water supply system in each reservoir zone is different from one another. Some zones have rather small areas but big difference in elevation and some others cover large areas with rather flat conditions on the contrary.

Water flow in the transmission networks is examined by a hydraulic analysis in order to grasp possible problems in an earthquake disaster and to find solution thereof. As for distribution networks, hydraulic analysis of the networks in a few typical reservoir zones is executed for giving idea on improvement of their water supply conditions.

### 4.3.1 Criteria for Hydraulic Analysis of Transmission Networks

#### (1) Modeling of Transmission Networks

Model of the transmission networks for a hydraulic analysis consists of a great numbers of nodes, pipes, tanks, pumps, valves, etc. and is prepared as shown in *Figure 4.3.1*. Such components of the model as deep wells, well pumps, transmission pumps, distribution reservoirs are listed both in Section 2.3 "Survey of the Existing Water Supply System" and in Section 1 of Appendix xx.

The network model consists of 209 nodes and 550 pipe components. Numbers of the pipe components are far bigger than those of nodes. It is a characteristic of the transmission networks of Tehran water supply system that two or more pipe components are connected to one node.

#### (2) Transmission Flow Rate

The day maximum water supply in 2005 is 3,172,996 $m^3$/day, which is applied for the hydraulic analysis. As total production of 3,134,970$m^3$/day recorded for the same day is slightly smaller than the above day maximum supply, it is adjusted accordingly to the maximum supply for analysis. Adjusted production and production of each water treatment plant are summarized as shown in *Table 4.3.1*.

#### (3) Zonal Distribution of Transmission Flow

Transmission flow rate to each reservoir zone is set on the basis of the water consumption values of the year 2002 by Lar consultants as shown in *Table 2.2.7* in Section 2.3. The flow rate to the newly established reservoir zones is defined considering population thereof.

### (4) Transmission Flow Rate after Earthquake Disaster

As for analysis of transmission flow rate after an earthquake disaster, several cases thereof including interruption of treatment plants, interruption of pumping stations and damage of transmission mains are considered.

The total transmission flow when a water treatment plant becomes out of operation is regarded as the total production of the other plants as listed in *Table 4.3.1*. This is because the production of all the plants except the newly built No.5 is operated nearly up to the designed capacity. It is also assumed that abstraction of groundwater will not change. Ratio of transmission flow are the smallest in case 2 and 3, i.e. they are approximately 60% respectively.

In case of damages of water transmission mains and pump stations, total flow rate is employed considering that all of the water treatment plants will be in operation in this case.

**Table 4.3.1 Transmission Flow Rate for Hydraulic Analysis**

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

## 4.3.2 Verification of Network Analysis

### (1) Verification of Model

Based on the above mentioned criteria, hydraulic analysis of the transmission networks are executed with the water CAD program.

It is concluded that the model of the networks is practicable considering the following results of the analysis;

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

The network model is as of July 2005, and production of plant No.5 is approximately 1/3 of its designed capacity. There is information that new distribution reservoirs have been put into operation and some transmission mains have been installed. It is suggested to execute hydraulic analysis of the transmission networks with the up-dated model to suite the present conditions.

Collection of data for the network analysis was started from the beginning of the study. However, some data was not up-dated, some included inaccurate values and others were not available. Thus, it took about one year for hydraulic analysis to be fulfilled. Even in the present model, some estimated data on issues such as reservoir water level, pump lift and elevation of nodes are included. In case more accurate results are necessary, these data should be examined.

Accuracy of analysis results would be greatly improved, if they are verified by measured flow rates in some strategic pipelines, on which flow meters should be installed in the future.

**(2) Outcome of Hydraulic Analysis**

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

### 4.3.3 Hydraulic Analysis in Earthquake Disaster

By using the network model, hydraulic analysis in earthquake disaster is undertaken. At first, cases to be analyzed are selected considering estimated damages of the water supply facilities studied in the previous sections. Basically, cases are selected considering that the facilities on or across the faults tend to be damaged by an earthquake.

**(1) Case Setting**

**1) Cases of Facility Damages**

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

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

Regarding treatment plants, No.3･4 and No.5 are located on the faults but the others are not. However, considering possible damages of upper facilities including water intake stations and raw water mains, cases of plant No.1 or No.2 to be damaged are also employed for the analysis.

Among the estimated 22 locations of transmission mains to be damaged, large diameter concrete pipelines crossing the faults are thought to be damaged most easily and affect the citizens greatly.

Hydraulic analysis is done for three cases of the pipeline damages, which includes damage of a twin 1,850mm pipelines located downstream of plant No.2, damage of a 1,350mm pipeline above reservoir No.7 and damage of both pipelines.

There are three pump stations located on the faults. Among them, station No.14 is the biggest and is employed for the analysis. There are several distribution reservoirs which are located on the faults. But these are not included in the cases for analysis because these reservoirs would be equipped with a by-pass pipeline between inlet and outlet pipelines. By using the by-pass line, water flow would not be cut even in case the reservoir structure gets damaged.

**2) Cases of Change in Operating Conditions**

There are a great number of pumps and valves installed in the transmission mains. Direction and amount of flow for ordinary operation is controlled by on/off of pumps, units of running pumps and open/close of valves. Without change in operation of these equipments, it is difficult to transmit water to different areas. Cases of changes in the operating conditions are also analyzed hereunder. The following three cases are applied for the study:

- No change in operating conditions: As direction and amount of flow for ordinary operation is already controlled, it is difficult to transmit water to different areas, in case when operating conditions of the equipment would not be changed. Thus, interruption in operation of the above facilities for each case would cause water supply interruption in wide areas.
- Maximum change in operation: In order to minimize damage effect, many of pump on/off, operating pump unit, pump running hour, valve open/close, valve opening and pipeline in use are changed accordingly. Results are obtained by hydraulic analysis.
- Realistic Change in Operation: In order to reduce damage effect realistically, only pump on/off and valve open/close are changed and the results are obtained by hydraulic analysis.

**(2) Results of Hydraulic analysis**

**1) No Change in Operation**

*Figure 4.3.2* shows service area of each water treatment plant as of July 2005. Speculation of water suspension area is shown in the figure, in case of no operation change in pumps, valves and pipes. Thus, wide area would suffer from water shortage by stoppage of each one of the five treatment plants.

**2) Maximum Change in Operation**

In order to minimize disaster effect, operation of many pipes, pumps and valves have to be changed as shown in Section 3 of Appendix-8. Results of the analysis of each case are shown in *Figure 4.3.3* and the damage level is described in *Table 4.3.3*.

As shown in the figure and table, damage level (represented in number of reservoirs with insufficient inflow) in each case diminishes except for Case 2 and 5, both of which have several reservoirs of insufficient flow. However, a lot of changes in operation must be made in these cases. It is ideal but not realistic to alter so many operating conditions manually in a short period after earthquake disaster.

By these analyses, it is recognized that 2,000mm concrete raw water mains to plant No.2 and 1,850 mm concrete pipelines are very important and need proper earthquake resistant measures.

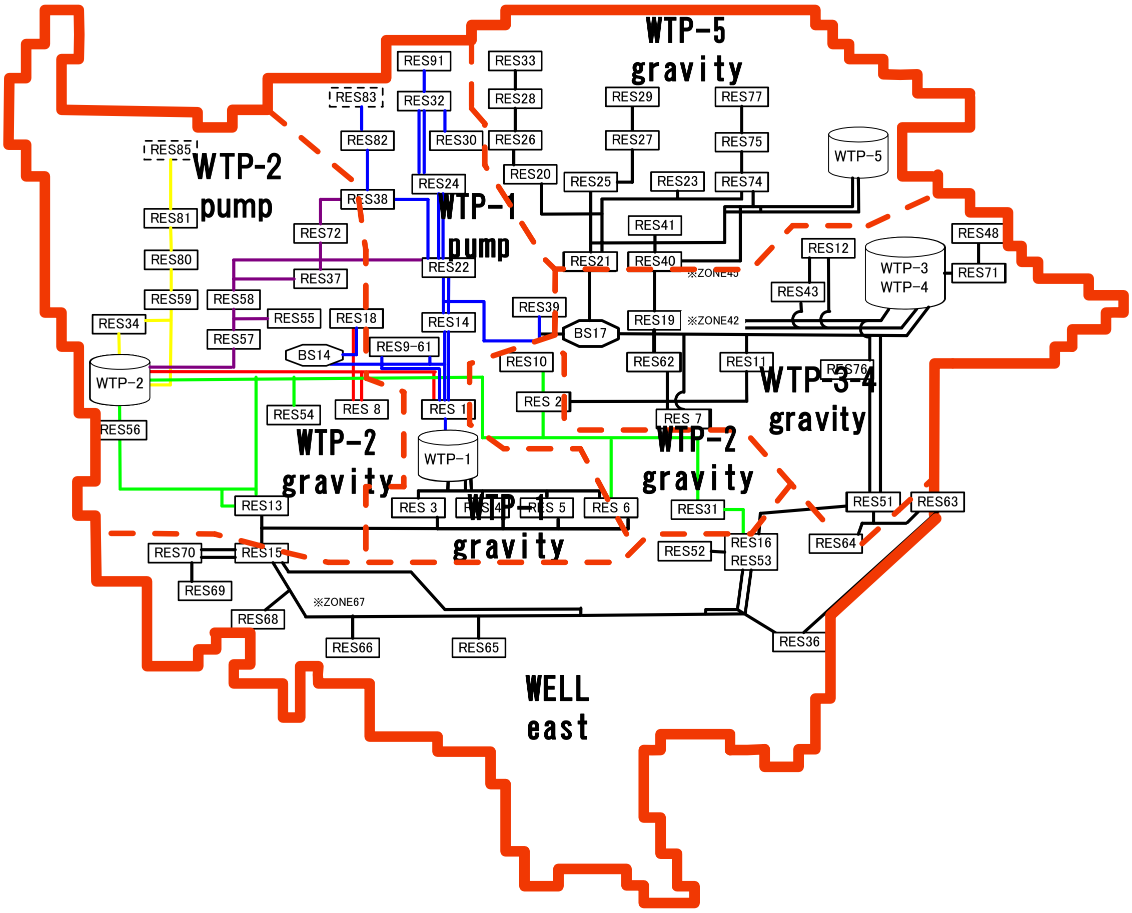



**Figure 4.3.2 Approximate Service Area of Treatment Plants**

### 3) Realistic Change in Operation

Within a realistic change in operation, the extent of damage level that could be reduced is examined. In this case, only on/off of pump and open/close of valve are changed from the original case mentioned in 4.3.2. Number of operation change is shown in *Table 4.3.3*. Except for the case 2 and 3, the number ranges from 10 to 20.

**Table 4.3.3 Number of Change in Operation**

| Status | Case1 | Case2 | Case3 | Case4 | Case5 | Case6 | Case7 | Case8 |
|---|---|---|---|---|---|---|---|---|
| Pump On/off | 2 | 10 | 6 | 4 | 6 | 2 | 6 | 3 |
| Valve Open/Close | 8 | 18 | 26 | 12 | 12 | 9 | 13 | 7 |
| Total | 10 | 28 | 32 | 16 | 18 | 11 | 19 | 10 |

Results of hydraulic analysis after the realistic changes made are shown in the right column in *Table 4.3.2*. Level of damage increases in all cases compared with the case of the maximum change. Minimization of damage occurrence (by retrofitting of facilities) or minimization of damage effect (by installation of by-pass pipelines) should be done.

**Table 4.3.2 Estimated Damage Level**

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

### 4.3.4 Preliminary Analysis of Distribution Network

In some reservoir zones, map of distribution network is already prepared. The zones for hydraulic analysis are selected from these zones:

- Zone No.27 shows big difference in ground elevation in the northern area,
- Zone No15～53 has a vast land area in the southern area,
- Zone No.12 has a middle condition between the above two zones.

Hydraulic analysis of distribution networks in the above reservoir zones is executed using Auto CAD program. On the basis of the analysis, improvement of the water supply conditions in each zone is suggested. Area, elevation and its difference are listed in the *Table 4.3.4*. Hourly peak factor was measured as 1.21 on July 15, 2006 at distribution reservoir No.27 and the figure was used for hydraulic analysis.

**Table 4.3.4 Outline of Distribution Zones to Be Examined**

| Reservoir Zones | Area | Elevation | Difference |
|---|---|---|---|
| No.27 | 3.03 km2 | 1,586 - 1,749 m | 163 m |
| No.12 | 2.15 km2 | 1,446 - 1,528 m | 82 m |
| No.15～53 | 61.39 km2 | 1,045 - 1160 m | 115 m |

Data of hydraulic model is obtained from TWWC and up-dated through discussion among TWWC and JICA team. Water demand allocation to each node is estimated based on area size of each node to supply water. Level of pressure reducing is estimated considering the elevation difference. Thus, result of the hydraulic analysis is thought as preliminary one. It is necessary to improve the accuracy before implementation.

#### (1) Reservoir Zone No.27

Reservoir zone No.27 is located in an area with a big elevation difference of 163m. Because of such difference, pressure is controlled by pressure reducing valves. By the hydraulic analysis with the above model (original model), it is found that some distribution pipelines would experience insufficient capacity. It is also found that No.27 zone can be divided into five (5) sub-zones without much effort.

Hydraulic analysis is also made with the improved model (basic model) considering the findings by the original model. By the analysis, important distribution trunk mains which should be earthquake resistant, location of valves for sub-zones and location of flow meters for appropriate monitoring and control are identified as shown in *Figure 4.3.4*.

By implementation of the above outcomes, the following merits are expected:

- Improvement of normal/routine flow conditions,
- More improvement of pressure control by establishment of sub-zones,
- More improved replacement of deteriorated pipelines,
- Localization of pipeline damage in earthquake disaster,
- Prioritization of emergency supply and restoration works in earthquake disaster.

**(2) Reservoir Zone No.12**

Reservoir zone No.12 is also controlled by pressure reducing valves. By the original hydraulic analysis, it is found that some distribution pipelines have insufficient capacity. It is also found that zone No.27 can be divided into two (2) sub-zones easily.

Hydraulic analysis with the basic model is executed considering the findings by the original model. By the analysis, important distribution trunk mains which should be earthquake resistant, location of valves for sub-zones and location of flow meters for appropriate monitoring and control are identified as shown in *Figure 4.3.5*.

By implementation of the above outcomes, such improvement in supply conditions as described in the preceding item (1) is also expected in zone No.12.

**(3) Reservoir Zone No.15～53**

Reservoir zone No.15～53 has vast land area of 60km2 located in the southern part of the city. The zone consists of water sources from distribution reservoirs No15、16、36、53 and contact tanks No.65、66、68. Distribution network has approximately 24,000 pipeline elements. Water is transmitted from a transmission/feeder main connecting reservoirs No.15 and No.16 through many distribution trunk mains.

Because of the large size of area and complicated system, it is difficult to control inlet flow rate, to execute leakage investigation and to prioritize replacement of deteriorated pipelines or prioritize restoration works.

Since a twin pipeline is arranged in both sides of the rather wide road, it is easy to form a lot of distribution sub-zones. By installing valves in strategic locations, 25 distribution sub zones can be created, and all of the above weak points are solved by the sub zone creation.

Important pipelines in earthquake disasters are identified and wait for replacement with earthquake resistant pipelines. These are shown in *Figure 4.3.6*.

Since a twin pipeline is arranged in both sides of the rather wide road, it is easy to form a lot of distribution sub-zones. By installing valves in strategic locations, 25 distribution sub zones can be created, and all of the above weak points are solved by the sub zone creation. By the analysis, some sub zones should work together (group of sub zones) to have enough pressure.15 main sub zones are made from these 25 distribution sub zones.

Hydraulic analysis is also made with the improved model (basic model) considering the findings by the original model. Important pipelines in earthquake disasters are identified and wait for replacement with earthquake resistant pipelines. These are shown in *Figure 4.3.6*.

Location of valves for sub-zones and location of flow meters for appropriate monitoring and control are identified as shown in *Figure 4.3.6*.

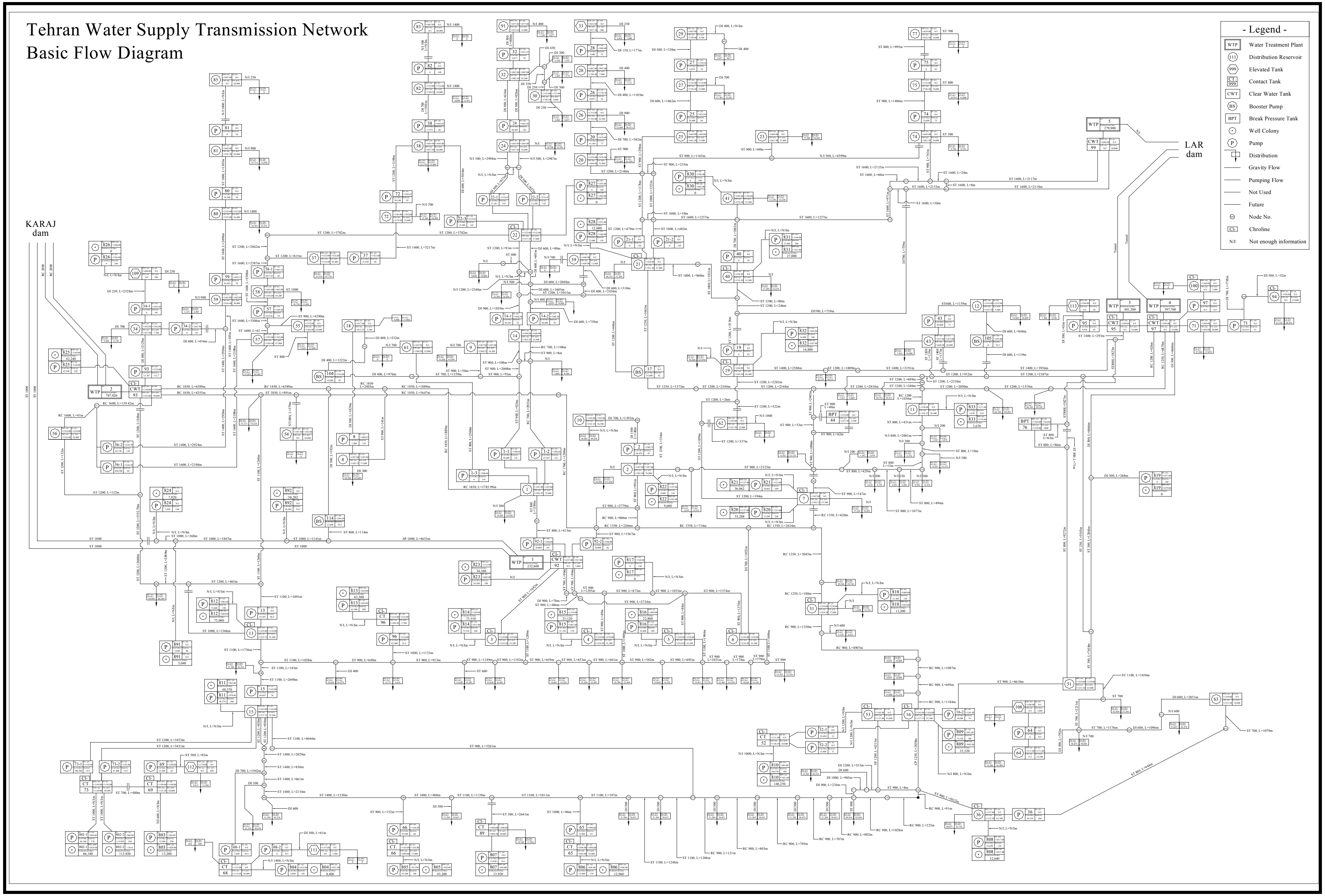



**Figure 4.3.1 Basic Flow Diagram of Transmission System**