Islamic Republic of Iran
Vice Presidency for Strategic Planning and Supervision

Guideline for Seismic Design of Sewage systems

No. 605

Office of Deputy for Strategic Supervision
Department of Technical Affairs

2012

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Chapter 1

General

1-General

This guideline has been developed based on similar documents in the high seismicity countries together with local experiences and experiences from other countries outstanding in the field of earthquake engineering. In line with gaining from other countries' experiences; it has been tried to pay attention to the localization issue and present subjects more simple and practical.

1-1-Objective

- The objective of this guideline is to secure public safety and prevent serious damage to sewage systems due to earthquake.

In this instruction offers methods for seismic design of municipal sewage system.

- Wherever we speak about sewage system in this instruction, we mean a system extending from membership fee of citizens to sewage treatment stations.
- Earthquake risks have damage and threatening nature. Therefore, the object of this instruction is to prepare acceptable safety conditions with respect to logical risk and economical conditions as well as considering the nature of earthquake risk and sewage systems' vulnerability.
- This instruction is about to prevent serious damages and public safety threats especially water pollution and sanitary issues.

1-2-Scope

The scopes of this guideline are installations of swage system including collection, transmission and treatment components

In general, this instruction covers the following components:

- Sewage treatment stations
- Pumping stations
- Culvert pipe
- Rectangular culvert
- Shield channels (tunnels)
- Manholes

The structurs of urban waste water system can be categorized as follows:

- Civil structur including tanks, buried line and foundation:(Table 1-1-A)
- Combinational structures from tanks in building structure(Table 1-1-B)
- Building structures (Table 1-1-B)

Also target components in urban sewage system is categorized in table 2-1.

Table1-1-A- the category of the structures of urban sewage system

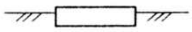
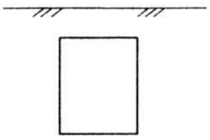
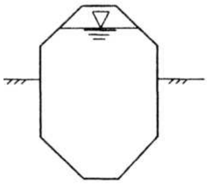
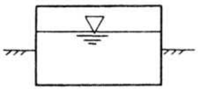
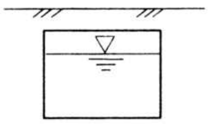
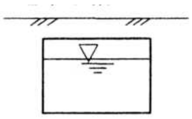
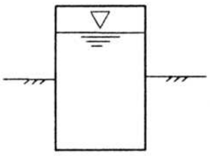
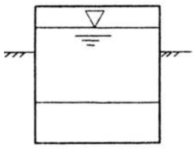
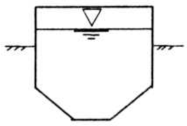
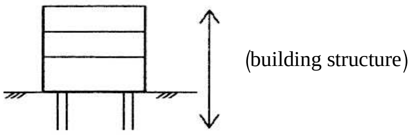
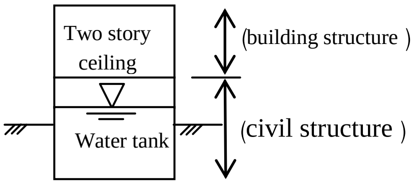
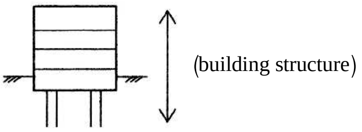
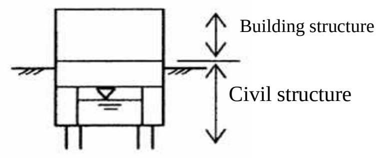
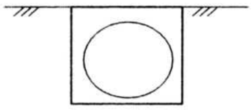
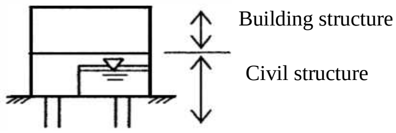
Civil structures			
Type III (plane structures)	Type II (underground linear-structures) Such as underground pipeline	Type I (tank/ source structure) Structures consist of sand basin, settling basin, condensed mud basin, mud absobtion source	
		I-2- Cylindrical water budget	I-1-Rectangular and circular water budget
Mat foundation for machinery 	Underground pipeline 	Mud absorbtion tank 	Rectangular tank 
	Underground water channel 	Underground tank  Surface channel 	Two story sand settling basin  Circular basin 

Table1-1-A- the category of the structures of urban sewage system

Building structure	**Composite building**
Type V (building structure) Office building, sludge disposal building, etc. if a water tank is in underground,certainly it is type IV.	Type IV (composite building) Composite building that are underground part of civil structure such as tank, and super part of building structure such as pumping station with sand tank and water tank with double arches, and so on.
Building without basement 	Water tank with double arches (two layer ceiling) 
Building with basement 	Pumping station with sand tank 
Underground fuel tank 	Surface water tank 

<table>
<tr><th>Target building</th><th>Classification criteria</th><th colspan="3">Structural classification</th></tr>
<tr><td>a.settling tank
b. reactor tank
c. condensed tank
d. storage tank
e. underground tank</td><td>1-Tank with double arch(two layer ceiling) is n't in this category
2- water tank that completely buried is in this category.
3- Tank or channel that is in ground level, is in this category.</td><td>I-1- circular and rectangular water tank</td><td rowspan="2">Type I- (tank/source structure)</td><td rowspan="4">Civil building</td></tr>
<tr><td>a. mud absorbtion tank</td><td>Airproof cylindrical water tank is in this category</td><td>Cylindrical water tank</td></tr>
<tr><td>a. underground pipeline
b. spouted conduit
c. outlet channel</td><td>1-coduit, manhole and inlet gate are n't in this category.
2- Linear conduit and underground pipeline are n't in this category.(above ground outlet sewage conduit is type I)</td><td colspan="2">Type-II-(buried linear structure)</td></tr>
<tr><td>a-Concrete foundation of desulfurization tower
b- concrete foundation and espcial oven for sludge burning</td><td>Concrete foundation plate of machinery is in this category.</td><td colspan="2">Type-III-(plane structure)</td></tr>
<tr><td>J.refinery with double arches
m. condensed mud tank with shelter and so on</td><td>Composite structure that building is located on water tank (civil structure), is in this category.</td><td>I-1- Water tank with double arches</td><td rowspan="2">Type-IV(composite structure)</td><td rowspan="2">Composite building</td></tr>
<tr><td>a. pumping station with shelter
b. combined office building with sand basin
c. sludge building with water tank in underground or in surface</td><td>Building structure that somewhat consiste water tank such as sand basin, is in this category.</td><td>I-2- building containing tank structure in basement or upper story</td></tr>
<tr><td>a. building for management, refinery, Disinfecting, machinery, electrical installation.
b. buried fuel tank</td><td>This category is containing building structures. But which category is containing water tank in basement must be located in IV group.</td><td colspan="2">Type –V-(building structure)</td><td>Building structure</td></tr>
</table>

– Iran 2800 code and Iran's National Building Regulations are used for seismic design of the structures of this system

– Subjects regarding to National Building Regulations, chapter 4, issue 360 and issue 123 can be used for seismic design for foundation of equipment together with results extracted from seismic design of related instrument from this guideline.

1-2-1-How This Instruction Has Been Structured

This instruction with the above mentioned scope has been structured as follows:

Chapter 1: General Features

Chapter 2: Fundamentals

Chapter 3: Seismic loading of sewage system's components

Chapter 4: Seismic design methodology and safety control

Chapter 5: Seismic design and safety control of treatment and pumping stations

Chapter 6: Seismic design and safety control of sewage culvert pipe

Chapter 7: Seismic design and safety control of rectangular culvert

Chapter 8: Seismic design and safety control of sewage system's shield tunnels

Chapter 9: Seismic design and safety control of sewage system’s components and manholes

1-2-2-Comments on How to Use This Instruction

Since this instruction is the first guide book inside country, similar to previous regulations and instructions, it normally has some ambiguities and problems. In order to minimize these problems in this instruction and solve them at the earliest possible time it would be beneficial to consider the following matters:

1-It has been tried to offer an instruction which its contents are not opposed to 2800 standard.

2-In the cases where it seems that there are no sufficient data in this instruction about loading of sewage components, one can use Iranian National Building Regulations-chapter 6.

3-For designing the concrete components of sewage system especially for gathering data about concrete materials specification, topic 9 of National Building Regulations, is applicable.

4- Topic 10 of National Building Regulations is considered as a supplementary for this instruction which is about steel components of installations.

5-Other similar instructions and documents which are prepared by national and international authors as a case instruction for seismic loading of sewage systems can be used provided that they are compatible with this instruction.

6-In order to use this instruction inside country more easily and more applicably we expect all users of this instruction to feedback us their opinions and comments and we will consider them in next versions of this instruction.

1-3-Related Codes and Regulations

1-3-1- Normative References

In preparing this instruction, different standards, regulations, instructions and codes have been used. We can point to some of important ones as follows:

– JWWA 1997: the specifications of seismic design and manufacturing of sewage installations. Japan Sewage Works Association. 1997

– JWWA 1997: the specifications of seismic design and manufacturing of water supply installations. Japan Water Supply Association. 1997

– Iran 2800 Code: Iranian Code of Practice for Seismic Resistant Design of Buildings, Standard No. 2800, Building and Housing Research Center, 2005

– Euro code 8: Design rules for the earthquake-resistant structures, Part 4: silos, storage tanks and pipeline systems, European Committee for Standardization, 2006

– Building Center of Japan (BCJ): manual for structural design and building stacks, 1982 (Stack-82)

– Japan Gas Association: seismic design of high pressure gas pipeline for liquefaction, JGA-207-01, 2001.

– Japan Road Association: Specifications for Highway Bridges, Part V, Seismic Design, 2002

– High Pressure Gas Safety Institute of Japan (KHK): Seismic Design Code for High Pressure Gas Facilities, 2006

– Japan Building Center: instruction for seismic design and manufacturing of building construction equipments, 1997.

1-3-2-Code Abbreviations

Abbreviation	Full Name
ALA2005	Seismic Guidelines for water Pipelines, ALA, 2005
ASCE7	Minimum Design Loads for Buildings and Other Structures, ASCE, 2006
AWWA96	AWWAD100-96
BCJ1997	Specifications of seismic design for building components, Building Center of Japan, 1997
BS EN1998-1	Euro code 8: Design of structures for earthquake resistance. Part 1,General rules, seismic actions and rules for buildings, European Committee for Standardization, 2004
BS EN1998-4	Euro code 8: Design rules for the earthquake-resistant structures, Part 4: silos, storage tanks and pipeline systems, European Committee for Standardization, 2006
JIS B8501	Japanese Industrial Standard, JIS B8501, Welded Steel tanks for oil storage, 2001
JGA1982	Recommended methods for earthquake-resistant design for high and medium pressure gas pipelines, Japan Gas Association, 1982
JGA2001	Recommended methods for earthquake-resistant design for high pressure gas pipelines in the areas with potential of liquefaction, , Japan Gas Association, 2001
JSWA2006	Seismic Design and Construction Guidelines for Sewage Installations, Japan Sewage Works Association, 2006
WSP064	Design Standard for Water Pipe Bridge, WSP 064-2007, Metallic Water Pipe Association
UBC97	Uniform Building Code, USA, 1997

Chapter 2

Fundamentals

2-Principles

Principles regarding earthquake design, design methods (safety control) and anticipated performances are presented summarily in this chapter. The most important of these principles are:

1- Two risk level following Iran 2800 code with attention to two acceleration and velocity spectrum compatible with Iran's condition and in accordance with regulations of Standard No. 2800

2- Consideration of earthquake load in two types including inertia force due to the acceleration effect in mass that exerted in to gravity mass center or centers and the force due to earth displacements and its application through interaction of soil and buried structure to the body in the contact with soil.

3- Using two method for design and safety control including allowable stress in the elastic limit of material behavior for risk level 1 and ductility method in non-elastic of material behavior for risk level 2

4- Using two level of performance as damage limit and ultimate limit which unceasing utilization and minimum cease are secured in the former and latter, respectively. With regard of the behavior of structural components, that remains undamaged in the elastic limit, in the former, but in the latter, passes from the yield boundary but bounds to the certain allowable limit of plastic deformation. This allowable limit after yield-allowable ductility- is determined by this guideline according to experimentations or experiences. They are described summarily in the following.

2-1-Design Earthquake

2-1-1-Risk Levels of Earthquake and their Return period

1-Two risk level mentioned in the following must be considered for seismic design of components of sewage network system.

Risk level 1: Maximum Operational Earthquake (MOE) (occurrence probability 50% during 50 years of assumed useful service).

Risk level 2: Maximum Considerable Earthquake (MCE) (occurrence probability 10% during 50 years of assumed useful service)

2-In Iran, magnitude (magnitude of momentum) and fault distance must be considered on the basis of occurrence probability of MOE and MCE in the facility sites.

1-In this guideline, useful service life of lifelines including desired gas facilities is considered relatively around 50 years. Maximum operational earthquake may be occurred once or twice during the service of gas facilities. Unacceptable failure modes during operation of facilities are confined to risk level 1 and operation of gas system continues reliably. In this risk level, occurrence probability of 50% during 50 years is in accordance with return period of 72 years. In standard no. 2800, overrun probability is considered around 99.5% which gives return period of about 10 years. Maximum earthquake of design is an earthquake with lower occurrence probability and longer return period than to earthquake of MOE. The behavior of gas system components in the risk level 2 is in the ultimate mode and the whole system, even if a member is damaged, must maintain its stability. The occurrence probability of 10% for earthquake with higher magnitude during 50 years is in accordance with return period of 475 years.

With regard of risk management, overrun probability of 10% has versatile and suitable application in the economic term with consideration of requisite safety. For some structures such as bridges which their life are considered up to about 250 years, this overrun probability in risk gives return period of 2475 years that gives overrun probability of about 2% for structures of useful service life of 50years such as buildings and lifelines that is not economic.

2-For estimation of Permanent Ground Deformation (PGD) due to fault displacement (faulting), liquefaction and landslide, earthquake magnitude M and fault distance R are required. M, R and other related seismic parameters are obtained from analytic or experimental relations resulted from designer desired region risk analysis, especially with regard to its seismicity records.

2-1-2-Seismic Design Spectra

1-Response spectra of seismic design for sewage facilities must be computed according to natural period and decay characteristics of structural systems. Also, load due to earthquake must be computed by means of these spectra.
2-Spectrum dynamic analyses for seismic safety control of structural systems must be done by mixing modal spectrum characteristics.
3-One of two following response spectra must be used for designing sewage facilities
A-Acceleration response spectrum for computation of inertia force due to the mass of above ground components
B-Velocity response spectrum for computation of interactional force due to the displacement of soil on the body of buried components.

1- In the application these spectra, following notes must be considered:

1-1-In this guideline, elastic response spectrum is used for decay of 5%

1-2-response spectrum for seismic design is obtained from following methods:

A-Site-specific spectra

Site-specific spectra are computed according to seismic activities, active faults and geomorphologic conditions. Regulations of standard no. 2800 are used for obtaining site-specific spectra. Moreover, velocity spectrum must be extracted for buried structures.

B-Probabilistic or deterministic spectra based on record of strong earthquakes

Probabilistic methods have more engineering applications. Spectra from these methods usually have lower values than to their equivalents from deterministic methods.

Generally in determination of design spectra, earthquake occurrence probabilities are considered on the basis of ground strong movements. Deterministic spectra are often used for conservative design and crisis management.

2- Analyse of dynamic response is a method for seismic safety control of structure, especially structures with complex behavior under earthquake. These analyses are expensive and time-consuming and only used when there is difficulty and uncertainty in application of response spectra.

3-Following points must be considered regarding to spectrum

3-1-acceleration response spectrum is used for above-ground structures. Also, these spectra are convenient for systems with several degrees of freedom with application of modal analysis method. In this guideline, acceleration spectrum available in the valid and current version of standard no. 2800 is used for computations relied on acceleration spectrum.

3-2-Velocity response spectra are used for seismic analysis and design of underground structures such as pipelines, shielded tunnels and underground reservoirs which their action are controlled with seismic behaviors of surrounding soils. Earthquake loading of such structures are done on the basis of displacement response in which, soil deformation in the location of buried structures are computed with usage of velocity response spectrum firstly and then interaction between ground and buried structures is determined by static methods.

3-3-Velocity and acceleration response spectra must be compatible with seismic design of power distribution facilities. In the first version of this guideline, a velocity response is proposed that is nearly compatible with standard no. 2800. For next versions it is required to develop a series of velocity spectrum (as acceleration spectrum in standard no. 2800).

2-1-3-Distribution of Seismic Intensity in Stories

Seismic design intensity of stories is used for sewage system components located on other facilities or in the upper stories. in stories simplified coefficient distribution (Ai) use for distribution of seismic intensity(KH), that is given by equation (2-1). This coefficient multiplied at KH in every stories.

$$A_i = 1 \Big/ \sqrt{\frac{H - x}{H}} \qquad (2\text{-}1)$$

H: Total height of stories

x: the height of stories above the stories of i

2-1-4-Vertical Seismic Intensity of Design

Seismic inputs of vertical direction must be considered for equipment which their behavior is sensitive to the vertical component of earthquake.Vertical seismic intensity of design Kv is given by equation (2-2):

$$K_V = \frac{1}{2} K_H \qquad (2\text{-}2)$$

Which, KH is seismic intensity of the design in horizontal direction.

In this guideline for each of components that is presented the chapter 5 and next chapters, their horizontal and vertical earthquakes are computed, appropriately. In almost all of the cases, vertical earthquake is accounted as half of horizontal earthquake.

2-2- Design Methods

Safety of designed equipment must be controlled via following methods:

1-Allowable stress design method which must be applied on the risk level 1

2-Ductile design method which compare existing ductile ratio of structure with allowable ductile ratio for risk level 2.

Note:

-In the cases which equipment are of very high importance or certain complexity exists in seismic behavior, convenient dynamic methods are used for control of above mentioned methods according to the design engineer.

1-For serviceability limit state, created stress in the structural component compare with allowable stress in elastic range.Generally, allowable stress design method is used in risk level 1 for operation earthquake

2-The basis of the ductile design method is to give more allowance to structure to absorb more energy (after yield point of material) for more strong earthquake with high acceleration (and velocity) so their components can absorb more strains. Computed ductility coefficient is controlled with formulae of this guideline with appropriate allowable ductility coefficient.

3-2-Anticipated functions in this guideline

Two functions are considered in this guideline for sewage system components for given risk levels:

- serviceability function (until before material yield)
- Risk level 1: designed components must not damage sewage system function effectively and their function must be continued unceasingly.
- Minimum serviceability of function (after material yield)
- Risk level 2: designed components may inflict drastic physical damage function but without any effect on lives, environment and sustainability of gas distribution system. Inflicted damage must be removable as soon as possible and faulted function must be rehabilitated.
- A-In risk level 1
- structural members must not be impaired any physical damage that interrupt system usage.
- This level is called “limit state or mode”.
- In this mode, each building member of system must be in the elastic extent of stress-strain relations and not be reached to yield limit.
- B-In risk level 2
- members of structural systems can be physically damaged parochially but systematic and structural sustainability must not be destroyed.
- This level is called “ultimate state or mode”.
- In this mode, non-elastic deformations (after material yield) may be occurred.

Table 2-1 shows required performance of sewage system's lines

<table>
<tr><th colspan="2">Required Performance</th><th colspan="2" rowspan="2">Sewage Line definition</th></tr>
<tr><th>Level of risk 2</th><th>level of risk 1</th></tr>
<tr><td>Supplying the minimum required flow</td><td>Supplying design flow</td><td>- The main line of sewage basin.
- The main line connecting pumping station and treatment station.
- The pipe line intersecting river or railway which requires difficult repairs operations if damaged.
- Connector line of outlet aperture of wide drainage area.
- Pipe line for emergency settlement or for missions to cope with natural disasters which plays sewage role.
- Other main lines with vital role in the performance of sewage system</td><td rowspan="3">Important Lines</td></tr>
<tr><td>Supplying the minimum required flow</td><td>Supplying design flow</td><td rowspan="2">The main line buried under road which plays the main role and has enough safety under the traffic load after earthquake.</td></tr>
<tr><td>Supplying road performance in the cases where the line is buried under road</td><td>Supplying road performance in the cases where the line is buried under road</td></tr>
</table>

-	Supplying design flow	**Other Lines**

As far as the capability of supplying design flow concerns, the channel should not be swelled out and its cross section should be in operational condition. Also, its stress should be less than allowable stress.

Supplying the minimum flow rate implies that supplying design flow is impossible due to cracks or subsidence but flow is not completely cut. In other words, in ultimate condition the channel should not be collapsed and should prevent the penetration of soil and sand even though it has been cracked.

Chapter 3

Seismic Loading of the Components of Sewage Systems

3-1-Load Patterns

The computational loads of the equipments of sewage systems could appear as follows:

- Dead Load i.e. the weight of all materials of construction incorporated into the building
- weight of inner materials of some equipments
- internal pressure (especially in cases, vessels, piping and pipe lines)
- water hydrostatic and hydrodynamic pressures
- soil pressure on buried components
- thermal load
- Earthquake vertical and lateral loads
- wind load

Regarding the type of sewage system component, the following tips should be considered:

- Wind load has no influence on buried structures.
- Unlike buildings, sewage system structures have no live human loads. But temporary loading in different level of building must be considered live load in seismic design.
- Some components like basin, pipe lines, culverts, shield tunnels and other ducts are under the pressure of the materials and products saved inside them.
- Chimneys and pipe lines between equipments are under excessive thermal loads.

3-2-weight calculations

To calculate the materials unit weight and different loads, sixth chapter of national buildings regulations should be used.

3-3-Load Combination

In this guideline, loads and load combinations of all equipments have been described after chapter 5.

The following load combinations should be considered:

1-General purpose applications

- Fixed load, moving load, Snow load (a surface covered with snow), internal water pressure, and soil pressure and so on.

2-Earthquake applications

Level of risk 1: is applied for operational condition and when water and soil pressures are not balance in tow sides of structure for example when we deal with excavation operation only in one side of a structure.

Level of risk 2: is applied for operational condition.

Note: the difference between loading conditions should be considered in all phases of construction process.

For tanks and reservoirs, all load combinations with MOE "Maximum Operational Earthquake" condition should be considered for both full and empty cases.

The complete empty situation should be considered for sanitary sewage and the complete full situation should be considered for rainfalls with MCE "Maximum Credible Earthquake" condition.

3-4-Equipments Type with Respect to Their Location

The location of the elements of sewage systems is generally as follows:

1-On-ground equipments
2-Under ground and buried equipments

3-5-How to Calculate Seismic Loads

Earthquake loads are applied on sewage systems equipments in the following forms:

1-Inertial force; generated due to the weight of equipments which their movement has not been constrained by soil. This force is generally generated and calculated in aerial and on-ground structures.
2-The force generated due to the displacement of bed soil applied on buried structures. In this case, soil displacement is multiplied by the spring constant available between soil and structure and the obtained force is applied on equipments.
3-In some cases we deal with buried structures in which their mass and materials saved inside them can generate inertia force as a result of an earthquake. In this condition both inertial force as well as the force generated due to bed soil displacement should be taken into account in calculations.

3-6-Impacts of Earthquake on Sewage System Installations

The impacts of earthquakes on sewage system installations could be categorized in two classes. Then, we can calculate seismic loads generated due to the contents of each class.

1-The dynamical effect of earthquake which is generated due to earth vibration (propagation of seismic waves in soil) which in turn results in the following three responses:
- acceleration (which generates inertial force for on-ground as well as station structures)
- Velocity (its influence on buried structures especially transfer and collector lines is higher than acceleration)
- Displacement (it causes serious damages to all types of structures especially buried ones)

2-Static impacts or Geotechnical threats; creates permanent displacement in ground including:
- Soil liquefaction (and lateral spreading especially in river and sea shores)
- Land slide (occurs in foothill regions with sharp slopes)
- Faulting (is considered in station structures located on fault hazard zones or their buried lines)

The different methods of applying seismic loads generating due to the above mentioned effects is presented in the guideline of "loading methods and the seismic analysis of vital arteries".

3-7-How to Apply Earthquake Effects on Sewage Systems

1- In order to calculate imposed loads on aerial and on-ground components we should calculate the inertial force, generated due to earthquake acceleration, applying on the mass of equipment. This method uses acceleration spectrum approach as per Standard 2800 Regulations.
2- In order to calculate the inertial force, generated due to acceleration, we use semis static (pseudo-static) approach. In the cases where the period of equipment is long or we deal with complex structures (the first mode of structure vibration is not governing) we use improved semi static (pseudo-static) method.
3- In order to calculate the force, generated due to earth displacement, applying on buried structures, displacement response method is employed. In this method following computing ground displacement in considered points, by determining the spring constant of the soil around structure we calculate the imposed force. In this method, we use an acceleration spectrum compatible with

the indicated values in 2800 standard or the specific velocity spectrum of site.

4- In the displacement response method, we can compute the strain of buried structure out of soil strain through calculating the strain of the soil around structure with respect to adherence rate between the buried structure and soil.

3-8-How to Calculate Earthquake Loads

Generally, we use semi static (pseudo-static) method in order to determine the seismic loads imposed on the aerial and on-ground components of sewage system. Regarding the shape, vibration specifications, importance factor of structure and failure mode of structure we can also use the following methods if necessary:

- improved semi static (pseudo-static) method
- dynamical analysis method (spectral or time history mode)

The semi static (pseudo-static) method is used for obtaining displacement and stress values of a high rigid structure in which earthquake load is considered as an equivalent static load. This equivalent static load is defined as the product of earthquake constant and structure mass.

In the improved semi static (pseudo-static) method, natural period, the damping rate of structure and inertial force of earthquake are considered. In this method, compared with static method, a revised constant is used.

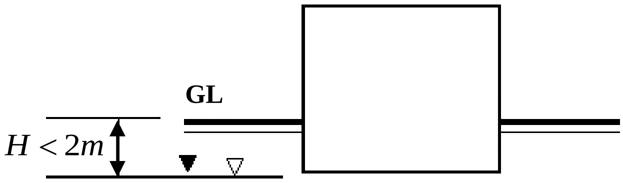
Besides these methods, in order to control the accuracy of the results of these simple static methods and to have an accurate understanding of seismic behaviors of components as well as to make sure of our calculations, we use spectral dynamic analysis with time history records. In these methods, the reliability of results depends on the fact that whether or not the selected constants and input accelerations are appropriate.

1-Ground level for Inertia

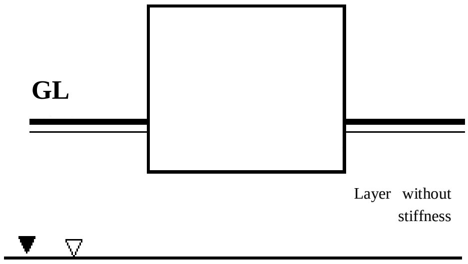
Ground level for inertia is the border between upper structure in which seismic load is considered, and lower structure, in which seismic load is not considered. Since seismic inertial force should be considered for under-ground section of structure, ground level for inertia should be considered below foundation level.

2-Base Level

Engineering base level is a level for which the intensity of MCE of bottom section is considered. In the case that it is not possible to determine this level, we should shift ground level to a lower surface as per Fig. 3-1.



Case 1: it is difficult to determine the design earthquake intensity of the bottom section due to structural problems like low depth of foundation.



Case 2: it is difficult to determine design earthquake intensity of the bottom section due to geological problems like layer's liquefaction capability.

▽ :Engineering base level

▼ :Ground level for inertia force

Fig. 3-1 Example of setting for ground level in seismic design

3-8-1-Importance Factor of Sewage Components

The importance factor of structure in terms of its importance is shown by (β_1) and is derived from table 3-1.

Table 3-1: (β_1) importance factor

low	moderate	high	very high	importance category
0.8	1	1.2	1.4	β_1

After earthquake, the necessity of continuously exploiting of the designed components and their safety levels are the second most important factor which plays significant role in raising the importance factor of that component in sewage systems. Table 3-2 shows the definition of different categories of importance factor and table 3-3 shows importance-based categories of equipments. In the cases where two importance levels are required, the opinion of contractor will determine the final importance level.

Table 3-2: Definition of Different Categories of Importance

Importance	Description
very high	those components whose failure can result in wide financial losses as well as fatalities and causes damages to environment and equipments
high	those components whose failure can result in cutting sewage flow or cause fatalities as well as financial and environment losses
moderate	those components whose failure disrupt sewage system
low	those components whose failure don't affect sewage system considerably and don't cause financial and environmental losses

The following consideration should be noted during determination of the importance factors of municipal sewage system and very high and high importance factors should be assigned to them:

- The installations which are potentially capable to create serious secondary disasters.
- The installations located at the downstream of sewage systems.
- Main installations with no supportive installations.
- The main collector line of important installations sewages.
- The main installations which are hardly repaired if damaged.

Importance factors should finally be revised regarding the region at which the sewage installation are located and in accordance with the values shown in table 3-3:

Table 3-3 importance factor correction regarding the region of installations

Importance factor correction	region
0.9	Mountainous
1.0	Normal
1.5	urban

3-8-2-Design Base Acceleration ratio

Design base acceleration ratio β_2 , is derived from table 3-4 based on the location of structure location.

Table 3-4: Seismic zone factor of design β_2 .

Low (1)	Moderate (2)	High (3)	Very high (4)	Design Base Acceleration Ratioin 2800 standard , seismic zone factor A is considered as a percentage of gravity acceleration
0.20	0.25	0.30	0.35	β_2

3-8-3-Magnification Factor of Soil Layers

The magnitude of earthquake force imposed on structure depends on the magnification factor of soil layers from bedrock up to ground level.

The magnification factor in terms of soil layers is shown by β_3 .

Table 3-5 shows magnification factor of different grounds (different type of soil).

Table 3-5: magnification factor of bed β_3

Soil type / Seismic zone factor	I	II	III	IV
low	1.5	1.5	1.75	2.25
moderate	1.5	1.5	1.75	2.25
intensive	1.5	1.5	1.75	1.75
Very intensive	1.5	1.5	1.75	1.75

In next section we will calculate MCE force through semi static (pseudo-static) method.

3-8-4-Earthquake Coefficient Calculations

3-8-4-1-semi static (pseudo-static) method

Design horizontal seismic coefficient K_{SH} , is derived from the following relation:

$K_{SH} = \beta_4 K_H$ (3-1)

Where:

K_{SH} = design horizontal seismic coefficient. In the case that K_{SH} <0.2, its value is considered 0.2.

K_H = horizontal earthquake intensity coefficient on ground.

$K_H = 0.3 \cdot \beta_0 . \beta_1 \cdot \beta_2 \cdot \beta_3$ (3-2)

β_4 : Is the magnification factor of horizontal response of structure which is 1 for heights <= 16m and for heights >16m it is derived from this relation: $0.0125h + 0.8$

h : is the height of structure which is measured from base level.

β_0 : Earthquake level. It is considered as 0.5 and 1 for risk level 1 and risk level 2, respectively.

3-8-4-2-Horizontal Seismic Force

Design horizontal seismic load (equivalent static force), F_{SH} is derived from relation (3-3) as follows:

$F_{SH} = K_{SH} W_H$ (3-3)

In which

F_{SH} = design horizontal seismic force (N)

K_{SH} = design horizontal seismic coefficient

W_H = weight of structure plus weights of dead and live loads.

3-8-5-Improver Semi Static (Pseudo-Static) Method

In the structures with long natural period, the improved semi static (pseudo-static) method is preferred. Following calculating earthquake coefficient through pseudo-static method, the obtained value should be multiplied by the weight of structure/equipment in order to compute horizontal/vertical seismic force.

3-8-5-1-Improved Horizontal Seismic Coefficient

Improved horizontal seismic coefficient is derived from relation (3-4) as follows;

$$K_{MH} = \beta_5 K_H \qquad (3\text{-}4)$$

In which;

K_{MH} = improved horizontal seismic coefficient. If K_{MH} <0.2 its value is considered 0.2

β_5 = the magnification factor of the horizontal response of structure which has been described in appendix under the title of "seismic loading of vital arteries."

3-8-5-2-Improved Vertical Seismic Coefficient K_{MV}

Improved vertical seismic coefficient K_{MV} is derived from relation (3-5) as follows:

$$K_{MV} = \beta_6 K_V \qquad (3\text{-}5)$$

For equipments with low importance factor it is not necessary to calculate vertical seismic coefficient. The value of β_6 is defined using the different values presented in different chapters as well as phase 2.

3-8-5-3-Improved Earthquake force

Improved earthquake force is calculated by multiplying the improved seismic coefficient and weight of structure as per relations (3-6) and (3-7):

$$F_{MH} = K_{MH} \times W_H \qquad (3\text{-}6)$$

$$F_{MV} = K_{MV} \times W_H \qquad (3\text{-}7)$$

Where;

K_{MH} = improved horizontal seismic coefficient derived from the relation (3-4)

K_{MV} = improved vertical seismic coefficient derived from the relation (3-5)

F_{MH} and F_{MV} , are respectively improved vertical and horizontal seismic force (N)

W_H = weight of structure plus weights of dead and live loads.

3-8-6-Dynamical Method

Dynamical method is usually employed in order to control the results of semi static (pseudo-static) method or for analyzing more important and sophisticated structures. In this method the mathematical model of equipment is analyzed under spectral or time history loading and using dynamic balance equations.

3-8-6-1-Spectral Method

1- For each $A_H(T)$ mode, horizontal response acceleration is derived from relation (3-8) as follows:

$$A_H(T) = \beta_5 \cdot \alpha_H \qquad (3\text{-}8)$$

Where;

$A_H(T)$ = horizontal response acceleration in natural period of T (cm/s^2)

β_5 = magnification factor of horizontal response (for simplification purpose and carefully it is considered 1.5 and 0.75 respectively for work periods less than 0.3 second and more than 0.3 second.)

α_H = horizontal acceleration on ground (cm/s^2) which is derived from relation (3-9):

$$\alpha_H = 350 \cdot \beta_1 \cdot \beta_2 \cdot \beta_3 \qquad (3\text{-}9)$$

2-For each $A_V(T)$ mode, vertical response acceleration is derived from relation (3-10) as follows:

$$A_V(T) = \beta_6 \cdot \alpha_V \qquad (3\text{-}10)$$

Where;

$A_V(T)$ = vertical response acceleration in the natural period of T, (cm/s^2)

β_6 = the magnification factor of vertical response (for towers with base skirt it is 1.5 and for other structures it is 2.)

α_V = vertical acceleration (cm/s^2) on ground level which is derived from relation (3-11):

$$\alpha_V = 175 \cdot \beta_1 \cdot \beta_2 \cdot \beta_3 \qquad (3\text{-}11)$$

3-8-6-2-Method of Time History Response Analysis

For Time History Response Analysis purposes, appropriate waves should be selected in which regarding the location of structure, the maximum horizontal acceleration is obtained through one of the following methods:

1-If inlet waves are used on bedrock we have:

$$\alpha_{HT} = 350 \cdot \beta_1 \cdot \beta_2 \qquad (3\text{-}12)$$

In which α_{HT} is the maximum horizontal acceleration on bedrock.

2-If inlet waves are used on ground surface we have:

$$\alpha'_H = \alpha_H = 350 \cdot \beta_1 \cdot \beta_2 \cdot \beta_3 \qquad (3\text{-}13)$$

Where;

α_H = the maximum horizontal acceleration on ground surface in spectral analysis (cm/s^2).

α'_H = the maximum horizontal acceleration on ground surface in time history analysis (cm/s^2).

3-6-8-3-Response of Displacement Method (for buried structures)

This method is based on the theory of "beam on elastic bed". In this method considering the first mode of soil shear vibration as well as using earthquake response spectrum the magnitude of displacement (drift) is calculated and regarding soil elasticity, the obtained value is converted to the effective force imposed on structure. In next chapters, we will describe seismic loading of each facility through applying the mentioned methods.

3-9-Earthquake Geotechnical Loading

In addition to ground movement during earthquakes, equipments should withstand against loads generating due to earthquakes geotechnical threats. The most important threats in this category are soil liquefaction (and its lateral dispersion), land sliding and fault.

3-9-1-Liquefaction

Although Iran is not potentially subjected to liquefaction, in river and sea shores however, as well as in the regions with small size gravels and higher level of ground waters this phenomenon threatens different installations including buried ones.

Seismic design with the purpose of reinforcing structures against liquefaction phenomenon should be implemented via investigation of seismic performance against ground permanent displacements (drifts) due to soil liquefaction and considering ground properties especially:

- The grounds which require seismic design against soil liquefaction should be identified and selected based on geographic, geomorphologic and ground properties as well as studying the properties of the location in which installations will be assembled.
- Among grounds with the above mentioned properties a ground should be selected for studying soil liquefaction phenomenon based on its properties, conditions, location of installing sewage equipments and the manner by which sewage installations are produces.
- Grounds of regions with surface slope of 1% and more should be studied from lateral dispersion effects point of view.
- Lateral dispersion effects should be assessed for regions which are located 100 m far from seawall with 5m and more height.
- Leakage effect should be assessed for regions in which sewage installations are constrained by a larger structure like bridge columns.
- In the cases where sewage installations like pipe lines have been installed on these structures, investigating leakage effect is not necessary.

The permanent displacement of ground due to liquefaction is considered as the following forms:

- Horizontal displacement due to lateral dispersion effect on slopped surface.
- Horizontal displacement due to lateral dispersion behind seawall.
- Ground subsidence.

Vertical/Horizontal liquefaction effect is calculated in accordance with loading methods and seismic analysis of vital arteries and is applied on buried structures in accordance with the assigned distribution.

In the cases where the generated strain of ground in the risk level 2 is about0. 25% (which is less than 0.30% allowable strain) the displacement response of ground is not taken into account in calculations.

According to road construction regulations, if we deal with accumulated soil, embankment dose not subject to liquefaction effect. Therefore floating may not be considered. Whether or not liquefaction phenomenon occurs, slope and embankment slide is inevitable. In the cases where sewage installations are constructed at these locations, designing phase should be carried out more carefully.

2-9-3-Land Slide

In mountainous lands where we deal with lands with sharp slopes and loose beneath soil layers, land slide is potentially possible which can cause damages to different water equipments.

In order to protect equipments against land slide threat, generating due to permanent ground displacement ,the following steps should be taken:

- It should be studied that whether or not the considered ground is potentially subjected to land slide
- The potential of occurrence land slide as well as slope shape change should be studied.
- The possibility of occurring land slide and slope shape change should be studied.
- The potential risks due to land slide and slope shape change should be studied.

3-9-3-Fault

It is inevitable for us to cross through regions which are potentially subjected to fault threat. Thus, the effects of active faults movement, on which our equipments are installed on the installed structures, should be considered.

- The existence of active fault should be determined by studying geological specifications of fault shape.
- Through geological inspections, geophysical discoveries, discovery boring as well as studying trenches it should be confirmed that whether or not a region lies inside active faults.
- In the cases where sewage installations intersect an active fault, in design phase, permanent ground displacement due to fault movement should be considered in order to achieve structures seismic efficiency.
- In the cases where fault movement is apparent on the surface of ground, sewage installations should be seismic designed in order to withstand fault movements.

The method of calculating and applying the loads imposed by geotechnical risks due to earthquake has been presented in loading methods and seismic analysis of vital arteries instruction.

3-10-Soil Type (Soil Category)

For simplification purposes, in this standard we use the soil types indicated in 2800 standard.

3-11-Considerations for Loading Method and Seismic Loads Calculations

Effective measures on the seismic response of structures could be categorized as follows:

- land specifications
- the mass, damping rate and stiffness of structure
- inlet seismic specifications

An appropriate method should be selected with respect to the above mentioned specifications.

Table 6-3 shows an appropriate method for each facility.

Table 6-3 loading methods and seismic calculations of sewage system components

<table>
<tr><th colspan="3">structure</th><th>Loading Method/Seismic Calculations</th></tr>
<tr><td colspan="3">Conduits</td><td>DAM و RDM</td></tr>
<tr><td rowspan="8">Water treatment station and pumping station</td><td colspan="2">Water reservoir structure</td><td>SCM</td></tr>
<tr><td colspan="2">Linear underground structure</td><td>RDM</td></tr>
<tr><td colspan="2">Plate structure</td><td>SCM</td></tr>
<tr><td rowspan="4">Sophisticated or complex structure</td><td rowspan="2">Water reservoir with double roofing</td><td>SCM</td></tr>
<tr><td>Building structure in accordance with standard 2800</td></tr>
<tr><td rowspan="2">Building structure with small pool or tank</td><td>SCM</td></tr>
<tr><td>Building structure in accordance with standard 2800</td></tr>
<tr><td colspan="2">Building structure</td><td>Building structure in accordance with standard 2800</td></tr>
</table>

SCM: Semi static Method; RDM: Response of Drift Method; DAM: Dynamic Analysis Method

Chapter 4

Seismic Design and Safety Control Methods

4-1 Seismic Design and Safety Control Methods

4-1-1 Target Elements

The most important elements of a municipal sewage system are:

- Pipes
- Culverts
- Small pools (Basins)
- Tanks/Reservoirs
- Treatment Station
- Pumping station

The structures of municipal sewage system could be divided into the following classes:

- civil structures including reservoirs, buried lines and foundations (see table 4-1-a)
- a combination of reservoir and building structures (see table 4-1-b)
- building structures (see table 4-1-b)

Table 4-2 classifies target elements of a municipal sewage system.

Table 4-1-a) Classification of Municipal Sewage System Elements

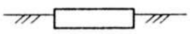
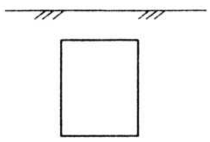
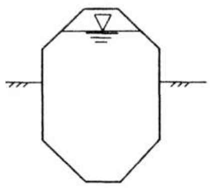
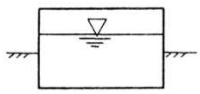
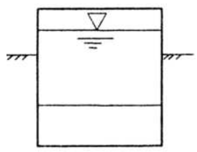
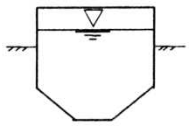
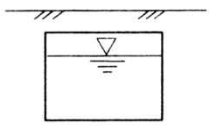
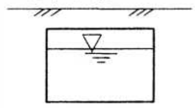
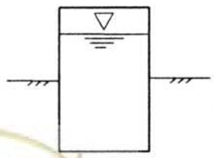
<table>
<tr><th colspan="4">CIVIL STRUCTURE</th></tr>
<tr><td rowspan="2">Type III: plate shaped structure</td><td rowspan="2">Type II buried linear structure
Like underground pipe line</td><td colspan="2">Type I : reservoir/tank
it contains wastewater or sludge like sand basin, sedimentation basin, sludge concentrating basin, sludge absorber tank and so on</td></tr>
<tr><td>I-2 cylindrical water tank</td><td>I-1 : rectangular and circular water tank</td></tr>
<tr><td rowspan="2">plate foundation for machineries
</td><td>underground pipeline
</td><td>sludge absorber tank
</td><td rowspan="2">rectangular tank

a two story sand trap tank

circular pool
</td></tr>
<tr><td>underground water channel
</td><td>underground tank

surface channel
</td></tr>
</table>

Table 4-1-b) Categories of Municipal Sewage System Elements

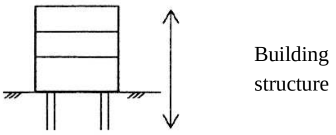
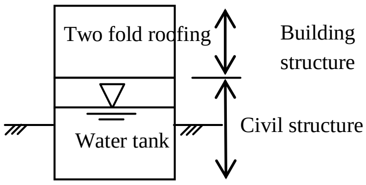
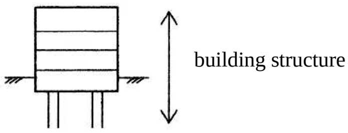
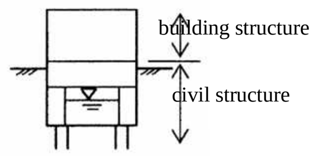
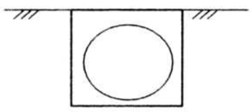
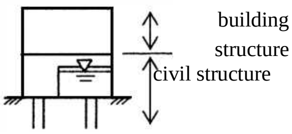
Building structure	Composite structure
Type v: building structure office building, sludge disposal building and so on in the case that a water tank is located at underground it would be a type V tank	Type IV: Composite structure it consists of a civil structure like tank at underground section and a building structure at surface like pumping station plus sand tank and water tank with double roofing and so on
building without basement 	waer tank with double roofing (two fold roofing) 
building with basement 	pumping station with sand tank 
underground fuel tank 	surface water tank 

Table 4-2 target elements classes in municipal sewage systems

Target Structure	Classification Indexes	Structure Class		
a. sedimentation pool b. reactor tank c. concentrator tank d. reservoir tank e. underground tank	1. a tank with a double roofing (two-fold roofing) is not place in this class 2. fully buried water tank is place in this class 3.	.\-I circular/rectangular water tank	type I tank/reservoir structure	civil Structure
f. sludge absorber tank	cylindrical water tank insulated against wind and water is places in this class	cylindrical water tank		
g. underground pipe line h. bridge aqueduct i. outlet channel	1. duct, manhole and inlet aperture are not place in this class 2. linear ducts and underground piping are placed in this class (the outlet of sewage duct which is located upper than ground surface is type I)	type II: buried linear structure		
j. concrete foundation and desulfurization tower	concrete plate (foundations) of machineries is placed in this class	type III: plate shaped structure		

k. concrete foundation and sludge burning tower				
l. treatment station with double roofing m. sludge concentrator tank with shelter and so on	a composite structure which locates on a water tank (civil structure) is placed in this class	water tank .۱–I with double roofing	IV– type composite structure	Comp osite Structure
n. pumping station with shelter o. office building combined with sand pool p. sludge building with underground or surface water tank	a building structure which includes to some extent a water tank structure like grave basin is place in this class	a building .۲–I with a tank structure locate at underground or top story	IV– type composite structure	Comp osite Structure
q. management, treatment station, disinfectant, machinery and power installations building r. buried fuel tank	this class is for building structures however, those structures which include underground water tanks should be placed in IV class	type V:building structure	type V:building structure	Building Structure

4-1-2 Trend of Seismic Design

4-1-2-1 Principles of Seismic Design Steps

The elements of a municipal sewage system are designed through one of the *allowable stress* and *ductile design* methods depending on the level of risk.

If we deal with the level of risk 1, the allowable stress method is applicable.

If we deal with the level of risk 2, the ductile design method is applicable.

(1) In the allowable stress method the sum of the stresses of elements should not exceed the allowable stress otherwise following an earthquake the elements will experience irreversible deformations.

(2)In the ductile design method plastic deformation of elements should be lower than allowable plastic deformation. If this condition is met the performance of elements would remain intact during and after an earthquake.

4-1-2-2 Design Stress Calculations

The calculated stress for a given structure is considered as sum of stresses generating due to internal forces, the weight of structure itself, elements and load of system in normal operational condition plus earthquake stress in the most critical condition.

4-1-2-3 Allowable Stresses

Allowable stresses for seismic design of installations are extracted from Iranian National Building Regulations. In the cases where this regulation offers no data for allowable stress one can use related valid codes with respect to the conditions.

4-1-2-4 Evaluation of Calculated Stress

If the sum of calculated stresses is lower than allowable stress this implies that estimated seismic performance is acceptable.

4-1-2-5 Designing Steps in Ductile Design Method

For seismic design of sewage system's components through ductile design method, one should follow procedures offered for each facility.

4-1-2-5-1 Design Earthquake Level

Ductile design method is employed for the cases in which risk level 2 is applicable.
Seismic designed structures should show a performance which is appropriate for design base earthquake force, liquefaction and ground displacement conditions.

4-1-2-5-2 Seismic Response Analysis

The deformation of elasto-plastic response is calculated through analyzing the response of structure to earthquake.

Similar to the response analysis method in which nonlinear behavior is considered as an elasto-plastic deformation, improved semi static (pseudo-static) method with nonlinear concentrated mass, modal analysis with equivalent linear member and time history analysis with elasto-plastic member are also applicable.

Among these analyses, we select an appropriate response analysis method with respect to nonlinear dynamic specifications of structure.

In order to apply seismic design on structures using response analysis method, as noted below, ductility factor is calculated:

1- energy method
2- equivalent linear response method
3- nonlinear response analysis method
The mentioned methods are described below.

1-energy Method

1-1-Ultimate plastic deformation design method

In the seismic designed structures, in which the first vibration mode is governing, ductility factor can be calculated by applying the low of conservation of energy for each failure mode.

a) Improved Design Base Earthquake Coefficient

Improved design base earthquake coefficient is derived from the magnification coefficient of normalized response.

b) Ductility Factor

Ductility factor, μ_P, of the damaged parts of a structure is derived from relation (4-1):

$$\mu_p = \frac{1}{4C}\left\{\left(\frac{K_{MH}}{K_y}\right)^2 - 1\right\} \qquad (4\text{-}1)$$

where ;

μ_p : is the ductility factor of the member related to the considered failure mode. If $K_{MH} \geq K_y$ then $\mu_p = 0$

K_{MH} : is structure's improved horizontal design base earthquake coefficient

K_y : is member's horizontal yield seismic coefficient at the start point of the yielding of failure mode. In such cases, the vertical seismic coefficient shall be applied to the worse condition.

C: is a constant which is defined with respect to failure mode.

C)Evaluation of Plastic Deformation

Relation (4-2) should be met:

$$\mu_p \leq \mu_{pa} \quad (4\text{-}2)$$

In which;

μ_p : is ductility factor of the member related to the considered failure mode

μ_{pa} : is allowable ductility factor

1-2-Yield Strength Design Method

For frame shaped (framed) and foundation structures, plastic seismic design is implemented through yield strength method.

a) Improved design base earthquake coefficient: is similar to the method of 1-1-a

b) Structural characteristic factor

Structural characteristic factor, D_S, is derived from relation (4-3) or proposed values in other regulations. The value of D_S should be ranged from 0.25 to 0.5.

$$D_s = \frac{1}{\sqrt{1+4C\mu_{pa}}} \quad (4\text{-}3)$$

in which;

D_S : is structural characteristic factor

C: is a constant depending on failure mode specifications

μ_{pa} : is allowable ductility factor of member with respect to failure mode

c) Seismic Capacity

Seismic capacity is calculated via relation (4-4)

$$Q_u = K_y \times W_H \quad (4\text{-}4)$$

Where;

Q_u : Seismic capacity

K_y : yield horizontal seismic coefficient at the start point of the yielding of the damaged member. In such cases, vertical seismic coefficient should be applied for the worse condition.

W_H : The operational weight of structure

d) Required Seismic Capacity

Required seismic capacity is calculated through relation (4-5):

$$Q_{un} = D_s \times K_{MH} \times W_H$$

In which;

Q_{un} : required seismic capacity

W_H : The operational weight of structure

e) Evaluation of Required Seismic Capacity

Required seismic capacity, Q_{un}, should not exceed the seismic capacity of Q_u.

2-Evaluation of Linear Response Analysis

For a member with nonlinear behavior which its capacity exceeds yield capacity, linear response analysis could be conducted through lowering stiffness below elastic stiffness, depending on nonlinearity rate and equivalent damping rate.

2-1 Linear Modal Response Analysis

Linear modal response analysis is conducted using acceleration response analysis in accordance with processes a to f as follows:

a) horizontal and vertical design acceleration spectrum is calculated through the following equations:

$$A_H^{(i)} = 350\beta_1\beta_2\beta_5 \qquad (4\text{-}6)$$

$$A_V^{(i)} = 175\beta_1\beta_2\beta_6 \qquad (4\text{-}7)$$

Where;

$A_H^{(i)}$, is design horizontal acceleration response of the first vibration mode

$A_V^{(i)}$, is design vertical acceleration response of the first vibration mode

β_1, is importance category factor

β_2, is design base acceleration ratio

β_3, is site amplification factor

β_5, is horizontal response magnification factor

β_6, is vertical response magnification factor

b) The stiffness of a member which is being seismic designed is reduced by a nonlinear order.

c) We can use a damping rate equivalent to plastic strain energy which is obtained through the nonlinear response of structure.

d) The magnitude of the response of R like shear force, momentum, acceleration and design displacement is calculated using an appropriate combined method for each vibration mode.

$$R = \sqrt{\sum_i R_i^{\,2}} \qquad (4\text{-}8)$$

In which:

R_i is the response of the i[th] mode.

e) Response displacement should be calculated through member's response value.

f) The ductility factor obtained from step e should not exceed allowable ductility factor.

2-2- Response Analysis by Applying Equivalent Load Method

Response analysis by applying equivalent load method is conducted in accordance with the processes of a to e as follows:

a) Analyzing equivalent load is selected by an appropriate method. If we can model the considered structure as a system with one freedom degree, the equivalent load is obtained through multiplying the weight of member and the improved design earthquake coefficient.

b) The stiffness of a member which is being seismic designed is reduced by a nonlinear order.

c) We can use a damping rate equivalent to plastic strain which is obtained through the nonlinear response of structure.

d) Response displacement should be calculated through member's response value.

e) The ductility factor obtained from step d should not exceed allowable ductility factor.

2-3 Equivalent Displacement Method

This method is conducted in accordance with processes a to d as follows:

a) The forced displacement in constraint (support) should be equal to the displacement of the response of supportive structure or the displacement of foundation due to ground movement.

b) The stiffness of a member which is being seismic designed is reduced by a nonlinear order.

c) Ductility factor is obtained through the displacement of member.

d) The ductility factor obtained from step c should not exceed allowable ductility factor.

3-Nonlinear Response Analysis

3-1 Time History Response Analysis

Time history response analysis is conducted in accordance with processes a to d as follows:

a) The specification of load-deformation behavior should be defined as a nonlinear cyclic model and results should be obtained directly from outcomes of time history analysis.

b) Earthquake wave should be applied with the maximum determined acceleration at occurrence point.

c) Ductility factor is obtained through the displacement of member.

d) The ductility factor obtained from step c should not exceed allowable ductility.

3-2 Static Response Analysis Using Equivalent Load Method

Static nonlinear analysis using equivalent load method is conducted in accordance with processes a to e as follows:

a) The equivalent load is selected by an appropriate method. If we can model the considered structure as a system with one freedom degree, the equivalent load is calculated by multiplying member's weight and improved design earthquake coefficient.

b) The improved design earthquake coefficient could be obtained using damping coefficient which is equivalent to plastic strain energy obtained from nonlinear response of structure.

c) The displacement of member is obtained through static analysis of model with nonlinear relation between load-displacement.

d) Plastic displacement ratio is obtained through member's displacement.

e) The ductility factor obtained from step d should not exceed allowable ductility factor.

3-3 Response Displacement Method

Response displacement method is conducted in accordance with processes a to d as follows:

a)The forced displacement in constraint (support) should be equal to the displacement of the response of supportive structure or the displacement of foundation due to ground movement.

b)The displacement of member is obtained through static analysis of model with nonlinear relation between load-displacement.

c) Ductility factor is obtained from member's displacement.

d) The ductility factor obtained from step c should not exceed allowable ductility factor.

4-1-2-5-3 Ductility Factor

Ductility factor is obtained through plastic deformation which in turn calculated through response analysis of the earthquake failure mode of equipments (both horizontal and vertical movements). Vertical force is considered for a part of failure in which damage development is more probable due to structural conditions as well as the failure mode of different installations.

4-1-2-5-4 Allowable Ductility Factor

The allowable ductility factor of a member is defined with respect to the specifications of plastic deformation like fatigue, buckling as well as elasto-plastic distortion within short term loading in the worse condition corresponding to equipment's earthquake failure mode.

4-1-2-5-5 Evaluation of Ductility Factor

If the sum of allowable ductility factors of all main members is equal or more than considered ductility factor, seismic performance of structure is evaluated as acceptable.

The failure mode and allowable ductility factor of each facility have been determined.

4-2 Trend of Conduit Design

Seismic design of conduits should be implemented in accordance with the following steps considering their importance.

1-The main transferring line

1-1-site evaluation

1-2-ground preparation

1-3 1-3-inspection of joints between conduits and manholes as well as joints between conduits

1-4 1-4-inspection of manhole and conduit body

1-5 1-5-liquefaction evaluation

2- 2-Other lines

2-1 2-1-site evaluation

2-2 2-2-ground preparation

2-3-inspection of joints between conduits and manholes as well as joints between conduits

2-4-inspection of manhole and conduit body

2-5-liquefaction evaluation (to make judgments about probable events and to prepare preventive measures against uplift phenomenon and so on)

a) In addition to the features of target installations, site conditions like seismicity, geological properties, soil type, the ups and downs of land and other factors should be evaluated.

b) In the risk level 1, design sewage flow should be established. In the risk level 2, the minimum sewage flow should be established.

c)For MOE condition, (maximum operational earthquake), designing step should be implemented through allowable stress method or in operational condition.

d) In the risk level 2, designing step should be implemented at ultimate condition.

e) In liquefaction grounds, uplift danger threatens conduit installations. Therefore, proper preventive measures should be prepared against this danger.

Seismic design of other lines should be implemented in the risk level 1 and considering cost and productivity issues.

1- The capability of design sewage flow in the risk level 1 should be met.
2- In the risk level 1, the design phase should be implemented through the allowable stress method.
3- In the risk level 1 in liquefaction area regarding the impacts of uplift phenomenon on installations and conduits, appropriate preventive measures should be prepared like soil congestion, making gravel embankment, improving land with sand and other actions,.

4-3 Trend of Designing Treatment and Pumping Stations

Seismic design of treatment and pumping stations should be implemented with respect to the effects of seismic waves and ground movements. In general, seismic design of treatment and pumping stations should be conducted in accordance with the following steps regarding the shape, size and performance of installations as well as site condition:

1- Evaluation and Data Gathering
2- Determining Conditions
3- stability Control
4- Sections ‘ Strength Control
5- Controlling Structural Details

Each procedure consists of the following contents:

1- Evaluation and data gathering
- Evaluation of the area in which the considered structure will be installed
- Evaluation of natural, social and environmental elements

2- Determining conditions
- analyzing the gathered data
- determining the elements which should be considered for seismic design purposes
- selecting design criteria based on initial and supplementary evaluations
- estimating seismic loading and predicting structure behavior during earthquake

3- Stability control
- controlling the stability of ground
- controlling the stability of the main body and foundation
- considering required preventive measures and subsequent changes of condition

4- Load Combination
- The most critical load combination should be applied in order to control the stresses of the considered members.

5- Structural Details Control

In design phase we should avoid from creation of weak structural points as much as possible. In the cases where it is impossible to do so, the structure should be designed such that movement or any other similar actions does not affect the performance of structure.

Use of joints especially in tanks should be avoided.

a) Considerations for foundation bed

In order to avoid stress concentration and subsequence damages of foundation and support, foundation beneath layer should be leveled.

b) Joints between structures
- both ends of structural joints should have the same shape
- it is recommended to use flexible joints

c) Expansion joint

- In the inlet aperture of pipe gallery like culvert or water tank, joints should not be employed as much as possible. If it is impossible to do so, a waterproof joint with high allowable tensile strength should be used.
- In structures with rectangular cross sections, expansion joint should not be used longitudinally.
- In a buried linear structure expansion length should be calculated through response displacement method.
- In the inlet aperture of pipes, axial joints should not be employed. If it is impossible to do so, flexible joint should be installed in tank's branch or joint section.
- The place of installing expansion joint should be selected with respect to the location of machineries and electric power installations.
- For the pipes crossing through expansion joint, flexible and expandable joints should be used.

d) Reinforcing bar

- In order to prevent appearance of wide cracks in openings, these openings should be reinforced by additional bars with small diameter.
- Around openings should be reinforced by armatures.
- In corners or joint sections, suitable supports like tensile diametrical bar should be installed.

c) Foundation of machineries and electrical installations

- Designers should describe how to fix machineries and explain the foundation type of machineries.
- Seismic loads should be taken into account via appropriate manners.
- Normal concrete (unreinforced concrete) should not be used.

d) Other considerations

- Facilities should be installed for emergency stops
- It is preferred to establish security using alternative systems.
- It is recommended to use vibration damper hanged screw and nut for ventilation channels or odor suction ducts. Also, it is recommended to install flexible materials in corners and to join corners to the body of structure.
- Preventative measures should be prepared in order to protect the threat of filling channels and electrical equipments with water.

4-4 Materials

Concrete and steel materials should be in accordance with Iranian National Building regulations, chapters 9 and 10 or other valid codes like ACI, AISC, ASTM and other specifications indicated in the initial design and in this instruction.

4-5 Allowable Values

1- Allowable response of components should be in accordance with this instruction or the allowable values indicated by manufacturers of parts or indicated in related codes. Below, we offer the minimum required compressive strength of concrete in different conditions:

- In water basins: $f_c \geq 28.1 \ \ N/mm^2$

- In prefabricated concrete pipe supports : $f_c \geq 25 \ \ N/mm^2$

- In structures, foundations, pavements, basins and other concrete structures: $f_c \geq 21.1 \ \ N/mm^2$

- In ducts and fireproof concrete: $f_c \geq 18 \ \ N/mm^2$

- In light concrete: $f_c \geq 18 \ \ N/mm^2$

- In anti sulfate cements, the minimum rate of cement should not be below $310 kg/m^3$ and in normal cement it should not be below $350 kg/m^3$.

2- When we apply load combinations, the allowable stress could be increased.
Table 4-3 shows the increase rate of the allowable stress:

Table 4-3 increase rate of allowable stress in different load combinations

Load Combinations	**Increase rate (%)**
fixed load+ overcharge+ temperature change+ concrete contraction	15
fixed load + overcharge + wind load	25
fixed load + overcharge + earthquake load (MOE)	**50**
fixed load + overcharge + temperature change + concrete contraction + earthquake load (MOE)	**65**
fixed load + overcharge + wind load + temperature change	35
fixed load + overcharge + specific load	**65**

Chapter 5

Seismic Design and Safety Control of Treatment and Pumping Stations

5-1-Base Idea of Design

The buildings of pumping and treatment stations should be seismic designed in accordance with this instruction as well as the latest issue of 2800 standard.
The role and place as well as the importance of pumping and treatment stations compared with different components of the related systems should be taken into account in design step
In seismic loading, the importance factor of these installations are determined with respect to the role they play in system as well as probable crisis which could be arose due to their malfunction and failure.

- The building structures of treatment and pumping stations should be classified into "very high and high importance" categories.
- Buildings with emergency repair and dangerous chemical materials save applications should be classified in "very high importance" category.
- Simple structures like garage, storage and stair which are separated form the main body should be classified in "moderate and low importance" category.

5-2-Load Combinations Employing in Design Process

Error! No table of figures entries found. Technical specifications of materials incorporated in designing these installations should be in accordance with Iranian National Building Regulations and other related literatures.
The most applicable materials are concrete and steel which their specifications could be extracted from Iranian National Building Regulations Chapters 9 and 10.
Use of related foreign standards and codes which have been referred in this instruction is permissible. (The agreement of employer is necessary.)

The strength and allowable stress are defined with respect to load combination.
Table 5-1 shows load combination and stress type.
In design process the most critical load combination should be considered.

Table 5-1 load combinations and resulted stress type

Allowable stress type	Load Combination			
	Snowy Regions	Normal Regions	Condition	Force Type
Normal allowable stress	Fixed load + live load	Fixed load + live load	Normal	Long term force
	Fixed load + live load + 0.7 of Snow load		Snow	
150% of normal allowable stress	Fixed load + live load + Snow load	Fixed load + live load + Snow load	Snow	Short term force
	Fixed load + live load + Wind load	Fixed load + live load + Wind load	Storm	
	Fixed load + live load + Wind load + 0.35 of Snow load			
	Fixed load + live load + Seismic load+0.35 of Snow load	Fixed load + live load + Seismic load	Earthquake	

5-3- Local seismic coefficient method for water tank in architectural structure

Design specified seismic coefficient of water tank within architectural structure by local seismic coefficient method is shown in Table V-4-1-5-4.

Table 5-2 seismic coefficient employed in designing water tanks within building structure

Tank place	Seismic safety classification			
	Specific building		General building	
	Important tanks	Normal tanks	Important tanks	Normal tanks
Upper stories and roof	**2.0**	**1.5**	**1.5**	**1.0**
Intermediate stories	**1.5**	**1.0**	**1.0**	**0.6**
Base story and basement	**1.5**	**1.0**	**1.0**	**0.6**

5-4-Composite Structures

Composite structures consist of civil structure and building structure.
The composite structures of treatment and pumping stations should meet civil structure requirements as well as the requirements of 2800 standard for building structures.

The buildings of treatment station and pumping station should considered as one of the following cases in terms of its related tanks:

1-Tank structure with double roofing

1-1-Building structure is placed on the civil structure of tank/reservoir

1-2-Reservoir structure/ tank with two folded roofing

2-Building and Inside Tanks

2-1 Facilities which include tank structure like sand basin should place on ground or at basement.

2-2 Building with tank structure (in the case that the tank is small it could be classified into building category)

5-5-Electric Power, Machineries, Pump and Piping Facilities

5-5-1-Definition of Facilities

The performance of electric power, machineries, pump and piping facilities should be compatible with the structure of the sewage system they have connected to.

Fig. 5-1 shows facilities classes

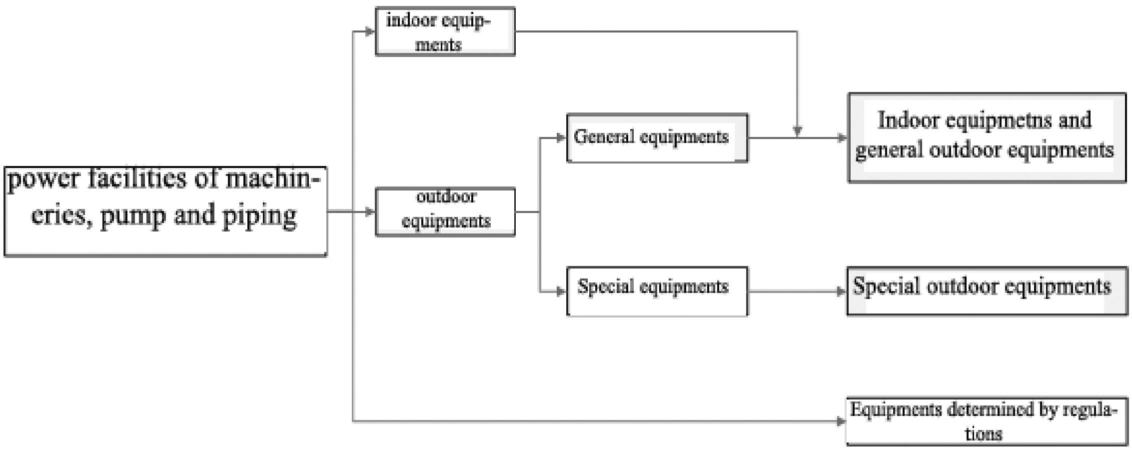


Fig. 5-1 Facilities Classification

- For indoor equipments as well as general outdoor equipments semis static method is applicable.
- For special outdoor equipments with the risk level 2, ductility design should be employed and designing steps should be compatible with civil structure, building structure and composite structure.
- As a default, in seismic design it has been assumed that civil structure and composite structure meet required conditions.
- Unless the vibration which is generated due to wave propagation, liquefaction and turbulence of inside liquid should be considered in design phase.

5-5-2-Bracing of Facilities

5-5-2-1-Braces and Supports of machineries

1- Equipments should be anchored to structure or foundation using an appropriate manner.
2- Sliding, overturn and failure problems along with their preventive measures should be considered in design and manufacturing processes.
3- The foundation of equipments should capable to transfer loads with sufficient security from indoor and outdoor equipments to ground.

The concrete foundation of machineries should be anchored to civil structure/building structure using anchor bolt, bar or any other proper tool.

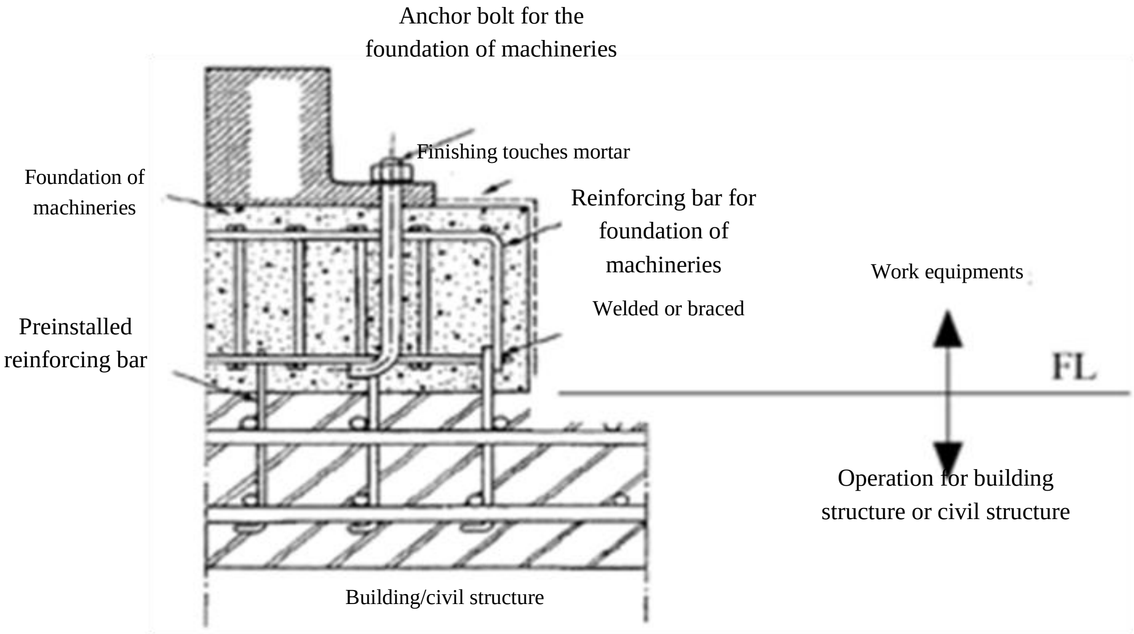


Fig. 5-2 Example of anchorage for concrete foundation

The vibrator insulator device installed in retaining structure should be equipped with a motion barrier protecting its slide.

It would be better to make the foundation of heavy machineries like generators and civil/building structure simultaneously.

5-5-2-2-Base and Bracing Support for Piping

The following notes should be considered in the design phase of the pipes of treatment and pumping stations:

- Breakage and cracking of pipes should be avoided.
- Generation of load on piping system due to relative displacement of installations should be avoided.
- Generation of load on piping system due to foundation sagging should be avoided.

1-The Parts Supported by Different Foundations

In the piping systems which rely upon different foundations or lead to the buried section we should use flexible and expansion joint (see Fig. 5-3).

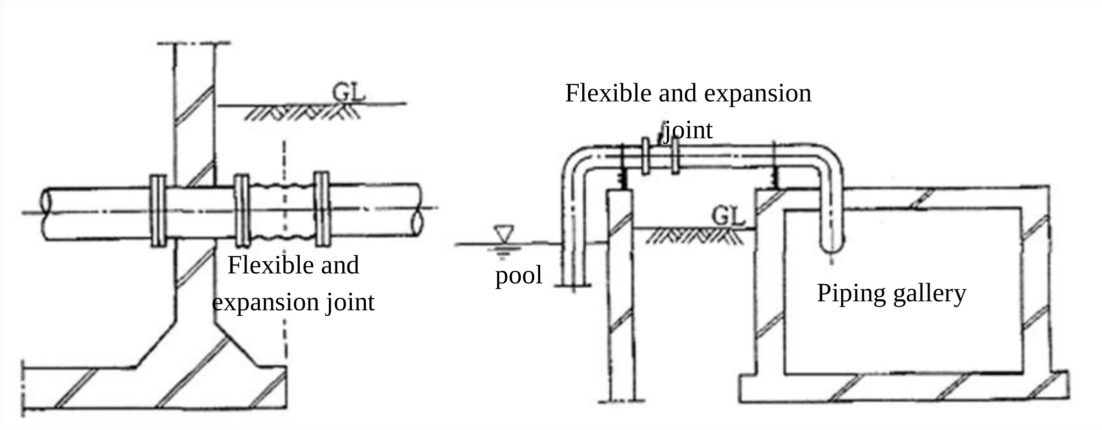


Fig. 5-3 typical flexible joint

2-It's better to anchor pipes to the main structure using a separate foundation instead of anchorage. For heavy parts like gate valves it's better to use a separate foundation.

3-Damage of main elements should be avoided.

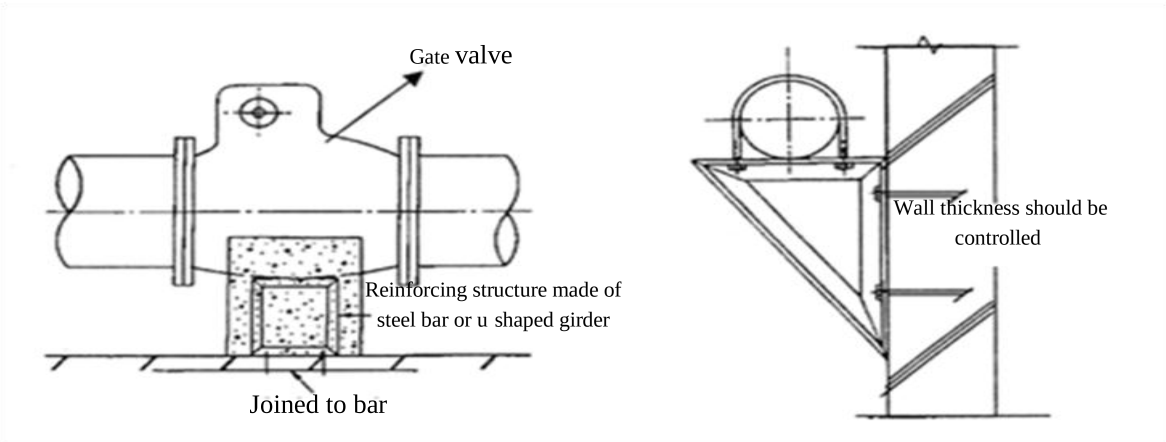


Fig. 5-4 typical bracing of supportive elements

4-In the sections where pipes cross through tank or reservoir wall, it is advised to use sealed pipes in order to avoid leakage problem. In order to avoid leakage in the outside of wall, the gate valve of tank should be installed in a dry well (see Fig. 5-5)

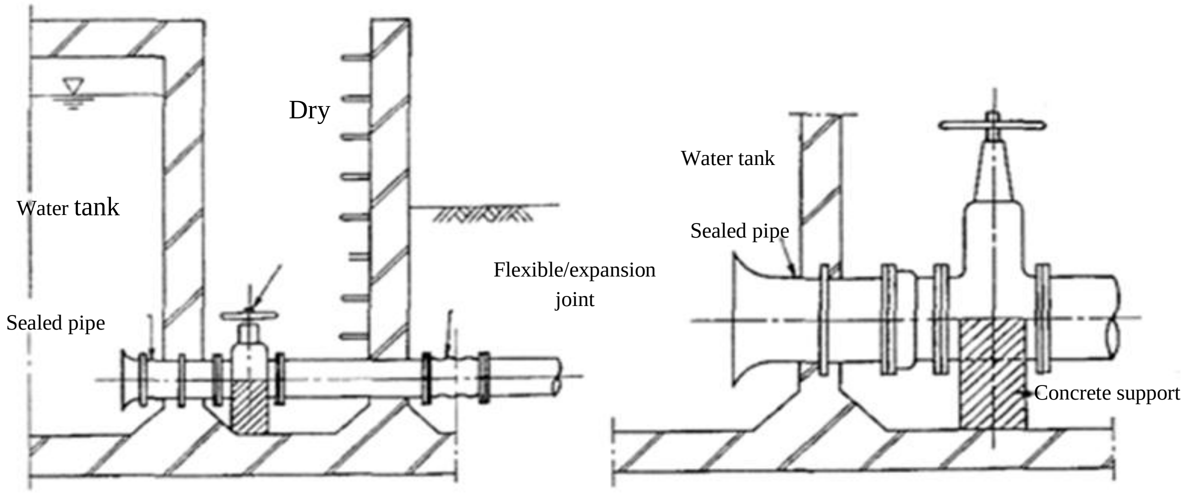


Fig. 5-5 a typical example shoes how to cross pipes through tank/reservoir wall

5-For ductile cast iron pipes it is advised to employ mechanical joints in the straight sections of piping system (for displacement absorbing purposes) and to use flanged or special sealed joints in the curved sections or the areas near equipments (for avoiding from pipe swelling out)

6-It's better to install high diameter pipes in bottom sections as much as possible and to anchor them horizontally.

7-Supports should be installed axially. In the case where pipes are installed upward, in the curved section, the pipe should have sufficient strength against vertical loads (see Fig. 5-6).

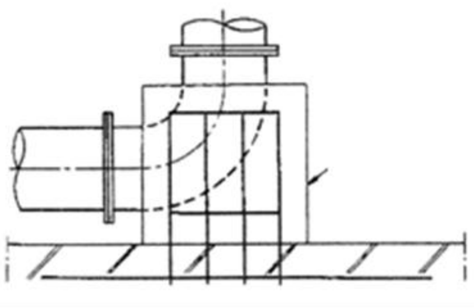


Fig. 5-6 vertical load support

8-Aerial pipes are supported by its steel framing as well as concrete foundation.

Damage of pipes due to unsymmetrical sagging of the main structure and pipe support is possible.

In order to avoid relative displacement due to geotechnical threats during earthquake employing flexible and expansion joints is inevitable.

In seismic design we should consider the concentration of stress in the corner sections of pipes in horizontal direction (see Fig. 5-7)

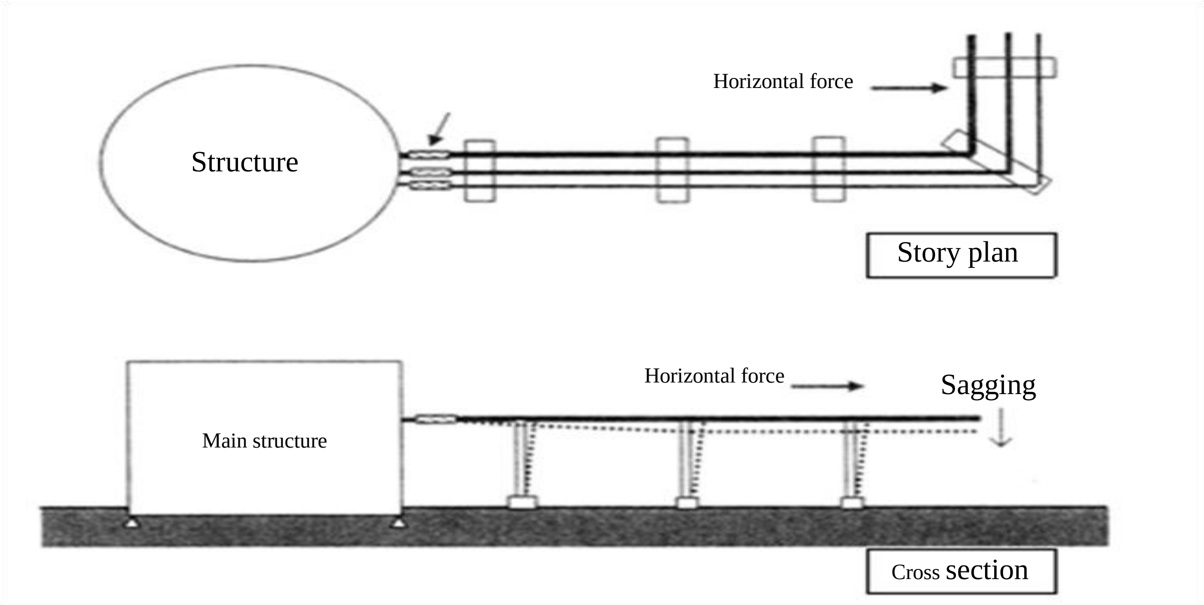


Fig. 5-7 a typical demonstration of unsymmetrical sagging

5-5-2-3-Anchor Bolt

1- All equipments should be jointed and anchored to structure using anchor bolt or any other appropriate tool.
2- In the cases where a seismic separator like spring or plastic is employed, seismic stopper should be installed.

5-5-3-machineries

5-5-3-1-General Considerations

- - In seismic design the safety level of machineries should be compatible with the safety level of the related civil and building structures.
- - Regarding the possibility of machine malfunction due to electric power outage or failure of cooling system, a back up system should be prepared.
- - Designer should consider secondary environmental threats due to leakage of dangerous saved materials.

5-5-3-2-Main Elements of Pumping Station

- - Safety level should be considered for the main elements of pumping station and its related equipments in order to assure its performance.
- - The location of the main elements of pumping station should be designed with respect to water depth as well as its preventive measures like floor drainage pump
- - In order to maintain and assure the performance of station, designing process should be carried out considering design parameters twice as much as their value in actual condition.

1-The main elements of pumping station as well as electric support devices like exclusive power generator should be capable to continue their performance during electric power outage and when water tank is not in service.
2-Generally, pump room is located in the lower level of sewage system.
3-In this room, pump and the connected electrical devices should be installed at the most top possible level.

5-5-3-3-Equipments of Sand Basin (Pool)

1- Engines and turbines should be installed at the most top possible level in order to keep their operation during raise of water level due to flood.
2- In order to avoid failure of devices like sand raking cage, elevator and sand pump, emergency power devices along with seismograph which will not go to out of service mode, should be installed.
3- The foundation of conveyer and funnel should be designed such that it is capable to withstand against mobile and seismic loads.

5-5-3-4-Installations of Treatment Station

1- Displacement of the expansion orifice of civil structure should be considered for treatment installations.
2- Turbulence effect should be considered in design phase.
3- Preventive measures should be prepared against invasion of water within pipe gallery.

- In chained sludge catchers, due to the effects of liquid turbulence, chain should experience the minimum amount of curvature and weakness point.
- Automatic shut off switch should be used.
- The anchor bolts of rail should be anchored to the main or additional armatures.
- Suspended sludge catcher should be securely and strongly anchored against vibration and turbulence.
- The situation in which railed sludge catcher is out of service should be considered.
- At least two double stories pumps (one operational and one service pump) should be installed in the gallery of pipe and a gallery should be divided into several blocks.

5-5-3-5-Water and Fuel supply Facilities

When water supply facilities are out of service or during power outage of vital arteries, the main pump and internal power generator should be fed with enough water and fuel.

5-5-3-6-Sludge Processing Facilities

Secondary accidents generating due to the leakage of flammable gases or sliding and overturn of facilities should be avoided.
In order to be ready to encounter with probable secondary accidents, seismograph and automatic shut off valve should be used.

5-5-3-7-High Capacity Sludge Processing Facilities

High capacity sludge processing facilities should be able to process a large volume of sludge which is generally obtained from several treatment stations. Appropriate preventive measures should be prepared for the following facilities:
1-Sludge transmission line

2-Temporary protection system
3-Emergency system for sludge transmission, treatment and processing

1-Required Actions to be Taken for Sludge transmission Line
1-1-making two main lines
1-2-making ring pipeline junction
1-3-installing distance meter

2-Required Actions to be Taken for Temporary Protection Systems
Temporary protection system should be made in the site of the following facilities:
2-1 Reactor tank
2-2 primary sediment tank
2-3 Rainfall tank
2-4 free space of sedimentation room

3-Required Actions to be Taken for Emergency Transfer System
In the cases that sewage treatment station is out of service, some systems should be considered for sludge transmission purposes.

5-5-4-Electric Power Facilities

5-5-4-1-General Considerations

1-In order to avoid sliding, overturn and breakage damages, facilities should be safely anchored to the main structure.
2- In the case that the height of a facility is higher than its width, the upper part of the facility should be anchored to structure.
3- The level of transportation, distribution and power generator facilities (in service mode) should be considered with respect to water buoyancy level.
4- Malfunction of protective relay due to seismic motion shall be prevented. If there is a possibility of secondary disaster, emergency stop device with seismometer shall be installed.

Sufficient floodwalls should be considered too.

This item covers issues like power receiver system including receiver unit, production (ready for service) unit, and power equipments with continuous service, DC source and similar devices, a kind of power receiver system like outright receiver network, single line and double line and so on.

Separate exclusive equipments should be considered for emergency facilities.

It is better to prepare a manual device (for emergency situations). The main line should be separated from support line. If it is impossible to prepare emergency power facilities, portable generators should be employed.

Protection relay collapse may result in secondary disasters like harmful gas leakage, flammable gas leakage, fire and so on. In order to prevent falsely operations, the following notes should be considered:

For mechanical relay :

- installing seismic contact point
- use of additional seismometers
- increasing delay time of relay operations
- paying attention to vibration properties

For electrical rely :

- increasing the number of the different kinds of relays
- Installing seismic type polar joint

– Installing fixed (motionless) relays

The seismoviewr of control unit is generally equipped with accelerometer. It is recommended to employ accelerometer at least in two directions. Also, use of emergency power source is recommended.

5-5-4-2-Transferring Facilities

In sewage units, high voltage transformation devices should be designed with respect to the characteristics of high voltage facilities.

For this, the following issues should be considered:

- The possibility of bus collapse due to the relocating of facilities
- The structure and foundation of facilities should be made integrated.
- Loose of aerial wires should be considered.
- For short distances, flexible conductor rods should be used.
- Installing twist absorbing device from isolator to support bus

5-5-4-3-Distribution Facilities

1-In sewage system, switchboard should be used within a cage.
2-Inside switchboard, there are different tools with different vibration characteristics and sufficient resistance should be considered for them.
3-In high voltage facilities, seismic resistant switchboard should be used.
4-The sheath of pipe or the supports of power cables should be seismic designed.

1-

1-1 Anti seismic switch board should have a strong frame along with fixed (motionless) relay

1-2 Cage of switchboard should be fixed strongly to structure using anchor bolts

1-3 Capacitors should be fixed strongly to the retainer devices within cage

1-4 in the cases where it's necessary to connect a rely, a key or any other device to the door of switchboard, it should be completely fastened to the door.

1-5 internal cable of cage should be anchored to frame strongly and with the minimum possible opening.

1-6 Sliding equipments should have a proper stopper.

1-7 for stories with free access, the frame of switchboard should be anchored to the concrete of floor. If the frame is on the story with free access, it should be reinforced by bracing support.

1-8 distribution equipments should meet electric power regulations.

2-

2-1 The effects of ground displacement on underground cable should be absorbed by PE flexible pipe, telescopic steel sliding protector pipe, expansion joint and son on.

2-2 in access channels and cable ends, some curvatures should be considered.

2-3 the end of cable should be completely anchored in order to prevent stress generation.

2-4 the distance between supports should be as short as possible in order to avoid free vibrations.

2-5 for cable cage, bracing or expansion joint should be installed in a proper distance. The cable should not be connected far from building or to the ends of pipe.

2-6 additional length should be considered for cable for earth connection purposes. The section of cable which will be used for connecting to earth electrode should have sufficient shear strength.

5-5-4-4-Facilities for Supervising and Control Operations

1- The type of supervising and control facilities depends on the type of treatment station and pumping

stations (parameters like scale, operation trend and machineries).
2- Equipments and measuring devices are very critical in supervising and control operations. For this, in planning and manufacturing phases, seismic considerations should be taken into account.

1-

1-1-It is better to use automatic control system locally and in all sections of the system but these local subsystems should be connected to central control system and judgment and final order should be issued by control center.

1-2-In concentrated supervising operations, the most important facilities like the main pump should have supportive facilities.

2-

2-1 It is better to use different types of single or multipurpose monitoring tools in order to monitor the variables of important factors like the water surface of pumps.

2-2 Equipments should have rigid body and they should be strongly anchored.

2-3 after installing transductor on pipe we should use a rigid pipe and anchor it to roof rock or to structure.

2-4 additional length should be considered for cables. The connected sections of cables should have enough strength.

2-5 in the case that sensor is broken, safety actions should be made to avoid secondary accidents.

5-5-4-5-Considerations about Exclusive Power Generator

1- Reliable generators which are in accordance with regulations should be used.
2- Before use of generator, its load capacity, load type (lights, engine system and so on) and operating method should be determined.
3- Employing both automatic and manual shut off systems is recommended.

1-1-In order to compute the required load of generator, the load of general treatment plus the load of disinfection facilities should be considered. Decrease or stoppage of RPM and temporary additional load should also be considered.

1-2-In general, use of multiple generators is preferred. Generator type (gas or diesel) should be selected with respect to its price, size, weight, oscillation, outlet gas and so on.

1-3-Fuel pipe should be made out of flexible pipes in order to be able to withstand against displacement between structures or ground sagging.

Table 5-3 typical equipments of an exclusive generator

Related equipment	Facilities	
Inflow gate, tools for sand raking, charging and discharging rock trashes	Sand pool (Basin)	**operation**
Sewage pump, rainfall sewage pump, pump additional appliances	Pumping facilities	
Sludge pile up and sand raking tool, sludge returning pump	Sedimentation pool	
Facilities of sodium hydrochloride infusion	Disinfection equipments	
Air compressor for equipments, sludge transmission pump	Sludge discharge equipments	
Pump for reprocessed water, sand filtration pump and micro filter	Facilities for reuse of treated water	
Aid equipments of generator and ventilator	Exclusive generator	

Emergency lighting, Power for help operations, DC power supply resource, fire fighting facilities, service pump, floor drainage pump, air ventilation appliances	Other facilities	

5-5-4-6-Special Facilities of Power Supply Source

- DC power supply system (Direct Current) and continuous power supply equipments are two kinds of special facilities of power supply source.
- Collapse, fall, the leakage of battery's electrolyte, terminal damage and similar damages should be avoided.

The following comments should be considered for service battery:

1-Sealed battery should be used.
2-A plastic separator should be placed between batteries and their retainer frame.
3-Multilayer battery holder is not suitable during earthquake from stability point of view.
4-Retainer frame should be anchored strongly to structure.
5-If battery is placed within switchboard case, a motion barrier should be used.
6-In the most section of straight lines, the cable which swells up from floor should be anchored to the cage with additional length and then to the terminal of battery.

Chapter 6

Seismic Design and Safety Control of the Culvert Pipes of Sewage System

6-1-Seismic Design Trend

Culverts should be seismic designed in a way so that they maintain their ideal operational level after earthquake.

1-Design and control steps of culver pipe facilities should be carried out as follows:

1-1-The main transmission lines should be seismic designed using allowable stress method or operational limit method in the risk level 1. Ductility method is applicable for the risk level 2.

1-2-Other lines should be seismic designed using allowable stress method or operational limit method in the risk level 1.

2-Fundamentals of Culvert Pipe Design.

In order to assure acceptable performance of the facility against earthquake the body of conduit should be flexible in order to capable to distribute earthquake force along body as much as possible as follows:

2-1 in the sections where the culvert is subjected to tensile force, the structure should be flexible and should be allowed to slide

2-2 in the sections where the culvert is subjected to compressive force, the capacity of absorbing the impacts of compressive movements should be prepared.

2-3 in the sections where the culvert is subjected to bending moment, the structure should be flexible.

2-4 in the sections where the culvert is subjected to shear force, the structure should be strongly anchored and have sliding allowance.

2-5 culverts should withstand against buoyancy force, sagging or lateral dispersion due to liquefaction. For this, required flexibility should be considered and preventive measures against liquefaction phenomenon should be prepared.

1-

In operational limit case (damaging ultimate limit) culvert pipes should be designed so that they show almost elastic response in the risk level 1. In ultimate limit state, shielded conduit should be able so that it could restart its operation immediately after repair operations. For this, culvert pipe system should be designed so that it does not disrupt when it is subjected to the risk level 2.

2-

2-1-in the connection point (joint section) where tensile force is active, the pipe should be allowed to slide as much as necessary in order to prevent any possible problem to flow.

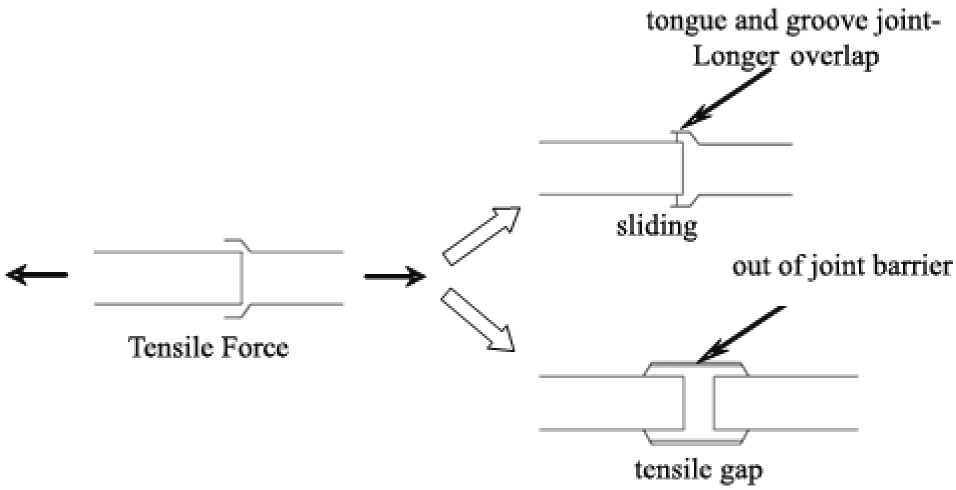


Fig. 6-1 Tensile Join

2-2-The structure of sections in which compressive force is active should be made out of materials with sufficient strength and bearing capacity.

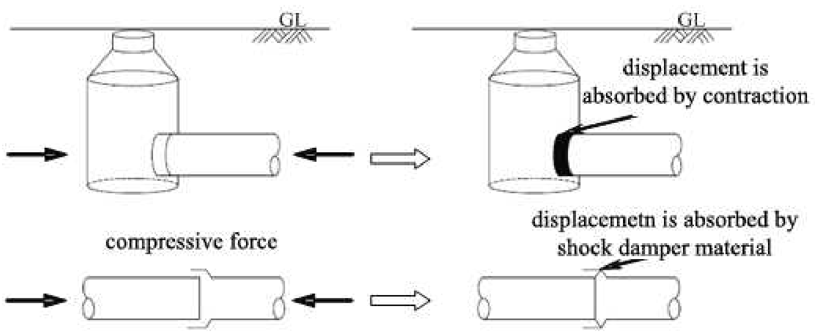


Fig. 6.2 Compress Join

2-3-the material and structure of the sections in which bending momentum is active, should have sufficient flexibility.

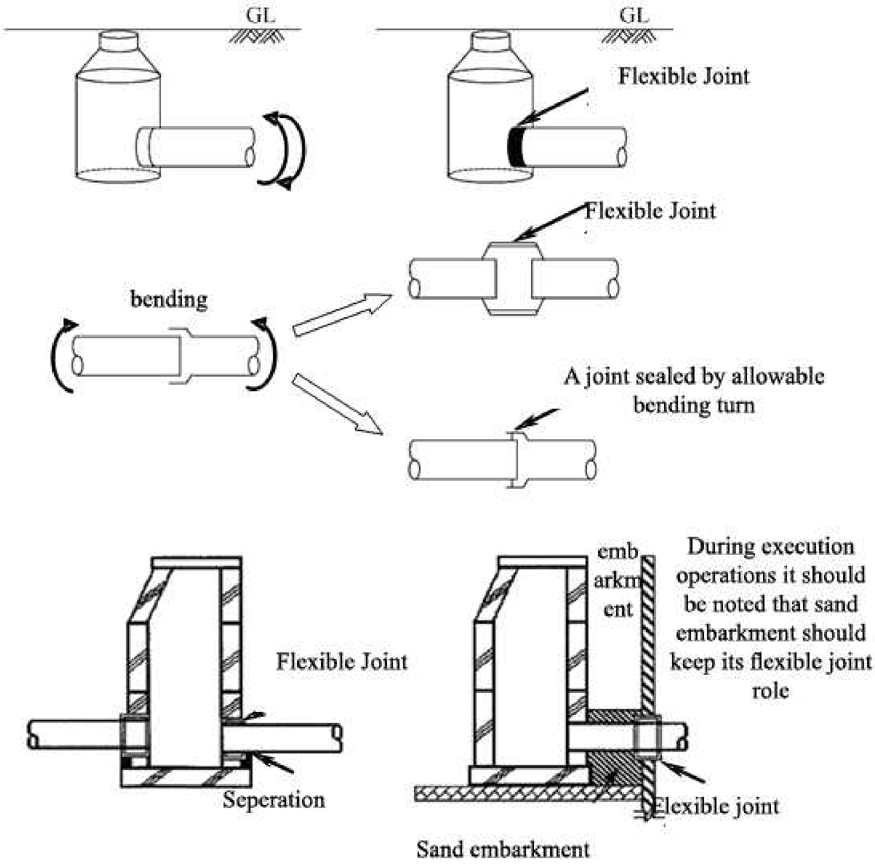


Fig. 6-3 bending behavior in joint

2-4-the structure of the sections in which shear force is active, should be made so that it could be capable to prevent sliding threat or restrict it and inhibit the penetration of sand into manhole.

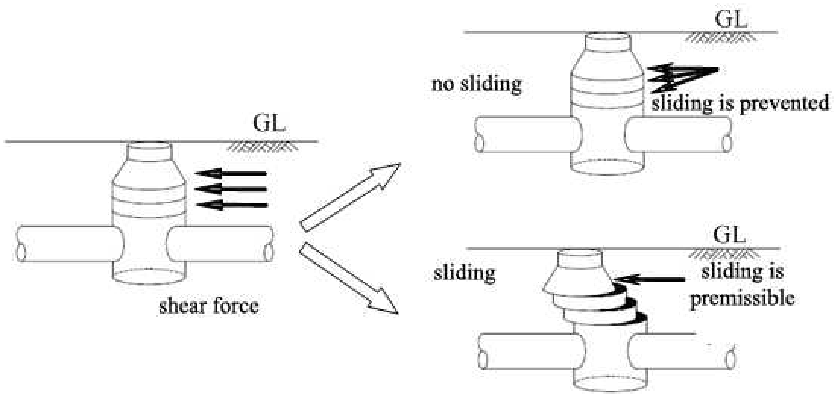


Fig. 6-4 sections under shear force

2-5-In order to encounter with uplift phenomenon, sagging or lateral dispersion due to liquefaction, flexible joints or long overlapped joints should be used or embankment should be improved in order to establish required flow.

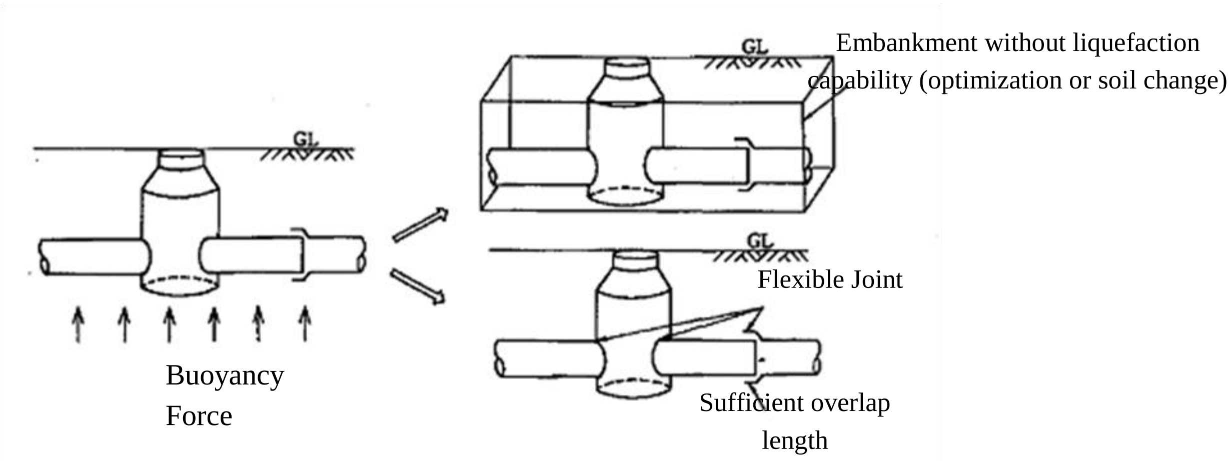


Fig. 6-5 section under buoyancy force

6-2-Spigot Joint Pipe (Tongue and Groove)

Table 6-1 shows spigot joint pipes applicable in the risk level 2.

Table 6-1 suitable position of spigot joint pipes applicable in the risk level 2

Appropriate State	Pipe position
Rotation angle and pulling our length should be within a range in which soil and sand could not penetrate inside pipe.	Connection between pipe and manhole
Rotation angle and pulling out length should be within a range in which soil and sand could not penetrate inside pipe.	Connection between pipes
The stress intensity of all materials of pipes should lie within ultimate limit state in order pipe overturn be avoided. Actions to be made in order to prepare a situation in which liquefaction could not disturb street traffic.	Main body of pipe

6-3-Design Trend

1-Items to be Seismic designed
- pipe and manhole connections
- connections between conduits
- cross section (normal plate of pipe axis)
- axial section of pipe (plate which includes pipe axis)
- uplift and leakage seal of pipeline

2-Actions to be made against earthquake

The most typical employed spigot joint pipes (tongue and groove joint) include:
- centrifugal reinforce concrete pipes, clay pipes (ceramic pipes), reinforced plastic composite pipes
- PVC pipe with plastic ring joint

– cast iron pipes for gravity flow lines with movable joins (as jacks)

Table 6-2 shows the items to be controlled

According to table 6-3, in other lines ductility design method could be eliminated.

In order to calculate pulling out length of joint, live load, temperature change, sagging and other related issues should be considered as the sources generating tensile force.

The following flowcharts have been prepared for reinforced concrete pipes.

Seismic design of clay pipe (ceramic pipe) is similar to that of reinforced concrete pipe.

In PVC pipe, axial stress (longitudinal stress) should be controlled in body. In plastic pipes reinforced by fiberglass as well as in DCIP(s), cross section stress should be controlled in body.

Transmission coefficient is determined with respect to pipe material, ground and pipe relative motion and earthquake risk level.

The correction factor of pipe stress should be applied for seismic fixtures (flexible and telescopic joints.)

Appropriate safety factor should be used with respect to pipe material as PVC pipe, steel pipe, plastic pipes reinforced by fiberglass. Table 6-4a and 6-4b shows required matters to be considered in controlling spigot joint pipes (tongue and groove join) in the main transmission line.

Table 6-2 Items to be controlled

ground susceptible to liquefaction (FL /)			judgment about liquefaction (the value of FL)	the changes of ground stiffness, sharp bend and so on	steep ground	axial strength		the cross section strength		connections between pipes		pipe and manhole connections		measures to be controlled	
(due to ground sinking)		(due to permanent strain)			due to permanent strain					(due to input motion)		(due to input motion)			
Slip out length	bending angle	Slip out length		Slip out length	Slip out length	stress intensity	pipe strain	stress intensity	bearing capacity	Slip out length	bending angle	Slip out length	bending angle	Structure Type	
D	D	D	D	A/D	D				A/D(+)	A/D(+)	A/D(+)	A/D(+)	A/D(+)	centrifugal reinforced concrete pipe	pipe with tongue and groove joint
D	D	D	D	A/D	D				A/D(+)	A/D(+)	A/D(+)	A/D(+)	A/D(+)	centrifugal reinforced concrete pipe	
D	D	D	D	A/D	D				A/D(+)	A/D(+)	A/D(+)	A/D(+)	A/D(+)	ceramic pipe (for open excavation operations)	
D	D	D	D	A/D	D	A/D(+)				A/D(+)	A/D(+)	A/D(+)	A/D(+)	PVC pipe (plastic ring)	
D	D	D	D	A/D	D			A/D(+)(x)		A/D(+)	A/D(+)	A/D(+)	A/D(+)	reinforced plastic composite pipe	
D	D	D	D	A/D	D			A/D(+)(x)		A/D(+)	A/D(+)	A/D(+)	A/D(+)	DCPI	

(+): implies that seismic design could be eliminated with respect to conditions
(x): design with approximate formulas
A: allowable stress design; D: ductility design; A/D: both allowable stress and ductility designs should be carried out

Table 6-3: Items to be controlled in spigot joint pipe (tongue and grove join) applicable in other lines

ground susceptible to liquefaction (FL /)			**judgment about liquefaction (the value of FL)**	**the changes of ground stiffness, sharp bend and so on**	**steep ground**	**axial strength**		**cross section strength**		**joins between pipes**		**pipe and manhole join**		**Items to be controlled**	
(due to ground sinking)		**(due to permanent strain)**			**due to permanent strain**					**(due to input motion)**		**(due to input motion)**			
Slip out length	**bend angle**	**Slip out length**		**Slip out length**	**Slip out length**	**stress intensity**	**pipe strain**	**stress intensity**	**bearing capacity**	**Slip out length**	**bend angle**	**Slip out length**	**bend angle**	**structure type**	
			A									A(+)	A(+)	centrifugal reinforced concrete pipe (for open excavation)	pipe with tongue and groove joint
			A									A(+)	A(+)	centrifugal reinforced concrete pipe (to plunge pipe into ground via hydraulic pressure)	
			A									A(+)	A(+)	ceramic pipe(for open excavation)	
			A							A(+)	A(+)	A(+)	A(+)	PVC pipe (plastic ring)	
			A							A(+)	A(+)	A(+)	A(+)	reinforced plastic composite pipe	
			A									A(+)	A(+)	DCPI	

(+): implies that seismic design could be eliminated with respect to conditions
A: allowable stress design; D: ductility design; A/D: both allowable stress and ductility designs should be carried out

In small diameter pipes seismic control procedures could be eliminated in the following conditions:

1-the diameter of pipe is below 700mm

2-pipe is linear positioned along horizontal direction and has no sharp bending

3-The ground (on which the pipe is placed) has no special condition like geographical steep. Also, the ground should not lie inside the separation band between soft and hard grounds

Note:

– Basically, it is the cross section of the soil of that region which should be used for seismic design purposes.

– In the case of employing the response of displacement method, when ground displacement is converted to an external force, it's necessary to use the horizontal response coefficient of the underneath layer, k_h . This coefficient should be determined with respect to ground condition as well as pipe size.

k_h , is derived from relations 6-1 to 6-3 (these relations are also applicable for manholes)

$$k_h = k_{h0}\left(\frac{B_h}{0.3}\right)^{-3/4} \quad (6\text{-}1)$$

$$k_{h0} = \frac{1}{0.3}\alpha \cdot E_0 \quad (6\text{-}2)$$

In order to calculate k_h , the equivalent width of foundation is derived from relation (6-3) as follows:

$$B_h = \sqrt{B \times D} \quad (6\text{-}3)$$

In the above relations we have:

k_{ho} : depends on the modulus of soil reaction. It is derived from loading test using a rigid disk (30cm diameter).

E_0: is ground deformation factor.

α: If the value of E_0 is obtained using N value (SPT test) (for example: $E_0 = 2800N\ kN/m^2$) , then $\alpha = 1.0$

If the value of E_0 is obtained using simple pressure test (triple axes test), then $\alpha = 4.0$

B_h : is the equivalent width of foundation (m) which is perpendicular to loading axis

D : is the diameter at surface center (m)

B: is effective length of conduits, the section in which deformation is happened uniformly.

4-In the case of applying the response of displacement method, the increase rate of α for short term loading should not apply in k_h .

Decrease rate of loading for a liquefied ground should not be considered in computing the value of k_h .

5-In vertical cross sections, the intensity of stress should be controlled for both normal and seismic conditions.

6-soil pressure loading in normal condition is carried out as follows:

- In this loading, live load is not taken into account (for both open excavation and pipe laying with hydraulic jack)
- The decrease rate of soil pressure due to pulling out of steel shield is not taken into account in the open excavating method.
- In the open excavation method the soil pressure of whole width of pipe should be considered.
- In the hydraulic jack pipe laying method the decrease rate of soil pressure should be taken into account.

7-Internal pressure is neglected for safety and reliability purposes.

8-When the intensity of stress at vertical section is controlled, permitted safety factor should be determined based on the torque value derived from the standard value of materials.

9-As far as connecting pipe bends via hydraulic jack pipe laying method concerns, slip out length due to operational works in the bending section + slip out length due to earthquake should be within allowable range.

10-If liquefaction phenomenon is happened at the around ground, the laid pipe will be subjected to buoyancy force. For this, proper preventive measures should be prepared against this threat.

Table 6-4a) seismic design measures and spigot joint pipe (tongue and groove join) design method

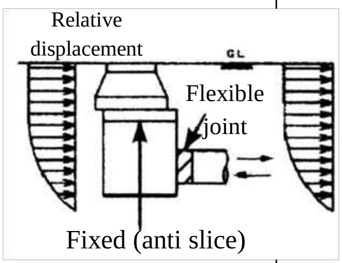
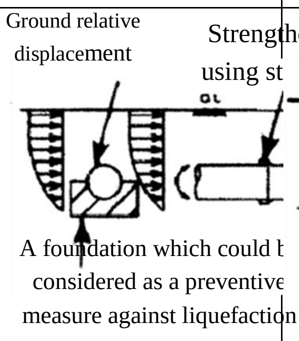
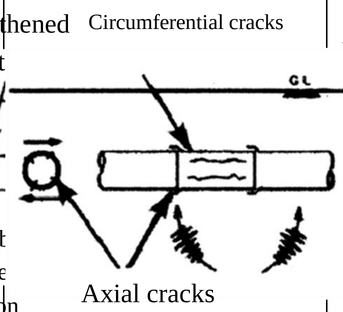
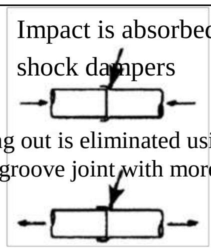
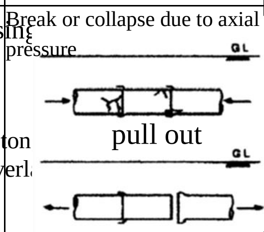
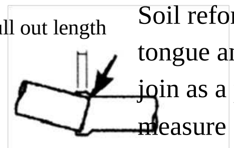
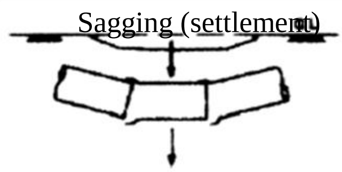
seismic design method				design seismic force and typical preventive measures		Typical Damages	location
is determined through settlement	is determined through ground permanent strain	the response of displacement method: wave length	the response of displacement method: velocity response spectra				
-	-	-	o	vertical displacement results in bending			Conduit and Manhole connections
-	-	-	-	axial pressure value			
-	o	o	o	Slip out value			
-	only for lateral dispersion	-	o	vertical relative displacement			Main body of pipe
-	-	o	o	bend			

Table 6-4b) seismic design measures and spigot joint pipe (tongue and groove join) design method

seismic design method				design seismic force and typical preventive measures		Typical Damages	location
is determined through settlement	is determined through ground permanent strain	the response of displacement method					
		wave length	Velocity response spectr				
-	-	-	-	axial pressure value			xtures
-	o	o	o	pulling out value			
(the settlement of the liquefied soil)	-	-	-	sagging value			

6-4-Design Trend

6-4-1-Seismic Design of Fixtures

Pipe and manhole joints and joins between pipes should be seismic designed separately.
in the cases where the site have special conditions like where the ground is susceptible to liquefaction, ground with no liquefaction potential but with sharp slopes and bends, the following items should be controlled in seismic design:

- 1-effects to be controlled:
  - 1-1-ground seismic motion effect
  - 1-2-liquefaction effect
  - 1-3-slopes effect
  - 1-4-sharp bends effect
- 2-fixtures to be controlled:
  - 2-1-pipe and manhole joints
  - 2-2-joints between pipes

1-

1-1-Rotation angle as well as pulling out length should be evaluated in order to control wave effect

1-2-the pulling out length due to liquefaction should be assessed in order to check pipe and manhole joint strength against liquefaction

1-3-Rotation angle and pulling out length due to liquefaction should be controlled in joins between pipes

1-4-in steep grounds the pulling out length generated due to ground permanent displacement should be controlled for both pipe and manhole joints and joints between pipes

1-5-Along a path with sharp bend which has been executed using hydraulic jack pipe laying method, the pulling out length generated due to wave effect should be assessed after estimating that length during pipe laying

2-

2-1-pipe and manhole connection

- Flexible joins should be used for damage minimizing purposes.
- Since ground displacement due to axial pressure is low, it is assumed that the capability of flow establishment is not damaged seriously.

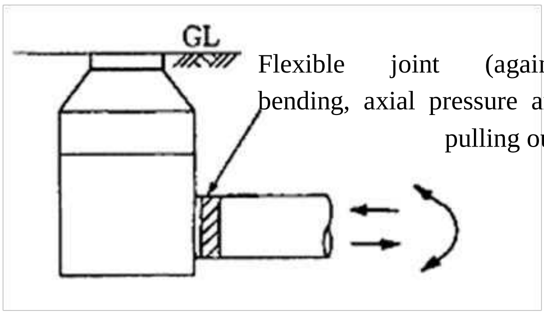


Figure. 6-6 Flexible Joint

a) Rotation angle due to wave effects

In order to determine rotation angle regardless of ground effects it is assumed that manhole and pipe have the same rotation angle. Rotation angle should be calculated through the following relations (see Fig. 6-7):

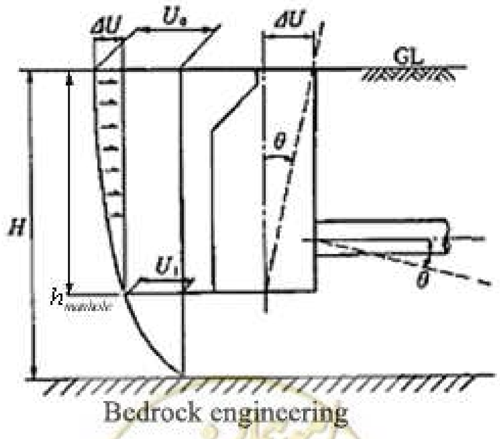


Fig. 6-7 joint loading

$$\theta = \tan^{-1}(\frac{\Delta U}{h}) \quad (6\text{-}4)$$

$$U_h(Z) = \frac{2}{\pi^2} \cdot S_v \cdot T_s \cdot \cos(\frac{\pi \cdot Z}{2H}) \quad (6\text{-}5)$$

$$\Delta U = U_h(0) - U_h(h) = U_0 - U_1$$

θ: is the rotation angle between manhole and pipe (Flexible rotation angle (rad)

$U_z(z)$: is the maximum displacement at depth $Z(m)$

$h_{manhole}$: is manhole depth (m)

S_v: is design velocity spectrum (m/s)

T_s: is the natural period of surface layer (sec)

$$T_s = 1.25 \cdot T_G$$

$$T_G = \sum_{i=1}^{n} \frac{4H_i}{V_{si}} \quad (6\text{-}6)$$

where;

T_G: is ground specific value

H_i: is the thickness of the ith layer (m)

V_{si}: is the mean shear wave speed of the ith layer (m/s). This parameter could be obtained from relations (6-7) and (6-8)

For gravel layer:

$$V_{si} = 100 \cdot N_i^{1/3} \quad (1 \le N_i \le 25) \quad (6\text{-}7)$$

For clay layer:

$$V_{si} = 80 \cdot N_i^{1/3} \quad (1 \le N_i \le 50) \quad (6\text{-}8)$$

Where;

N_i: is the mean of N of the ith layer due to SPT. if $N_i = 0$; then: $V_{si} = 50\, m/s$

b) Pulling out length due to wave effect

Pulling out length of pipe from manhole is calculated through relation (6-9) as follows:

$$\delta = \varepsilon_{gd} \cdot \ell \quad (6\text{-}9)$$

In which;

δ: is pulling out length

ε_{gd}: is ground strain due to wave effect

$$\varepsilon_{gd} = \frac{\pi}{L} U_h(Z) \quad (6\text{-}10)$$

Where;

L : is harmonic wave length

$U_h(Z)$: is the maximum displacement of ground at the depth of conduit pipe

Z : is the depth of pipe center

ℓ : is pipe effective length

c) liquefaction effect (pulling out length due to ground permanent strain)

The pulling out length of pipe from manhole is derived from relation (11-6) based on ground strain:

$$\delta = \varepsilon_g \cdot \ell \qquad (6\text{-}11)$$

in which ε_g is ground permanent strain which has been indicated in table (6-5)

d) the effect of steep ground (pulling out length due to ground permanent strain)

In the cases where pipe is mounted on steep ground which is not potentially subjected to liquefaction (slope more than 5%) or is mounted on embankment, pulling out length with the permanent strain ε_g specified in the table (6-5) should be determined through relation (6-11)

e) In the cases where manhole location has sharp bends, at first the pulling out length during execution should be calculated. Then, the obtained value is deducted from allowable pulling out and the final pulling out length is implemented.

Table 6-5 ground permanent strain in terms of topographical conditions

permanent strain [%] ε_g	**topographical condition**
1/5	A liquefied ground adjacent to seawall (less than 100m to seawall)
1/2	A liquefied ground (100m or more to seawall)
1/3	Steep non liquefied ground (embankment, surface slope<=5%)

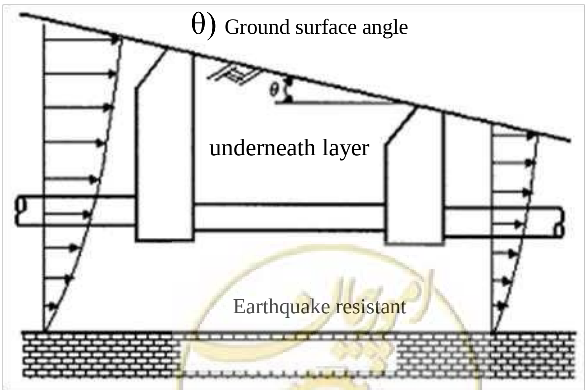


Fig. 6-8 steep ground

In the case where as Fig. 6-9 a pipe is laid through use of hydraulic jacks and it intersects the boundary of soft and hard (stiff) layers, additional pulling out length should be considered.

$$\delta = \varepsilon_{gd2} \cdot \ell \qquad (6\text{-}12)$$

ε_{gd2} : is the value of ground strain at boundary layer ((0.5%)=0.005)

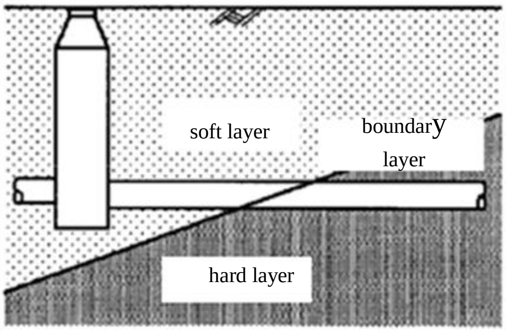


Fig. 6-9 schematic view of ground where ground layers are changed

2-2 pipe joints

Joints are displaced due to ground permanent strain in the liquefied grounds or steep grounds or due to tensile stress which in turn is generated due to wave effects.

Also, settlement due to soil loose can result in hinge displacements.

Circumferential crack of pipe is possible due to the elimination of curvature position which in turn is happened due to the elimination of pressure. Therefore, in seismic design hinge bend and embedded length should be considered.

The joint should be flexible joint if necessary, as per Fig 6-10 and the pipe head should be longer.

In order to prevent the destruction of pipe ends due to pressure, a plastic ring or washer could be used for absorbing impact shocks.

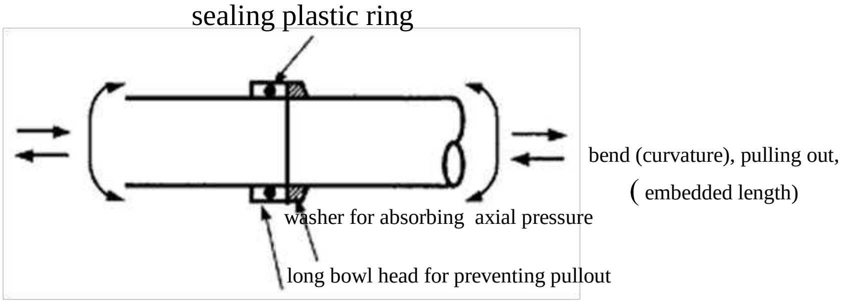


Fig. 6-10 earthquake resistant joint

The necessary conditions of joint are as follows:

a) rotation angle due to wave effective

The rotation angle of joint in which pipe body don't experience any crack is derived from relation (6-13) as follows:

$$\theta = \left(\frac{2\pi}{T_s}\right)^2 \times \frac{U_h(Z)}{V_s^{\,2}} \ell \qquad (6\text{-}13)$$

In which θ is the rotation angle of joint (rad)

b) pulling out length due to wave effective

Pulling out length is calculated as described in section 1-b

c) liquefaction effect (pulling out length due to ground permanent strain)

Pulling out length due to ground permanent strain is derived from relation (6-11) , which has been described before, based on ground permanent strain specified in table (6-5)

d) liquefaction effect (rotation angle and ground settlement)

The rotation angle generated due to ground settlement which in turn is generated due to liquefaction effect should be calculated from relation (6-14) through simulating the sagged pipe between manholes using second order curve.

$$\theta = 2 \cdot \tan^{-1}\left(\frac{4h}{L_{manhole}{}^{2}} \cdot \ell\right) \qquad (6\text{-}14)$$

In which;

h: is ground settlement due to liquefaction effect (m). If the considered ground in the site is a liquefied ground the value of h is considered as 5% H_{FL} in which H_{FL} is the total thickness of whole liquefied layers.

If embankment is only liquefied the value of h is considered between 7.5% H_{FL} and 10% H_{FL} in which H_{FL} is the distance from pipe bed to excavation surface.

e) liquefaction effect (pulling out length due to ground settlement)

Pulling out length due to ground settlement which in turn is generated due to liquefaction is derived from relation (6-15) (see Fig. 6-11):

$$\delta_{s\max} = \frac{\ell}{\cos\left(\frac{n-1}{2}\right) \cdot \theta} - \ell \qquad (6\text{-}15)$$

$\delta_{s\max}$: is the maximum pulling out length

n : is the number of pipes at manholes' spans

f) steep ground effect (pulling out length due to ground permanent strain)

In the case where pipe is mounted on a steep ground (ground slope > 5%) with no liquefaction potential the pulling out length is derived through relation (6-11) using the permanent strain, ε_g , specified in the table (6-5)

g) sharp bend (curvature) effect (pulling out length)

If pipe lies inside the boundary of soft and hard ground, the value of pulling out length which is derived from relation (6-12) should be considered too

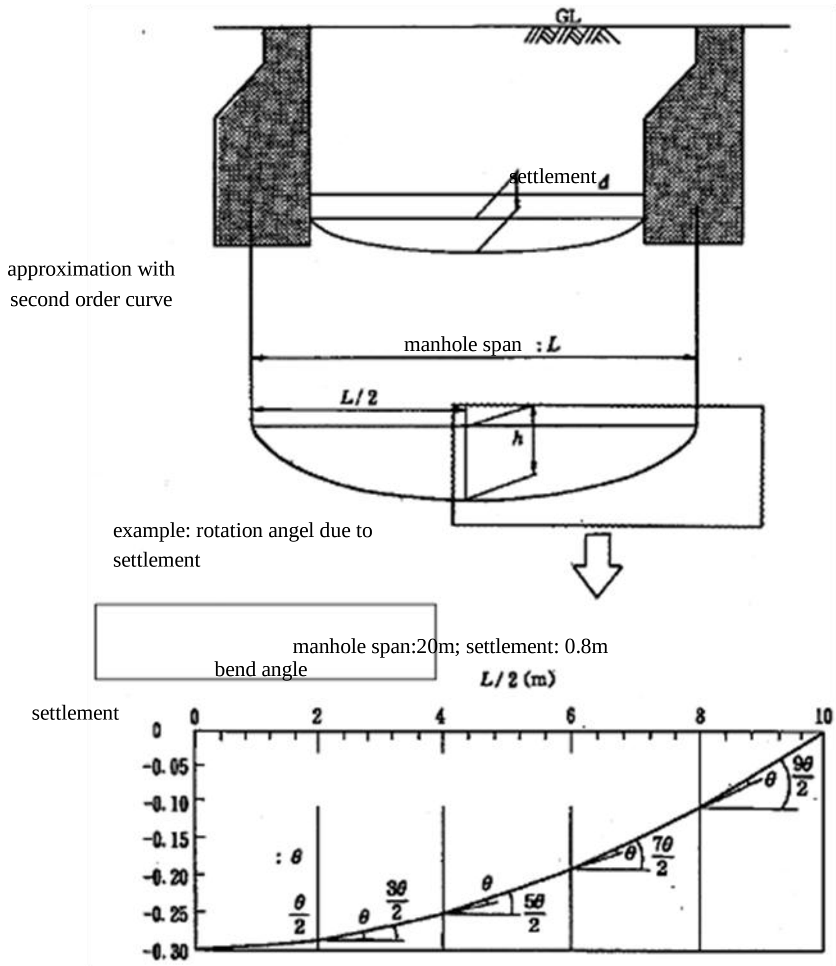


Fig. 6-11 pullout length due to settlement

Note:

If pipe is mounted on a ground with steep bedrock, the value of ground strain increases.

The additional strain is derived from relations (6-16) and (6-17):

$$\varepsilon_{G2} = \sqrt{\varepsilon_{G1}^{2} + \varepsilon_{G2}^{2}} \qquad (6\text{-}16)$$

$$\delta = \varepsilon_{G2} \cdot \ell \qquad (6\text{-}17)$$

In which;

ε_{G2} : is the strain of ground with steep engineering bedrock

ε_{G1} : is the strain of normal ground (uniform ground) which is derived as per the relation (6-10)

ε_{G3} : is ground strain due to steep bedrock (if $\theta \geq 5°$; we have $\varepsilon_{G3} = 0.35$)

This effect should be controlled in such conditions in which pulling out length has limited safety margins. Pulling out length should be evaluated using item b-2.

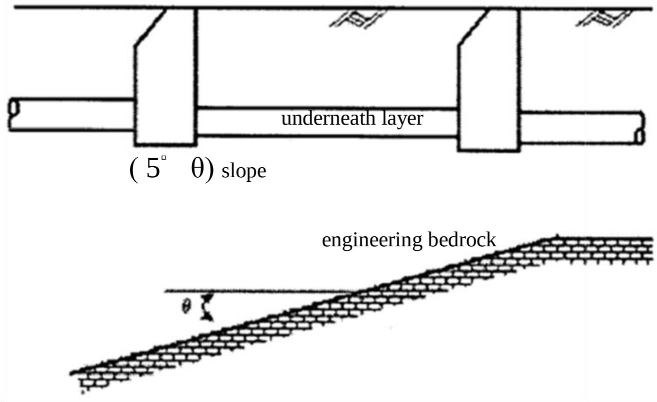


Fig. 6-12 the site condition of steep bedrock

6-4-2-Seismic design of pipe body

The following items should be checked in seismic design of pipe body: 1-cross section (normal to axis) 2-longitudinal section

1-

Generally, cracks are generated in the direction of pipe body axis due to shear strain which in turn is generated as a result of wave propagation.

For seismic evaluation purposes in addition to vertical load, the relative displacement of ground in the direction of depth should be converted to load and added to the vertical load.

Regarding situation, seismic control could be neglected in small diameter pipes with tongue and groove joint.

1-1-Vertical load P_h, horizontal load P_v and soil reaction factor P_r should be calculated for normal conditions.

1-2-Seismic load is obtained through converting relative displacement of ΔU to external force as a result of ground spring factor.

The reaction factor of underneath soil, k_h, is used as the spring factor of ground.

$$\Delta U = U_h(h_1) - U_h(h_2) \qquad (6\text{-}18)$$

In which;

h_1: is the depth up to the upper surface of pipe

h_2: retaining depth from foundation (m)

$$Q_h = \Delta U \times k_h \qquad (6\text{-}19)$$

In which k_h is the horizontal reaction factor of the underneath layer

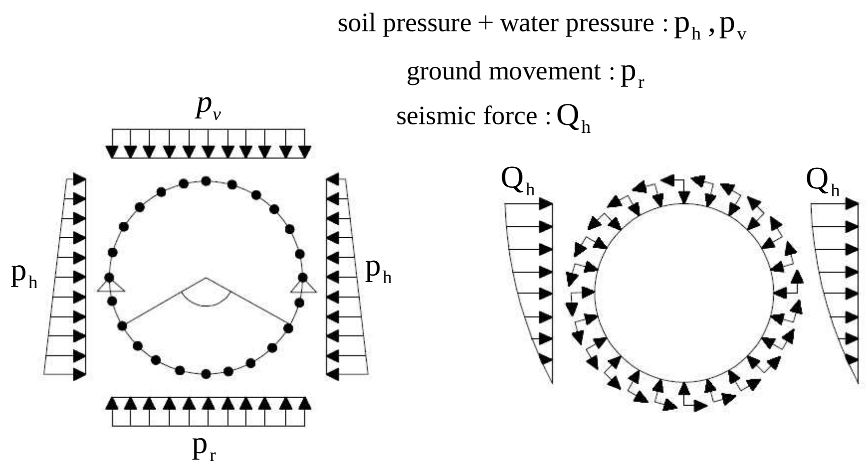
1-3-The cross sectional force of pipe is calculated using frame model with respect to the above mentioned loading conditions

Approximate calculation method could not be employed for reinforced composite pipes as well as DCIP pipes.

The necessary requirements for approximate calculation are as follows:

- surface layer has constant characteristics
- surface layer responses in the first mode

– pipe and surface layer show linear behavior
– the effect of inertial force is not considered for pipe
– the overburden depth is higher than pipe diameter and pipe is not mounted too near to bedrock



(in normal condition) (in seismic condition)

Fig. 6-13 a typical example of frame calculation model for a pipe with circular cross section which has been modeled using 24 frames

$$M(\theta) = \beta \cdot \frac{3\pi \cdot EI}{2R \cdot H} \cdot U_h \times \sin(\frac{\pi \cdot H_c}{2H}) \times C \times \sin(2\theta)$$

$$Q(\theta) = -\beta \cdot \frac{3\pi \cdot EI}{R^2 \cdot H} \cdot U_h \times \sin(\frac{\pi \cdot H_c}{2H}) \times C \times \cos(2\theta)$$

$$N(\theta) = -\beta \cdot \frac{3\pi \cdot EI}{R^2 \cdot H} \cdot U_h \times \sin(\frac{\pi \cdot H_c}{2H}) \times (1 + \frac{G_s \cdot R^3}{6 \cdot EI}) \times C \times \sin(2\theta) \quad (6\text{-}20)$$

Where;

$M(\theta)$: is bending moment at pipe cross section ($kN.m/m$)

$Q(\theta)$: is shear force at pipe cross section (kN/m)

$N(\theta)$: is axial force at pipe cross section (kN/m)

θ : is the angle between pipe crown and the point in which stress is calculated

H : is the thickness of surface layer (m)

H_c : is the depth at pipe center (m)

R : is pipe diameter (average diameter) (m)

I : is the second moment of pipe surface applying per axial length unit (m^4/m)

E : is the modulus of elasticity of pipe (kN/m^2)

G_s : is shear modulus (kN/m^2)

β : is accuracy correction factor (generally it is 1.3)

U_h : is the amplitude of ground surface displacement (m)

$$I = \frac{b \cdot t^3}{12} \quad (6\text{-}21)$$

$$G_s = \frac{\gamma_t}{g} \cdot V_{SD} \quad (6\text{-}22)$$

Where;

b : is pipe length unit is axis direction ($1.0 = m/m$)

t : is pipe thickness (m)

γ_t : is the specific weight of wet soil (kN/m^3)

g : is gravity acceleration ($9.8 m/s^2$)

V_{SD} : is the velocity of the shear wave of surface layer (m/s)

Note: V_{SD} of the ith layer is calculated through relation (6-23) and the value of V_{si} is obtained from elastic wave and PS tests.

$$V_{SDi} = C_u \times V_{si} \quad (6\text{-}23)$$

In which;

C_u : is correction factor based on the magnitude of ground strain. if $V_{si} < 300 m/s$, then $C_u = 0.8$, otherwise $C_u = 1.0$

ν_s : is dynamical poisson coefficient of surface layer

$$\nu_s = \frac{2 - (V_s / V_p)^2}{2 - 2(V_s / V_p)^2} \quad (6\text{-}24)$$

Where;

V_s : is shear wave velocity (m/s)

V_p : is expansion wave velocity

Table (6-6) shows the mean values of dynamical poisson coefficient

Table 6-6 mean values of dynamical poisson coefficient

considerations	ν_s	**geographical specifications**
above underground water level	0.45	alluvium/old alluvium
below underground water level	0.50	alluvium/old alluvium
	0.40	soft rock
	0.30	hard rock

C : is a coefficient related to ν_s.

$$C = \frac{4(1-\nu_s) \cdot G_s \cdot R^3}{(3 - 2 \cdot \nu_s) \cdot G_s \cdot R^3 + 6(3 - 4 \cdot \nu_s) \cdot EI} \quad (6\text{-}25)$$

Note:

The above relation should be employed in high diameter pipes.

the results of frame model are conservative to some extent but the results derived from the relations of reinforced plastic as well as DCIP pipes are not conservative at all.

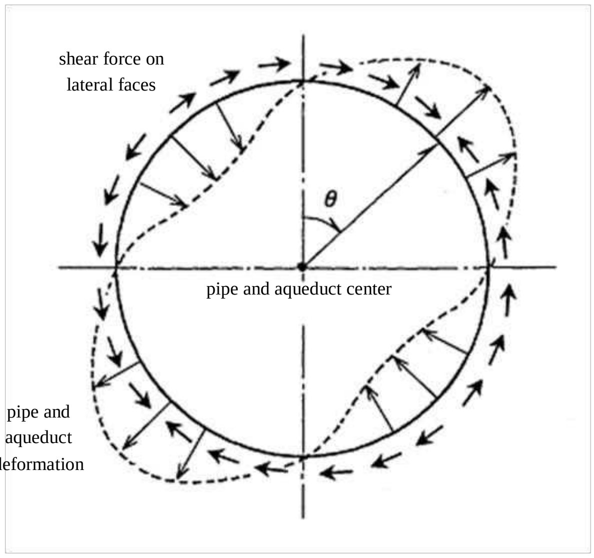
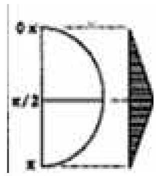


Fig. 6-14 (reference) of surface shear force (shell) and pipe deformation

Table 6-7a approximate formulas (in typical condition)

triangular loading $q_t = q_{e2} + q_{w2} - q_1$	**lateral loading** $q_1 = q_{el} + q_{w1}$	**vertical loading** $p_1 = p_{e1} + p_{w1}$	**loading**
$M = \frac{(6-3y-12y^2+4y^3)}{48} \times q_1 \times R_c^2$	$M = \frac{1}{4} \times \left(1-2y^2\right) \times q_1 \times R_c^2$	$M = \frac{1}{4} \times \left(1-2x^2\right) \times p_1 \times R_c^2$	**bending moment** M (KN · m/m)
$N = \frac{y+\delta y^2-4y^2}{16} \times q_1 \times R_c^2$	$N = q_1 \times R_c \times y^2$	$N = p_1 \times R_c \times x^2$	**axial force** N (KN/m)
$Q = \frac{(x+\delta x^2 \cdot y-4x \cdot y^2)}{16} \times q_1 \times R_c$	$Q = q_1 \times R_c \times x \times y$	$Q = -p_1 \times R_c \times x \times y$	**shear force** Q (KN/m)
		D_0 is not taken into account in seismic design	**considerations**

Table 6-7b approximate formulas (in typical condition)

weight of section itself $p_{g1} = \pi \cdot g$		**the reaction of underneath layer** $q_r = k \cdot \delta$		**loading**
$(\frac{\pi}{2}) \le \theta \le \pi$	$0 \le \theta \le (\frac{\pi}{2})$	$(\frac{\pi}{4}) \le \theta \le (\frac{\pi}{2})$	$0 \le \theta \le (\frac{\pi}{4})$	
$M = \left\{ \begin{matrix} \frac{-\pi}{8} + (\pi - \theta)x \\ -\left(\frac{5}{6}\right)y - \frac{\pi}{2}.x^2 \end{matrix} \right\} \times g \times R_c^2$	$M = \left\{ \left(\frac{3}{8}\right)\pi - \theta.x - \left(\frac{5}{6}\right)y \right\} \times g \times R_c^2$	$M = (0.1513 - 0.2643y^2) \times q_r \times R_c^2$	$M = \left(0.2346 - 0.354y^2\right) \times q_r \times R_c^2$	**bending moment** M (KN · m/m)
$N = ((\theta - \pi)x + \pi \cdot x^2 - \frac{y}{6}) \times g \times R_c$	$N = \left\{ \theta \cdot x - \frac{y}{6} \right\} \times g \times R_c$	$N = (-0.7071 + y + 0.707x^2)y \times q_r \times R_c$	$N = 0.3536y \times q_r \times R_c$	**axial force** N (KN/m)
$Q = \{(\pi - \theta) \cdot y - \pi \cdot xy - \frac{x}{6}\} \times g \times Rc$	$Q = -(\theta \cdot y + \frac{x}{6}) \times g \times R_c$	$Q = (1 - 0.7071y)xy \times q_r \times R_c$	$Q = 0.3536x \times q_r \times R_c$	**shear force** Q (KN/m)
		symmetrical adjustments $\pi / 2 \le \theta$ 		**considerations**

In this table we have $x = \sin\theta$ and $y = \cos\theta$

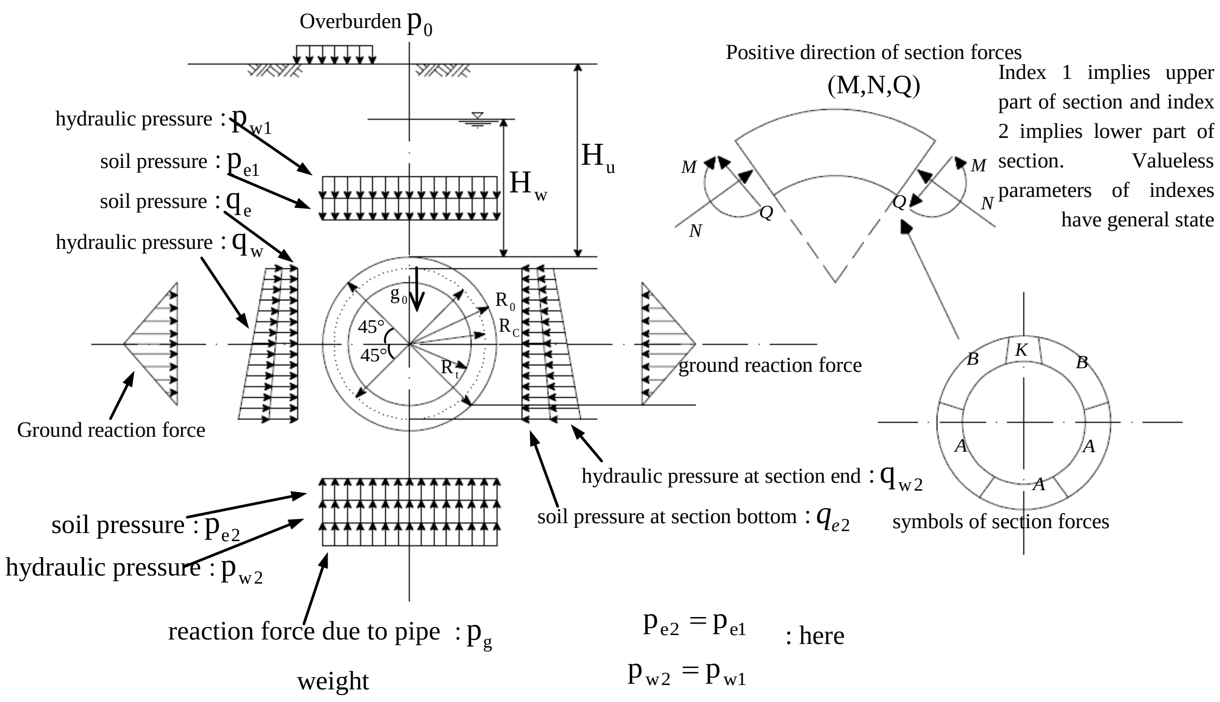


Fig. 6-15: stable loading situation (according to table 6-7)

R_0, R_C, R_i : are the diameters of conduit pipe (respectively left to right: outside diameter, surface center diameter and inside diameter) (m)

θ : is the angle between pipe crown up to point at which stress is calculated (deg)

H_u : is overburden depth (soil depth) up to pipe crown

H_W : is water overburden depth up to pipe crown

p_0 : is overburden in surface (in seismic design it could be eliminated)

g_0 : is the weight of length unit (external circumference unit) in axial direction

p and q : are respectively loading intensity in vertical and horizontal directions

δ : is pipe displacement due to the pressure of soil resistance

$$\delta = \{2p_{ew} - q_{ew} - (q_{e2} + q_{w2})\} \times \frac{R_C^{\ 4}}{24(\eta \cdot EI + 0.0454\kappa \cdot R_C^{\ 4})} \qquad (6\text{-}26)$$

In which;

η : is overburden rate due to bending stiffness (EI) (in which we assume $\eta = 1.0$)

κ : is the reaction factor of underneath layer (MN/m^3)

λ : is soil pressure factor in horizontal direction

2-

In integrated conduits, axial strain is higher that circumferential strain.

In PVC pipes, tensile stress is controlled in axial section.

$$\sigma_X = \sqrt{\gamma \cdot \sigma_L^{\ 2} + \sigma_B^{\ 2}} \qquad (6\text{-}27)$$

$$\sigma_L = \alpha_1 \times \xi_1 \times \frac{\pi \cdot U_h(z)}{L} \times E \qquad (6\text{-}28)$$

$$\sigma_B = \alpha_2 \times \xi_2 \times \frac{2\pi^2 \cdot D_{outer} \cdot U_h(z)}{L^2} \times E \qquad (6\text{-}29)$$

Where;

σ_X : is stress in axial and circumferential directions at $x(m)$ from flexible joint (kN/m^2)

σ_L and σ_B : are respectively axial stress (kN/m^2) and bending stress (kN/m^2)

$U_h(z)$: is ground displacement in horizontal direction at the depth of z from pipe center (refer to the relation 6-5)

L : is wave length (m)

E : is the modulus of elasticity of pipe

D_{outer} : is outside diameter (m)

γ : is superposition factor (the value of γ ranges from 1.00 to 3.12 with respect to pipe importance)

α_1 and α_2 : are transmission constant respectively in axial and circumferential directions

ξ_1 and ξ_2 : are correction factors of the stress of a pipe with flexible fixtures. If the pipe has no flexible fixture then we have $\xi_1 = \xi_2 = 1$.

$$\alpha_2 = \frac{1}{1 + (\frac{2\pi}{\lambda_2 L})^4} \qquad \alpha_1 = \frac{1}{1 + (\frac{2\pi}{\lambda_1 L'})^2} \qquad (6\text{-}30)$$

$$\lambda_2 = \sqrt[4]{\frac{K_{g2}}{EI}} \qquad \lambda_1 = \sqrt{\frac{K_{g1}}{EA}}$$

$$L' = \sqrt{2} \times L \qquad (6\text{-}31)$$

L' : is apparent wave length

K_{g1} and K_{g2} are ground stiffness coefficients respectively in axial and circumferential directions

$$K_{g2} = C_2 \frac{\gamma_{teq}}{g} V_{DS}^2 \qquad K_{g1} = C_1 \frac{\gamma_{teq}}{g} V_{DS}^2 \qquad (6\text{-}32)$$

In which γ_{teq} is the converted specific weight of surface layer (kN/m^3)

$$\gamma_{teq} = \frac{\sum \gamma_{ti} \cdot H_i}{H} \qquad (6\text{-}33)$$

In which;

γ_{ti} : is ground specific weight at the ith layer (kN/m^3)

H_i : is the thickness of the ith layer (m)

H : is the thickness of surface layer (m)

V_{DS} : is the velocity of shear wave at surface layer

C_1 and C_2 : are the constants of ground stiffness modulus respectively in axial and circumferential directions

ξ_1 and ξ_2: are correction factors of the stress of a pipe with flexible fixtures. If the pipe has no flexible fixture then we have $\xi_1 = \xi_2 = 1$

$$\xi_2 = \sqrt{\phi_3^2 + \phi_4^2} \quad ; \quad \xi_1 = \frac{\sqrt{\phi_1^2 + \phi_2^2}}{\exp(\nu'\cdot\lambda_1 \cdot L') - \exp(-\nu'\cdot\lambda_1 L')} \qquad (6\text{-}34)$$

$$\nu = \ell_{joint} / L$$

$$\nu' = \ell_{joint} / L'$$

$$\phi_1 = \{\exp(-\nu'\cdot\lambda_1 \cdot L') - \cos(2\pi\cdot\nu')\}\exp(\mu'\cdot\lambda_1 \cdot L') - \{\exp(\nu'\cdot\lambda_1 L') - \cos(2\pi\cdot\nu')\}\exp(-\mu'\cdot\lambda_1 \cdot L') + 2\sinh(\nu'\cdot\lambda_1 \cdot L')\cdot\cos(2\pi\cdot\mu')$$

$$\phi_2 = 2\sin(2\pi\cdot\nu')\cdot\sinh(\mu'\cdot\lambda_1 \cdot L') - 2\sin(2\pi\cdot\mu')\cdot\sinh(\nu'\cdot\lambda_1 \cdot L')$$

$$\phi_3 = f_3 e_3 - f_1 e_2 - f_4 e_1 - \sin(2\pi\cdot\mu)$$

$$\phi_4 = e_4 + f_2 e_3 - f_2 e_2 - f_5 e_1 - \cos(2\pi\cdot\mu) \qquad (6\text{-}35)$$

Table 6-8: the following relations are used for calculating the coefficients of the relations (6-34) to (6-35)

$$f_1 = \frac{1}{\Delta}\left[\{C_1(C_4 - C_1) - C_3(C_3 + C_2) - C_1\cos(2\pi v)\}\frac{2\pi}{\beta L} + (C_3 + C_2)\sin(2\pi v)\right]$$

$$f_2 = \frac{1}{\Delta}\left[C_1(C_3 - C_2) - C_4(C_3 + C_2) + (C_3 + C_2)\cos(2\pi v) + C_1\frac{2\pi}{\beta L}\sin(2\pi v)\right]$$

$$f_3 = \frac{1}{\Delta}\left[\{C_1(C_4 + C_1) - C_2(C_3 + C_2) - C_1\cos(2\pi v)\}\frac{2\pi}{\beta L} + (C_3 + C_2)\sin(2\pi v)\right]$$

$$f_4 = \frac{1}{\Delta}\left[\{C_3(C_4 + C_1) - C_2(C_4 - C_1) + (C_2 - C_3)\cos(2\pi v)\}\frac{2\pi}{\beta L} - 2C_1\sin(2\pi v)\right]$$

$$f_5 = \frac{1}{\Delta}\left[(C_3 + C_2)^2 + C_1C_4 - 2C_1\cos(2\pi v) - (C_2 - C_3)\frac{2\pi}{\beta L}\sin(2\pi v)\right]$$

$\Delta =$	$(C_3 + C_2)(C_3 + C_2)2C_1^2$	$\beta =$	$\sqrt[4]{K_{g2}/4EI}$	$e_3 =$	$\cos(\mu\beta L)\sinh(\mu\beta L)$
$C_1 =$	$\sin(v\beta L)\sinh(v\beta L)$	$C_2 =$	$\sin(v\beta L)\cosh(v\beta L)$	$e_4 =$	$\cos(\mu\beta L)\cosh(\mu\beta L)$
$C_3 =$	$\cos(v\beta L)\sinh(v\beta L)$	$C_4 =$	$\cos(v\beta L)\cosh(v\beta L)$	$\mu =$	X/L
$e_1 =$	$\sin(\mu\beta L)\sinh(\mu\beta L)$	$e_2 =$	$\sin(\mu\beta L)\cosh(\mu\beta L)$	$\nu =$	ℓ / L

6-5-Allowable values

Allowable values are determined in accordance with this clause.

1-structural steel

Allowable stresses of structural steels should be in accordance with AISC codes.

Allowable displacement and curvatures

1-1-design deflection values of members should not exceed the following values:

- beams of steep roofs $L/200$
- floor beams $L/300$
- pipe pile beams $L/300$
- the floor beams of the retainers (supports) of equipments $L/450$ (manufacturer advises should be considered)
- cantilever beams $L/400$
- support beams of overhead cranes (vertical, under the maximum wheel load) $L/800$
- support beams of overhead cranes (horizontal, under the maximum wheel load) $L/1600$
- Horizontal frames $H/300$ (in which L is beam span and H is frame height)
- In any situation, the deflection of steel structures' members should be in accordance with "UBC" (table D-16) and "AISC" (section 1.13) codes.

1-2-joint

- fabric steel joints should be bolts, nuts or weld joints
- the thickness of gusset plates should not be below 8 mm

2-reinforced concrete

The allowable stresses of bars and concreters should be in accordance with ABA or ACI 318 codes.

2-1 concrete resistance

The minimum required compressive resistances are as follows:

- for water pools $f_c \geq 28.1 \ \ N/mm^2$
- for prefabricated concrete supports of pipes $f_c \geq 25 \ \ N/mm^2$
- for structures, foundations, pavements, basins and other concrete structures $f_c \geq 21.1 \ \ N/mm^2$
- for ducts and fireproof concrete $f_c \geq 18 \ \ N/mm^2$
- for light concrete $f_c \geq 18 \ \ N/mm^2$

In anti sulfate concretes, the minimum amount of cement should not reach below $310 \ kg/m^3$

In normal concretes, the minimum amount of cement should not reach below $350 \ kg/m^3$

2-2-reinforcing bar

a) deformed bar

Deformed bars should be within grade 60 (the minimum yield stress $f_y = 414 N/mm^2$) in accordance with ASTM615 or other related standards.

b) normal carbonic bar

Normal bars should be within grade 40 (the minimum yield stress $f_y = 276 N/mm^2$) in accordance with ASTM615 or other related standards.

c) welded bar

Welded bars should be within grade 70 (the minimum yield stress $f_y = 485 N/mm^2$) in accordance with ASTM A496 and A497 standards or any other related standards provided that employer consent be considered.

2-3 bracing bolts, plates and steel shapes for fitting

The material of bracing bolts, plates and steel parts for embedding purposes should be in accordance with ASTA A36 or other related materials provided that employer consent be considered.

2-4-bolts

The bolts of structural fixtures should be in accordance with ASTM A325 or other related standards.

In secondary joints, bolts should be in accordance with ASTM A307 Grade A or other related standards.

Normal nuts which are in accordance with ASTM A563 or other related standards could be employed.

Washers should be in accordance with ASTM F436 or other related standards.

The allowable stress of other members should be compatible with the standard which is referred by employer.

Note:

In order to check the tensile stress of bolt, use f_t

If a bolt is under tensile and shear stresses at the same time, its safety should be controlled as follows:

a) $\tau \le f_s$

b) $f_{ts} = 1.4 f_t - 1.6\tau$, $\sigma \le \text{Minimum}(f_t, f_{ts})$

Where;

τ : is shear stress of bolt

σ : is tensile stress of bolt ($\sigma = R_b / A_r$)

f_s : is allowable shear stress of bolt generating due to shear force

f_t : is allowable tensile stress of bolt generating due to shear force

f_{ts} : is allowable tensile stress of bolt generating due to join effects of shear and tensile forces $f_{ts} \le f_t$

3-Shear force of bolt is derive as product of cross section area and f_s and 0.75.

Chapter 7

Seismic Design and Safety Control of Rectangular Culverts

7-1-Operational Level

Table 7-1 describes culvert status in the maximum design earthquake state

Table 7-1 necessary requirements to be taken into account for seismic design of each part of rectangular culvert

Required condition	Culvert part
Bending angle and pulling out length should be within a range in which soil and sand could not penetrate inside	Culvert and manhole connection
Bending angle and pulling out length should be within a range in which soil and sand could not penetrate inside Culverts which are joined using strong prefabricated fixtures, should maintain the minimum required flow capacity even in the case of fixture loose and deformations due to unsymmetrical settlements	Connections between culverts
The stress intensity of all components should be considered at ultimate limit in order to prevent culvert collapse In the case of open excavation operations, flow block due to liquefaction of embankment soil should be avoided	Main body of culverts

7-2-Design Trend

1- The following considerations should be taken into account in seismic design of culverts:
  1-1-culver and manhole connection
  1-2-connections between culverts
  1-3-cross sections (normal plate of pipe axis)
  1-4-axial section (section which includes pipe axis)
  1-5-uplift and sagging of pipe body
2- Preventive measures against earthquake

In this section, wherever we speak about rectangular culvert, we mean a culvert with quadrangular or rectangular section which is manufactured using reinforced job mix concrete or prefabricated parts joined to each other using bolts and nuts or other proper fixtures. This section covers open culverts too.

The items which should be controlled are in accordance with table 7-2.

Table 7-3 shows that seismic design is not necessary for other lines

Fig. 7-2 Items to be controlled in the rectangular culverts of the main pipeline

Ground susceptible to (FL 1.0) liquefaction			judgment about liquefaction (FL value)	Ground changes, sharp bend and so on	Steep ground	Axial strength (resistance)		Cross section strength (resistance)		connections between culverts		Culvert and manhole connection		Items to be controlled	Structure type
(due to ground settlement)		(permanent strain)			(permanent strain)					(due to input movement)		(due to input movement)			
Slip out length	Bend angle	Slip out length		Slip out length	Slip out length	Stress intensity	Bearing capacity	Stress intensity	Bearing capacity	Slip out length	Bend angle	Slip out length	Bend angle		
D	D	D	D	A/D(*3)		A(*1)	D(*1)	A(*1)	D(*1)	A/D		A/D	A/D	Job mix	Rectangular culvert
D(*4)	D(*4)	D(*4)	D	A/D(*3)	D(*2)	A/D(*6)		A(*1)	D(*1)	A/D(*7)	A/D(*7)	A/D	A/D	prefabricated	

1*: frame analysis should be employed.

2*: in the case of using no axial bracing.

3*: this instruction offers no design method. Therefore, other analysis like dynamical analysis should be employed.

4*: Since this instruction offers no design method, therefore in the cases where there is axial bracing in joint other analysis like dynamical analysis should be employed.

5*: Since this instruction offers no design method, therefore for job mix concrete other analysis like dynamical analysis should be employed.

6*: in axial bracing tensile stress should be controlled

7*: instead of checking bending angle or slip out length, the opening value and tensile stress of bracings should be controlled.

A: Allowable stress design; D: ductile design; A/D: both allowable stress and ductile designs should be carried out.

Table 7-3 Items to be controlled in the rectangular culverts of other lines

Ground susceptible to (FL 1.0) liquefaction			judgment about liquefaction (FL value)	Ground changes, sharp bend and so on	Steep ground	Axial strength (resistance)		Cross section strength (resistance)		Joins between culverts		Culvert and manhole join		Items to be controlled	
(due to ground settlement)		(due to permanent strain)			(permanent strain)					(due to input movement)		(due to input movement)		Structure type	
Slip out length	Bend angle	Slip out length		Slip out length	Slip out length	Stress intensity	Culvert stress	Stress intensity	Bearing capacity	Slip out length	Bend angle	Slip out length	Bend angle		
			A							A		A	A	Job mix	Rectangular culvert
			A							A		A	A	prefabricated	

A: Allowable stress design; D: ductile design; A/D: both allowable stress and ductile designs should be carried out.

Note:

1-Basically, this is the soil section of the considered site which should be used for seismic design purposes.

2-In the displacement of response method, when ground displacement is converted to an external force, it would be necessary to use the reaction factor of underneath layer in horizontal direction i.e. k_h. In order to calculate the reaction factor of the underneath layer refer to the methodology described in manholes section. The equivalent width of foundation, B, to be used for calculating the value of k_h, is similar to the described comments in the relation (6-3). In prefabricated culverts, B should be applied per length unit. In job mix culverts it could be extend up to 10 m.

3-In the displacement of response method, the increase rate of α in short loading condition should not be considered for k_h. Also the decrease rate of loading of the liquefied ground should not be considered for k_h.

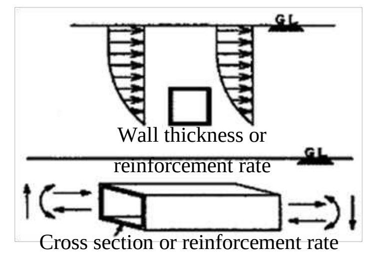
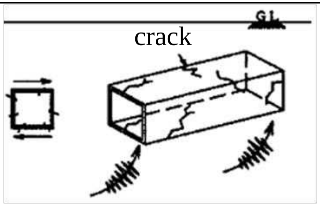
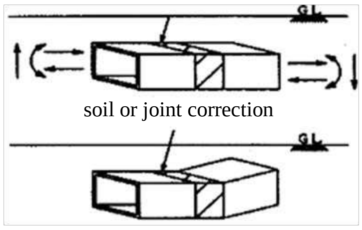
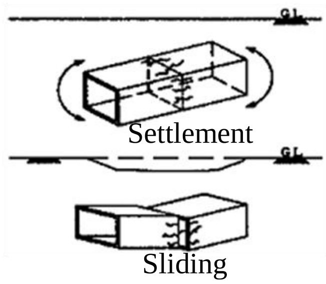
4-In vertical section, the intensity of stress should be checked for both normal and seismic design and load decrease rate in the liquefied ground should not be considered for k_h.

5-In rectangular culverts, in order to compute the thickness of members and bar laying parameters, first of all the displacement of response method should be implemented in vertical section at the risk levels 1 and 2 and then the distribution of bars in axial section should be determined. In prefabricated culverts, if a barrier is installed in axial direction the members of this barrier should be checked. Correction factor (decrease) should be applied when stress is controlled in axial direction.

6-The seismic design of open culvert should be carried out similar to culverts with no upper member.

7-Rectangular sections are vulnerable to liquefaction. If appropriate preventive measures are prepared, one can neglect liquefaction potential in calculations.

Table 7-4 anti seismic action and seismic design method (for rectangular culverts)

seismic design method				typical ant seismic actions and seismic design patterns		typical damage forms	section
ground settlement	ground permanent strain	response of displacement					
		wave length	S_V				
–	–	–	o	Relative displacement towards depth			culvert
–	o (to be checked)	o	–	axial force			
–	–	o	o	shear force	Flexible joint (axial, shear, bending) 		joint
–	–	o	o	bending			
o	–	–	–	settlement			

7-3-Calculations Trend (methods, calculation model and foundation)

7-3-1-seismic design of joints

Seismic design of joints should be carried put separately for culvert and manhole connection as well as connections between culverts.

If the considered site has specific conditions like the case in which we deal with a ground susceptible to liquefaction, a ground with no liquefaction potential but with sharp slope, sharp bend along path and other conditions, seismic design should be carried out regarding the following matters:

1-issues to be considered in calculations:
- 1-1-ground movement effect
- 1-2-liquefaction effect
- 1-3-slope effect
- 1-4-sharp bend effect

2-joints to be seismic designed and to be safety controlled:
- 2-1-manhole and culvert connections
- 2-2-connections between culverts

1-Here, "manhole and culvert connection" means a joint which is wider than culvert. Therefore, access to the manhole installed upon culvert is impossible. If culvert is made on a ground susceptible to liquefaction the length of mould for in-situ position should be longer in order to overcome unsymmetrical settlement.

1-1-In order to control wave effect, bend angle as well as pulling out length should be checked in manhole and culvert connections. In connection s between culverts, the inspection of bending angle could be neglected for both in-situ and prefabricated cases.

1-2-In order to control liquefaction effect, the pulling out length due to ground permanent strain should be checked in manhole and culvert connections. In connections between culverts the following issues should be controlled:

- the pulling out length due to ground permanent strain
- bending angle due to settlement
- pulling out length due to settlement

1-3-Pulling out length should be controlled in manhole and culvert connections as well as connections between culverts.

1-4- In the cases where a joint is placed in a section with sharp bend, the pulling out length should be controlled in both manhole and culvert connections and connections between culverts.

2-

2-1-manhole and culvert connection

a) bending angle due to wave effect

Bending angle should be derived from the relation (6-4) similar to pipes with tongue and groove joint.

b) Pulling out length due to wave effect

For in situ condition, the pulling out length of conduit from manhole should be implemented considering the total length of block.

$$\left|U_j\right| = u_0 \times \overline{uj} \qquad (7\text{-}1)$$

$\left|U_j\right|$: Telescopic length (m) (expansion and contraction)

u_0: is relative displacement in axial direction in the case that beam is considered as an infinite continuous beam

$$u_0 = \alpha_1 \times U_a \qquad (7\text{-}2)$$

Where:

U_a: is horizontal displacement of ground in axial direction (m)

$$U_a = \frac{1}{\sqrt{2}} \times U_h \qquad (7\text{-}3)$$

U_h: is horizontal displacement of ground in rectangular culvert (m)

$\overline{uj}$: is joint displacement factor

$$\overline{uj} = \frac{2\gamma_1 \times \left|\cosh\beta_1 - \cos\gamma_1\right|}{\beta_1 \times \sinh\beta_1} \qquad (7\text{-}4)$$

$$\alpha_1 = \frac{1}{1 + (\frac{\gamma_1}{\beta_1})^2} \qquad (7\text{-}5)$$

$$\beta_1 = \ell \times \sqrt{\frac{K_{g1}}{E \cdot A}} \qquad (7\text{-}6)$$

$$\gamma_1 = \frac{2\pi\ell}{L'} \qquad (7\text{-}7)$$

Where:

E : is the modulus of elasticity of rectangular culvert (kN/m^2)

A : is culvert cross section area (m^2)

ℓ : is the frame length of rectangular culvert (m)

K_1 : is ground stiffness factor per culvert length unit in axial direction

γ_{teq} : is converted specific weight in surface layer

If in a prefabricated culvert no axial bracing is considered, the relation (6-9) should be applied for tongue and groove joint considering the effective length of the prefabricated culvert.

c) liquefaction effect (pulling out length due to ground permanent strain)

The behavior of continuous culvert in both in situ and prefabricated cases is not predictable in liquefied ground. Therefore, the pulling out length due to ground permanent strain should be checked using dynamical analysis or any other appropriate method. In the case of prefabricated culvert with no axial bracing, the relation (4-11) should be applied.

d) steep ground effect (pulling out length due to ground permanent strain)

If a prefabricated culvert with no axial bracing is installed on steep ground with no liquefaction potential the pulling out length is obtained by substituting ground permanent strain (section c of table 6-5) in the relation (4-11). For job mix condition or prefabricated block with axial bracing as far as the block behaves as an integrated structure against settlement, we can neglect ground steep effect.

e) sharp bend effect (pulling out length)

If a manhole is located in a region with sharp bend, at first the construction pulling out length should be considered. Then, by deducting the obtained value from allowable pulling out length, the final pulling out length is controlled.

2-2-Connections Between Culverts

a) pulling out length due to wave effect

In the case where the join of the in situ conduit is located in manhole span, the pulling out length is derived from the relation (7-1). For prefabricated culvert with no lateral bracing it is derived from the relation (6-9) similar to pipe with tongue and groove join.

b) steep ground effect (pulling our length due to ground permanent strain)

Similar to section 2-1d, if a prefabricated culvert with no axial bracing is located on steep ground with no liquefaction potential the pulling out length is obtained by substituting ground permanent strain (section c of table 5-6) in the relation (6-11). For job mix condition or prefabricated block with axial bracing, as far as the block behaves as an integrated structure against settlement, we can neglect ground steep effect.

c) sharp bend effect (pulling out length)

Refer to section 2-1-e

Note:
If a culvert is fabricated using prefabricated blocks with no axial bracing and by open excavation method and it intersects the boundary layer of soft and hard layers of ground, boundary effect is small due to existence of embankment. Therefore, we can neglect pulling out length control. For continuous type, (job mix or prefabricated with axial bracing culverts) it has not been defined how to consider the effective length of ℓ . Therefore, dynamical analysis or any other related method should be employed.

7-3-2-Seismic Design of Rectangular Culvert Body

The following investigations should be carried out for seismic design of conduit body:
1-investigating vertical section (normal to axis)
2-investigating axial section

1-investigating vertical section (normal to axis)

In a rectangular culvert with a relative small cross section the effect of vertical section (normal to axis) is negligible. For this, we can neglect vertical section control. In a rectangular culvert with a relative large cross section the effect of surface shear force (shield) is relatively high. For this, vertical section should be controlled. In the dynamical model shown in Fig. 7-1 the relative displacement at depth as well as surface shear force for upper and lower stories and side wall should be considered.

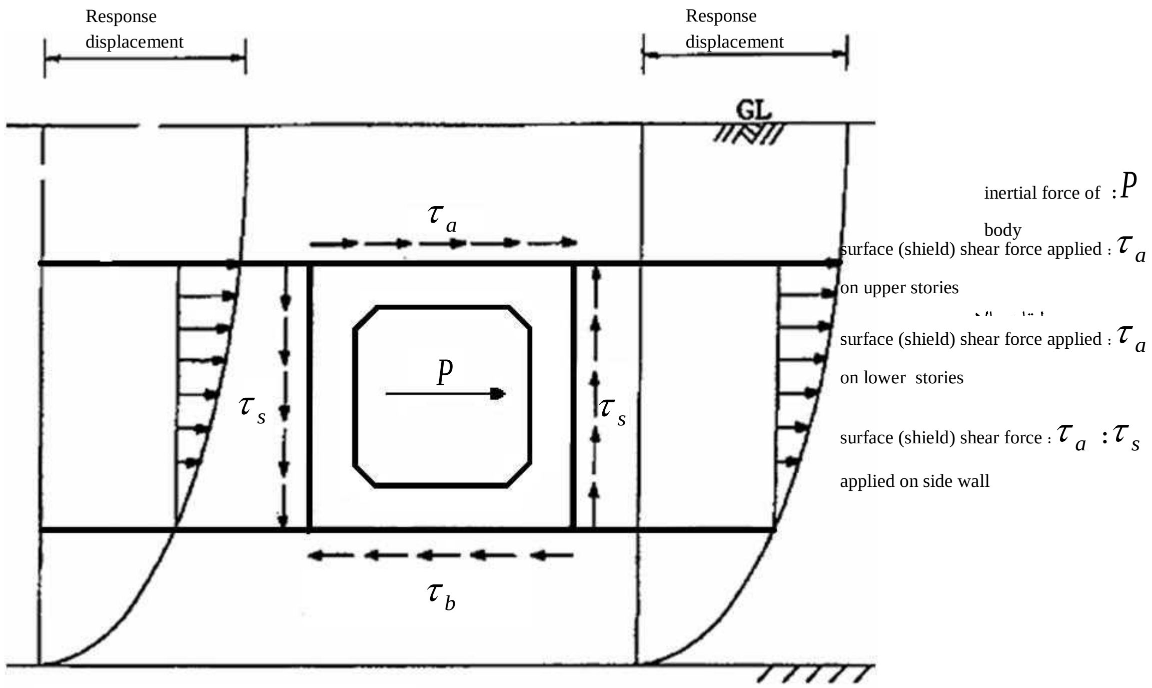
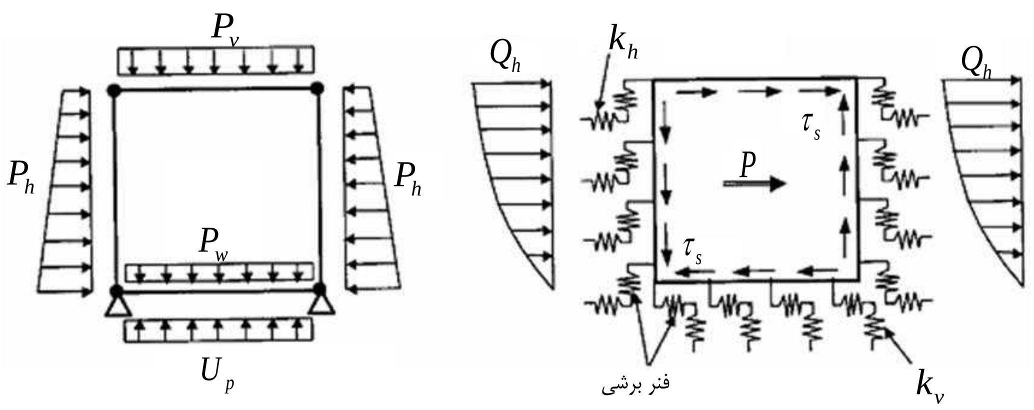


Figure 7-1 forces applying on the vertical section of a rectangular culvert

Fig. 7-2 shows a typical computational model. In analytical model a combination of the fixed loads of normal condition (water and soil pressures), seismic force and surface shear force should be employed.



buoyancy force : U_p

ground elasticity in horizontal direction : k_h

seismic force : Q_h

ground elasticity in vertical direction: : k_v

surface shear force : τ_s

water pressure + soil pressure : P_h
in horizontal direction

inertial force for structure : P

net weight: P_w

water pressure + soil pressure : P_v
in vertical direction

Figure 7-2 computational model for rectangular culvert

if the weight of structure is almost equal to the weight of soil, we can neglect the inertial force of culvert body, P. In the case that the inertial force should be considered relation (7-8) should be used:

$$P = K_H \times W_b \qquad (7\text{-}8)$$

Where;

K_H : is design seismic coefficient in horizontal direction with respect to risk level

W_b : is the weight of rectangular culvert (kg)

P : is the inertial force of culvert body (N)

2-axial section investigation

The axial force of culvert section should be calculated through the displacement of response method and the quality of bar distribution should be determined based on the result of this investigation. The internal force of axial section should be corrected due to the incline of force effect. If we consider the length of standard block 20 m the following equations show how the force to be corrected:

$$\xi_1 = 900 \cdot L^{-1.8}$$

$$\xi_2 = 1.16 \cdot L^{-3.8} \times 10^6 + 890 \cdot \lambda_2^{3.7}$$

$$\xi_3 = 5.31 \cdot L^{-3.7} \times 10^5 + 145 \cdot \lambda_3^{2.9} \qquad (7\text{-}9)$$

In which;

ξ_1, ξ_2 and ξ_3 :are the correction factors of section forces in which the indexes 1, 2 and 3 respectively stand for axial section, axial section in horizontal plate and axial section in vertical plate.

λ_1 and λ_2 ; are relative stiffness ratio ($1/m$)

If the length of block be decreased, the correction factor is increase. In seismic design for the risk level 1 if the correction factor is below 0.1 its value should be considered 1. For the risk level 2 the actual obtained value should be used.

In the prefabricated type with axial bracing the length of equivalent block is increased and the pulling out length in manhole joint tends to be increased. Axial bracings should be determined with respect to probable damages like unsymmetrical settlement of culvert due to liquefaction, subsequent settlements as well as economical and operational considerations.

If the length of block or the length of prefabricated blocks which have been axially connected to each other is close to ground wave length the occurrence of resonance phenomenon is possible. Therefore, its better that the wave length of rectangular culvert is not the same as ground wave length.

7-4-Acceptance Criteria

The results of the seismic design of rectangular culvert should be controlled through the following method:

1-Design condition for the risk level 1: design condition should be considered allowable stress or ultimate operational limit.

2-Design criterion for the risk level 2: design condition should be considered ultimate limit condition.

3-Anti seismic actions

- 3-1-displacement damping
- 3-2-supplying sufficient strength in vertical section (through considering wall thickness and main bar lay)
- 3-3-supplying sufficient strength in vertical section (bar distribution, block length, axial bracing)

1- Safe operation at the risk level 1 condition should be as follows:

- 1-1-The necessary condition of a joint is that it should be water sealed. The value of design condition is determined via adding a safety margin to the maximum allowable safety factors of materials. To act within a safety margin, steps to be taken as per conduit with tongue and groove join.
- 1-2-The allowable stress of the materials of culvert body should be the same as the design condition value in order to avoid settlement due to crack.

2-the expected efficiency at the risk level 2 should be as follows:

- 2-1-the necessary condition of a joint is to prevent penetration of water and sand. The maximum safety factor of materials should be proportional with design condition.
- 2-2-For culvert body, the disrupt strength of materials should be the same as the design condition value in order to avoid the collapse of conduit section.

3-Anti Seismic Actions

- 3-1-Displacement damping should be considered for culvert and manhole connections as well as connections between conduits and joins employed in areas with difficult environmental conditions like sharp bending. In order to decrease axial stress due to ground displacement, in manhole and culvert connections as well as connections between culverts, expansion joint should be used.

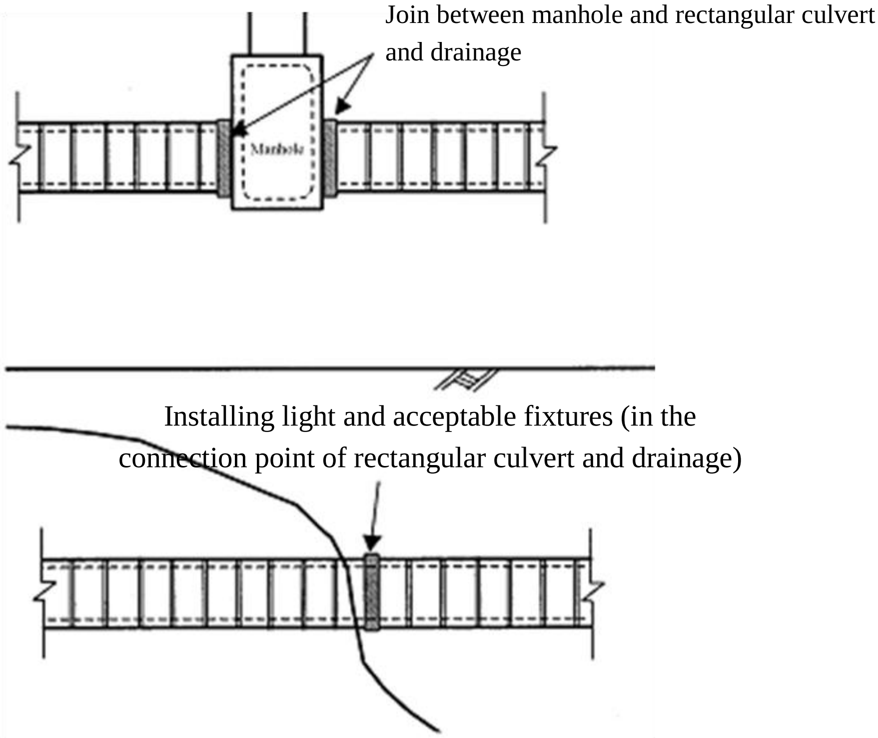


Figure 7-3 anti seismic actions for rectangular culvert

3-2-The thickness of wall and its reinforcement rate should be evaluated in vertical section in order to make sure about its sufficient strength. Basically, the main element (wall thickness and reinforcement rate) is derived from the calculations of vertical section. But in the case that the strength in axial section is insufficient the initial design approach should be changed.

3-3-In axial section the required strength should be obtained through increasing bar distribution rate or determining block length with respect to the length of axial bracing. Incensement of the rate of bar distribution may be uneconomic for this, it's better to reform design trend in vertical section and to recalculate wall thickness and its reinforcement rate. If the length of blocks or bracing is too long this may result in increasing stress or displacement rate. In this state, employing shorter block is recommended in order to damp displacement rate and decrease axial stress.

7-5-Continuous Conduits

– A continuous conduit is a conduit which behaves as an integrated part whether or not it includes joints.

– The required performance of a continuous conduit is similar to that of a pipe with tongue and groove joint.

7-5-1-Design Trend

In the seismic design of continuous conduits the following issues should be considered with respect to pipe material specifications:

1-the following point should be considered for seismic calculations:

1-1-pipe and manhole connections

1-2-connections between pipes

1-3-vertical section (normal plate of pipe axis)

1-4-axial section (section which includes pipe axis)

1-5-uplift and sagging of pipe body

2-preventive measures against earthquake

In this section continuous conduit means a pipe which is connected via adhesive materials (joints), flange and screw or bolt joint as per the following pipes.

In this type of pipes manhole spans behaves as a continuous line.

1-PVC pipe with adhesive joint

2-DCIP pipe employed for under pressure elements along with a joint which is validated by designer

3-steel pipe with rigid joint like weld joint or plate (flanged) joint

1-

Fig. 7-5 shows items to be controlled in design procedures for the main transmission line. Fig. 7-6 shows this for other lines.

- If the influence of liquefaction on pipe is expected, anti seismic design steps should be taken

- In order to calculate pulling out length of joint, live load, internal pressure, temperature variations, available settlement and other related factors should be considered due to the fact that they generate tensile force.

Table 7-5 shows the items to be controlled in DCIP and steel pipes.

Table 7-5 items to be controlled in continuous pipes of the main line

ground susceptible to liquefaction (F_L 1.0)			(F_L value) judgment about liquefaction	ground stiffness changes, sharp bending and so on	steep ground	strength in axial direction		strength of cross section		connections between conduits		conduit and manhole connections		items to be controlled
due to ground settlement		(due to ground permanent strain)			(due to ground permanent strain)					(due to input movement)		(due to input movement)		structure type
slip up length	bending angle	slip up length		slip up length	slip up length	stress intensity	pipe strain	stress intensity	bearing capacity	slip up length	bending angle	slip up length	bending angle	
D		D	D			A/D						A/D	A/D	PVC (rubber ring)
			D			A/D				A/D	A/D			DCIP
			D			A/D	A/D			A/D	A/D			steel pipe

A: allowable stress design; D: ductile design; A/D: both allowable stress and ductile designs should be carried out

Table 7-5 items to be controlled in continuous pipes of other lines

ground susceptible to liquefaction (F_L ١/٠)			(F_L value) judgment about liquefaction	ground stiffness changes, sharp bending and so on	steep ground	strength in axial direction		strength of cross section		connections between conduits		conduit and manhole connections		items to be controlled
due to ground settlement		(due to ground permanent strain)			(due to ground permanent strain)					(due to input movement)		(due to input movement)		structure type
slip up length	bending angle	slip up length		slip up length	slip up length	stress intensity	pipe strain	stress intensity	bearing capacity	slip up length	bending angle	slip up length	bending angle	
			A									A	A	PVC pipe with adhesive joint
			A											DCIP
			A											steel pipe

A: allowable stress design; D: ductile design; A/D: both allowable stress and ductile designs should be carried out

7-5-2-Calculations Trend

7-5-2-1-joint design

The seismic design of continuous pipe should be carried out considering the specifications of pipe material, site condition, liquefaction possibility and the following issues: 1-the following consideration should be taken into account in calculations 1-1-ground movement effect 1-2-liquefaction effect 2-The following joins should be seismic designed and controlled: 2-1-manhole and pipe connections 2-2-connections between pipes

Required preventive measures should be prepared for PVC pipe, which is installed in a ground susceptible to liquefaction phenomenon, in order to encounter with liquefaction risks. If the risk of lateral dispersion due to liquefaction is potentially high, the pulling out length due to ground permanent displacement as well as ground settlement should be taken into account.

In the join point of manhole and pipe:

a) In PVC pipes the bending angle of manhole and pipe joint should be calculated similar to the pipe with tongue and groove joint.

b) In PVC pipes the pulling out length of pipe from manhole due to ground movement should be calculated similar to rectangular culvert case (relation 7-1).

Ground stiffness factor is derived from relation (7-10) with respect to pipe shape:

$$K_1 = C_1 \cdot G_s \qquad (7\text{-}10)$$

In which;

K_1 : is ground stiffness factor

C_1 : This coefficient is 1.5 for PVC pipes

G_s : is the modulus of shear stiffness (kN/m^2) (refer to relation 6-22)

c) In PVC pipes, the pulling out length of pipe from manhole due to ground permanent displacement is derived from relation (7-11):

$$\delta = \frac{\tau' \cdot \pi D \ell}{2EA} \qquad (7\text{-}11)$$

Where;

δ : is pulling length of manhole and pipe connection

τ' : is the maximum frictional stress of liquefied ground ($0.001 N/mm^2 = 1.0 kN/m^2$)

D : is pipe outside diameter (m)

ℓ : is the length of pipe with adhesive joins between manholes (m)

E : is the modulus of elasticity of pipe (kN/m^2)

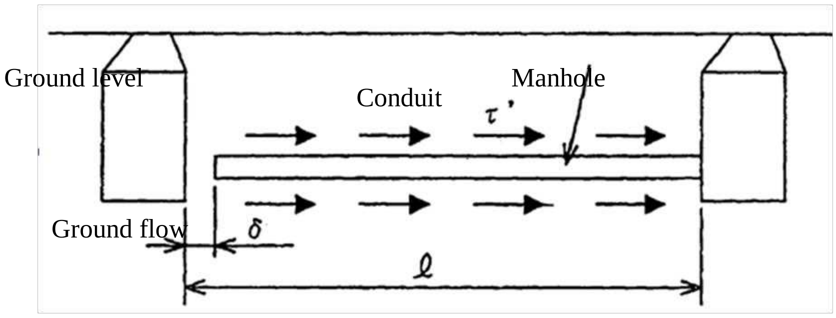


Figure 7-4 the pulling out length of pipe and manhole connection due to liquefaction (for PVC pipe with adhesive joint)

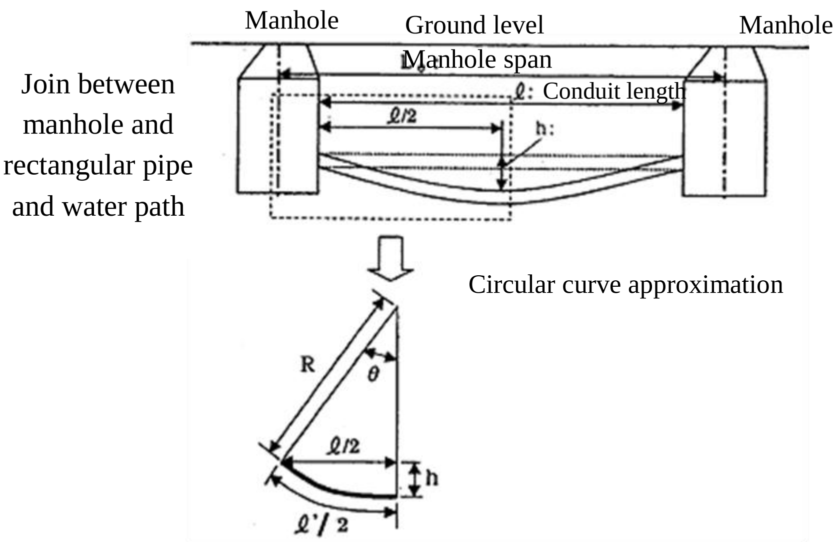


Figure 7-5 the pulling out length and ground settlement due to liquefaction (for PVC pipe with adhesive joints)

$$\delta = \frac{\ell'}{2} + \frac{\ell}{2}$$

$$\frac{\ell'}{2} = R \cdot \theta$$

$$\theta = \sin^{-1}\left(\frac{\ell/2}{R}\right)$$

$$R = \frac{h^2 + (\ell/2)^2}{2h} \qquad (7\text{-}12)$$

Where;

δ : is the pulling out length of pipe and manhole connection

ℓ : is the length of adhesive joint pipe between manholes (m) (is almost equal to manhole span L_0)

h : is ground settlement (m) (to obtain h, refer to detailed descriptions of the relation 6-14)

7-5-2-2-Seismic Design of Continuous Conduit Body

Pipe body should be controlled in axial direction with respect to the specifications of pipe material.

Vertical section control (normal to axis) could be neglected.

1-The method of calculating axial stress in PVC adhesive joint pipe is similar to that of PVC pipe with tongue and groove joint with plastic ring.

2-The method of calculating axial stress of under pressure DCIP and steel pipes is similar to that of the joint of urban water supply pipe.

7-5-3-Allowable Values

The allowable response values of components should be in accordance with the initial design values including the regulations and instructions prepared by the manufacturers of components for all structures.

7-5-4-Acceptance Criteria

The results of the seismic calculations of continuous conduits should be checked as follows:

1-The design condition for the risk level 1: design condition for the risk level 1 should be allowable stress or ultimate operational limit

2-The design condition for the risk level 2: design condition for the risk level 2 should be ultimate limit.

3-anti seismic actions

Anti seismic actions should be considered from the following matters point of view:

3-1-displacement damping

3-2-supplying sufficient strength for vertical section

1-Safe operation at the risk level 1 condition should be as follows:

The necessary condition of a joint is that it should be water sealed. The value of design condition is determined via adding a safety margin to the maximum allowable safety factors of materials. To act within a safety margin, steps to be taken as per conduit with tongue and groove join. The allowable stress of the materials of pipe body should be the same as the design condition value in order to avoid settlement due to crack.

2-the expected efficiency at the risk level 2 should be as follows:

The necessary condition of a joint is that it should prevent the penetration of water and sand. The maximum safety factor of materials should the same as design condition value. For pipe body, the disrupt strength of materials should be the same as the design condition value in order to avoid the collapse of pipe section. Displacement damping should be considered for longer allowable length joints in order to damp displacement as much as possible. In order to make sure about safety in axial direction, the strength of material and pipe type should be considered.

Chapter 8

Seismic Design and Safety Control of Shield Tunnels of Sewage System

8-1-Shield Tunnels and Their Performance

– In loose grounds, the use of shield tunnel for sewage transmission purposes is one of the design elements of that system.

– The body of these tunnels with longitudinal and radial joints should meet necessary performance requirements at related risk levels.

– Tunnel and manhole join should be seismic designed and safety controlled too.

Table 8-1 shows the idealistic performance of different elements of a shield tunnel.

Table 8-1 required performance of different elements of a shield tunnel

Elements of shield tunnel	Requirements
Manhole and conduit connections	Bending angle and pulling out length should be within a range in which penetration of sand and water is avoided.
Primary coating	Ring joints should not be broken and loose of joints should lie within a range in which resealing operations is possible
Secondary coating	A coating with or without reinforcing bars, even in the case of appearance of cracks there should be no barrier against flow

8-2-Design Trend

The following items should be taken into account in seismic design regarding the specifications of pipe material:

1-items to be considered in seismic design:

1-1-axial compression of pipe

1-2-axial tension of pipe

1-3-cross section(normal plate of pipe axis)

1-4-connection between manhole and conduit

1-5-uplift of the main body (conduit)

Coated tunnel should be designed for the following items:

1-segments (reinforced concrete, steel and composite segments) and their coatings

2-fixtures (connections between joints and between joint and structure)

The main policy of the seismic design of shield tunnel is that each part of coating should lie inside elastic range at the risk level 1 and at the same time some elements like joint ring should not be disrupted. Ring joints should be opened up to a range in which emergency repair at the risk level 2 is possible on order to avoid penetration threat.

In designing the main pipeline the items indicated in table (8-2) should be considered. For other lines refer to table (8-3).

In shield tunnels segments are fastened to each other by screws and nuts. Therefore, when a segment is subjected to axial compressive force, the stiffness of conduit would be the same as that of the segment. Moreover, when shield tunnel is subjected to axial compressive force, the concentration of load is on joint. For this, design should be carried out for both axes.

Also, for special coated conduits like a conduit with sharp bend along its path or a conduit without secondary coating, the analytical methods shown in table (8-4) are applicable.

Table 8-2 items to be controlled in the shield tunnels of the main pipeline

Ground susceptible to liquefaction (F_L 1.0)			Judgment about liquefaction (F_L value)	Ground stiffness changes, sharp	Steep ground	Strength in axial direction		Strength of cross section		Connections between conduits		Manhole and conduit connection		Items to be controlled	
(due to ground settlement)		(due to ground permanent strain)			(due to ground permanent strain)					(due to input movement)		(due to input movement)			
Slip out length	Bending angle	Slip out length		Slip out length	Slip out length	Stress intensity	Conduit strain	Stress intensity	Bearing capacity	Slip out length	Bending angle	Slip out length	Bending angle	Structure type	
A/D*	A/D*	A/D*	D	A/D*		A/D		A/D Frame analysis				A/D	A/D	Steel segment	Tunnel type
A/D*	A/D*	A/D*	D	A/D*		A/D		A/D Frame analysis				A/D	A/D	Concrete segment	

* Design trend has not been identified therefore; a trend which includes dynamical analysis should be employed

A: Allowable stress design; D: Ductility design: A/D: both allowable stress and ductility designs should be carried out

Table 8-3 items to be controlled in the shield tunnels of other pipelines

Ground susceptible to liquefaction (FL 1.0)			Judgment about liquefaction	Ground stiffness changes, sharp bend and so on	Steep ground	Strength in axial direction		Strength of cross section		Connections between conduits		Manhole and conduit connection		Items to be controlled	
(due to ground settlement)		(due to ground permanent strain)			(due to ground permanent strain)					(due to input movement)		(due to input movement)			
Slip out length	Bending angle	Slip out length		Slip out length	Slip out length	Stress intensity	Conduit strain	Stress intensity	Bearing capacity	Slip out length	Bending angle	Slip out length	Bending angle	Structure type	
			A									A	A	Steel segment	segment type
			A									A	A	Concrete segment	

A: allowable stress design

Table 8-4: List of analytical methods for shield tunnels

Analysis model	Analytical model type	Analysis methods categories
Dynamical analysis	Beam-spring model	3D analysis (axial, horizontal, vertical)
Dynamical analysis	Two dimensional FEM	
Displacement response	Beam with equivalent stiffness model	Axial (horizontal)
Displacement response or Dynamical analysis	Beam-spring model	
Dynamical analysis	Two dimensional FEM	
Displacement response	Approximate equations	vertical
Displacement response	Frame or homogenous ring model	
Displacement response or Dynamical analysis	Beam-spring model	
Dynamical analysis	Two dimensional FEM	

In next section, we recommend some items in order to remember you how to calculate the standard values of shield tunnels (straight conduit in homogenous ground). Also, Fig. 8-1 shows how to calculate the elasticity coefficient of conduits.

1-The standard segments of shield tunnel are selected in primary design step at normal/fixed condition. At first the segments should be seismic evaluated and then seismic preventive measures should be taken into account if necessary.

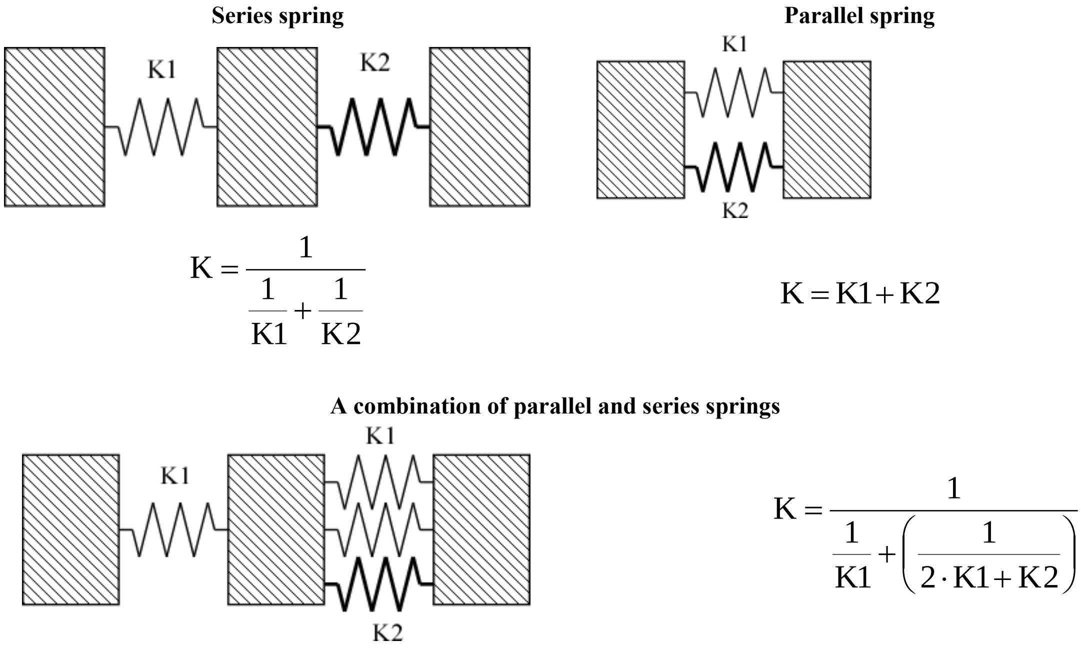
2-First of all, seismic evaluation should be carried out in axial direction since this is axial direction which has the most impact on design condition.

3-If the selected segments require main structural reforms, seismic values should be recalculated form normal/fixed condition point.

During inspection of axial direction, the equivalent stiffness of conduit is obtained from the stiffness of each section including segments, joint screw and so on. The equivalent stiffness varies along conduit length (Compressive or tensile.)

Considering each component of segment coating (segment, joint screw, washer, joint plate and so on) as a separate spring, the equivalent stiffness is obtained as the inverse elasticity coefficient of each component similar to total elasticity coefficient.

Fig. 8-1 shows how to convert the spring of each component to whole model.



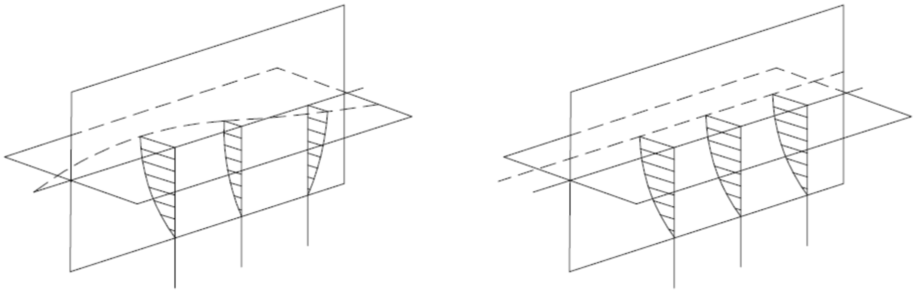
$$K = \frac{1}{\frac{1}{K1} + \frac{1}{K2}}$$

$$K = K1 + K2$$

$$K = \frac{1}{\frac{1}{K1} + \left(\frac{1}{2 \cdot K1 + K2}\right)}$$

Figure 8-1 the trend of calculating the elasticity coefficient of conduit

Fig. 8-2 and table 8-5 show the conceptual interpretation of converted equivalent stiffness.



Non uniform conduit affected by wave | Uniform conduit

Figure **8-2 the concept of equivalent stiffness conversion**

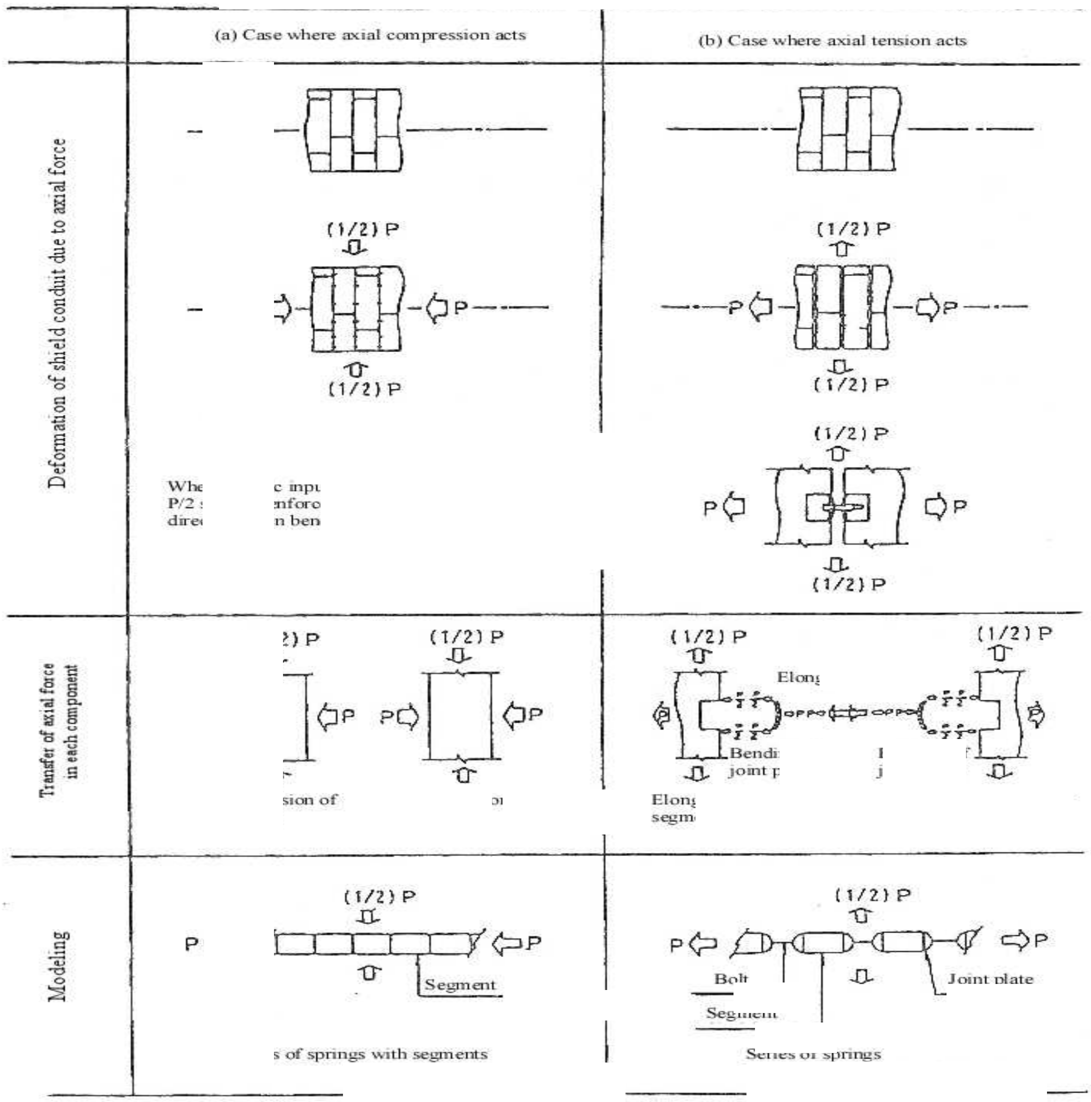


Table 8-5 the behavior of shield tunnel and evaluation of stiffness

1-If the secondary coating is non reinforced concrete, its stiffness is not taken into account in calculations while in the case where the secondary coating is reinforced concrete it should be converted and the thickness of segment should be increased with respect to the converted stiffness.

2-Phenomena like diffusion of waves entering from a conduit into earth, cut of wave propagation due to non uniformity of ground, friction between circumferential side and around ground have not taken into account yet but if a calculation method be offered for these phenomena the sectional force especially axial tension force should be decreased.

3-The calculations of vertical section should be carried out using frame model and operational and earthquake loads should be combined with each other. In the case of conduits with relative large diameters like shield tunnels the effect of shear force along circumferential side should not be taken into account.

4-In calculating cross section via response displacement method, the reaction factor of underneath layer in horizontal direction i.e. k_h , should be calculated through relation (8-1):

$$k_h = k_{ho}\left(\frac{B_h}{0.3}\right)^{-3/4} \quad (8\text{-}1)$$

$$B_h = \sqrt{B \times D} \quad (8\text{-}2)$$

Where;

B_h : is the width of converted load of foundation perpendicular to loading direction (m)

D : is conduit diameter (m)

B : is effective length of conduit (m) which corresponds to a length at which uniform deformation is happened.

In the case of employing standard segment the value of B could be 10 m.

5-The trend of seismic design of the vertical section of steel segment at the risk level 2 as well as the trend of investigating reinforced concrete coating has not presented in ultimate limit design method yet. Therefore, designer should define a method in which for example moment considers effective section as a full plastic section.

6-Generally, the depth of a shield tunnel is deeper than that of other conduits. Therefore, this type of conduit has sufficient strength against buoyancy force due to liquefaction. As far as the investigation of buoyancy force in shield tunnel concerns, rectangular conduit and beam-spring analytical model approaches could be used.

Section force and equivalent stiffness should be derived from the following relations:

$$P_h^C = \alpha_1^C \frac{\pi u_h}{L} (EA)_{eq}^C \quad (8\text{-}3)$$

$$P_h^T = \alpha_1^T \frac{\pi u_h}{L} (EA)_{eq}^T \quad (8\text{-}4)$$

$$P_v^C = \alpha_1^C \frac{\pi (u_h + u_v)}{L} (EA)_{eq}^C \quad (8\text{-}5)$$

$$P_v^T = \alpha_1^T \frac{\pi (u_h + u_v)}{L} (EA)_{eq}^T \quad (8\text{-}6)$$

$$M_h = \alpha_2 \frac{4\pi^2 u_h}{L^2} (EI)_{eq} \quad (8\text{-}7)$$

$$M_v = \alpha_3 \frac{4\pi^2 u_h}{L^2} (EI)_{eq} \quad (8\text{-}8)$$

$$Q_h = \alpha_2 \frac{8\pi^3 u_h}{L^3}(EI)_{eq} \qquad (8\text{-}9)$$

$$Q_v = \alpha_3 \frac{8\pi u_h}{L^3}(EI)_{eq} \qquad (8\text{-}10)$$

Where;

P_h^T and P_h^C : are respectively axial compressive and tension force due to wave propagation in horizontal plate (tf)

P_h^C and P_v^T : are respectively axial compressive and tension force due to wave propagation in vertical plate (tf)

M_h and M_v : are bending moment due to the propagation of wave respectively in horizontal and vertical plate (tf)

Q_v and Q_h : are shear force due to the propagation of wave respectively in horizontal and vertical plate (tf)

$(EA)_{eq}^T$ and $(EA)_{eq}^C$: are respectively the equivalent stiffness of axial tension and compression (tf) (obtained from relations (8-20) and (8-21)

$(EI)_{eq}$: is the equivalent stiffness of bending (tf) (obtained from relations (8-21)

u_h : is ground displacement in horizontal direction at the depth related to shield center point obtained from response displacement method (m)

u_v : is ground displacement in vertical direction at the depth related to shield center point (m) obtained by applying half of the wavelength of the horizontal direction of earthquake.

L : is earthquake wavelength (m) which is defined as the mean of the harmonic wavelength of surface layer and bedrock layer

α_1^C , α_1^T , α_2 , α_3, are the rate of strain transmission from ground to structure which is derived from relations (8-11) to (8-14)

$$\alpha_1^C = \frac{1}{1+(2\pi/\lambda_1^C L_i)^2} \qquad (8\text{–}11)$$

$$\alpha_1^T = \frac{1}{1+(2\pi/\lambda_1^T L_i)^2} \qquad (8\text{–}12)$$

$$\alpha_2 = \frac{1}{1+(2\pi/\lambda_2 L)^4} \qquad (8\text{–}13)$$

$$\alpha_3 = \frac{1}{1+(2\pi/\lambda_3^T L)^4} \qquad (8\text{–}14)$$

$$\lambda_1^C = \sqrt{\frac{K_{g1}}{(EA)_{eq}^C}} \qquad (8\text{–}15)$$

$$\lambda_1^T = \sqrt{\frac{K_{g1}}{(EA)_{eq}^T}} \qquad (8\text{–}16)$$

$$\lambda_2 = \sqrt[4]{\frac{K_{g2}}{(EI)_{eq}}} \quad (8\text{–}17)$$

$$\lambda_3 = \sqrt[4]{\frac{K_{g3}}{(EI)_{eq}}} \quad (8\text{–}18)$$

$$L_i = \sqrt{2 \cdot L} \quad (8\text{–}19)$$

K_{g1}, K_{g2}, K_{g3}: are ground reaction factor along axial direction and normal plate of horizontal and vertical directions

7-The equivalent stiffness of tunnel should be derived through the following relations:

$$(EA)^C_{eq} = E_S A_S \quad (8\text{-}20)$$

$$(EA)^T_{eq} = \frac{1}{(K_S / K_j) + 1} \times E_S A_S \quad (8\text{-}21)$$

In which;

$(EA)^C_{eq}$: is the equivalent stiffness of axial compression (tf)

$(EA)^T_{eq}$: is the equivalent stiffness of axial tension (tf)

E_S: is the modulus of elasticity of segment (tf/ m^2)

A_S: is cross section area of one ring of segment (m^2)

l_S: is the length of one ring (m)

K_S: is axial stiffness of one ring (tf/ m) derived from relation (8-22)

$$K_S = \frac{E_S A_S}{l_S} \quad (8\text{-}22)$$

K_j: is the axial stiffness of all rings of fixtures (tf/ m) derived from relation (8-23)

$$K_j = n k_j \quad (8\text{-}23)$$

Where;

k_j: is the axial stiffness of one joint ring (tf/ m)

n: is the number of the rings of fixtures per joint

8-The equivalent bending stiffness of tunnel is derived from relation (8-24):

$$(EI)_{eq} = \frac{\cos^3 \phi}{\cos\phi + (\pi/2 + \phi)\sin\phi} \cdot E_S \cdot I_S \quad (8\text{-}24)$$

$(EI)_{eq}$: is equivalent bending stiffness (tf/ m^2)

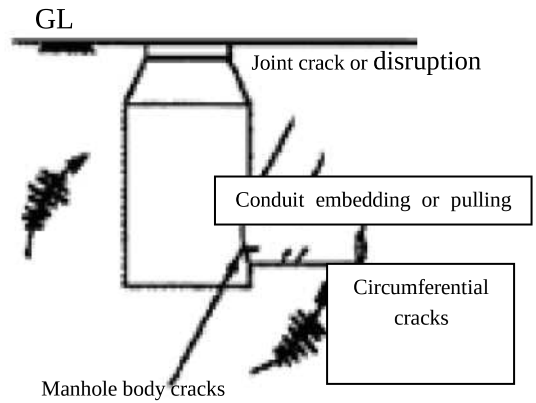
I_S: is the inertia moment of segment (m^4)

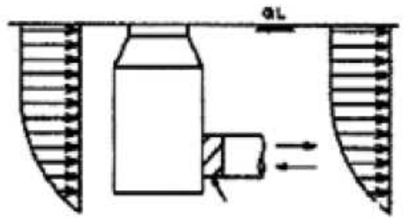
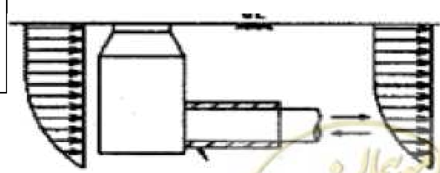
ϕ: is the angle between cross section center and neutral axis which is derived from relation (8-25)

$$\phi + \cot\phi = \pi\left(\frac{1}{2} + \frac{K_j}{E_S A_S / I_S}\right) \quad (8\text{-}25)$$

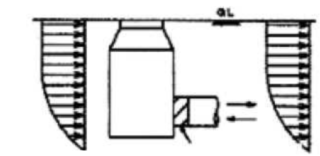
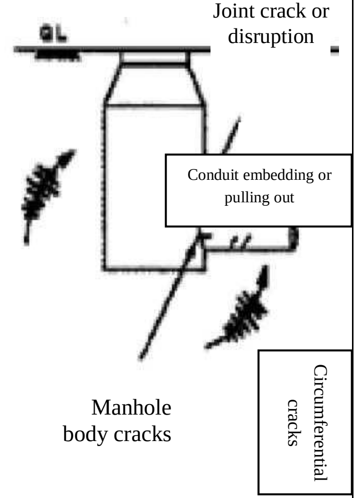
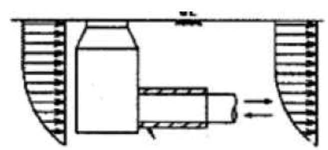
Seismic preventive measures identified in table (8-6) should be applied in the sections in which the obtained value is higher than allowable value.

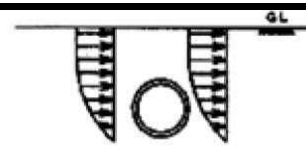
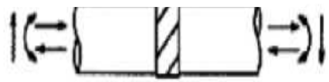
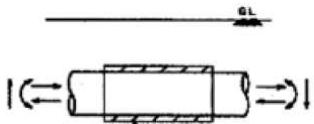
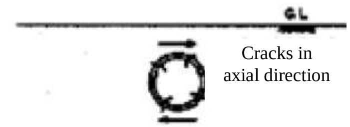
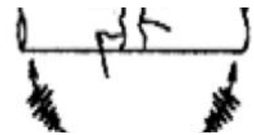
Figure 8-6 preventive measures and design method

Seismic design method				**Preventive measures and design inputs**		**Typical damages**	**section**
Due to ground settlement	**Due to ground permanent strain**	**Response displacement method**					
		L	S_V				
–	–	–	*O*	Relative displacement in vertical direction (bending)			**Conduit and manhole connections**

Seismic design method					Preventive measures and design inputs	Typical damages	section
Due to ground settlement	Due to ground permanent strain	Response displacement method					
		L	S_V				
–	–	–	–	Embedded length	 Fitting flexible joint (bending, compressive, tensile)  Fitting insulator layer (injection insulator materials like asphalt, silicon and so on)		

Seismic design method				Preventive measures and design inputs	Typical damages	section
Due to ground settlement	Due to ground permanent strain	Response displacement method				
		L	S_V			
-	*O*	*O*	*O*	Pulling out length		

Seismic design method				Preventive measures and design inputs		typical damage	section
Due to ground settlement	Due to ground permanent strain	Response displacement method: L	Response displacement method: S_V				
-	-	-	O	Relative displacement in vertical direction (bending)	 Fitting flexible joint (bending, compressive, tensile)		Conduit and manhole connection
-	-	-	-	embedded length			
-	O	O	O	Pulling out length	 Fitting insulator layer (injection insulator materials like asphalt, silicon and so on)		

-	-	-	O	Relative displacement in vertical direction	 Estimating part strength Flexible part fitting (if necessary) (axial force, bending force, compressive force)   Fitting insulator layer (injection insulator materials like asphalt, silicon and so on)	 Cracks in axial direction Circumferential cracks, (secondary coating)  Cracks in axial direction (secondary coating)	**Conduit body**
-	-	O	-	Axial force			
-	-	**O**	**O**	Shear force			
-	-	**O**	**O**	bending			

8-3-Calculation Steps

8-3-1-seismic design of joints

The input movement at the connection point between manhole and tunnel should be evaluated. Appropriate considerations should be taken into account for grounds susceptible to liquefaction, steep grounds, and margins of soft and hard grounds, special sections of conduits with sharp bends and so on.

1-The following items should be evaluated:

1-1-the effect of seismic wave motion

1-2-the effect of specific conditions like site conditions or operational requirements

2-The connection point of Manhole and tunnel should be evaluated.

The following standard items of the joint elements of shield tunnels should be evaluated:

1-the effect of seismic wave motion

– Bending angle and pulling out length should be investigated.

2-the effect of specific conditions

– In special conditions like the above mentioned situations, we expect relative large responses (pulling out length and bending angle) and they have to be evaluated. In such cases, the response displacement method is not appropriate as it's not accurate enough for such conditions. Therefore, designer should use other analytical approaches. The main seismic join is the connection point of manhole and conduit.

3-manhole and conduit connection

The bending angle between manhole and pipe tunnel with tongue and groove joint is derived from relation (8-26):

$$\theta = \tan^{-1}(\frac{\Delta U}{h}) \qquad (8\text{-}26)$$

$$\Delta U = U_h(0) - U_h(h) = U_0 - U_1$$

In which;

θ : is bending angle between manhole and conduit (the bending angle of flexible joint)

$U_h(Z)$: is the maximum horizontal displacement at depth z(m) derived from response displacement method

3-2 pulling out length

The pulling out length at the connection point of manhole and conduit is the same as that of a pipe with tongue and groove joint and is derived from relation (8-27):

$$\delta = \varepsilon_{gd} \cdot l \qquad (8\text{-}27)$$

Where;

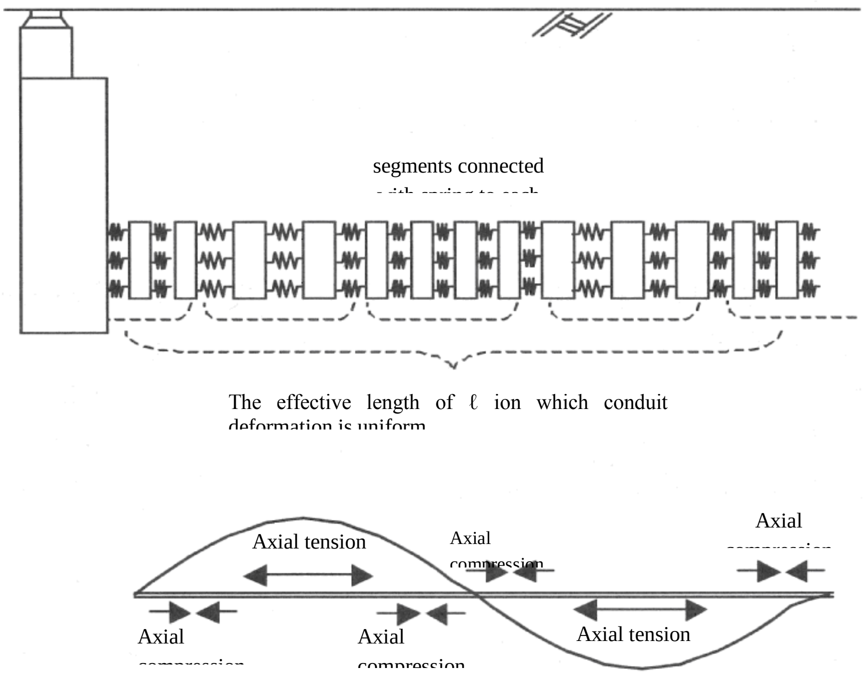
δ : is pulling out length (m)

ε_{gd} : is ground strain due to wave propagation. It is derived from relation (8-28)"

$$\varepsilon_{gd} = \frac{\pi}{L} U_h(z) \qquad (8\text{-}28)$$

.

The effective length of conduit, l , is a section of conduit in which deformation is uniform. The shield tunnel of a structure is an integrated structure itself and it is deformed like an accordion due to wave propagation as per Fig. 8-3. Generally, the length of shield tunnel span is higher than wave length L. For this, accurate estimation of effective length is difficult and for instance if the effective length is estimated smaller than its actual value, then pulling out length would be smaller. For this, designer should take into account the effects of variations of ground stiffness, wave size and diffusion of waves from conduit to ground.



Note: a n area along axis in which generated tension force is lower than wave length L

Pulling out occurs as tension force is generated

Figure 8-3 a demonstration of effective length when segment behave like an integrated structure

8-3-2-Seismic Design of Shield Tunnel Body

Body of a conduit should be evaluated for the following items with respect to the specifications of materials:

1-investigating axial section (for deformations due to axial compression)
2-investigations along axial direction (for deformations due to axial tension)
3-investigating along vertical direction

When wave motion generates axial compressive force in shield tunnel the stress intensity of segments and fixtures should be evaluated in terms of the stiffness of axial compressive side. Fig. 8-4 shows the impact of ground response displacement. Seismic design in this condition requires axial compressive stiffness, EA_{eq}^{C}, and axial torsion compressive stiffness EI_{eq}^{C} as the equivalent compressive stiffness. Also, equivalent cross section area, A_{eq} , and equivalent moment inertia, I_{eq} , corresponding to A_{eq} ,is required.

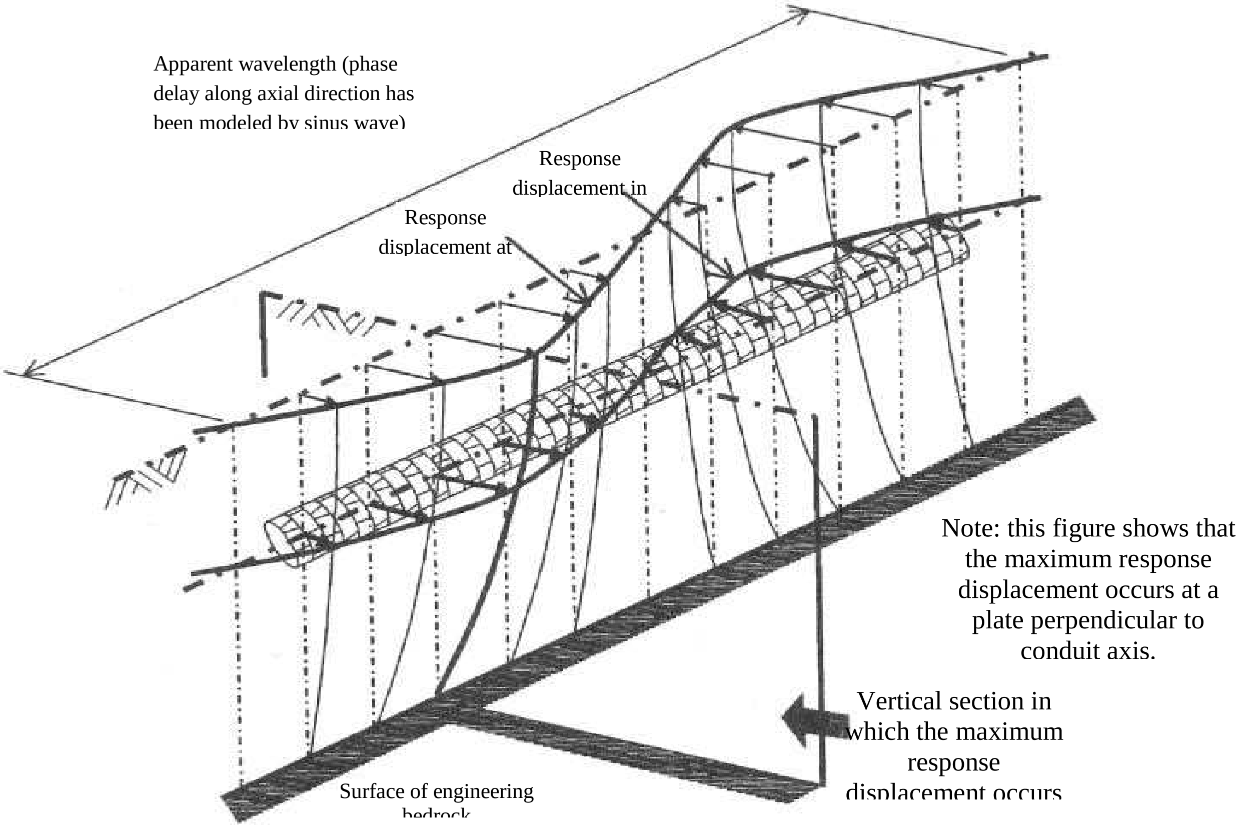


Fig. 8-4 the impact of ground displacement on shield tunnel during earthquake

When wave motion generates axial tension force in shied tunnel, the stress intensity of segments and fixtures should be evaluated in terms of the stiffness of axial tension side.

In concrete segment the distribution of stress should be evaluated based on the results of stress calculations.

This process needs axial tension stiffness, EA_{eq}^{t}, and axial torsion compression stiffness, EI_{eq}^{t}, as the equivalent compression stiffness. The stiffness is obtained through converting shield tunnel to a spring with respect to member's size including segment, joint bolt, joint plate and washer. If the obtained values are higher than allowable values, the following considerations should be taken into account:

1-Regarding to the existence of axial compression stress if the obtained values are higher than the calculated allowable values, permanent strain will be occurred but flow could be established yet. Therefore, requirements like construction condition, actual volume of flow and so on should be completely evaluated. In concrete segments the reinforcing rate should be increased following validation process. Applying secondary coating as a reinforcing coating is possible but it will results in negative effects and will increase equivalent tension stiffness.

2-In the case that axial tension stress exceeds allowable value before changing the number, diameter and length of screws, recalculations should be carried out with respect to the increased resistance.

3-In axial tension, the increase of screw length is an effective parameter but at first its dimension should be checked in order to use them in one raw.

4- In axial tension fitting elastic washer is an effective parameter. The elasticity coefficients of these washers should be determined accurately. For calculating the intensity of stress in vertical section, the obtained values for normal and seismic conditions through frame analysis model should be added to each other.

4-1-in concrete segment at first the armature laying rate (bar distribution) should be considered. in steel segment the height of the segment should be taken into account and calculation process should be redone in axial direction.

4-2-the height of segment should be increased within standard limits.

4-3-in designing high diameter tunnels designer should use appropriate number of nodes with respect to the expected analysis time and accuracy.

8-4-Allowable Values

The allowable response of components should be in accordance with the values determined by manufacturers of components.

8-5-Acceptance Criteria

The results of the seismic design calculations of coated tunnels should be checked in accordance with the following steps:

1-Design condition at the risk level 1: design condition should be allowable stress or operational limit.

2-design condition at the risk level 2: design condition should be ultimate limit

3-seismic preventive measures

Seismic preventive measures should be prepared based on the following items:

3-1-displacement damping rate

3-2-supplying strength in axial direction

3-3-supplying strength in the surface of vertical section

4-Joint opening should be below 2 mm with respect to crack width in operational and maintenance situations.

5-The allowable stress of materials should be the same as design value, with respect to conduit type, in order to avoid leakages due to cracks.

6-The necessary condition of joint is that no soil and sand could penetrate inside conduit. The maximum allowable value of materials should be the same as design values. The maximum allowable opening of joint ranges from 2mm to 5mm.

7-In conduits, disruption strength of materials should be the same as design condition value in order to avoid collapse of conduit section.

Chapter 9

Seismic Design and Safety Control of Manholes

9-1-Seismic Design and Safety Control of Manholes

Manholes belonging to sewage systems are dimensionally larger than manholes of other vital arteries. Therefore, they are more vulnerable against different movements of ground. The target elements of this section are in situ manholes with circular and rectangular cross sections as well as concrete prefabricated manholes. Two main sections of manholes including manhole body and connection point between manhole and conduit are very important items of design.

Table 9-1 shows the expected performance of these two main parts:

Table 9-1: expected performance

required performance	manhole elements
bending angle and pulling out length should be within a rage at which no sand and soil could penetrate inside	connection between manhole and conduit
the stress intensity of any kind of manhole should be within ultimate limit range if the construction operations is done by open excavation method blocking of emergency paths due to the liquefaction of embankment depot should be avoided The width of opening between the joint of prefabricated block should be within a range at which no sand and soil could penetrate inside	main body of manhole

9-2-Seismic Design Input

Two risk levels i.e. risk level 1 and 2 are considered for seismic design.
Manhole is more sensitive to relatively permanent displacement of ground compared with ground shakes. Therefore, geotechnical threats especially liquefaction have higher influence on manhole and its join to conduit.

9-3-Design Trend

Seismic design of manhole should be carried out with respect to the following items as well as regarding the specifications of its material:

1-the following items should be seismic designed and safety controlled:
- vertical section
- horizontal section
- joints between prefabricated blocks
- floating of the main body due to liquefaction

2-preventive measures against earthquake

Table (9-2) and table (9-3) show respectively the items to be controlled in the main pipeline and other lines:

Table 9-2: items to be controlled in the manholes of main pipeline

liquefaction acceptance level (value of FL)	horizontal section	vertical section		items to be controlled / structure type	
	stress intensity	stress intensity	Opening width		
D	A/D	A/D		in situ (circular section)	manhole type
D	A/D	A/D		in situ (rectangular section)	
D	A/D	A/D	A/D	prefabricated (secondary product)	

Table 9-2: items to be controlled in the manholes of other lines

liquefaction acceptance level (value of FL)	horizontal section	vertical section		items to be controlled / structure type	
	stress intensity	stress intensity	Opening width		
A	A	A		in situ (circular section)	manhole type
A	A	A		in situ (rectangular section)	
A	A	A	A	prefabricated (secondary product)	

A: Allowable stress design; D: Ductile design; A/D: both allowable stress and ductile designs should be carried out

1-The following items should be taken into account in design and analyses:

1-1-the profile of the soil of intact ground should be used. In the cases where the excavation area is wide and the soil profile of embankment differs from that of intact ground, both profiles should be taken into account.

1-2-the reaction factor of soil, k_h, is derived from relation (9-1):

$$k_h = k_{h0}\left(\frac{B_h}{0.3}\right)^{-3/4} \quad (9\text{-}1)$$

$$k_{h0} = \frac{1}{0.3}\alpha \cdot E_0 \quad (9\text{-}2)$$

Where;

k_h : is the reaction factor of soil in lateral direction (kN/m^3)

k_{h0} : is the k_h corresponding to plate bearing test using rigid disk (disc dia.=0.3 m)

α : is live overburden coefficient in short term loading condition which is employed for calculating the value of k_{h0}

E_0 : is the ground deformation modulus (kN/m^2). In order to obtain the value of E_0, we use the value of N obtained from SPT test as $2800 \times N$

k_v : is derived from relation (9-3):

$$k_v = k_{v0}(\frac{B_v}{0.3})^{-3/4} \quad (9\text{-}3)$$

$$k_{v0} = \frac{1}{0.3}\alpha \cdot E_0 \quad (9\text{-}4)$$

Where;

k_v : is the reaction factor of soil in vertical direction (kN/m^3)

k_{h0} : is the k_v corresponding to plate bearing test using rigid disk (disc dia.=0.3 m)

α , E_0 : are the same factors described in k_h

1-3-the equivalent width of foundation for calculating k_h is derived from relation (9-5):

$$B_h = \sqrt{A_h} \quad (9\text{-}5)$$

In which;

B_h : is the equivalent width of foundation (m) perpendicular to loading axis (m)

A_h : is the area of loaded zone along side (lateral) direction (m^2)

In manholes with rectangular cross section we have:

A_h =H (the length of side (lateral) wall (m)) ×D (manhole width (m))

In manholes with circular cross section we have:

A_h = H (the length of side 9lateral) wall (m)) × 0.8D (diameter)

The equivalent width of foundation B_v for calculating k_v is derived from relation (9-6)

$$B_v = \sqrt{A_v} \quad (9\text{-}6)$$

Where;

B_v : is the equivalent width of foundation (m) perpendicular to loading axis (m)

A_v : is the area of loaded zone along vertical direction (m^2)

In manholes with rectangular cross section we have:

A_v : is the area of manhole foundation (m^2)

In manholes with circular cross section we have:

D(m): is manhole diameter and A_v is not used

k_s , k_θ and k_v are determined as follows:

$$k_s = \lambda \times k_v \quad (9\text{-}7)$$

In which;

k_s : is soil shear elasticity constant (kN/m^3)

λ : is the ratio of soil reaction factor in horizontal direction to vertical direction which ranges from 1/3 to 1/4

$$k_\theta = k_v \times I \quad (9\text{-}8)$$

k_θ: is the torsion elasticity constant of soil (kN×m/rad)

I : is the moment inertia of manhole foundation (m4/m)

Live load is not taken into account i normal condition

1-4-in calculating lateral cross section (horizontal cross section) the intensity of the generated stress in both normal and seismic conditions should be evaluated.

Additional load generating due to earthquake is determined as follows:

$$\omega_b = \{\Delta U(z) - \delta(z)\} \times k_{hi} \quad (9\text{-}9)$$

In which;

ω_b : is additional load due to earthquake (reaction factor due to response displacement) (kN/m^2)

If the value of ω_b is negative the additional load is considered in reverse direction and the absolute value of ω_b should be added to the value of ω_b obtained in normal condition.

$\Delta U(z)$: is relative displacement of ground (m) at depth z (m)

$$\Delta U(z) = U_h(z) - U_h(h) \quad (9\text{-}10)$$

Where;

$U_h(z)$: is displacement of ground (m) at depth z (m)

$U_h(h)$: is ground displacement at the beneath level of manhole (m)

$\delta(z)$: is displacement of members (m) at depth z (m)

k_{hi}: is soil reaction factor in horizontal direction at the ith node (kN/m^3)

1-5-since it is impossible to predict the direction of wave propagation in "in situ" manhole with rectangular cross section calculations should be carried out in both short and tall faces.

2-preventive measures against earthquake include the following items:

- In the large in situ manholes of main pipelines wall thickness as well as the number of reinforcing bars should be increased in order to cope with shear force generating due to earthquake.
- In the manholes which are joined to several conduits, openings around areas should be reinforced by additional bars.
- In prefabricated manholes joint loose (opening) should be avoided through designing joint points between blocks.
- If the design condition of stress intensity is not established, the in situ case should be used.
- In the cases where displacement should be controlled flexible joint or any other proper joint should be used as joint members.
- Appropriate preventive measures should be prepared in manhole and conduit during liquefaction phenomenon.

9-4-Design Trend

9-4-1-seismic design of the joint between blocks

The opening (loose) of joints between blocks should be considered in the seismic design of the vertical section of prefabricated manholes.

9-4-2-seismic design of manhole body

Manhole body should be designed in both horizontal and vertical directions In designing side section of manhole, it should be checked that whether or not the number of bars are sufficient in annular direction at appropriate depth in order to cope with ground reaction (see Fig. 9-1)

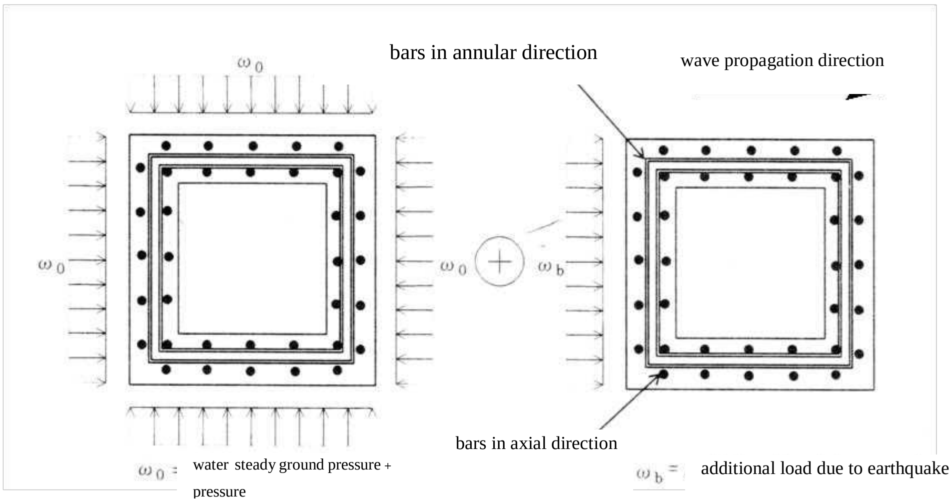


Figure 9-1 considered load in lateral section (side section) (manhole with rectangular cross section)

– In order to calculate the shear force of a manhole with circular cross section, the area of cross section should be converted to the equivalent rectangular cross section at each seismic input level.

9-5-Allowable Values

The allowable values of components responses should be in accordance with the specifications presented by manufacturer.

9-6-Acceptance Criteria

The results of seismic calculations are checked as follows: 1-Design condition at the risk level 1: the design condition at the risk level 1 is allowable stress or operational limit. 2-Design condition at the risk level 2: the design condition at the risk level 2 is ultimate limit. 3-seismic preventive measures Preventive measures against earthquake should be prepared based on the following items: 3-1-supplying strength in vertical section (increasing wall thickness, extending axial bars) 3-2-supplying strength in lateral (side) section (increasing wall thickness, extending axial bars) 3-3-the mechanism reconnecting joint opening (prefabricated manhole joint) 3-4-displacement damping (joint for conduit)

Items 1 and 2 are similar to section 9-3. The only difference is that in order to avoid penetration of soil into manhole, regarding to the joint of prefabricated manhole, opening width should be below 10 mm.

3 seismic preventive measures

– In designing the vertical section of manhole first of all wall thickness as well as fitting armatures along axial direction should be evaluated (see Fig. 4-39).
– In order to strengthen lateral section, in design of this section we should fit armatures along annular direction.
– In each earthquake level, in order to meet opening condition of prefabricated manhole, type of joint as well as block height should match with each other. If it is not possible, in situ manhole should be used.
– Flexible joint should be used for joining manhole to conduit if necessary.
– If rigid foundation is applied on sand embankment, manhole and the rigid foundation should be separated from each other in order to prevent the influence of conduit on manhole.

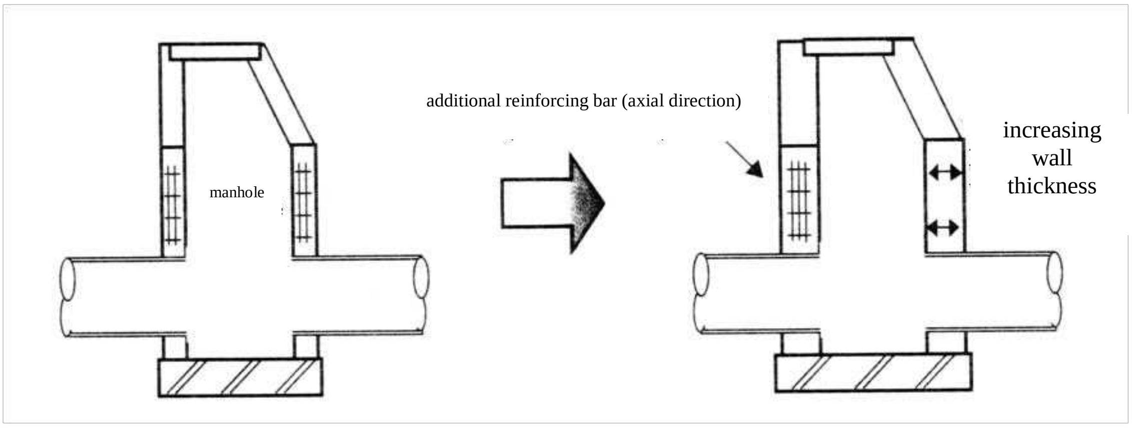


Figure 9-2 changing type of manhole

9-7-Seismic Design of Other Conduit Facilities

9-7-1-crossing conduits (inverted siphon) and deviation room

1-If covered pipe is used in crossing conduits (inverse siphons) the outer pipe should be considered as conduit and it should be seismic designed.
2-In the connection pint of manhole and conduit in inner pipe flexible joint should be used.
3-In deviation room, if ground displacement between in and out discharge conduits is high, in addition to reinforcing bars, if necessary, an appropriate tool should be used in join point in order to damp displacement.

The deviation room should be reinforced as per Fig. 9-3

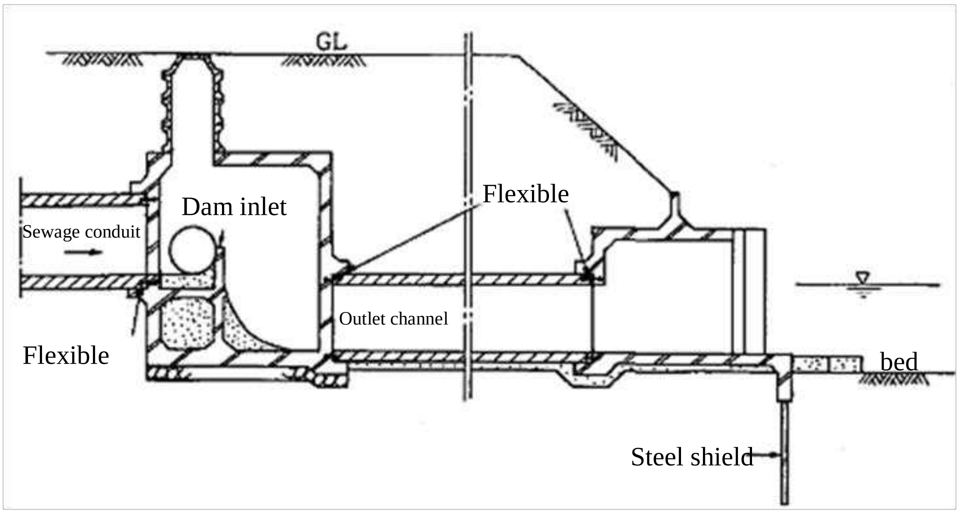


Figure 9-3 typical example demonstrating how to reinforce deviation room

9-7-2-under Pressure Sewage Pipe and Sludge Transmission Pipe

The following considerations should be taken into account in designing under pressure pipes of municipal sewage systems as well as sludge transmission pipes:

1-Sewage path should be a two ways path (multi flow) and connection pipes should be used between main pipes

2-The pipe connected to bridge should have expansion joint if necessary

3-For more information about seismic design trend of pipe body and joint refer to municipal water supplying instructions

One could refer to seismic design trend of continuous conduits presented in this instruction as well as municipal water supplying system instruction in order to get more information about the seismic design of home under pressure sewage pipes and sludge transmission pipe.

Clause 1:

In order to avoid destructive impacts on this type of conduits, additional paths should be used

In order to minimize destructive impacts on this type of conduits, employing connection pipe and sliding gate is recommended

Clause 2:

In the bridges carrying pipe, pumping station and treatment station in which relative displacement between structure and conduit is high during earthquake, installing expansion joint would be effective.

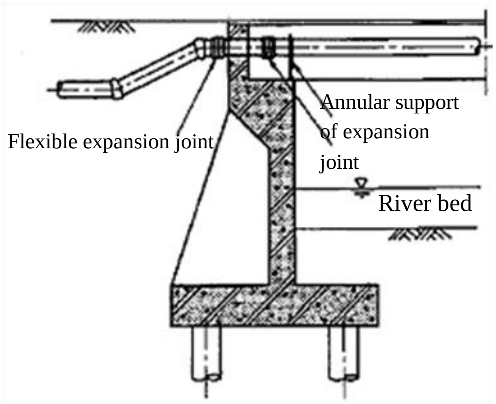


Figure 9-4 typical example of a conduit added to a bridge

Installing flexible joint is also effective against unsymmetrical settlements, seismic shake or liquefaction of conduits in soft grounds or the boundary layer of soft and hard grounds.

9-7-3-Transversal Pipe

Transversal pipe should be a simple structure with immediate repair capability. The sections of this pipe which are important should have sufficient strength against earthquake.

In the cases where the main pipe is mounted deeper and the underground water level is high, it is recommended that a connection pipe (junction) between main pipe and transversal pipe be installed or several transversal pipes be integrated as one pipe in order to decrease number of joints.

In the important sections of pipeline like joints of managing and network control units or sections in which repair operations take longer times due to site condition appropriate considerations should be taken into account in design step in order to prevent pulling out of transversal pipe like use of tongue and groove joint or employing flexible joint (see Fog. 9-5).

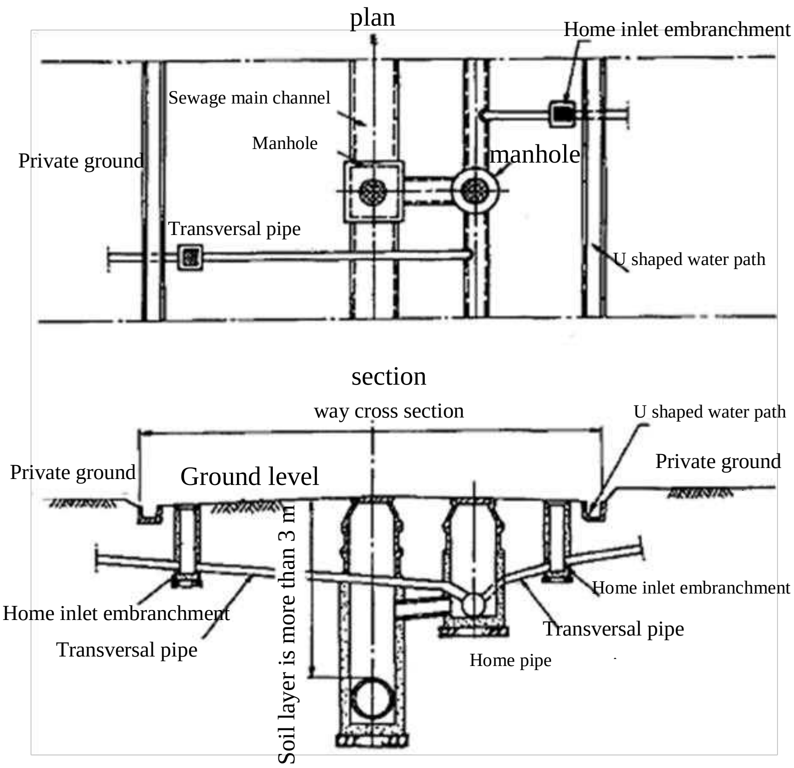


Figure 9-5 a typical example of installing home embranchment pipe

If these instruments are used, seismic design of elements is not necessary.

The seismic design of transversal pipe is similar to that of conduit with tongue and groove joint

The following items should be considered in seismic design steps:

1-the transversal pipe connected to important conduits (at both risk levels)

  1-1-the pulling out length of the joint of the main pipe which is generated due to ground movement

  1-2-pulling out length between transversal pipes

2-the transversal pipe connected to other lines (at the risk level 1)

  2-1-the pulling out length of the joint of the main pipe which is generated due to ground movement

  2-2 -pulling out length between transversal pipes

9-7-4-Pipeline Bridge

Seismic design of Pipeline Bridge should be carried out with respect to the following items:

1-Performance

  For more information about design steps refer to detailed specifications indicated in municipal water supplying systems instruction.

2-upper structure

  For more information about design steps refer to detailed specifications indicated in municipal water supplying systems instruction as well as bridge specifications

3-lower structure

  For more information about design steps refer to bridge specifications and this instruction

4-joining pipe to bridge

The strength of join against earthquake should be approved. Fracture and collapse of supportive joints should be avoided.

Clause 1:

The following items should be considered for upper structures:

1-

1-1-water internal pressure

1-2-thermal expansion of member

1-3-weight

1-4-wind load

1-5-forces generating due to the contacts of the bodies of trees, ships and so on

1-6-maintenance corridor and its weight

1-7-snow and antifreeze material load

2-

2-1-installing air vent

2-2-allowable displacement

2-3-preventive measures against corrosion

2-4-site of construction operations

2-5-expenses and productivity

The relative displacement between ground and the pipe of around support may reach to higher values during earthquake. Therefore, appropriate instruments should be used for damping this displacement. Also, appropriate crash preventive instruments should be prepared.

Clause 2:

The following items should be taken into account for lower structures. Also, refer to municipal water supplying system instruction as well as road and bridge instruction:

1-

1-1-the weight of upper structure

1-2-the structure of the layers of ground and the depth of engineering bedrock

1-3-unsymmetrical settlement and lateral dispersion

1-4-Soil pressure, underground water pressure, buoyancy force and inverse friction.

1-5-Abutment structure, abutment foundation and guide wall

1-6-Heel structure

1-7-forces generating due to the contacts of the bodies of trees, ships and so on

2-

2-1-site of construction operations

2-2-expenses and productivity

Judgment about liquefaction, preventive measures against liquefaction, the impacts of liquefaction on the foundation as well as displacement of heel, during earthquake, should be evaluated