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Vice Presidency for Strategic Planning and Supervision

Guideline for seismic evaluation and rehabilitation of gas supply systems

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Chapter 1

General

1-1-Generals

In modern societies, gas systems product demanded energy for power generating and transportation and is used for producing of demanded commodities and other necessary services such as heating, and services which require energy to sustain life in the desirable level. Earthquake is one of the natural disasters, which could damage this system and causes interruption of gas flow and creates secondary disasters such as explosions, fire and poisoning. If we are not aware of scale of vulnerability for supplying security and safety and we do not execute sufficient seismic retrofitting, damages and consequences of earthquake will increase and if we are unable to control the situation, a disaster could occur and situation become critical.

1-2-Goals

The target of the evaluation of vulnerability and seismic retrofitting of urban gas system is to know the security and seismic reliability of gas network and decreasing of consequences of earthquake on gas network and its components.

Saving integrity and continuous function of urban gas system will result in hazard prevention for people, assets and environment.

Vulnerability evaluation and seismic retrofitting covers all activities of detection of deficiencies, probable damages and their consequences and includes reduction, elimination and treatment in a logical level, so major goals of this guideline are:

- Definition and determination of general requirements of evaluation of seismic vulnerability of existed gas system which will be used uniformly in a national level.
- Introduction of seismic retrofitting methods for components of the existed gas system, risk reduction management and emergency situation and afterwards critical conditions.

1-3-Scope of Work

Contents of this guideline could be used for all components of gas lifelines in production parts, transportation lines and urban distribution in different volume and sizes.

Contents of this guideline are prepared for enhancement of engineering knowledge in the field of seismic safety, but user must undertake the responsibility of correct interpretation and the using of contents of this guideline.

Contents of this guideline will be reviewed and updated during time and users should use the last update version of this guideline.

Evaluation of immunes again other natural and artificial parameters and their related consideration aren't in the framework of this guideline and if you need, you must investigate supplementary.

Requirements of this guideline are identical for permanent and temporary facilities.

1-4-Target components

Target components are divided into two major sections as follows:

- Station components including buildings, non building structures, facilities and non structural elements in refineries and pressure control stations.

- Linear components (gas transportation pipelines) and network components (gas distribution)

Station components are mostly on-ground except in a few cases, but pipelines and networks are mostly buried and only in few cases are on-ground.

Generally, station structures are affected by ground acceleration response to earthquake but pipeline and network structures which are mostly buried are affected by ground velocity response to earthquake.

Station facilities have two types of inside and outside the building.

In contrary to buildings where the mass is uniformly distributed in height, stationed structures of lifelines have no uniform mass distribution. Therefore, earthquake induced inertia forces are exerted in the mass centers. This force is equal to structure mass multiplied by modified acceleration in the form of seismic coefficient.

This force is obtained from multiplying mass of structure to modified acceleration in the framework of earthquake factor.

In the case of storage structures like cylinder or spherical storage tanks, earthquake induced inertia force could be exerted on fluid mass statically or dynamically.

About some structures that is half-buried, according to used analysis method and its math model is seismic loaded properly.

Effects of inertia force in pipeline and network structures decreases drastically moving from on-ground to underground.

Long pipeline and network structures either on-ground or underground are very sensitive to relative displacement exerted on them. This relative displacement produces strain and stress in the structure.

In buried structures the behavior is controlled by the soil behavior and its mass is negligible comparing to surrounding soil mass.

Those gas system components and their types which are discussed in this guideline for seismic retrofitting and evaluation are presented in table 1-1

Table 1-1 Target components in this guideline

Component Name	Type
Processing Facilities and Refinery	Station
Pump and Pressure Control Station	Station
Main Transportation High Pressure Pipelines	Liner
Distribution Control Centers (Dispatch)	Station
Low & Medium Pressure Distribution Pipelines	Liner
Office Buildings and warehouses	Station
Customers branches and risers	Station

1-5-Correlated Provisions and Standards

Correlated Standards and instructions with this guideline are as follows:

- The last version of 2800 standard of Iran, seismic design of buildings
- Buildings Seismic Retrofitting Instruction, publication number360, President Deputy Strategic Planning and Control (PDSPC)
- Buildings Fast Evaluation Instruction, publication number364, President Deputy Strategic Planning and Control (PDSPC)

- Buildings Retrofitting and Evaluation Description of Services, publication number 251, President Deputy Strategic Planning and Control (PDSPC)
- Vulnerability Analysis and Seismic Retrofitting of Non-Reinforced Masonry Buildings" Instruction (published by Building Deputy of Ministry of Housing and Urban Planning)
- Iran National Building Provisions, Ministry of Housing and Urban Planning

Other guidelines and criteria which might become necessary in the projects could be used only if they are consistent with the philosophy of this guideline and fulfill its minimum requirements.

1-6-Structure of the guideline

This guideline comprises of following chapters:
Chapter 1: Generals
Chapter 2: Seismic evaluation procedure
Chapter 3: Seismic evaluation methods
Chapter 4: Seismic retrofitting procedure and methods
Chapter 5: Seismic retrofitting methods in refinery
Chapter 6: Retrofitting methods in tanks
Chapter 7: Retrofitting methods in pipelines
Chapter 8: Retrofitting methods in buried pipelines
Chapter 9: Retrofitting methods in internal facilities
Chapter 10: Retrofitting methods in other non building structures
Appendice1: categorizing of network consumer.
Appendice2: fragility function
Appendice3: references

Chapter 2

Seismic Evaluation Procedure

2-1-Seismic Performance Evaluation Approaches

In this guideline the seismic evaluation is defined in two phases, namely pre evaluation and evaluation.

In pre evaluation phase, with speedy evaluation of the lifeline's condition, the need for conducting the seismic evaluation is decided and the level of the required study is determined.

Then the evaluation phase, is divided into initial evaluation and detailed evaluation.

- Initial evaluation includes qualitative methods which are relatively fast to determine vulnerable components or safe ones and preparing a list of components which need detailed evaluation. Initial evaluation methods used in this guideline are based on worksheets and qualitative or quantitative scoring methods

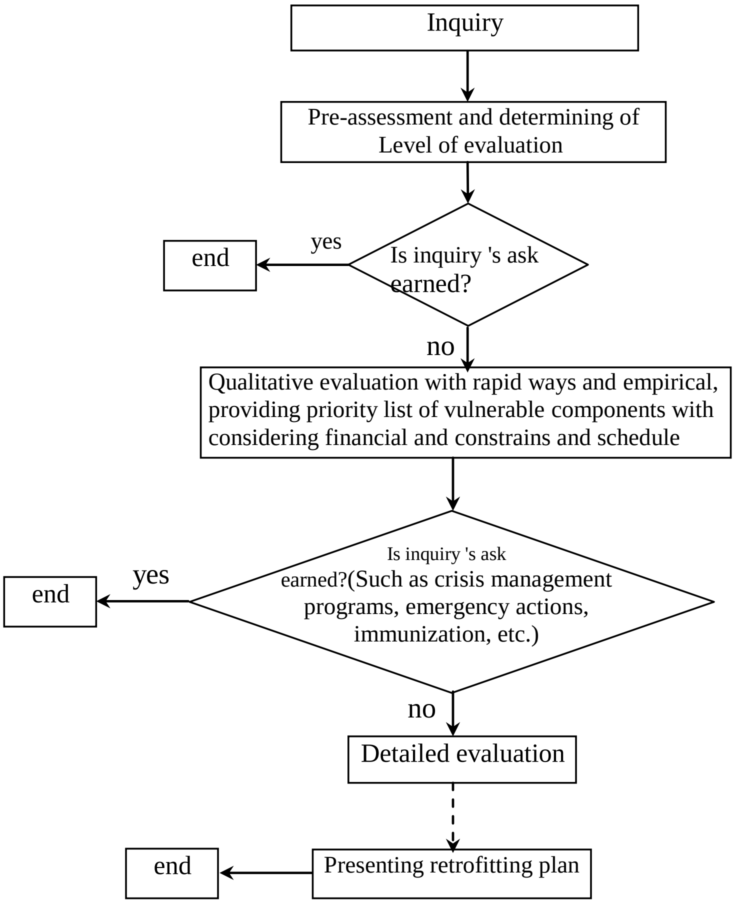


Fig. 1 controlling procedure of system's performance targets

- Detailed evaluation includes experimental and analytical approaches. Experimental methods are based on damage modes, statistics and documents of previous earthquakes and analytical methods are based on modeling, numerical and calculation analysis. Analytical methods have two levels which level one is similar to simple methods and mostly static methods and level two includes dynamic and non linear methods for components with special conditions or complex seismic behavior.

2-2-Pre Evaluation

Persons in charge of gas lifeline system should always have enough knowledge about safety and proper seismic performance of its own facilities. Otherwise they have to request for evaluation of performance of gas facilities. Level and detail of this request depends on the knowledge of persons in charge.

Before start of evaluation, pre evaluation will be conducted by operation engineers or other persons in charge with following goals:

- Risk intensity identification and general vulnerability evaluation for this risk, in order to determine the required volume of detailed evaluation.
- Assuring that resources and necessary expertise for conducting the evaluation is available.
- Determining the proper scope of work based on the request, available resources and timetable.

2-2-1-Effective Parameters in Performance Evaluation

Main parameters in a performance evaluation are:

- Hazard (H)

Seismic hazard includes initial and secondary hazard. Initial hazards include ground vibration and movements and related deformation like liquefaction, slope slide and faulting.

Secondary hazards include explosion, fire, environment pollution and similar which are caused by initial hazards.

- Vulnerability (V)

Vulnerability includes casualties, physical damages to facilities, installations and buildings, control and operational systems, environment, commercial, financial & industrial activities, safety of installations and investment and society and cultural heritage.

- System's Performance (S)

Gas lifeline system's performance during earthquake will be evaluated and judged based on outputs, or operational targets and or lack of safety and interruption in performance.

Important performance targets of a gas system are:

- Customers and facility workers' safety
- Continuity of gas flow and system's reliability
- Damage prevention
- Prevention of environmental damages

2-2-2-Seismic hazard identification

Initial hazards including vibration and permanent ground displacement are measured with intensity, acceleration and ground movement.

The most common criteria for measuring vibration is peak ground acceleration (PGA) which could be obtained from zoning maps or local investigations.

Zoning maps also could be used for hazard study of permanent deformation including, liquefaction, land sliding and faulting which mostly are based on peak ground displacement (PGD).

Data obtained from these maps are approximate and should be used with caution. For example a region is classified as a high risk zone for land slide only because a small part of it is located on an unstable slope.

Secondary hazards like explosion, fire, environmental pollution, etc, should be studied locally and depending on the case. Table 2-1 shows criteria used for determination of relative hazard levels.

Table 2-1 Criteria used for determination of relative hazard levels (H situation)

Seismic hazard level	**PGA**
Low (L)	0.15g<PGA
Medium (M)	0.15g≤PGA≤0.5g
High (H)	PGA>0.5g

2-2-3-Seismic Vulnerability identification

Vulnerability potential in different gas facilities varies depending on the type of seismic hazards.

Table 2-2 shows the general categorization of seismic vulnerability in three levels, high (H), Medium (M) and low (L).

If a component or a system is located inside a building, vulnerability of that component and building should be considered simultaneously.

For example, if a building has a collapse risk or a compulsory evacuation is necessary, then the facilities inside that building are in risk.

Table 2-2 vulnerability degree of components due to seismic damage (V situation)

Seismic hazard	**Vulnerability degree**							
	Security, control and auto shutoff systems	Refineries	High pressure pipelines	Low and medium pressure pipelines	Pressure adjusting and reducing stations	Risers	Storage tanks	Central office, maintenance and operational buildings
Seismic vibration	H	M	L	L	M	H	H	H
Ground permanent deformation due to earthquake (faulting, liquefaction, landslide)	L	M	H	H	M	M	M	L

2-2-4-Seismic Performance

Seismic performance depends on:

- Intensity and rate of hazard
- Vulnerability of system or component
- Consequences of damage including human loss, financial, service shot off, environmental effects and others
- Permanents redundancy of the system under evaluation(high, medium and no redundancy)
- Scale of the system

In pre evaluation, performance is shown by level index I_L that is defined as multiplication of H, V & S

I_L=H × V × S or I_L= H × V × max (C_{LS}, C_{FL}, C_{SD}, C_{EI})(2-1)

Where:

H= hazard coefficient (low=1, medium=2, high=3) according to table 2-1

V= vulnerability degree (low=1, medium=2, high=3) according to table 2-2

S= system performance degree (maximum value of C_{LS}, C_{FL}, C_{SD}, C_{EI})

C_{LS} = life safety consequences degree, between 1-3 (table 2-3)

C_{FL} = financial loss consequences degree, between 0.5 -6 (table 2-3)

C_{SD} = service down consequences degree, between 0.5 -6 (table 2-3)

C_{EI} = environmental consequences degree, between 1-3 (table 2-3)

In table 2-3 redundancy modification coefficient (R_c) is used to determine financial loss (C_{FL}) and service down consequences (C_{SD}) degrees.

This modification coefficient is used to justify the decrease in consequences due to redundancy of the system.

Redundancy modification coefficient shows the flexibility and substitution possibility under special conditions.

For example, for a given facilities, due to lack of alternatives for serving an important customer, redundancy coefficient might be considered 2 (without redundancy). In the same time customer might consider the redundancy coefficient as 0.5 due to supplemental energy resources.

Service down (C_{SD}) coefficient might vary due to nature and characteristics of the inquiry and also who carries out the evaluation.

There are similar considerations, during the application of redundancy modification coefficient to financial loss (C_{FL}).

For example, for a given facilities, financial loss due to repair of a damage, might not be significant for an industrial customer or a district which doesn't have any facilities to provide substitution energy resources.

In normal condition, redundancy coefficient is assumed one.

Table 2-3 Categorizations for system performance disorder consequences (S situation)

Consequences	**Intensity of consequences**		
	Low (normal)	**Medium (non critical)**	**High (critical)**
Life safety (C_{LS})	Lowest effects on life safety; without any important effect on workers or people in the vicinity of facilities $C_{LS}=1$	Damage or shut down might injure workers or people in the vicinity of facilities $C_{LS}=2$	Damage or shut down might have significant life safety effects on workers or people in the vicinity of facilities $C_{LS}=3$
Financial loss (C_{FL})	Less or low effect $C_{FL}=R_c$	Damage or gas shut off could lead to great financial losses but these losses have less or low effect on financial integrity of facilities $C_{FL}=2R_c$	Damage or gas shut off have great impact on financial integrity of facilities and one or few big and important customers $C_{FL}=3R_c$
Service down (C_{SD})	Less or low effect on covered population $C_{SD}=R_c$	Gas shut off has effect on small population (less than 10%) and lasts for less than one day & has no special effect on important & vital customers $C_{SD}=2R_c$	Gas shut off will result on: 1- Effects a significant population (more than 10%) 2- It has potential to effect population more than 100000 3- Will cause wide spread shut off and lasts more than one day. 4- Will effect performance and operation of important & vital facilities $C_{SD}=3R_c$
Environmental effects (C_{EI})	Less or low effect on environment $C_{EI}=1$	Damage or shut off may cause limited damages to environment $C_{EI}=2$	Damage or shut off may cause big damages to environment (It will take months or years to clear the effects) $C_{EI}=3$

The value of R_C for the system with high redundancy will be 0.5 (element damage will not decrease system performance), and for medium redundancy will be 1.0 (element damage will decrease system performance) and for no redundancy will be 2.0 (the element's function could not be replaced).

In approximate scoring values 1, 2 and 3 are used for low, medium and high redundancy, respectively.

Final step in scoring is the comparison of level index I_L with a set of pre set limitations where they define recommended basic levels for performance evaluation. (Table 2-4)

Based on the all possible combination of input parameters, level index could vary between 0.5 and 54.

Performance evaluation for basic level is determined with following limitations:

Basic level is used as a start point for evaluation and later it might become necessary for more complete evaluations. Sometimes the requesting party might ask for special level of studies based on its own needs.

Table 2-4 Selection of evaluation levels

Level Index (I_L)	**Basic level for performance evaluation**
$I_L \leq 6$	No need for seismic evaluation
$7 \leq I_L \leq 17$	Usually initial evaluation is sufficient (level 1)
$17 \leq I_L \leq 35$	Initial & detailed evaluation with experimental and ordinary calculation (level 2)
$I_L \geq 35$	Initial & detailed evaluation with precise calculation (level 3)

2-2-6-Planning for Evaluation Study

Data necessary for seismic evaluation are different from study type obtained from levels of above mentioned table. After determining level using below table, it is possible to determine the relevant risk level or vulnerability level for study, using tables of this chapter.

In addition to guides of tables of this chapter, other factors like cost, timetable and inclusion of many risks, should be considered in planning for seismic evaluation study.

Sample for recommended levels for evaluation analysis of hazard (H), vulnerability (V) and system (S)

Request item	Request source	Level		
		H	V	S
Request for study of general condition of the system	External	1	1	1
Request from customers for study of service reliability	Ditto	1	1	1
General request for total study by mass media or people	Ditto	1	1	1
Collaboration with technical groups	Ditto	1	1	1
Request for study of facilities in a landslide region	Ditto	2	1	1
Request for study after an accident in facilities site by an authority.	Ditto	1	2	1
Request for study after an accident in critical facilities Site by an authority.	Ditto	2	2	2
Request for detailed hazard study of a set of facilities by an authority.	Ditto	3	1	1
Request for detailed hazard study of facilities by an authority.	Ditto	3	2	1
Request for determination of detailed hazard data & criticalness by an authority	Ditto	2	1	2
Change in necessary performance level in the new provisions	Ditto	3	3	3
Request for determination of service shut down potential under a local and specific hazard by an authority	Ditto	2	1	3
Request for determination of service shut down potential in critical facilities by an authority	Ditto	3	3	3
Request for determination of service shut down potential with detailed study of local hazards by an authority	Ditto	3	1	3
Request for necessary data for initial design of facilities under different hazards	Internal/external	3	1	2

Request for determination of unprecedented & huge service shut down potential by an authority	Internal/external	3	3	2
Request of higher rank manager for study of financial situation in case of hazard occurrence	internal	1	2	1
Request for risk management or insurance	Ditto	1	2	1
Investors concerns	Ditto	2	2	2
Request for study of general situation by higher rank managers	Ditto	2	2	2
Request for determination of the most critical facilities according to hazard zoning by higher rank managers	Ditto	1	1	3
Request for additional study and determination of vulnerability details of critical facilities	Ditto	1	2	3
Request for determination of service of critical facilities (like hospitals) after occurrence of hazard	Ditto	2	2	3
Request for complete study of the system under natural disaster by manager	Ditto	3	2	3
Request for control of gas installations under specific hazards by board of directors of gas company	Ditto	1	1	1

Table 2-5 hazard evaluation matrixes for gas system

Relevant action with hazard level of 1, 2, or 3		**H3**	**H2**	**H1**
1.1	Earthquake hazard- surface rupture of fault			
1.1.1	Study of region's active faults maps, if they exist	♦	♦	♦
1.1.2	Study of topographic maps	♦	♦	♦
1.1.3	Study of aerial photos, if they exist	♦	♦	
1.1.4	Site survey and inspection (by an expert geologist)	♦	♦	
1.1.5	Locating active faults by excavation	♦		
1.1.6	Estimating movement and displacement of faults by experimental methods	♦	♦	
1.1.7	Determining fault displacements and their occurrence possibility By boring holes, sampling, determining of age and analysis	♦		

Relevant action with hazard level of 1, 2, or 3		**H3**	**H2**	**H1**
1.2	Earthquake hazard- liquefaction			
1.2.1	Study of documents on seismicity of the region	♦	♦	♦
1.2.2	Probabilistic seismic hazard assessment (PSHA)	♦	♦	
1.2.3	Study of topographic maps	♦	♦	♦
1.2.4	Study of surface geologic maps	♦	♦	♦
1.2.5	Study of existing geotechnical data	♦	♦	♦
1.2.6	Minimum excavation and boring, standard or cone penetration tests		♦	
1.2.7	Extended excavation and boring, standard or cone penetration tests	♦		
1.2.8	Initial field inspection and survey (by expert geotechnical engineers)	♦	♦	
1.2.9	Identifying soils with liquefaction potential by judgment	♦	♦	♦
1.2.10	Identifying soils with liquefaction potential by data analysis	♦	♦	
1.2.11	Estimating lateral displacement by experimental methods	♦	♦	
1.2.12	Estimating liquefaction potential using liquefaction maps	♦	♦	
1.2.13	Detailed analysis using programs like FLAC (Fast Lagrangian analysis of continua), estimating liquefaction probability & spread of lateral displacements	♦		

Relevant action with hazard level of 1, 2, or 3		**H3**	**H2**	**H1**
1.3	Earthquake hazard- strong ground motion			
1.3.1	Study of documents on vibrations and seismicity of the region	♦	♦	♦
1.3.2	Study of seismic hazard maps of the region, if they exist	♦	♦	♦
1.3.3	Study of geologic maps of ground surface	♦	♦	♦
1.3.4	Determining factors which help for ground vibration	♦	♦	
1.3.5	Estimating levels of ground vibrations by judgment and available maps	♦	♦	♦
1.3.6	Estimating levels of ground vibrations by experimental methods	♦	♦	
1.3.7	Estimating levels of ground vibrations by analytical methods	♦		
1.3.8	Execution of probabilistic seismic hazard assessment in whole system	♦		

Relevant action with hazard level of 1, 2, or 3		**H3**	**H2**	**H1**
1.4	Earthquake hazard- landslide			
1.4.1	Study of geologic maps of ground surface	♦	♦	♦
1.4.2	Study of topographic maps	♦	♦	♦
1.4.3	Study of aerial photos, if they exist	♦	♦	
1.4.4	Study of regional rainfall maps	♦	♦	♦
1.4.5	Site survey and inspection (by an expert geologist)	♦	♦	
1.4.6	Study of seismic maps of the region	♦	♦	♦
1.4.7	Landslide potential evaluation with engineering judgment	♦	♦	♦
1.4.8	Landslide potential evaluation using slope stability maps	♦	♦	
1.4.**9**	Landslide potential evaluation with experimental & statistical analysis	♦	♦	
1.4.10	Landslide potential evaluation with analytical method	♦		

Relevant action with hazard level of 1, 2, or 3		**H3**	**H2**	**H2**
1.5	Earthquake hazard- Tsunami			
1.5.1	Locating of facilities in 20 km distance from beach	♦	♦	♦
1.5.2	Study of cost topographic maps	♦	♦	♦
1.5.3	Study of bathymetric maps in costal area (near cost)	♦	♦	
1.5.4	Study of recorded data of tidal waves	♦	♦	♦
1.5.5	Estimate tsunami flood potential using engineering judgment	♦	♦	♦
1.5.6	Estimate tsunami flood potential using judgment & tsunami probable sources evaluation	♦	♦	
1.5.7	Flood analysis of area	♦		

Table 2-6 Vulnerability evaluation matrixes

Relevant action with hazard level of 1. 2, or 3		V3	V2	V1
1	Pipeline vulnerability evaluation due to ground displacement			
1.1	Risk evaluation for passing through areas with ground displacement potential by engineering judgment for different levels of permanent displacement	♦	♦	♦
1.2	Detailed analysis of few pipelines according to the pipe diameter, wall thickness, displacement direction compared to pipe direction and etc.	♦	♦	
1.3	Detailed analysis of pipeline for special site	♦	♦	
1.4	Determination of pipeline strain criteria based on available data of pipe condition & welds and review of papers on pipes performance	♦	♦	
1.5	Determination of pipeline strain criteria using numerical models	♦	♦	
1.6	Determination of pipeline analysis acceptance criteria using laboratory programs and finite element analysis of pipe shell	♦		
1.7	Evaluation of Facilities using estimation and experimental data of historical events (statistical) with minimum data collected at site	♦	♦	♦
1.8	Evaluation of facilities using site data obtained from steps 1.2 till 1.5 and precise and detailed data	♦	♦	
1.9	Facilities evaluation using actual site data obtained from steps 1.2 till 1.6 and structural analysis results of selected facilities	♦		

Relevant action with hazard level of 1, 2, or 3		V3	V2	V1
2	Damage evaluation of important and critical buildings			
2.1	Data collection through interview with execution managers of facilities and building repair and maintenance workers	♦	♦	♦
2.2	Determine critical functioning of inside buildings and Damages which defect or shut down these functions	♦	♦	♦
2.3	General inspection of site for evaluation and data collection about general vulnerability of buildings, their content & adjacent facilities and support	♦	♦	
2.4	General inspection of site for parallel hazard evaluation of external resources, structures and adjacent facilities	♦	♦	
2.5	Buildings' & supporting facilities' performance evaluation by judgment or experimental data (statistical) of past events or using experimental evaluation of damages with minimum site data	♦	♦	♦
2.6	Review of architectural and structural drawings, calculations, foundation evaluation reports & past structural evaluation to evaluate building capacity	♦	♦	
2.7	Independent structural calculations to evaluate building capacity	♦	♦	
2.8	Computer structural analysis to evaluate building response	♦		

Relevant action with hazard level of 1, 2, or 3		**V3**	**V2**	**V1**
3	Reservoir tank evaluation			
3.1	Evaluation of structural integrity of reservoir tank by engineering judgment	♦	♦	♦
3.2	Evaluation of structural integrity of reservoir tank using credible standard or reservoir equivalent design method	♦	♦	
3.3	Tank overflow evaluation due to sloshing	♦	♦	
3.4	Evaluation of effects of tank overflow on floating roofs (internal or external)	♦	♦	

Table 2-7 Vulnerability evaluation matrixes

Relevant action with hazard level of 1, 2, or 3		**S3**	**S2**	**S1**
1	System performance evaluation			
1.1	System maps evaluation	♦	♦	♦
1.2	Systems performance evaluation on natural hazards/past events	♦	♦	♦
1.3	Constructing system's critical model	♦	♦	
1.4	Coinciding system's model on different hazard maps (GIS)	♦	♦	
1.5	Estimation of system's performance using expert judgment (minimum 3 cases)	♦	♦	♦
1.6	System analysis for limited scenarios (minimum 3 cases)	♦	♦	
1.7	Reliability and probability analysis of system	♦		

Table 2-8 Necessary effort for hazard, vulnerability and performance analysis of the system in different levels

Vulnerability level			□ 1-15 person-day work ▒ 3-10 person-week work ■ 3-9 person-month work			
V3	V2	V1				
▒	□	□	H1	Hazard level	S1	System performance level
▒	▒	▒	H2			
■	■	▒	H3			
▒	▒	▒	H1	Hazard Level	S2	
▒	▒	▒	H2			
■	■	■	H3			
■	▒	▒	H1	Hazard level	S3	
■	■	▒	H2			
■	■	■	H3			

2-3-Seismic Evaluation Steps

After performing pre evaluation and determining study levels, for seismic evaluation it is necessary to clarify performance importance, vulnerability, and hazard and target performance level. These parameters which determine volume of evaluation efforts for each element and are as follows:

1-Performance importance and total value of system
2-Seismic hazard calculation
3-Determine performance level of elements/system
4-Initial seismic evaluation
5-Initial vulnerability determination
6-Detailed seismic evaluation
7-Detailed vulnerability evaluation

2-3-1-Importance determination of element or System

The first step in seismic evaluation is to determine importance and role of system in the network which is according to table 2-3 and is based on disorder consequences of system performance. Sub systems and internal elements will be categorized based on their role and relative importance in gas supply system according to table 2-9, after categorization of the systems.

Importance determination is shown in Table 2-10, according to the effects of the combination of internal elements and whole system.

Table 2-9 Categorizations of sub systems and internal elements

Type	Definition	Vulnerability effect on performance
Major	Has direct role in system performance	Gas shut off
Supplementary	Has supplementary or redundancy role in system performance	Disorder in gas supply
Secondary	Has not major or supplementary role in system performance	unclear

Table 2-10 Determine importance with combination of internal elements and total system

Sub system or internal element / Total system	Major	Supplementary	Secondary
High (has direct role in network performance)	Very high	High	Medium
Medium (has supplementary or redundancy role in network performance)	High	Medium	low
Low(does not have major or supplementary role in network performance)	Medium	Low	low

Obtained importance levels are defined consequently as follows:

1-Very high: Elements which their vulnerability will cause critical conditions, casualties and huge financial losses.
2-High: Elements which their vulnerability will cause gas flow shut off, service shut down and financial losses.
3-Medium: Elements which their vulnerability will cause disorder in gas flow.
4-Low: Elements which their vulnerability doesn't have any effect on system.

2-3-2-Seismic Hazard Levels

Three levels are defined for seismic evaluation of seismic hazard as follows:

- First level of seismic hazard: Maximum operation earthquake (MOE)
- Second level of seismic hazard: Maximum design earthquake (MDE)
- Third level of seismic hazard: Maximum considered earthquake (MCE)

These seismic hazard levels are equivalent to below safety levels where the precise definition for importance degrees is given in table 2-11

- Operation safety: in this level probable damages should not disrupt gas supply.
- Design safety: in this level probable damages might cause temporary disruption in gas supply but should not cause a general damage, collapse, fire, explosion, network instability and etc.
- Critical safety: in this level despite high performance damages, no system performance damages should occur and therefore it is necessary to do arrangements for reduction of secondary effects.

Table 2-11 seismic hazard level

Seismic hazard level	**Probability of return period in 50 years (years)**	**Safety level**
1	99.5% (75 years)	Operation safety
2	10% (475 years)	Design safety
3	2% (2475 years)	Critical safety

2-3-3-Performance Level of System Elements

Definition of performance levels based on hazard level and importance degree of facilities is given in table 2-12.

Table 2-12 Definition of performance levels based on seismic level and importance degree

	Seismic hazard levels (performance level)		
Importance	**1 (Operation safety)**	**2 (Deign safety)**	**3 (Critical safety)**
Very high	Without any damage and disruption in performance	No casualties Minor damages to facilities but still operate	No casualties Damages to facilities but system operates and no critical condition
High	Without any damage and disruption in performance	No casualties Damages to facilities but system operates	No casualties Damages to facilities & probability of temporary disruption on system operation
Medium	No casualties Minor damages to facilities but continues to operate	No casualties Damages to facilities & probability of temporary disruption in system operation	No casualties Damages to facilities major disruption in system & facilities operation but possible to repair and restore in acceptable time
Low	No casualties Minor damages to facilities but system operates	No casualties Damages to facilities major disruption in system & facilities operation but possible to repair and restore in acceptable time	Not necessary

Chapter 3

Vulnerability Evaluation Methods

3-1-Target Components

Target components are introduced in table 3-1 of this guideline and generally are categorized to linear and stationed components.

Looking from seismic performance point of view, this categorization is divided into single performance of each component and systematic performance of all components of a system.

Among stationed components, for all buildings including control and logistic building and similar ones, it should be done according to present seismic evaluation guidelines.

Table 3-1 Target components for seismic evaluation

Type	Title	Performance	Components
Station Type	Refineries	Single components	equipment
			Non-Building Structures
			Buildings
			Non-structural elements
		Systems	-
	Pressure Adjusting Station	Single components	equipment
			Non-Building Structures
			Buildings
			Non-structural elements
		Systems	-
Linear (Network)	High Pressure Transmission	Single components	Non-Building Structures
		Systems	-
	Low & Medium Pressure Distribution	Single components	equipment
			Non-Building Structures
			Buildings
			Non-structural elements
		Systems	

3-2-General Approach to Determine Vulnerability

In figure 3-1, the general approach to determine vulnerability and seismic retrofitting of lifelines is shown. This approach is divided to following four activities:

1-Data collection of structures, facilities, and equipments including data of single components and systems from process and performance point of view

2-Review geotechnical data and seismicity of region, including soil properties and secondary problems like landslide, liquefaction and cross faulting and study of seismic history and active faults

3-Review seismic vulnerability

4-Seismic retrofitting in case it is necessary.

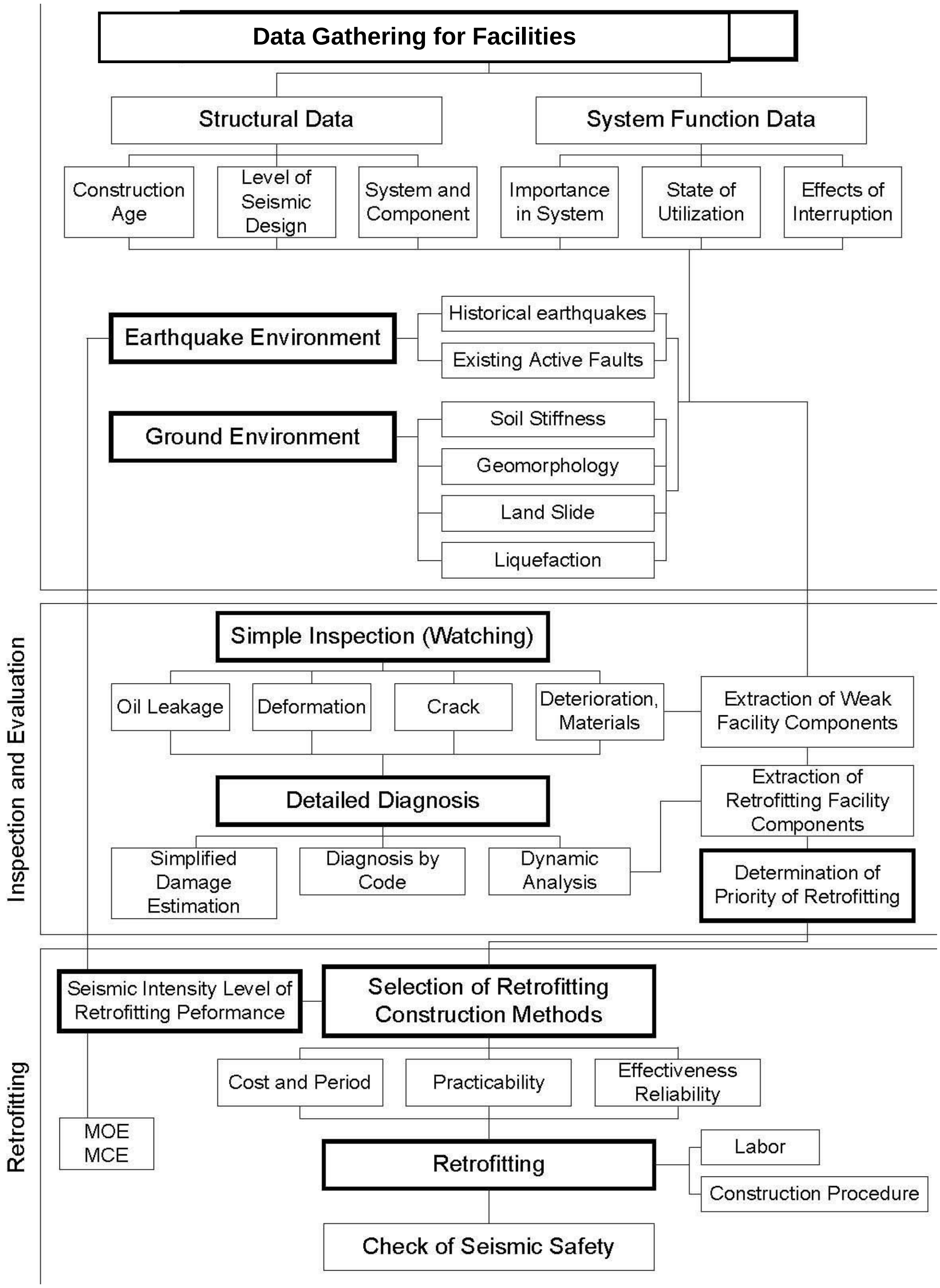


Fig 3-1 General Procedure to determine vulnerability and seismic retrofitting

3-3-Seismic Evaluation Methods of Components

Initial and detailed seismic evaluation methods for stationed structures like buildings, non-building structures, facilities and non-structural elements and linear and network structures is given in Table 3-2.

Table 3-2 Seismic Evaluation Methods of Components in Different levels According to Chapter 2

Component	Assessment Methods Level 1	Assessment Methods Level 2	Assessment Methods Level 3
Building Structures	Rapid assessment	Rapid assessment	Detailed assessment
Non-Building Structures	Qualitative assessment worksheet and scoring method	Seismic behavior control by reviewing design documents and using simple and equal static code methods	Analyze of dynamic and interaction behavior by analytical and numerical modeling
Equipment	Qualitative assessment worksheet and scoring method	Seismic general stability control by reviewing design documents and using simple and equal static code methods or empirical methods based on failure curves	Analyze of dynamic and interaction behavior by analytical and numerical modeling
Non-structural Elements and Building Internal Equipment	Qualitative assessment worksheet	Qualitative assessment worksheet	General stability control using simple and equal static or empirical methods
Above and Underground, High and Low Pressure Transmission and Collection Pipelines	Qualitative assessment worksheet and scoring method	Seismic general stability control under geotechnical hazards (sliding, faulting, liquefaction, …) and nearby structure impact by reviewing design documents and using simple and empirical methods	Analyze of dynamic behavior under geotechnical hazards (sliding, faulting, liquefaction, …) and nearby structure impact by analytical and numerical modeling

3-3-1- Seismic Evaluation of Buildings

Key issues on evaluation of functionality of buildings are as follows:

- Economical value of the structure and remaining years of operation life
- Building's functionality including number of residents under threat inside structure and those structural damages, which could release dangerous materials and make casualties outside the structure
- Structure's functionality and economical & social consequences if there is damage to its service due to earthquake
- Historical importance of the structure and effects of seismic retrofitting to historical and cultural resources
- Seismic risk of the site
- Comparison of retrofitting cost to its obtained benefit

Initial seismic evaluation or level one for steel and reinforced concrete buildings will carry out according to instruction number 364 of President Deputy Strategic Planning and Control (PDSPC). The title of this instruction is "Fast Visual Evaluation Method for Steel and Reinforced Concrete Buildings" and for masonry buildings the "Fast Qualitative Evaluation Method" which is given in chapter 3 of instruction number 376 of the above-mentioned organization, will be used.

Detailed assessment in the level 3 of concrete and metal buildings will be done using term of reference in publication No. 251 as the title of term of reference for seismic retrofitting of existing buildings and

Instruction No.360 from President deputy strategic planning and control as the title of instruction for seismic retrofitting of existing Buildings.

Detailed assessment of existing masonry buildings will be done using instruction for vulnerability analysis and seismic retrofitting of existing unreinforced masonry buildings (building undersecretary of ministry of housing and urban development).

3-3-2-Seismic Evaluation of Non-Building Structures

Initial evaluation of non-building structures will be carried out in components and it will be as follows:

- Study of seismic design documents with emphasis on structures as-built conditions if there is any
- Site investigation, preparation and utilizing seismic worksheets with emphasis on structure type and qualitative scoring
- Utilizing simple and static equivalent code method and control of general seismic stability

In the initial evaluation of non-building structures, usually system's study will not carry out.

If in this stage, the components are vulnerable, then the detailed evaluation of components and whole system will be done.

Detailed evaluation of non-building structures will be done by modeling and numerical analysis. This study includes dynamic behavior and structural interaction analysis.

Utilizing detailed method for complex structures or those with indeterminate dynamic behavior or with considerable interaction with surrounding environment and other structures is necessary.

3-3-3-Equipments' Seismic Evaluation

Seismic evaluation of equipment will be carried out as follows:

- Study of seismic control documents with emphasis on installation condition including seismic tests documents and performance control by its maker.
- Quantitative scoring method.
- Simple and equivalent static code method and control of general seismic stability.

In the initial evaluation of equipment, usually system's study will not be carried out.

In case, in this stage the components are vulnerable then the detailed evaluation of components and whole system will be done.

Detailed evaluation of equipment will be done by modeling and numerical analysis. This study includes dynamic behavior and structural interaction analysis.

Utilizing detailed method for complex structures or those with indeterminate dynamic behavior or with considerable interaction with surrounding environment and other structures and facilities is necessary.

3-3-4-Seismic Evaluation of Non-Structural Elements

Seismic evaluation of architectural and internal elements of buildings like walls, racks and false ceiling and internal installments like plumbing and canals will be done in one-step and will be done using following guidelines and instructions:

- Seismic retrofitting of buildings publication number 360
- Seismic design of gas lifeline instruction
- Seismic retrofitting of oil installments guideline
- Seismic assessment of power plant, publication number 360
- Other authoritative references, which are introduced in this guideline

3-3-5- Seismic Evaluation of Network and Pipelines

Initial evaluation of network and lines are done as follows:

- Study of seismic design documents of network, if there is any
- Preparation and utilizing seismic worksheets with emphasis to network type and qualitative scoring
- Simple and equivalent static code method and control of general seismic stability
- Utilizing damage curves of components and general vulnerability determination of network using combinatorial formulation based on reliability (see appendix 2)

Detailed evaluation of network and lines is done as follows:

- Seismic vulnerability numerical analysis of components
- Determination of general vulnerability of the network using combinatorial formulation based on reliability

Seismic evaluation of structures in the vicinity of distribution network should be done on a case-by case base according to relevant instructions (publication number 360 and 364 of PDSPC for steel or reinforced concrete buildings and publication number 376 for masonry material buildings) and quantitative methods should be used as much as possible. If quantitative evaluation methods are not possible, qualitative evaluation methods should be used according to relevant instructions. For very important components of the network, quantitative evaluation of structures on the close vicinity is necessary.

3-4-Inspection and Filling Worksheets in Level One Qualitative Evaluation

Site inspection usually will be done by a qualified engineer or a team of engineers. This method should be done in a determined manner and systematically so that the continuity and completeness of work is achieved.

Usually the steps are as follows:

- Meeting with clients, technicians, persons in charge of standards and safety engineers or other beneficiaries in order to discuss about the goals of inspection and getting the necessary facilities for the team.
- Identification of equipments, structures and other desired components. If review has been done as part of risk analysis or safety analysis, engineers in charge of site investigation should reconsider the assumptions used in risk analysis for probable future earthquake in critical systems.
- For purposes like insurance evaluation or determining total risk, if the review is optional, then evaluating engineers should visit major equipments and structures.
- Categorizing vulnerability modes.
- Collection of local data like seismic risk, fault location, opening in the soil.
- Systematic site inspection of components using worksheet for each section so that evaluation is documented and rules are reminded.
- Review of drawings when it is necessary to control adequacy of reinforced concrete, determining anchorage detail or diagnose and determine necessity of issues like fire proof coverings, isolations and etc. where the visual inspection is not possible.
- Review analysis for elements with critical conditions or any sections which seems to have seismic risk. These risks include risk of release of poisonous materials, pollution or any unacceptable performance like disruption in economy and trade.

- Documentation of weak and suspicious cases for clients and persons in charge of standards including adequate explanation like retrofitting of operations, storage of extra evaluation and etc. should be carried out.
- Structural and mechanical recommendations which might decrease the above mentioned risks. Engineer should consult with process and safety engineer and managers for economical evaluation and possibility of execution of retrofitting solutions.
- Prioritizing of recommended risk reduction activities should be done based on consequences of risk evaluation.

In practice, teams should walk along the line and inspect the major components. For example, each component should be inspected for cases like leakage of dangerous materials, possibility of fire and reaction with other materials and explosion or collapse.

Most of these inspections should be carried out independent from initial risk analysis.

It is recommended that site inspection teams have interaction with risk analysis teams.

Seismic evaluation teams including safety engineers should be able to explain probable earthquake effects on facilities to clients. For example:

- All facilities will vibrate simultaneously without warning.
- Vibration may take 10 seconds or more. In very large earthquakes (larger than 8) vibration lasts for about 60 seconds.
- Possibility of dismissing reserve gas.
- It is probable that many systems like telephone, water and … damage simultaneously and for long time.
- It is probable that buried pipes broke.
- Vulnerable elements of specific equipments and piping system may stop working.
- Essential services located out of region might be unavailable due to occurred problems in lifelines (like bridges and highways) or extra ordinary operation.
- Safety of operators or families is prior to safety of equipments so it is not recommended to use operators to decrease damages.

Site inspector should be in close contact with operators, client, safety engineers and other officials of the project.

For example, a civil engineer knows great problem in connection with carrying dangerous pipes.

But must be underlined that every potential damage needs to decrease.

More important factors in hazard Prioritizing include consideration such as continues operation or how to preserve generation.

During a destructive earthquake there is the possibility that facilities outside the site are destroyed for long time.

In this case, it seems necessary to prepare a reserve gas and water reservoir.

Local inspection team must identify other effective urgency systems in system operation in order decrease earthquake effect is considered.

In this regard the need for alarming system and fire extinction system, telecommunication system and deterrent system for better operation after the earthquake should be emphasized.

Major technical consideration points during inspection include:

- Earthquake risk level: In regions with low seismic risk, big buildings and vessels that designed for wind load nonetheless, might damage cause of ground motion.
- Intensity of Geotechnical risks (faulting, ground failure and land sliding): Inspecting team should be careful about probable damages to buried pipes and equipments, which are based on different structural system due to geotechnical risks near the site. If fault is crossing from the site, evaluation should include additional geotechnical investigations.
- Applicable standards during the construction phase: Applicable standards and seismic design methods might change comparing to initial design time.
- Evaluation of total capacity of new equipments should be emphasized. In the evaluation of older equipments, damages like deformation damaged concrete, steel corrosion and etc should be emphasized.
- If the overall quality of repair and maintenance is not suitable, site-inspecting team should evaluate number of lost bolts and nuts, non-repaired damages, site modifying & changes especially in the first inspection and the same is valid for connection.
- Process safety engineers and clients should be informed and assured about the initial evaluation of safety, pollution or economical consequences of damages through the site inspectors.
- Site inspectors should be careful about the regions vulnerable to corrosion. This is not that much related to surface corrosion but includes cases like structural strength reduction due to decrease in thickness, holing or layering. Regions where there are corrosion materials like acids or places with accumulated water are vulnerable to corrosion.
- Another region where corrosion might be a problem is where the concrete cover has peeled off and rears are exposed to environment. These regions are considered as a restoration case. As cracking is considered as one of the concerned cases with high priority in facilities, inspecting teams might help in finding these areas.
- During the simple inspection, engineers could also evaluate installed facilities which have problems. These problems might be seen in welds or bolts. For example extension anchorages might not have sufficient length and could not act up to their designed tensioned capacity.
- Seismic interaction occurs when there is no sufficient gap between two units to prevent collision. This might occur due to slide of unanchored facilities; sway of suspension pipes, cable racks, and electrical boxes hit each other, walls or other structural elements.
- Unsymmetrical displacements usually causes damages to facilities fixed to structural systems. Engineers should be aware of conditions where installments like pipes, ducts and etc should have sufficient flexibility for movement. Flexibility is a key characteristic against decreasing damage to facilities.
- Another concern is water sprinkle systems where it might affect the electrical facilities. Fire extinguisher pipe (used for earthquake caused fire) might affect electrical facilities.
- Other structures in the vicinity of distribution network might collide with network components and cause damage. This vulnerability might be evaluated. First those structures which are close enough to the network which upon complete are partial collapse might collide with network components should be identified. Then these structures must go under seismic evaluation.
- Seismic assessment adjacent building of distribution network

- Demanded operational level in assessment of this building, for design hazard level according to related procedures must be equal to Threshold collapse and for component with high importance is considered safe life.
- If it is n't possible to assess the quantitative evaluation for Gas lifeline components' evaluation could be done using recommendations, worksheets and retrofitting & evaluation guidelines used for petroleum facilities.

3-5-Collection of Necessary Data for Evaluation in Level 2 and Level 3

Collection of necessary data for quantitative evaluation should be done with in a planned manner. Resources for determining and collecting the necessary data are as follows:

- Present documents in different phase of design, operation and periodic maintenance: These documents should be compared with present status of the network and they should be updated if necessary.
- Inspection and data collection with visual and measurements methods: For this purpose if it becomes necessary, sample core should be taken and top layers and covers should be taken (without disrupting the performance or behavior of the component) and requested parameters and data are measured.
- Conducting the necessary tests: If data couldn't be obtained from documents or present catalogues and it become necessary, then tests should be conducted. The most important tests are those used to obtain soil type, characteristics and mechanical properties of material. In general non destructive test are preferable. If it becomes necessary to conduct a test on connecting equipments like bolts or insulators and similar, at least the test piece should be substituted with similar sample. In any case during coring or test, damage or weakening on any elements of the network should be prevented.

3-5-1-Design and Operation Documents' Collection

In the beginning of seismic evaluation study, structural documents of facilities including buildings, non building structures and equipments should be collected as much as possible and reviewed thoroughly.

Workshop drawings should be conformed to the executed ones and updated if there are big inconsistencies. Data collection related to changes and probable repairs and influential accidents on behavior of facilities is necessary.

Reports of soil mechanic and material tests and also risk analysis studies should be collected as much as possible and checked.

3-5-2-Visual Inspection and Extraction of Evident and Obvious Problems

In this stage of data collection, study and review is done in order to find evident and obvious problems where they cause clear weakness in the seismic behavior of facilities.

Comparison of shop drawings, as-build and installation drawings with present status of facilities is necessary in this stage.

3-5-3-Conducting Soil Mechanics and Material Test and Risk Analysis

This stage of data collection should be done if according to consulting engineers' judgment, the above mentioned data collection is not sufficient for initial or detailed evaluation. Client's approval is compulsory.

Table 3-3 shows the conditions where the soil mechanics and material test are necessary and shows the content of these tests too.

Standard and general test definitions for buildings are according to the "seismic retrofitting and evaluation of present buildings instruction" (publication number 360). For non building structures and facilities, there is no given set of tests and contents of tests should be given by consultant engineer and client's approval.

Table 3-3 Soil Mechanics and Material Tests

Comparative Importance of the System	Soil and Material Data	Level of Tests
Very High	available	Standard
	Not available	Complete
High	available	-
	Not available	Standard
Medium	available	-
	Not available	Standard
Low	available	-
	Not available	-

3-6-Seismic Evaluation Using Modeling and Numerical Analysis

Modeling and analysis methods are based on determination and comparison of seismic need-capacity of facilities, structures and their connections.

Modeling and numerical analysis include following two major aspects:

- Suitable modeling based on dynamic and mechanical specifications.
- Seismic loading and numerical analysis based on the model. Loading details are according to "power systems seismic design instruction"

Following numerical analysis methods for structures are recommended:

- Equivalent static method
- Spectrum method
- Time history method

3-6-1-Equivalent Static Method

For seismic analysis of facilities where the first vibration mode is the dominant mode, the equivalent static method is recommended according to non building structural section of standard 2800.

For facilities with natural period less than 0.03 seconds it is acceptable to multiply maximum floor acceleration to the elements' mass and apply this force into the mass center of the element without need for intensification factor.

3-6-2- Spectral Method

In complex facilities where vibration modes are apart from each other, it is recommended to use spectral analysis method according to the non building structural section of 2800 standard.

3-6-3-Time History Method

For seismic evaluation of complex facilities with vibration modes close to each other where their numbers do not have big differences with each other, it is recommended to use time history method according to non building structural section of 2800 standard to control the results obtained from spectral method.

3-7-Seismic Interaction of Systems

Seismic interaction of systems is a collection of effects on seismic behavior and intensification of earthquake effects including undesired changes in dynamic characteristics due to structural interaction, collision of adjacent systems, collapse of systems on each other, relative displacement of adjacent systems and changes in environmental and operational conditions which will alter operation of systems or damage the operators.

Usual causes of interaction could be categorized as follows:

1-Adjacency: Any effects resulting on malfunction of system due to adjacency of systems including collision, relative displacement and structural interaction

2-Rupture and collapse: Any effects resulting on malfunction of system due to failure, rupture and collapse

3-Sprinkles: Effects due to rupture of pipes or malfunction of fire sprinkles, which might cause short circuit or power plants units become out of reach.

4-Flooding: Effects due to flooding and submergence of systems and becoming inaccessible

5-Fire: Effects due to fire including smoke distribution, destruction of systems

Each system, which is under the negative effects of above-mentioned interactions, is called "interaction target" and those systems, which their malfunction is the cause of interaction is called "interaction source"

Those interactions, which cause failure or malfunction of the system, are called "considerable interactions" and if the effects are negligible then it is called "non considerable interaction".

Evaluation of effects of seismic interaction in "interaction target" could be done with one of the following 4 methods:

1-Ignoring the effects of interaction (non considerable interaction)

2-Modifying of "interaction source" in order to eliminate interaction effects (considerable interaction)

3-Increase the relative importance of "source interaction" up to target interaction systems (considerable interaction)

4- Improving suitable performance for facilities of "target interaction" in scoring method (considerable interaction) unless facilities of "source interaction" (by assuming relative importance) will be evaluated equally as facilities of "target interaction" (approach number 3).

3-8-Acceptance Criteria

Facilities will be vulnerable when the sum of seismic load combination and other applicable loads will exceed the seismic capacity of the elements. Seismic capacity of elements will be calculated based on seismic design guidelines.

3-8-1-Load Combinations

Load combinations for vulnerability evaluation of non building components are as follows:

Dead Loads + Service Live Loads + Horizontal component of Earthquake (in two independent directions) + Vertical component of Earthquake (in two independent directions)

In above load combination, in seismic design level, earthquake loads (horizontal and vertical) should be multiplied by 1.4.

3-8-2-Stability Controls

In non anchored components, in addition to strength needs and seismic capacity, toppling, sliding and displacement controls also should be done.

Safety factor for sliding is the ratio of passive loads to active loads in two crossing independent directions. Safety factor for toppling is the ratio of passive moments to active moments in two crossing independent directions.

Unanchored elements and facilities should not be controlled for toppling and sliding against seismic loads. Minimum safety factors for toppling and sliding in both risk levels are 1.75 and 1.5 respectively.

3-8-3-Acceptance Criteria in Non Linear Dynamic Methods

Generally in non linear dynamic methods, evaluation and acceptance is based on criteria which are combination of load and displacement.

In gas distribution networks, according to facilities and network operation, if non linear analysis is done then stresses and internal forces in non deformable components (controlled with force) should be controlled in the same way as it is done in linear methods (which is given in previous sections).

In deformable components which enter non linear area, displacements and rotations should be in a level not to interrupt the operation of the component under consideration.

Decision on this issue should be done based on technical specifications of facilities and judgment of experts.

Chapter 4

Seismic retrofitting methods and procedures

4-1-Prioritizing retrofitting activities

Prioritizing retrofitting activities will be done according to following indices:

- Level index I_L
- Change of performance level
- Retrofitting cost
- Ease of execution of retrofitting method

The general method for prioritizing retrofitting activities is based on risk analysis.

To do this analysis, it is necessary to determine what will happen if retrofitting activities are not done and it will be decided based on the result of this vulnerability study.

Consequences of abolishing retrofitting will be considered in five categories namely, casualties, possibility of social or political unrest due to time of flow shut off, direct financial losses to facilities, economical losses due to shut down of lifelines and environmental damages. These criteria will determine general safety of the structure or facility.

The highest priorities are the first two categories. In other categories by comparing retrofitting cost and estimated damage losses, the risk of un-retrofitting will be determined and then it will judged.

In risk analysis damage modes and different retrofitting levels also could be compared.

4-2-Seismic retrofitting procedure

Seismic retrofitting procedure for structures and facilities is a try & error one and when structures' vulnerability is found then it will be done as follows:

1-Selection of retrofitting methods based on damage modes of structures & facilities and their performance.

2-The findings of retrofitting methods should be implemented on structural model and vulnerability should be checked again until the required performance is obtained.

3-Comparison of acceptable retrofitting methods based on cost, time and ease of execution indices through value engineering and prioritizing retrofitting methods of structures and facilities.

4-Categorizing seismic retrofitting of elements of the system based on clause 4-1

4-3-Retrofitting selection method approach

Seismic damage reduction methods for structures and facilities could be categorized into two general categories as follows:

- Hardware methods in shape of retrofitting, correction or in final shape renewal
- Software methods in shape of change in operation plan, change in performance level and increase of safety and reduction of possibility of occurrence of secondary disasters

Retrofitting method depends on the dominant failure mode of facility. Therefore selection of proper retrofitting methods is directly related to credibility of results of vulnerability evaluation. In these studies failure mode and amount of damage should be determined clearly.

Depending on hazard level, failure mode could be different and this issue should be considered in selection of retrofitting method so that all probable failure modes could be controlled by suitable retrofitting.

In the study of failure modes and presenting retrofitting methods all initial and secondary failure modes should be considered. Secondary failure modes include ground permanent displacements, fire, explosion, interaction and collision of structures and collapse of debris and other cases.

4-4-Type of retrofitting method

In next chapters, seismic retrofitting methods of structures and gas supply system will be presented according to seismic vulnerability modes in four sector namely, refinery, tanks, transmission and distribution pipelines and other related structures.

Chapter 5

Seismic Retrofitting Methods for Refineries

5-Refinery

The target components in a refinery in this guideline are as follows:

- Piping and pipelines rack: Pipelines are divided into different categories namely tank piping, process piping, on-ground/ under-ground piping and facilities' piping.
- Horizontal tank: This guideline could be used for seismic design of horizontal tank (with storage capacity of 3t or 3000 m^3 or more)
- Tower and vertical tank: Includes tower (In high pressure gas facilities tower are reaction, separation, purification, condensing units and etc which has length equal to or more than 5m), condenser (vertical cylinder type with body length equal to or more than 5m) and vertical tank (with storage capacity of 3t or 3000 m^3 or more)
- Spherical tank: This guideline could be used for seismic design of spherical tank (with storage capacity of 3t or 3000 m^3 or more)

5-1-Piping and pipe supporting rack

5-1-1-Damage modes

Piping system of gas refinery and petrochemical factories will damage a lot during an earthquake. Pipe damage is divided into piping system damage and supporting structure damage. Damages usually are divided into damage to pipe element (pipe and supports) and piping system due to inertia force induced by relative displacement and ground movement.

1-seismic damage to piping system
  a) Seismic damage of pipe and pipe support
    i) Seismic damage of pipe
      1-Cracking and butt type weld break
        This occurs when the weld is defective or weld strength is less than main pipe strength and effect of decrease of bending moment in knee is not forecasted. If surface defects exist like cracks along thickness or weld incomplete penetration in low temperature, brittle break in low temperature may occur as well.
      2-Loosened flange connection
        This occurs when the leakage start moment in flange is less than steel pipe yield moment and bending moment reduction in knee is not expected.
      3-Crack, yield and pullout of bolts in piping facilities
        Plastic deformation only in bolt section is developing because bolt root is small in threaded part.
      4-Pipe wall crack on weld surface in pipe support
        In main piping of furnace or in long, high diameter and thin thickness pipes and etc, if displacement due to heat expansion of pipe is restrained in longitudinal direction of pipe in one point, this kind of crack will show itself in the welding point of support to pipe wall.
      5-Cracks in PVC pipes

PVC pipes have less deformability comparing to steel and plastic deformation in knee should not occur. Deformability of these pipes will diminish in rapid strains and they are weak in impact as well.

6-Crack in cast iron manhole

Cast iron manhole is made from brittle material. Most of the failures are due to inability to absorb energy or low bending moment capacity of pipes because their relative stiffness is weak.

ii) Seismic damage to support structure of pipe

Following cases have been reported after damage occurred in pipes which do not lead to leakage:

1-Pipe vibrates and pipe span elongates due to support failure because of low strength

2-Pipe vibrates and pipe damages due to improper function of support due to its age.

3-Pipe damages due to relative displacement of facilities on both sides of pipe

4- Pipe damage due to relative displacement between tower and supporter because of failure of tower stabilizer which is connected to supporter. Bending of stabilizer's support will absorb much of the earthquake energy and less energy will transfer to pipe. An energy absorber support is a method to overcome this problem. Big deformation of support due to relative displacement of ground will decrease its effect on pipe.

b) seismic damage in piping system

Seismic damage in piping system is due to inertia force and ground displacement.

i) Seismic damage due to inertia force and ground displacement

Most of the damages are due relative displacement and secondary disasters caused by vibration and pipeline displacement.

1- Pipeline failure due to relative displacement between tower and adjacent frame structure. (support response displacement)

2-Pipeline failure due to relative displacement between tower and frame structure caused by support beam vibration (support response displacement)

3-Break of small pipes due to relative displacement caused by vibration of big diameter pipes. (pipeline response displacement)

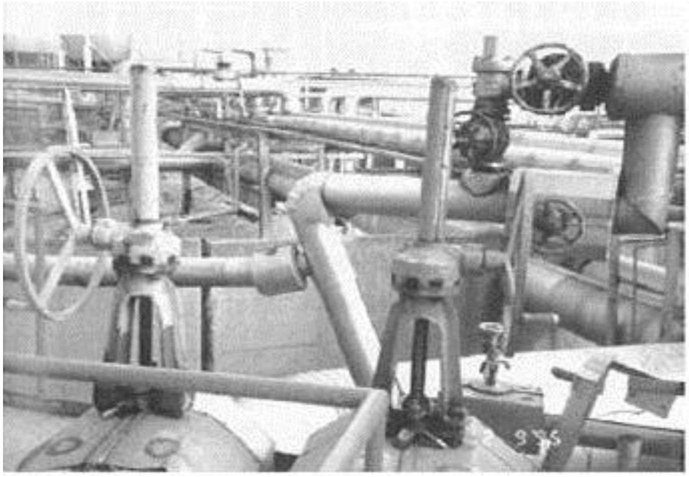


Figure 5-1 Damages in pipes with small diameter

4-Pipe fall down from support (pipe slide)

5-Release from support spacer (pipe slip)

6-Failure in pipeline facilities due to displacements caused by high vibrations of shutdown of emergency valve

7-Failure of connected pipelines and failure of generator due to relative displacement caused by generator movement above separator desk (slip of support structure)

Following damages are also probable although they are not confirmed.

8-Pipe fall down due to separation of suspended connecting fixtures (pipe response displacement)

9-Pipeline failure due to relative displacement caused by cylindrical tank uplift force

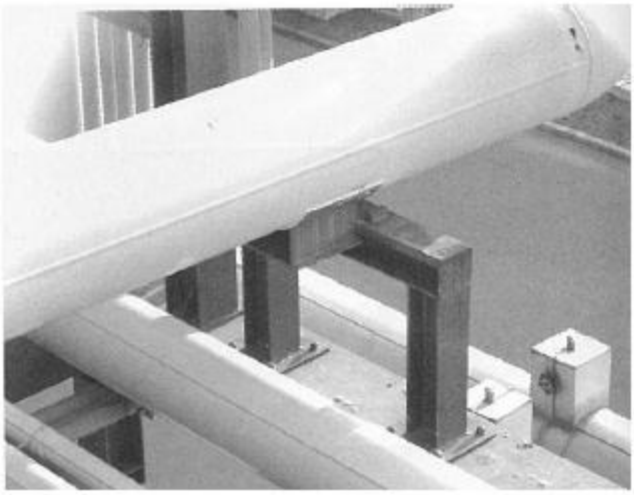


Figure 5-2 Pipe separation from support due to acceleration response

Cooling of pipe due to stop of work, will cause pipe to contract and could lead to pipeline break.

If pipe fall down is due to support vibration and structural issues like stabilizers are considered, most of damages should be prevented seriously.

ii) Damages due to ground relative displacement

Following cases are reported due to ground movement. Relative displacement due to liquefaction is a unilateral loading which does not cause fatigue. But if earthquake force is big like Hyogoken Nanbu Earthquake, it will cause serious damages.

1-Damage due to relative displacement caused by pump & tank settlement sit on spread foundation.

2- Damage due to relative displacement caused by settlement and vibration around tank with pile foundation.

3- Crack in nozzle of cast iron pump, crack of sheath and axial misalignment due to movement and settlement of pump with independent foundation.

4-Damage due to collision of secondary pipes (small diameter) with adjacent structure when main pipe is displaced with ground movement.

5-Damage of flexible pipelines due to relative displacements more than designed ones.

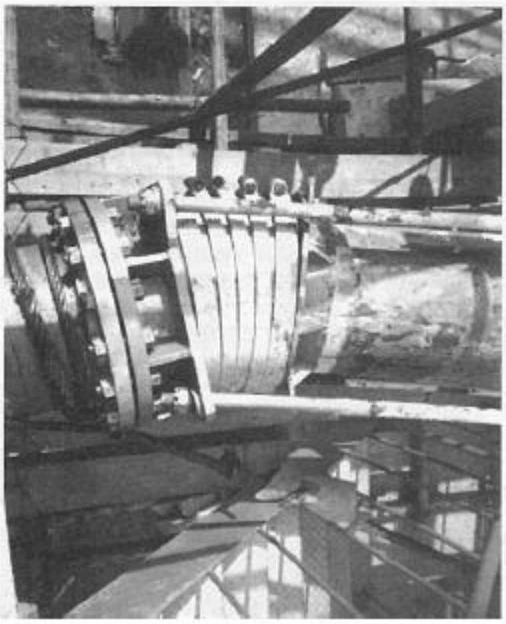


Figure 5-3 Hinge of flexible pipe looses functionality

6- Flange leakage due to low flexibility of pipeline when relative displacement is more than allowed displacement in flexible pipes.

7- Damage of pipeline facilities due to displacement caused by settlement and displacement of aerial tank with independent columns.

In clauses v and VI it is recommended to make pipes and supports flexible for relative displacement more than allowed displacement of flexible pipe.

For clause vii, common foundation is necessary in order to prevent pull out of emergency cut off valve and aerial tank.

2- Supported piping system

Earthquake effect on piping system which are supported with facilities or structures like towers, tanks and framed shaped structures, are as follows:

a) Inertia force effect of supporting structure

b) Effect of relative displacement between supported points due to displacement of supporting structure

c) Effect of relative displacement between supported points due to settlement and horizontal displacement and misalignment of support foundation caused by ground deformation

d) Effect of collision of adjacent structure (high diameter pipes) due to great vibrations or relative displacement

e) Damage of piping system due to collapse of support structure

Figure 5-4 Damage to piping system due to damage to building

f) Damage to piping system due to collapse of adjacent structures

g) Damage to free fall of masses from top

Clauses ii and iii are due to relative displacement but loading of clause ii is cyclic and loading of article iii is continuous and single sided.

High diameter pipes of supporting structure are small pipes junction from itself.

3- Structural consideration in seismic design of piping system

Dynamic characteristics of facilities or structures in earthquake are affected by their configuration. Damage mode of piping system supported by facilities is in fact the damage mode of supporting structures.

Table 5-1 shows issues on types of piping system.

Table 5-1 Issues on types of structures in seismic design of piping system

	Piping system type	**Seismic design points**
Tank piping	Around tank floor with low temperature	Prevention of contraction of heat nozzle, settlement
	Around the tank with dangerous materials	Ground and tank settlement
	Perimeter of spherical tank	Vibration and settlement of spherical shell
	Perimeter of horizontal vessel	Settlement
On ground piping and connected to structure	Tower perimeter	High vibration of tower tip
	Tower perimeter with supporting structure	Relative displacement between tower & structure frame
	Piping of furnace and boiler	Prevention of heat nozzle contraction
	Compressor perimeter	Releasing pipe reaction
	Pump perimeter	Foundation settlement
	Heat exchanger perimeter	Relative displacement
	Air cooling fans perimeter	Prevention of heat nozzle contraction
	Over pipe supporting (rack) structure	Slide and fall down of piping
On ground & underground piping	Underground piping	Settlement and ground displacement
	Inside manhole piping	Manhole floor uplift force
	Piping near quay	quay movement
	Water channel with high diameter	Axial slide control
Piping attachments	Emergency shut off valve perimeter	Relative displacement (vibration of upper part & independent pier movement)
	Air tank perimeter	Relative displacement (independent pier movement)

In addition to inertia forces, tank pipes are sensitive and vulnerable to relative displacement between tank and ground and process pipes are vulnerable to relative displacement between facilities, structures and pipes.

On ground and underground pipes are influenced by ground movement and pipes attachments and facilities are vulnerable to displacements between pipes, facilities and structures including fast emergency shutoff valve.

Liquefaction is effective on all pipes and its effect is stronger in near coastal areas. Categorization of weak points or damage status is possible through investigation of pipeline and attached facilities' performance.

In general, the vulnerable points and modes are as follows:

- Flange connection
- Flexible pipe and connection
- Valves
- Pump
- Pipe branches and curved pipes
- Pipe system on the supporting structure
- Threaded connection

- Touch and collision of pipes and structures adjacent to each other
- Pipes with small cross section
- Pipe in the vicinity of entering a wall
- Collapse of pipe supporting structure

Damage modes are as follows:

a) Flange connection

Seismic forces will loosen the flange connections and poisonous and flammable contents will leak and cause serious damages.

To prevent connection displacement (which is caused by bending moment), special arrangements is necessary.

b) Flexible pipe and connection

With proper use of pipes and connections, it is possible to absorb earthquake's force and displacement. Nevertheless, when lateral displacement increases flexible pipes are unable to absorb these forces, and this condition damages pipeline and its supporting structures.

c) Valves

Even if valves are built from steel, stress concentration in points will cause crack and cause valve leakage. Bending moments are concentrated in areas where pipes and plate valve stiffness are different and could cause problems.

d) Pump

When pumps faces pipes, weak areas will form in the connection area of pipe and pump and this could cause problems to pump.

Bending moments will cause stress concentration in areas where there is stiffness difference between pump and pipe.

e) Pipe branches and curved pipes

Bending moments will cause stress concentration due to different shape and sizes in branches and curved pipes in comparison to other pipes. This will cause pipes to rupture. Cast iron pipes will damage more. Steel pipes are not immune from damage.

f) Threaded connections

High stiffness in threaded connections (knee and branches) will cause damages in straight pats of pipes and straight pipes and mechanical connections will cut out with tension force.

g) Touch and collision of pipes and structures adjacent to each other

Independent movement of pipelines and supporting structures in an earthquake will cause collision and this will lead to damage to both systems.

h) Pipe over supporting structure

Small pipes, which are in contact with big pipes, will cut off due to inability of small pipes in absorbing bending stress and axial tension.

i) Pipes with small cross section

When pipes sit on many supporting structures, there are situations where supporting structures damages and pipe separates from supporting structure. The reason for this damage is relative displacement between pipes and supporting structure.

j) Pipe in the vicinity of entering a wall

Pipes are damaged due to extra bending moment and in places where pipes are in contact with concrete wall like in entrance to pump room, will damage. To solve this problem, pipe perimeter should be filled with soil or soft material.

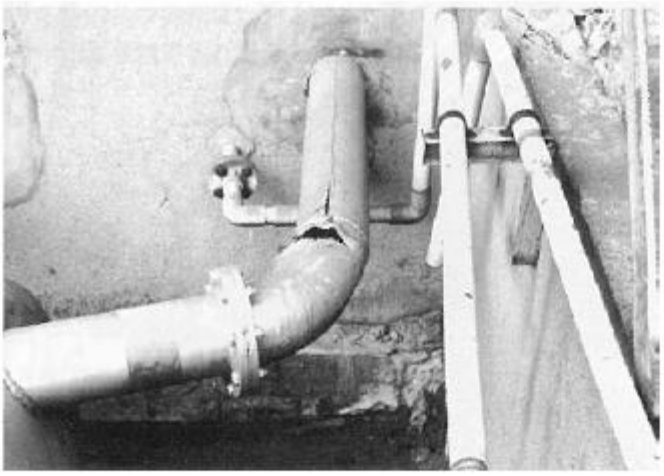


Figure 5-5 Pipe break in entrance to wall

k) Collapse of pipe supporting structure

When pipe supporting structure, like frame is collapsed, piping system will greatly damage.

5-1-2-Seismic assessment

The first step in seismic assessment is assessment of piping system. In this method, total piping system will be considered for seismic performance and then assessment will start as follows:

1- Qualitative assessment using RBM method and local inspection
2-Detailed assessment
3- Retrofitting measures
4- Execution of retrofitting measures

The first step in detailed assessment is to define level and target of assessment.

A good method named allowed span method is explained in seismic design guidelines for gas supply system and could be used for pipes with low importance.

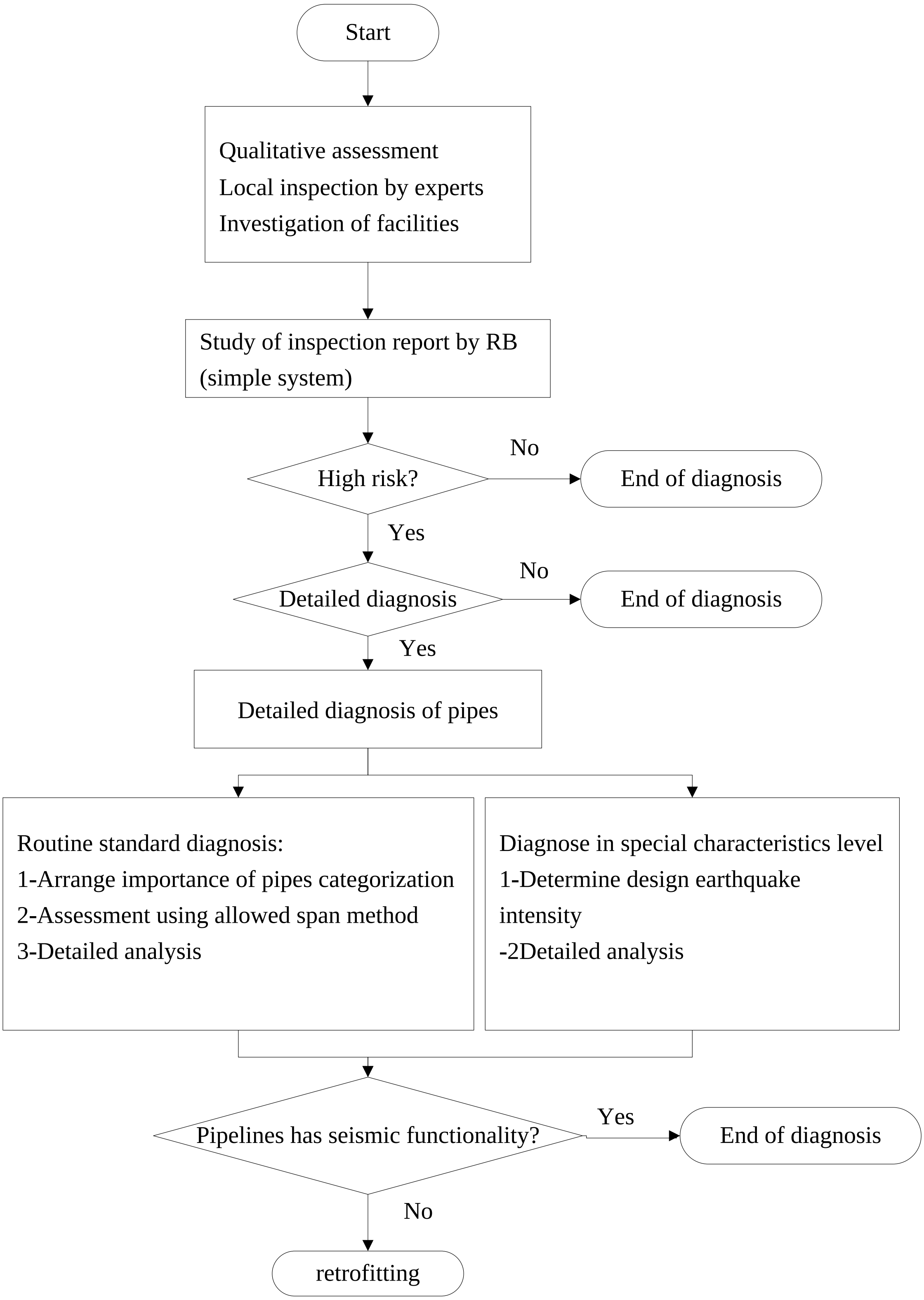


Figure 5-6 Seismic assessment flowcharts for existing piping system

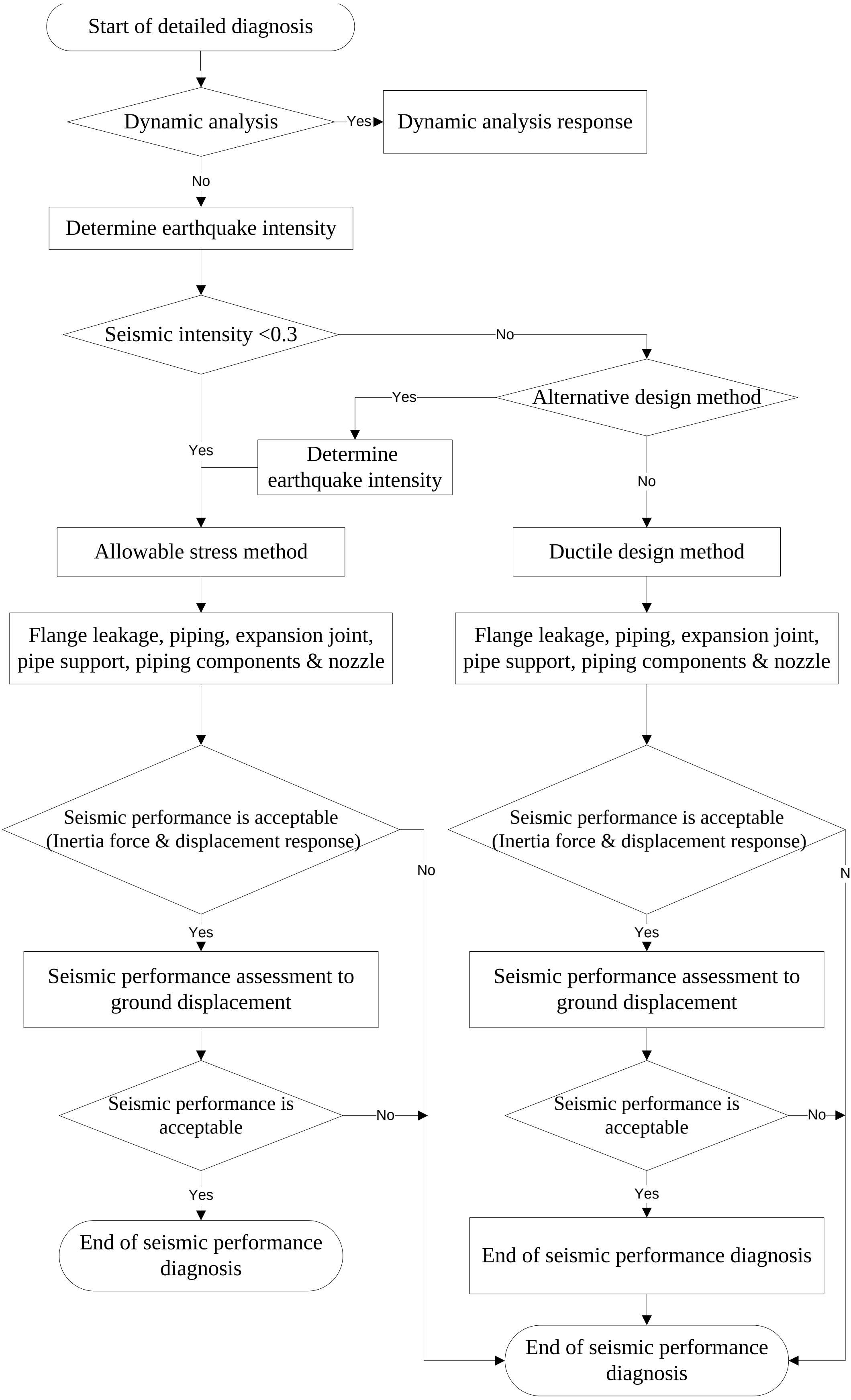


Figure 5-7 detailed design flowcharts

For the first step, it is proper to consider all piping system for seismic performance assessment and its flowcharts is shown in figure 5-7.

First method: Qualitative assessment using maintenance method based on RBM risk and local inspection.

Second method: Detailed assessment

Third method: Retrofitting measures

Forth method: Execution of retrofitting measures

As it is impossible to carry out retrofitting measures without assessment, inspection table will be necessary to advance the methods consequently.

1- Qualitative assessment using RBM method and local inspection

Before anything else, doing seismic performance assessment using RBM technique has special priority comparing to other methods.

One advantage of this method is recognizing assessment priority in short time in a qualitative way.

Qualitative assessment using RBM technique is risk based maintenance.

This technique will show failures due to aging and presents a new method for inspection and maintenance, which assess the damage based on its occurrence probability and size. Details of RBM are mentioned in API 581.

Using this method, qualitative assessment could be used to recognize priority in most of facilities.

1-1-

The procedure for qualitative assessment using RBM technique is as follows:

a) Input data

Following data are used as input data in piping system

i) Assessment of damage possibility

Will be done based on the probable earthquake size (seismic design intensity) area condition (including possibility of liquefaction), execution condition, aging and structural factors (including piping system strains and etc)

ii) Assessing size of damage

Will be done based on damage type, occurrence of secondary damage, damage spread factor, reconstruction factor and fake disasters.

b) Inspection of existing facilities for input data (including local inspection)

Is mentioned before, all input data, seismic plan technical specifications and drawings of facilities have been studied and inspection have been done and location of facilities are approved. In this case, it should be clarified whether a seismic standard has been used or an independent seismic intensity has been utilized.

c) Output

Input data will be studied in a qualitative assessment system and results will be presented in a matrix, which gives scale and scale of damages as output. According to this output, risk degree could be determined. Following figure is an example of data output. If scale of damage is severe due to leakage and length of damage, then detailed assessment will be recommended.

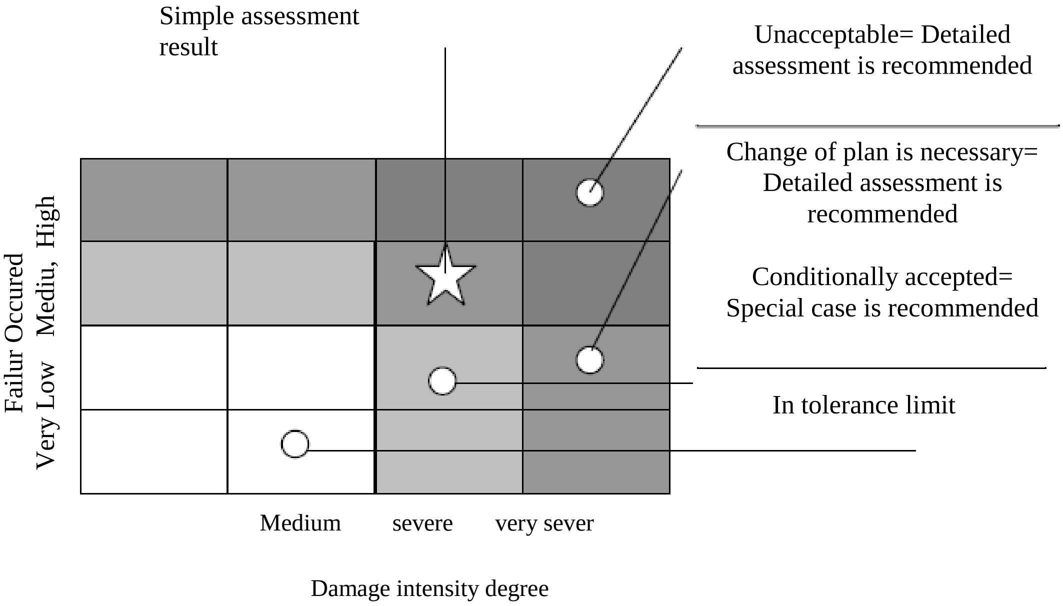


Figure 5-8 Output scheme of qualitative assessment using RBM method

2- Detailed seismic assessment

a) Determine target and performance level

The first step in detailed seismic assessment is to determine assessment target and seismic performance level.

b) Allowed span method

If piping categorization from importance point of view is second degree or less, allowed span control method will be used for assessment based on seismic design guidelines.

If the results are acceptable, assessment will finish, otherwise assessment will continue with detailed assessment.

c) Detailed analysis

Flowchart for detailed assessment of piping system is shown in figure 5-6.

It is possible to assess minor tensions in tank nozzles, towers and pipes supports using numerical analysis.

5-1-3-Retrofitting of pipeline and pipe supports

Basics of retrofitting are as follows:

1-Retrofitting based on qualitative assessment

Although some measures must be done regarding the defects fund in local inspection, but in minor damages, measures are limited to daily inspection and simple studies and quantitative concept for measures related to enhancing seismic strength will be determined. For major damages, study should be done with detailed assessment.

2-Retrofitting based on detailed assessment

a) Points on detailed assessment

Following points should be considered in retrofitting activates.

i) Structural discontinuity and stress concentration should be avoided as much as possible.

Coordination and total integrity of facilities from functionality point of view, sizes and economy should be considered.

Existing and new structure should act as a one structure.

b) Section under retrofitting

In this guideline, retrofitting measures are mentioned based on damage modes to piping system and its details will be given in coming articles of this section.

c) Retrofitting study condition

Before starting detailed assessment, following points should be clarified:

i) Is it possible to stop functions for retrofitting measures of pipes?

ii) Are there space and execution limitations in retrofitting conditions like retrofitting of pipe support?

d) Selection of different retrofitting measures

Following measures should be studied based on assessment results and necessary calculation should be carry out, in order to control them.

i) Change of piping system constraints

ii) Decrease seismic design coefficient by changing natural frequency in support structure.

iii) Avoid relative deformation in pipes as much as possible.

Heat tension calculation is necessary for control of deformation and pipeline restraints.

e) Control flanges and valves with eccentricity

Finally, calculation to control flange strength, valves with eccentricity, expansion joints in pipes supports and towers and tank nozzles will carry out.

3- Retrofitting measures using results of qualitative assessment

Following points will be considered when piping system will be changed due to defects and damages found in local inspection.

a) It is recommended to do the nozzle strength control against forces exerted from connecting pipes, after securing flexibility of pipe system.

b) It is recommended that pipes connecting adjacent tanks directly to each other have bends.

c) It is recommended that pipe is not connected to tank directly.

d) It is recommended that the pipe coming out of ground has bend.

4-Retrofitting measures using detailed assessment results

Measures for reduction of seismic damages using detailed assessment results are as follows:

4-1-Eliminating weak points of piping system including:

a) Weld control: weakness of welds should not be overseen. Brittleness due to low temperature in areas with cold weather is seen.

b) Limitation on using brittle material: It is recommended to avoid using cast iron valves and PVC pipes in piping system in order to avoid break during earthquake.

c) Avoid thread connection: In order to avoid breaks during earthquake, weld connection should be used. If thread connection is used relative displacement should not occur.

d) Flange connection: it is not recommended to use flanges in areas with high bending moment but it could be used where there is no big bending moment.

e) Avoid bends with big thickness: it is recommended to avoid angle change in pipes with big thickness.

f) Proper structure of pipe support: support structure will distribute support reaction in wider area.

g) Management of corrosion in pipes: corrosion and decrease in thickness specially slimming in a narrow area should be considered.

h) Avoid decrease in cross sectional area: Decrease in cross sectional area in local points should be avoided.

4-2-Remove structural defects of pipe support

Following points should be considered about pipe's supports:

a) Weld control: In design and execution it should be noted during installation of stabilizer in framed structure no breaks occurs in corner weld.

b) Management of damage to pipe support: It should be note that functionality of support according to design targets should be taken into account as part of repair and maintenance phase.

4-3-Pipe support for the seismic design

In general, anchor (constraint), pile (support for dead load), vertical anchor (displacement constraint in vertical direction to axis) and so on, control vibration and sliding of pipe. Special tools, including anti vibration hydraulic device, anti vibration spring device and damping support could be used.

4-4-Decreasing inertia force and response displacement effects

a) Pipe support should be located in a proper place so that pipe vibration is under control and avoid extra bending and axial force.

b) Pipe support should be located in a proper place so that extra vibration and pipe slide is under control and avoid effects in small diameter pipes like collision with other structures, fall down from support and joints failure.

c) Flexibility to absorb relative displacement

d) Pipe with small displacement response is located specified place and location.

e) Control support structure's vibration

4-5-Decrease foundation movement effects

Decreasing foundation movement due to ground movement could be obtained by following items:

a) Using common foundation

b) By use of flexibility, relative movement will be absorbed

c) Combination of item a and b

Relative movement between support points due to foundation movement could exceed few ten centimeters in both horizontal and vertical dimensions. It is possible to absorb this movement with plastic deformation using bend connections and also using free slide support.

5- Retrofitting measures

Examples of retrofitting measures are as follows:

5-1-Reduction of inertia force and response displacement effect

An example of inertia force reduction and response displacement effect is shown in figure 5-9

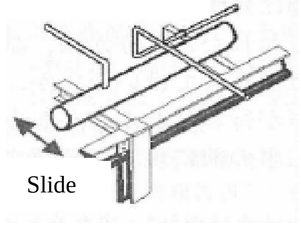
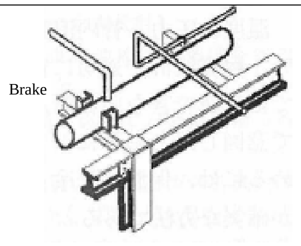
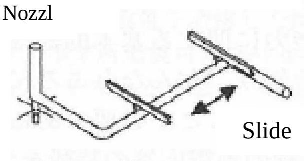
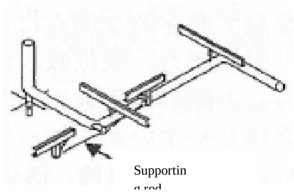
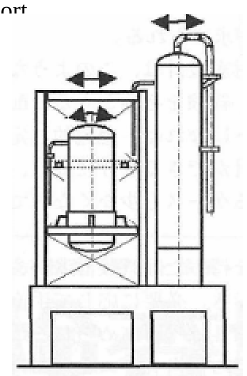
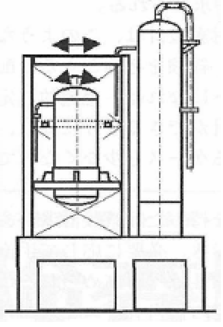
Example	Increasing effect	Decreasing effect
Example 1	**piping on rack** 	
Example 2	Piping of compressor 	
Example 3	Piping around tower with framed support 	Pipe connection in lower level and lower relative displacement 

Figure 5-9 Example of decreasing inertia force and response displacement effects

In example 1, brake is used to prevent relative displacement of secondary pipe and prevent collision of adjacent small and weak structure due to bigger pipe slide on framed structure.

In example 2, vibration of suspended pipes is restrained by use of rod so that seismic force is not exerted on compressor nozzle.

In example 3, Pipe is lowered to a position where its displacement response is small then pipe goes into a framed structure so that the pipe on framed structure has no effect from relative displacement of tower support (altitude).

In top of the tower could consider cyclic support (lug) until locking is controlled and is decreased relative displacement for anchor

5-2-Decreasing effect by foundation movement

An example of decreasing effect by foundation movement is shown in figure 5-10.

In example 1, for pump settlement a common and integrated one-part foundation is executed and nozzle effect has decreased.

In 2nd example, free support is executed and ground settlement effect is decreased.

In 3rd example, for output pipe of horizontal cylindrical tank, roller type support is used and movement is allowed to prevent extra bending and torsion.

In 4th example, regarding filling and depleting of tank pipe with flat floor and in low temperature after producing flexibility in order to absorb large vertical and horizontal relative displacement, pipe movement on support is freed.

In 5th example, horizontal relative displacement in a cross over road is absorbed with horizontal slide.

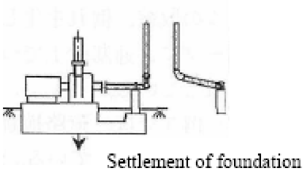
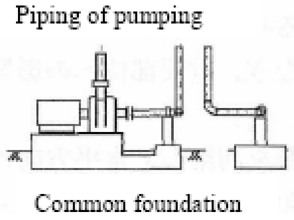
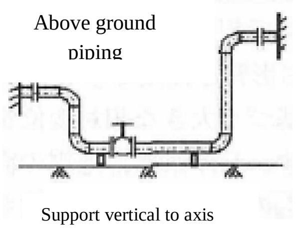
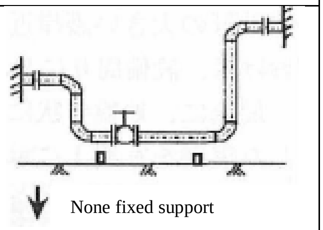
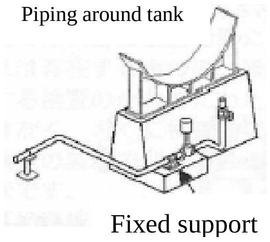
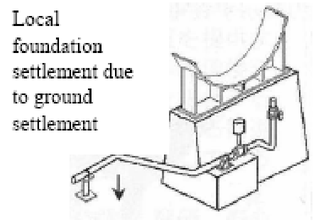
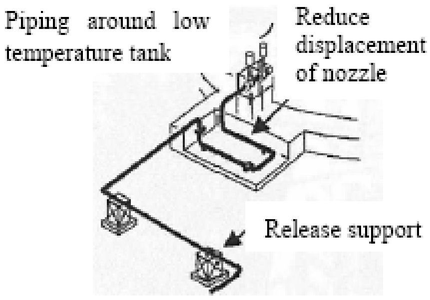
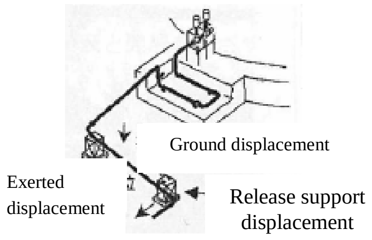
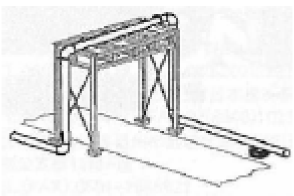
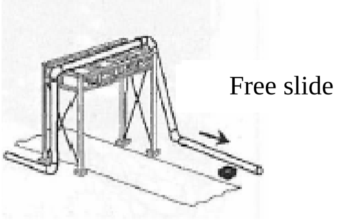
Example	Increasing effect	Decreasing effect
Example 1		
Example 2		
Example 3		
Example 4		
Example 5		

Figure 5-10 Examples of decreasing effect by foundation movement

Table 5-2 Example of seismic performance assessment and related measures

Item	Pipes	Result of seismic Performance assessment	Actions	Notes
Inefficiency of restraints along the pipe in direction vertical to pipe axis	All pipes	As the restraints vertical to pipe axis is not sufficient support stress in vertical direction to pipe axis exceeds allowable value	Vertical restraints will be added	More attention to vertical pipes(pipe fall down from rod supports)
Inefficiency of restraints in pipe in longitudinal axis direction	Most of the pipes over racks	Stress in edge of bend of a straight pipe and also support of vertical pipe exceeds the allowable stress because it is not restrained in longitudinal direction	restraints is added in longitudinal direction to pipe support	Attention is needed to extra support of pipe in order to increase support strength during earthquake
Inefficiency of restraints in pipe junctions	Pipes in racks and equipments around pipes	As the restraints in junction pipes are inadequate, stress in connections exceeds allowable stress	Pipe support perpendicular to pipe axis is added to junction pipe	For junction connections stress concentration is high and stress increases easily
Inefficiency of restraints in equipments around nozzle	Connecting pipe between equipments and nozzle	Extra force is exerted to nozzle during earthquake because restraints are inadequate and stress exceeds allowable value	In order to decrease load on nozzle, joints will be added	Pipes connected to tank might have high seismic coefficient because pipe's importance list has same importance as equipments till gas shout off valve
Relative displacement effect during earthquake	Pipes supported by supporting structures	Due to relative displacement between different structures and crossed pipes between these structures during earthquake, stress exceeds allowable stress	With reduction of supports vertical to pipe, flexibility increases	With reduction of pipe support stress due to earthquake acceleration will increase and therefore measures related to changing of support is not enough

5-1-4-Execution safety and cost

After presenting approximate retrofitting measures, possibility of execution should be studied.

If it is not possible to stop operation to change of pipes, then retrofitting needs more study.

It is difficult to have relative displacement absorption capacity and strength against earthquake acceleration if pipes pass each other and cross between different structures and it will not be sufficient to change pipes for retrofitting measures and needs to change support conditions. In this case, limiting conditions should be studied. Decision for retrofitting measures will be made based on safety, practicability and economy.

After calculating retrofitting and renewal costs, if retrofitting cost is equal to or more than renewal cost, then renewal will be recommended. In this case, many alternatives like change of pipe direction and other methods could be used.

5-2-Horizontal vessel

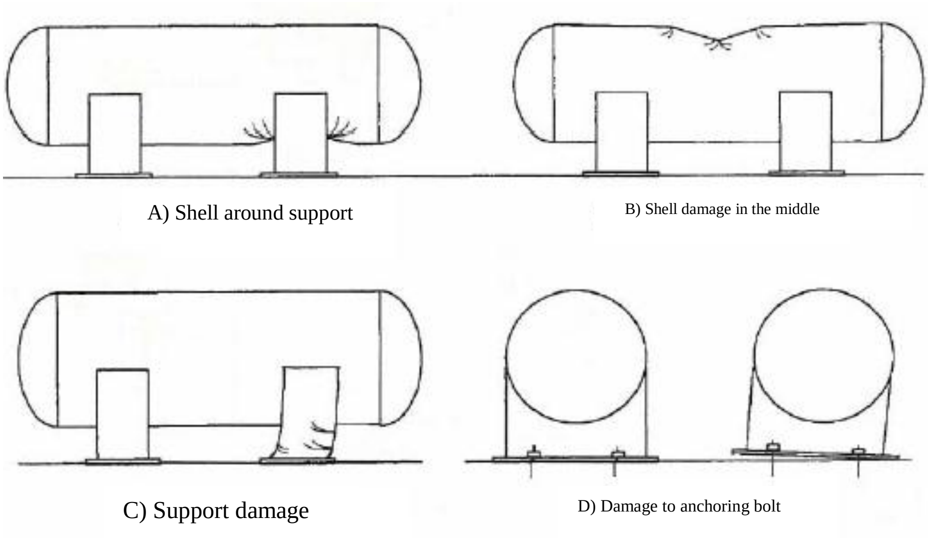
Vessels or horizontal chambers are pressurized thin cylinders which are used to store high pressurized materials. Their shape characteristic is longitudinal cylindrical body with two semi spherical parts in both ends.

For seismic performance analysis, assessment and seismic retrofitting, its body, saddle supports and connection to foundation and foundation itself should be considered.

In this section seismic assessment and retrofitting with attention to their usage in gas supply system and their performance during past earthquakes and damage modes will be presented.

5-2-1-Damage modes

In design of new facilities, calculations are based on four cases of damage to shell on seats, shell in the middle cross section, seats and anchoring bolts. Damages modes are shown in figure 5-11.



A) Shell around support

B) Shell damage in the middle

C) Support damage

D) Damage to anchoring bolt

Figure 5-11 Damage modes to vessel

5-2-2-Seismic assessment flowchart

The assessment method which is shown in figure 5-12 is detailed method.

Another method is presented for simplifying of analytical model and calculation method in which damage state and corresponding studies are investigated for easy evaluation of existed equipment with different installation state.

This method is used for stress calculation in support and judge about strength using allowable stress method.

For those equipments which are not compatible with analysis, assessment should be done with detailed method including dynamic response analysis and precise modeling.

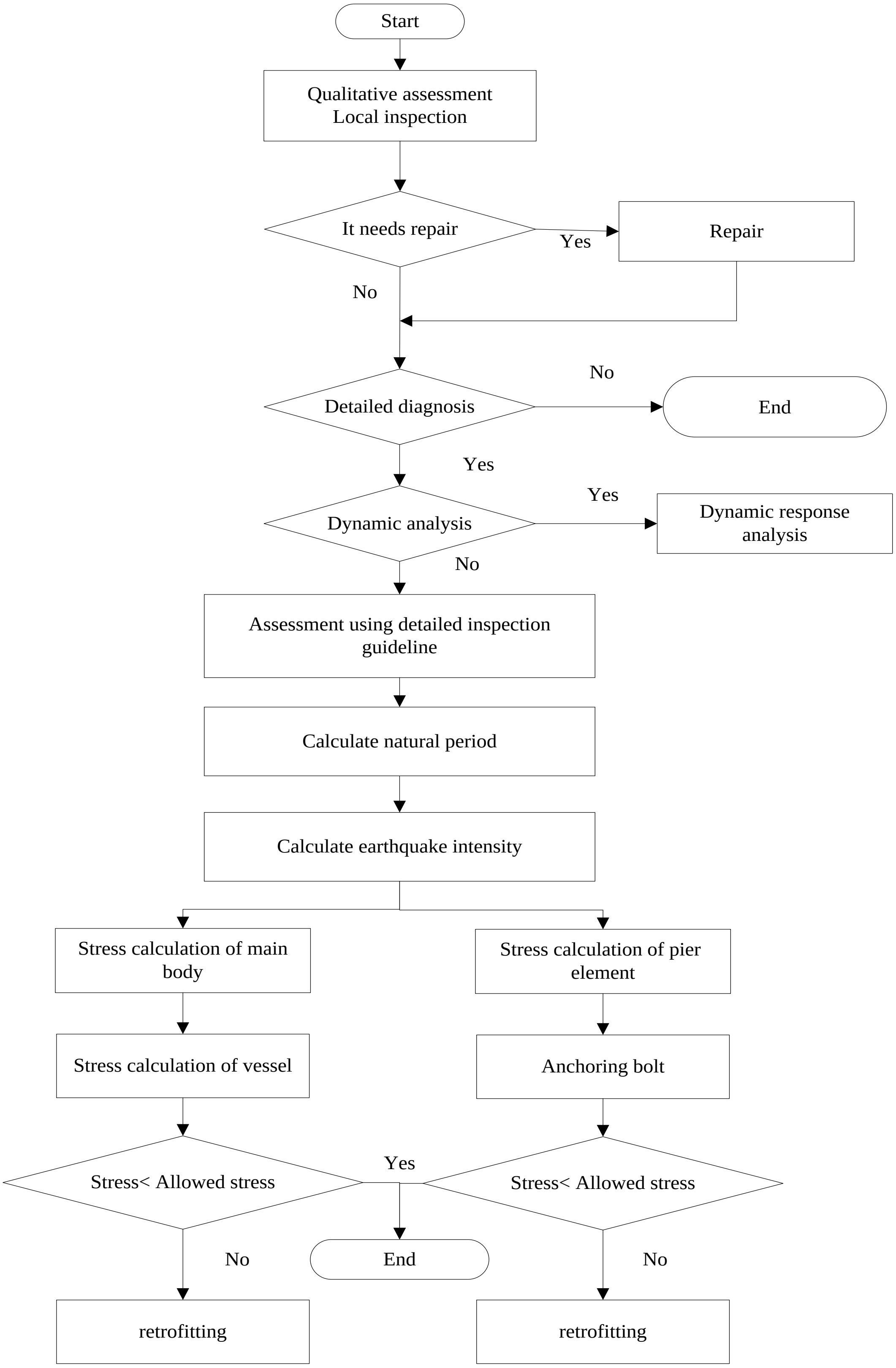


Figure 5-12 Vessel assessment flowcharts

5-2-3-vessel retrofitting

- Priority for retrofitting of vessel is based on spread of damage after earthquake.
- One of the major factors is the distance from central site’s borders.
- Other factors are gas type and its danger to human in case of leakage.
- Social and economical damage scale and their reconstruction costs are in the next priorities.
- Each damage mode is prioritized according to its spread scale.
- Damage intensity factor is determined according to danger level to human, costs and other mentioned factors.
- Detailed qualitative assessment method is a method to determine damage modes and recommends suitable ways for their prevention.
- For determining retrofitting priorities, is determined retrofitting criteria's.

The basics of retrofitting method are as follows:

1- Retrofitting based on qualitative assessment

If equipments are identified defective, should be measured and evaluated.

In minor damages, measurements should be in daily and simple basis and qualitative descriptions should be used for retrofitting measures of seismic strengthening.

In major damages, detailed assessment and studies should be sued.

2- Retrofitting based on detailed assessment

a) Important points are as follows:

i) The section under pressure should not be measured and tested continuously.

ii) Stress concentration and structural discontinuity should be avoided.

iii) Total integrity of facilities including functionality, measurement, economy, etc should be considered.

iv) Existing and new structure should function as one system.

b) Part that should be improved:

In this guideline, retrofitting actions are explained for limiting damage modes and easy controlling of seismic resistance of excited equipments, with considering to installation and its different characteristics.

Substantially Detailed evaluation is based on simplified detailed evaluation and damage is limited to several modes.

3-Retrofitting based on simplified detailed assessment

a) Conditions to use simplified detailed assessment

Usually anchored bolts are the weakest points in vessels. In cases where following conditions are met, retrofitting design of bolts could be done with simple calculations:

i) There is no serious corrosion of in tank, supporting structure and foundation elements.

ii) Actual structure’s dimensions, weight and shape should be used in calculations.

iii) Pipes and its piers should not have considerable effects on seismic performance of the main structure.

iv) Tank should be assumed as a solid structure.

v) Center of gravity and center of stiffness are matched and no torsion vibration is generated.

vi) Foundation should sit directly on ground and height of foundation pier should be less than 3 meter from ground level to lowest face of base plate of column.

Even if structure’s conditions changes due to sever corrosion or repair or retrofitting, still it is possible to obtain seismic strength with this simple method unless the measured effective thickness and structure shape in retrofitting design and repair changes.

b) Allowable stress limits

Allowable shear stress of anchorage bolt is assumed as $\frac{1}{\sqrt{3}}S_u$.

In this formula S_u is bolt’s tension strength. The simplified method is a method where horizontal response amplification coefficient is taken 2.

In simple method for structural calculation of shear strength of anchoring bolt, increased seismic strength could be ignored to enhance the strength of bolt.

4-Retrofitting based on detailed assessment

Vessels which could not be assessed by simplified detailed assessment method should be studied using design standard with measured dimensions during qualitative assessment phase.

Stress conditions for improved facilities should be assessed for total damage condition.

Seismic strengthening measures are shown in figure 5-13.

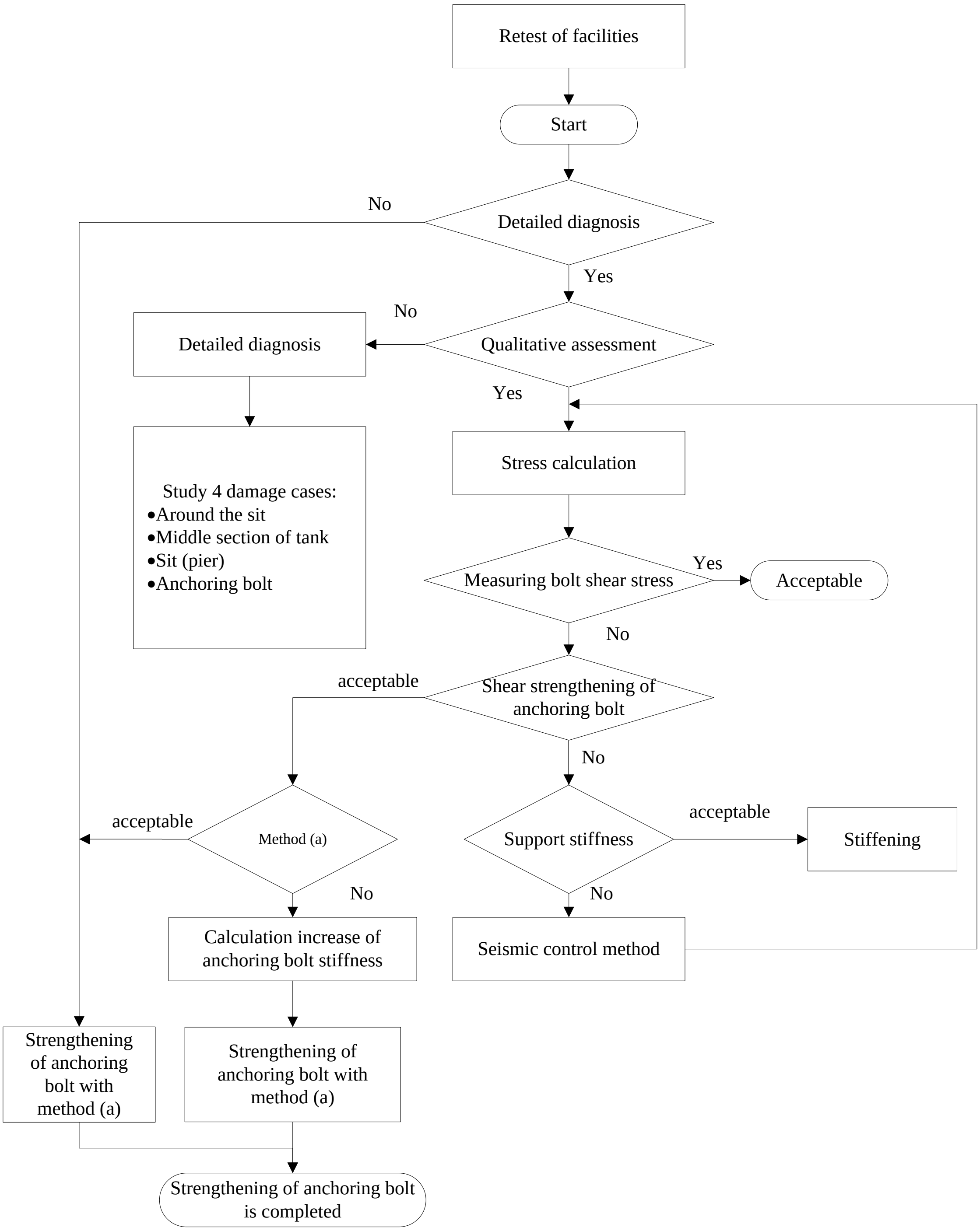


Figure 5-13 Flowcharts for retrofitting measures of vessels

5-2-4-Retrofitting methods

1-Retrofitting methods based on field study results

Retrofitting measures for facilities, which are considered defected by study, is as follows:

Usually this action is actions with easy function.

Safety study of during construction and retrofitting effects should be done before execution.

1-1-Foundation

If there is crack in foundation, concrete repair methods like resin injection will be used but crack sizes should be relatively small.

1-2-Corrosion

If there is real threat to bolts, first the corrosion should be removed and then painting and oiling should be done.

1-3-Damage to bolt and nut

Bolts are threaded again and nuts are replaced with new ones

1-4-Loosening

- If bolt is bent and nut is not placed properly in its place and doesn’t sit completely on the base plate, it should be fixed by inserting washer between base plate and bolt.
- Bolts are fastened steadily using special wrenches

1-5-Adding pipe

a) It is recommended that adding place of pipe is anchored directly from tank side.
b) Stairs, corridors and … should be located beside main structure on the ground or inside the main structure.
c) Supporting pipes for measuring devices and valves should be short.
d) Valves and pipes should be connected to tank even if they are anchored with short pipes so they behave like a solid structure and have the same seismic characteristics.
e) It is recommended to consider a void space between valve and supports in exit valve and stop valve which is connected beneath the tank and is protected by ground.
f) Pipe outlet has sufficient strength against exterior pressure and pipe flexibility also should be considered.
g) It is recommended that pipes connecting adjacent tanks have U-shaped and knee bend.
h) Pipes entering supporting walls of liquid tanks should have curves and direct pipe should be avoided.
i) It is recommended pipes which enter ground have bends in the beginning.

2-Seismic retrofitting measures based on detailed assessment

2-1-Shear strengthening of anchoring bolts

Vessels’ retrofitting measures using detailed assessment methods are shown in figures 5-14 to 5-22. These methods are selected based on vessel type.

Existing sections are connected to new strengthened sections with bolts.

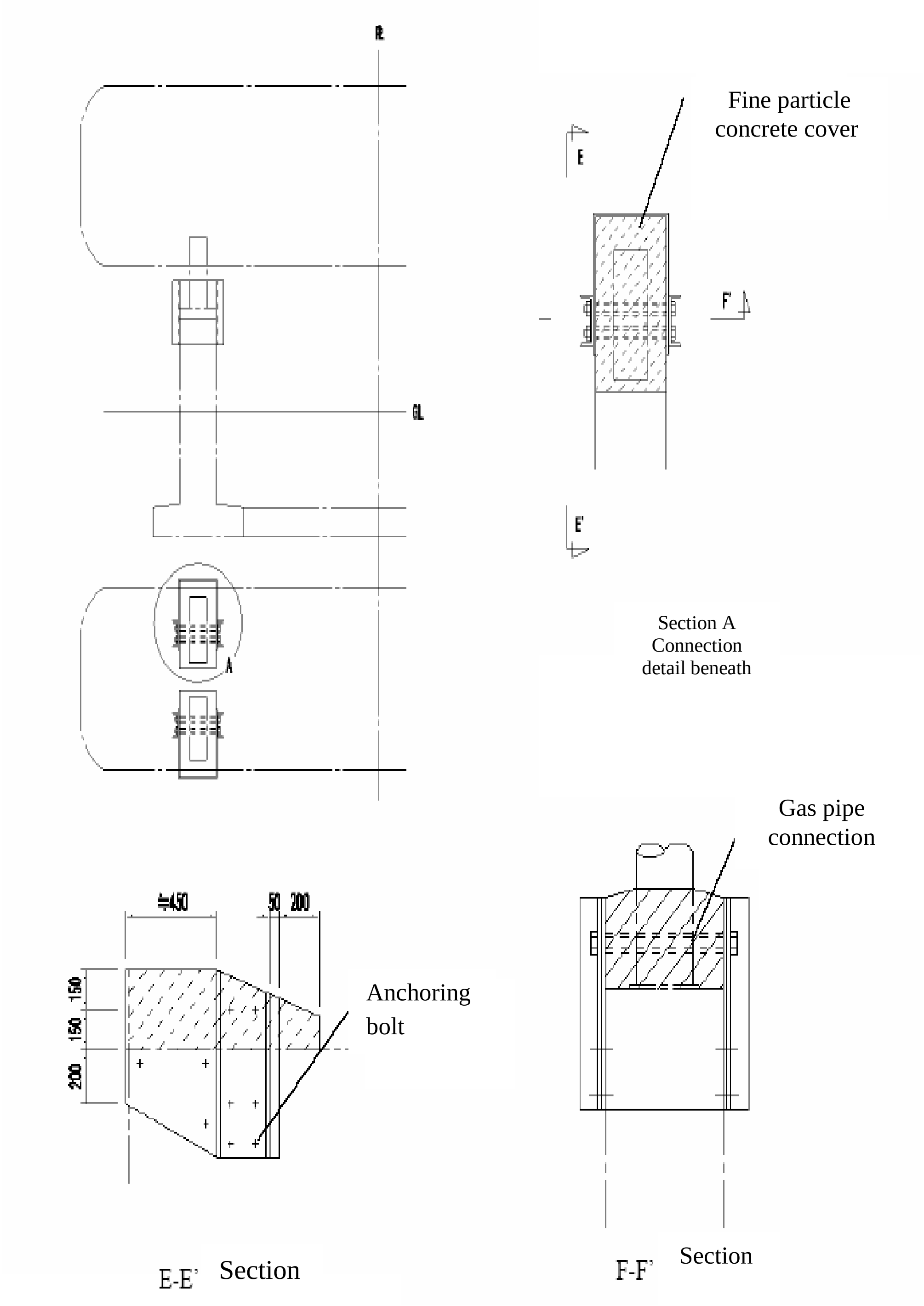


Figure 5-14 Seismic retrofitting of anchored bolts with extension of restraint length in concrete (a)

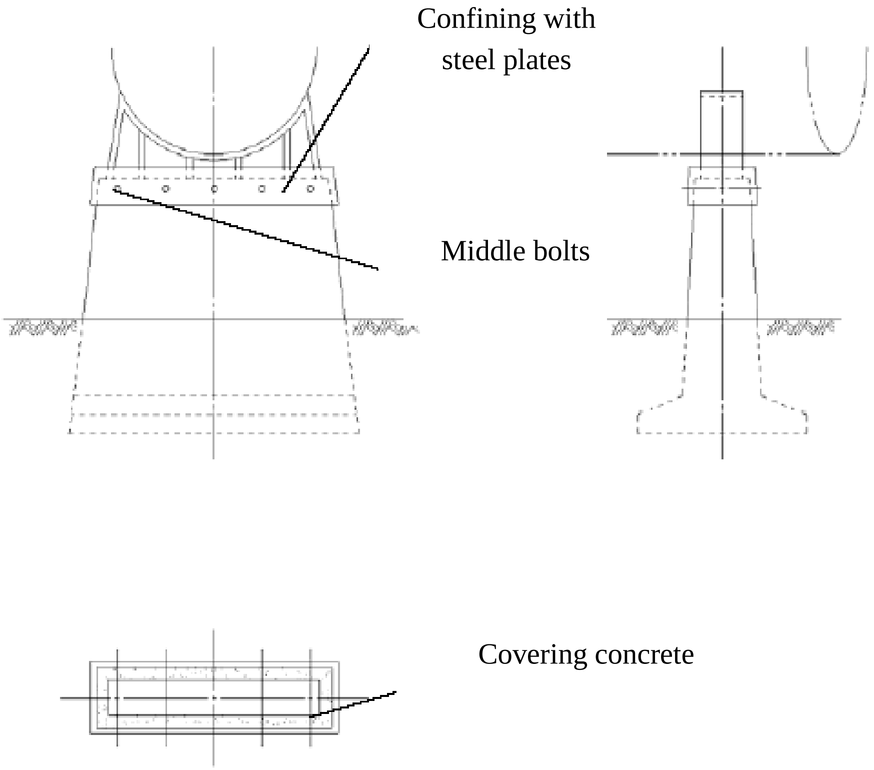


Figure 5-15 Example of seismic retrofitting of anchored blots with extension of restraint length in concrete (b)

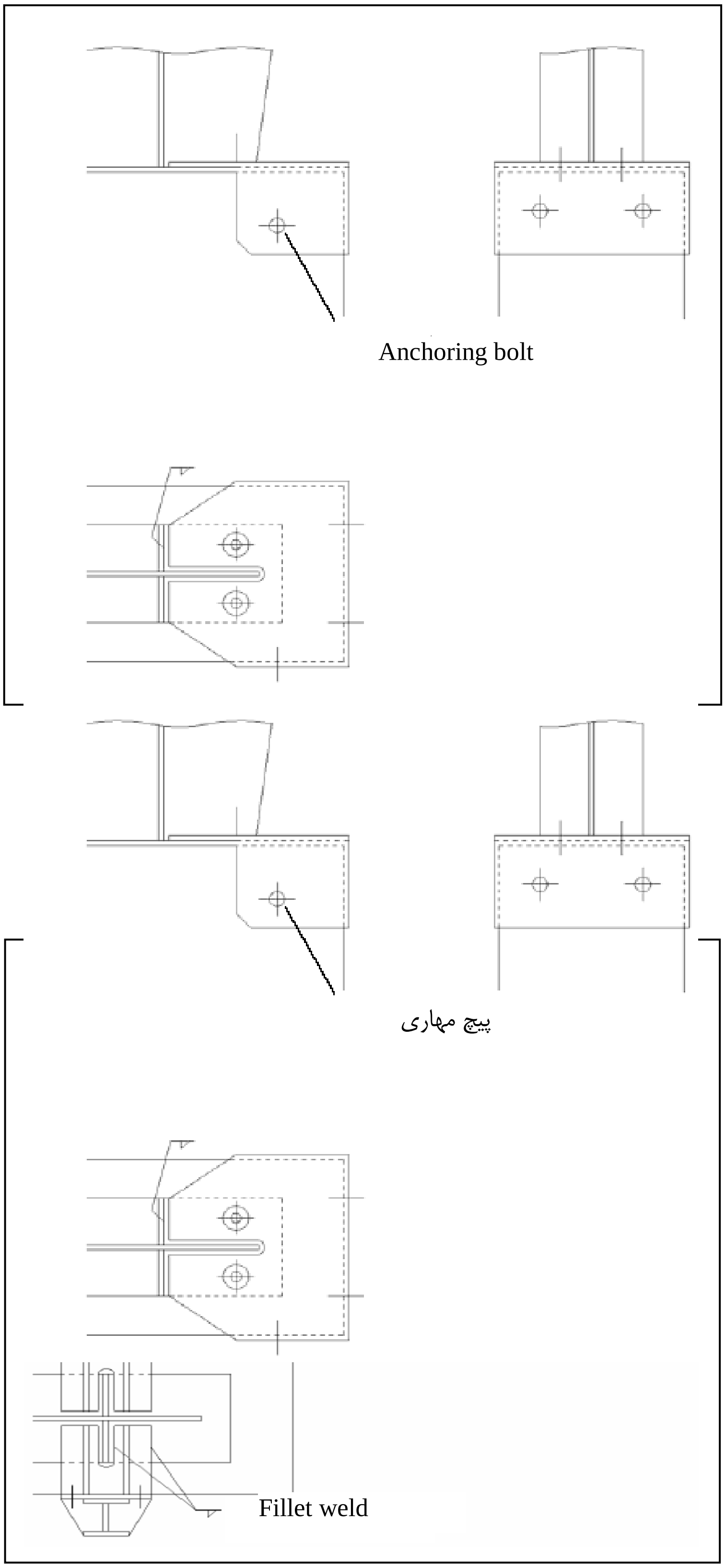


Figure 5-17 Example of seismic retrofitting of anchoring bolts (d)

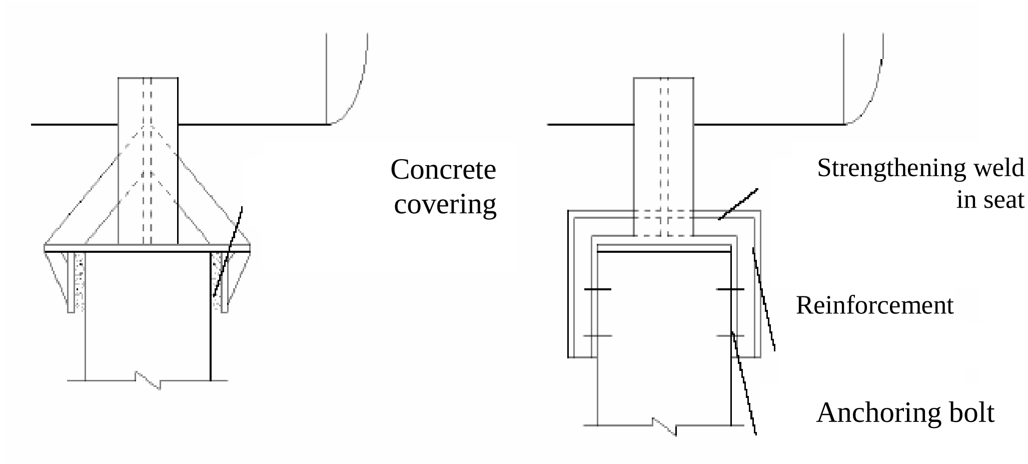


Figure 5-18 Example of seismic retrofitting of anchoring bolts (elf)

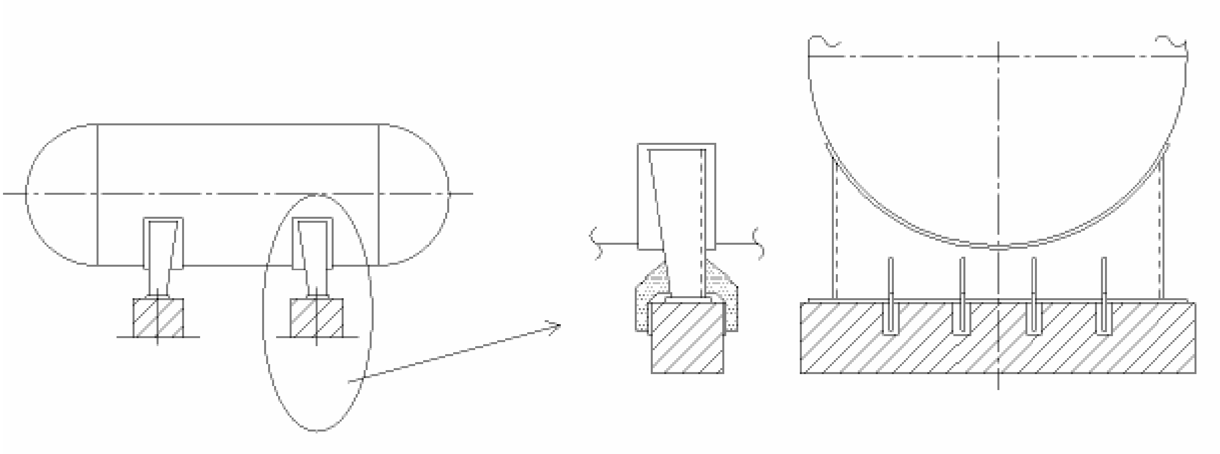
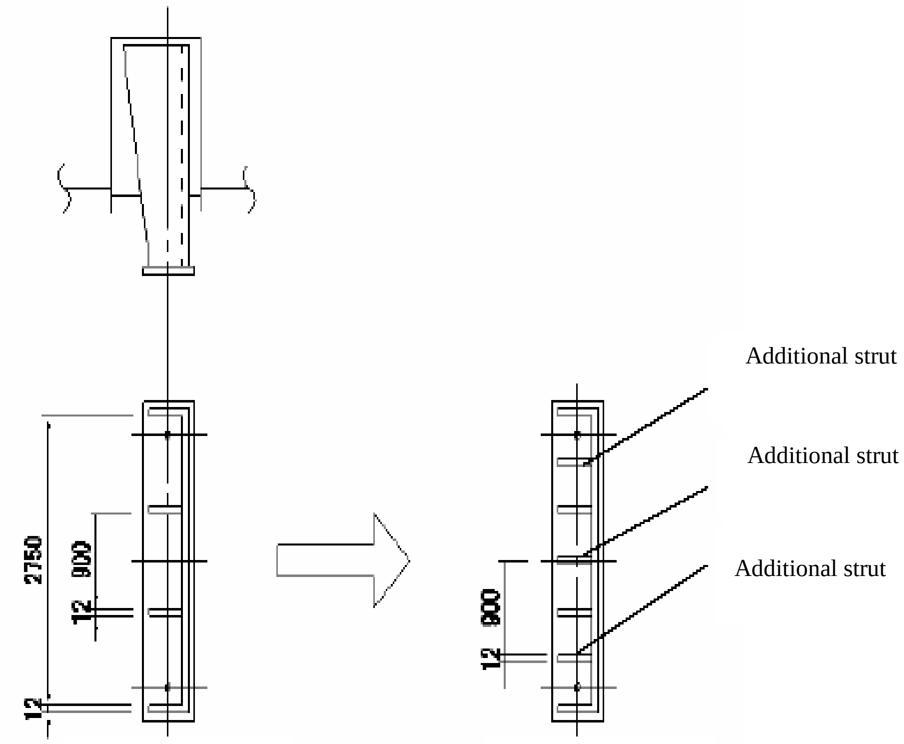


Figure 5-19 Example of seismic retrofitting of anchoring bolts (g)

2-2-Decreasing pressure stress of seat (stress release)

By addition of steel frame, pressure stress distribution will become uniform and will avoid stress concentration in special points.



Before strengthening

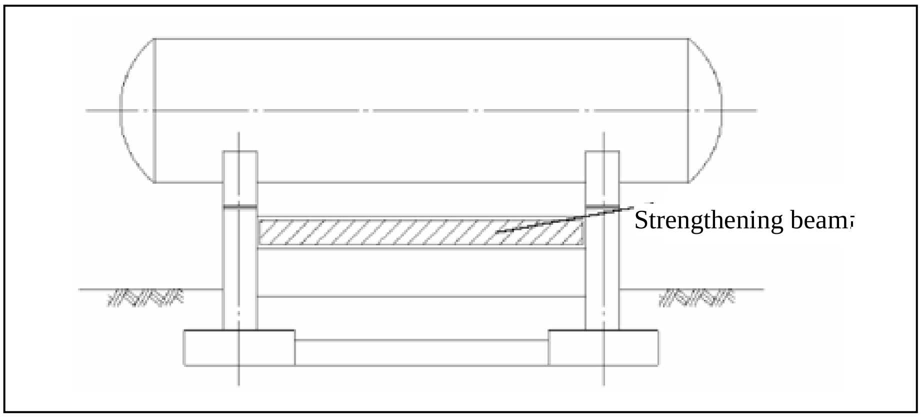
After strengthening

Figure 5-20 Example of decreasing pressure stress of seat (stress release)

2-3-Strengthening support structure

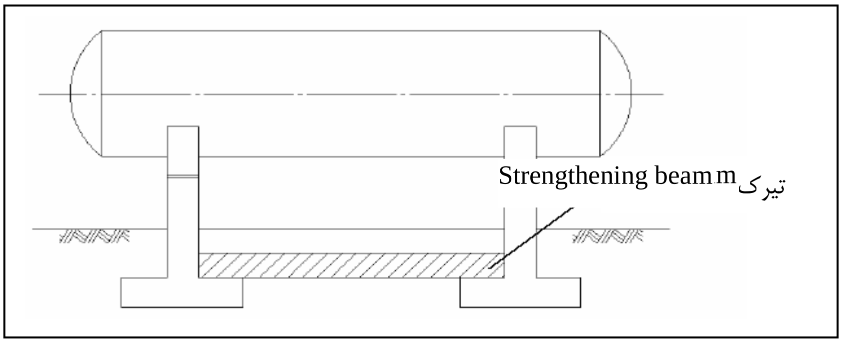
a) Strengthening with beam in on-ground section

In this case, vibration will be dealt by modifying stiffness of support structure and decreases of natural period.



Increase stiffness with beam

b) Strengthening with beam in underground section



Increase stiffness with underground beam

c) Strengthening with increasing foundation dimension

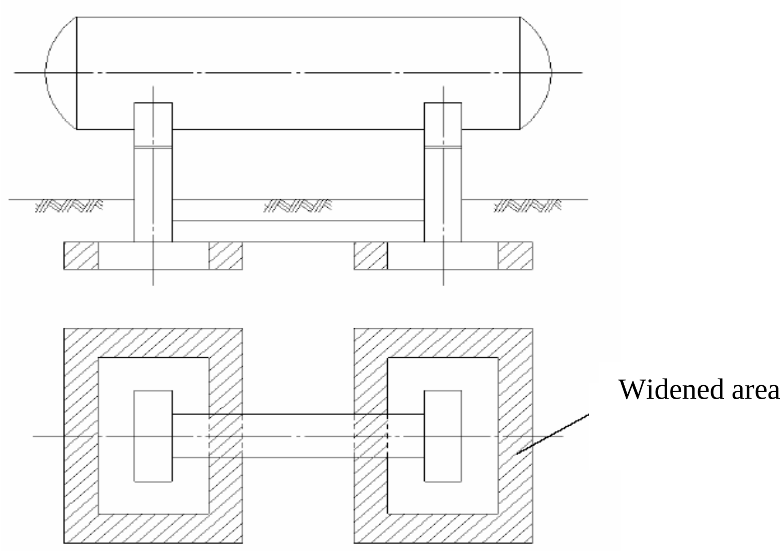
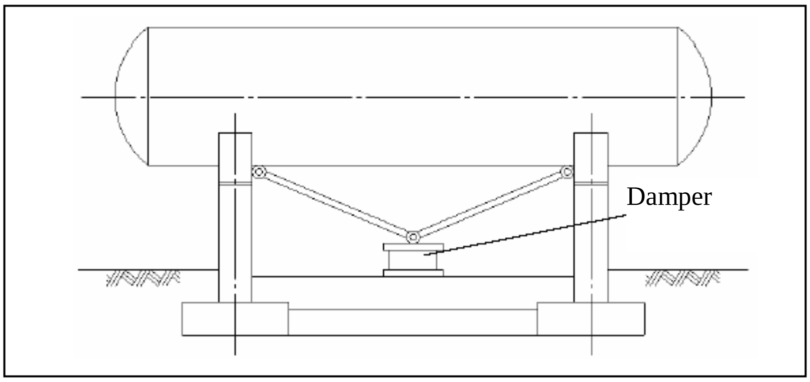


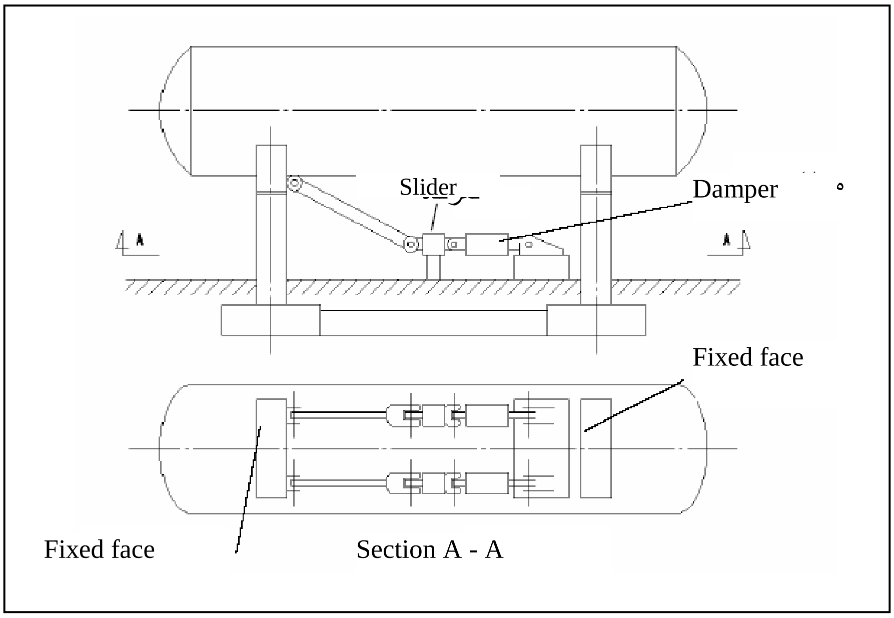
Figure 5-21 Example of increasing stiffness with strength increase of foundation & pier

d) Vibration control method

In this method seismic effects will decrease by using an extra damper in support.



First example of a damper



Second example of a damper

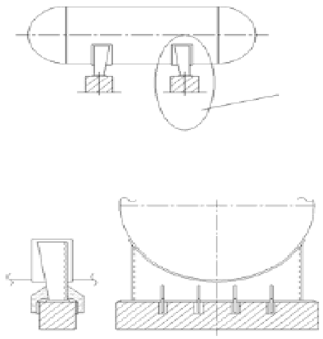
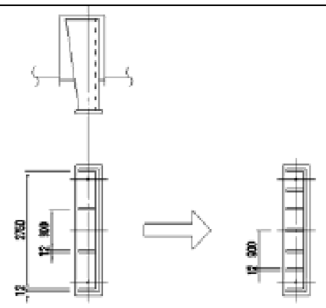
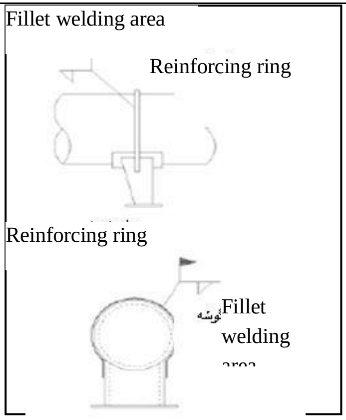
Figure 5-22 Determination of retrofitting method based on safety, applicability and cost

Cost of different retrofitting methods are calculated and then compared based on safety and applicability.

Selection of suitable method considering to location and cases is different because cost of retrofitting is depended to material cost in different time and location.

Comparison table given in table 5-3 could give good guidelines for comparing retrofitting alternatives and selecting the best of them.

Table 5-3 Comparison of retrofitting measures

Facilities	Method	General view of reinforcement	Retrofitting criteria				
			Deformability	**Strength**	**Cost**	**Applicability**	**Limitation in plan**
Vessels	Reinforce anchoring bolt with addition of dividing plates		○	●	○	○	○
	Note	When there is improper stress in anchoring bolts					
Vessels	Reinforcing the seat by adding brace		○	●	○	○	○
	Note	When seat strength is not enough					
Vessels	Reinforcing seat by use of reinforcing ring		●	●	●	∆	∆
	Note	In cases where tank stress is more than allowed stress and Welding is allowed, this method has limitations					
● shows the method with best effect, ○ shows the method with good effect and ∆ shows no clear effect (unknown)							

5-2-4-other countermeasure

By limiting liquid level inside tank, instead of imposing retrofitting methods, seismic safety could be increased.

By decrease of liquid level, natural period of structure reduces and seismic force decreases considerably.

In usual performance against earthquake it is assumed that 90% of the tank is filled with liquid. Effective weight W_{eb} is determined according to natural period and modified horizontal seismic force as follows:

$$F_{MH} = K_{MH} . W_b \qquad 5\text{-}1$$

$$W_b = W_D + \alpha W_L \qquad 5\text{-}2$$

W_D: Tank dead weight (kgf)

W_L: Stored liquid weight inside tank (upper limit weight after imposing decreasing criteria) (kgf)

α: Effective rate of liquid weight obtained from figure 5-23

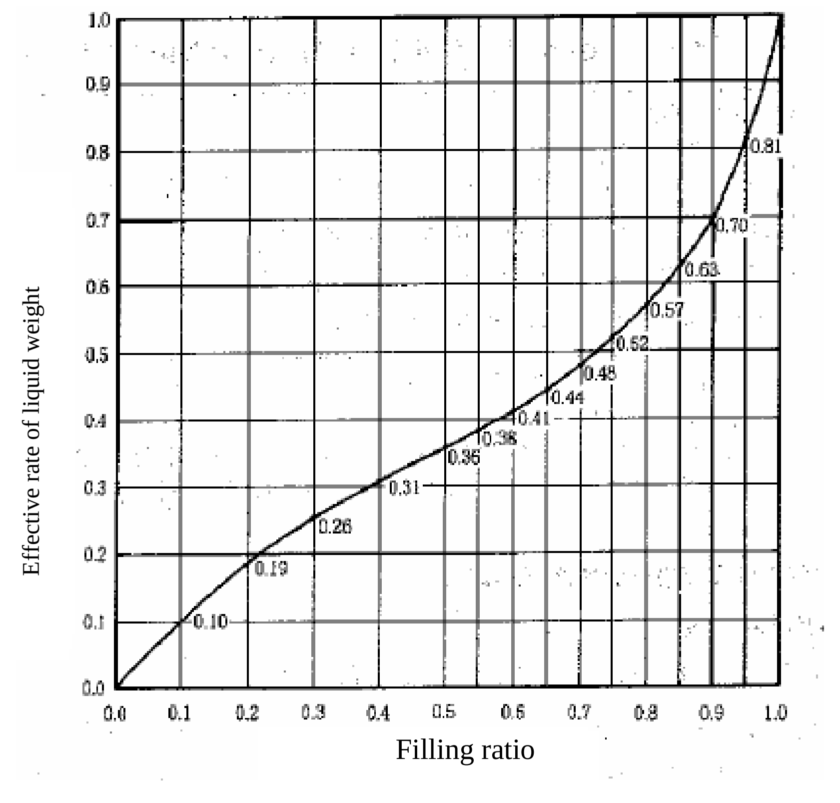


Figure 5-23 Effective rate of liquid weight

5-3-Tower and vertical tank

5-3-1-Damage modes

Common case of damage is loosening of anchoring bolts and concrete failure.

No damage is exerted on tank due to seismic force.

If wall thickness decrease observed during inspection, safety control of tank is mandatory.

Seismic strength of support section like pier is as important as chambers in towers. Toppling is an important damage case in a tower.

Tension strength of anchored bolts and buckling stress of pier should be controlled in this type of damage.

a) Damage case in a skirted tower (skirted)

- i) Shell
  - 1-tension yield
  - 2-compressive buckling
- ii) Skirt
  - 1-compressive buckling
- iii) Anchoring bolt
  - 1-tension yield
- iv) Base plate
  - 1-Bending yield

b) Damage of pier tower

- i) Shell
  - 1-tension yield
  - 2-compressive buckling
- ii) Pier
  - 1-Yielding
- iii) Anchoring bolt
  - 1-tension yield
  - 2-Shear yield
  - 3-Combination of tension and shear yield
- iv) Pier connections

c) Damage of handle

- i) Shell
  - 1-tension yield
  - 2-compressive buckling
- ii) Adjusting bolt
  - 3-tension yield

5-3-2-Seismic assessment

Retrofitting procedure flowchart based on allowable stress method is as follows:

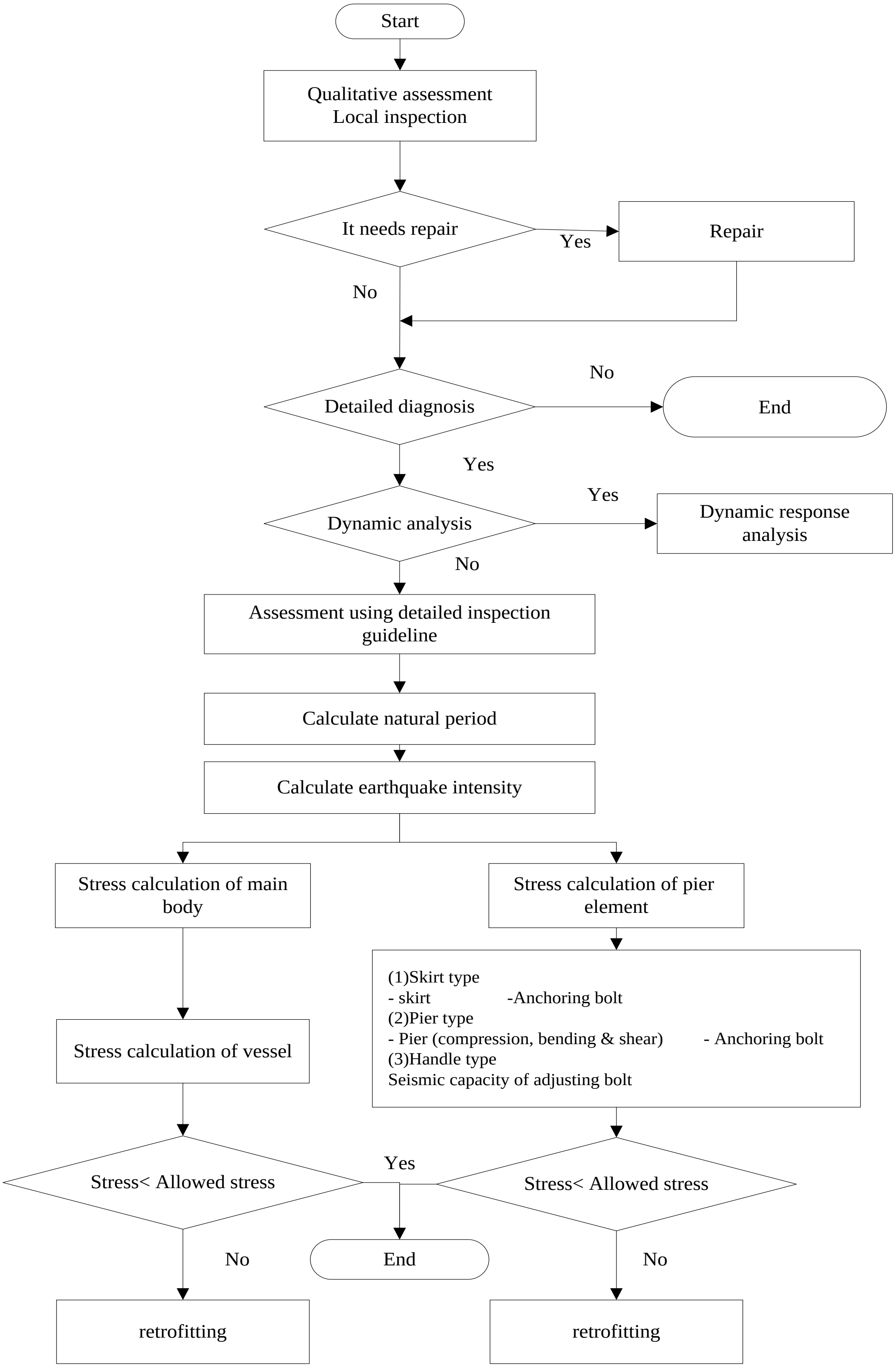


Figure 5-24 detailed assessment flowcharts for tower and vessel

There is another simplified method in order to simplify the analytical model and calculation method from which is done by extraction method of dominant damage mode and related study to easy evaluation of existed systems with different installation state.

It is possible to control the stress in support and seismic strength of facilities by extracting dominant damage mode using allowed stress method.

For facilities with complicated seismic behavior, assessment should be done using detailed assessment method which included dynamic response analysis and precise modeling.

5-3-3-Tower and vertical vessel retrofitting

- Priority for improving tower and vertical vessel is determined by amount of damage to tower and vertical vessel due to earthquake.
- The main factor for prioritizing retrofitting is the importance degree and determined based on site distance from borders, gas type and pipeline capacity
- Major factor is human loss if there is a gas leakage
- Other factor is social and economical damage. These factors will affect customers and reconstruction cost of buildings and etc.
- Priority for improving tower and vertical vessel in each damage mode is determined by scale of affects on tower and vertical vessel in failure.
- Affection coefficient is risk degree to human life, reconstruction cost and others.
- Simplified detailed evaluation is a method for reducing damage ratio that is created easily.
- Necessary factors should be defined for determining of retrofitting priorities.

Basics and method of retrofitting are as follows:

1-Retrofitting based on qualitative assessment

- For minor damage, works are limited to a daily inspection and a simple study and quantitative concept is determined for enhancing seismic strength.

2-Retrofitting based on detailed assessment

a) Points which should be considered in retrofitting plan

- Area under pressure should not be operated repeatedly.
- Stress concentration and structural discontinuity should be avoided
- Balance and harmony between all facilities like workability, dimensions and economic approach should be provided.
- Existing and new structure should act as one unit.

b) Section which should be improved:

In seismic retrofitting, it is necessary to study seismic strength of most of facilities, which have different specifications and installation requirements.

For this purpose, in this section simplified detailed assessment will be explained based on damage due to earthquake and a case study.

This method is focused on dominant damage cases and is limited for retrofitting measures related to damage shape.

Stress in section under study is calculated and seismic strength is determined based on allowed stress and ultimate strength of element.

In this guideline, retrofitting plan usually is based on simplified detailed assessment with focus on some damage case. But towers and vertical vessels which are not proper for present conditions should be studied according to design guideline.

3-Simplified detailed assessment

In simplified detailed assessment it is assumed that there is no considerable damage on tower, skirt, pier, handle, frame and foundation.

In the first inspection which will be done with high precision, strength reduction due to corrosion or change and damage due to repair will be studied before detailed assessment.

This is because to consider structure material with specification without corrosion dates.

If structure's specification in construction time has changed due to severe corrosion or repair and retrofitting, then seismic strength will be controlled with this simple method and plates' effective thickness will be controlled for corrosion and structure shape will be controlled by drawings for changes due to repair and retrofitting.

a) Damage mode

In the study of toppling of towers, tension strength of anchoring bolts and buckling strength of skirt or pier should be considered.

In cone tower (with skirt) compression stress in pier skirt and tension stress in anchoring bolt will be calculated.

In towers with pier, compression, bending and shear stress will be calculated in base and tension and shear stress will be calculated in anchoring bolts.

In towers with lug support, tension stress in adjusting bolt should be studied.

Allowed design stress method will be used for new structure.

b) Limit of allowed stress

Limit of allowed stress will be determined by yield strength.

This limit is as follows and is extended to a level to absorb seismic energy with non-elastic deformation in support structure.

Table 5-4 allowable limitations

Facilities	**Section**	**Stress type**	**Allowed stress limit**
Towers with skirt supports	Skirt (margin)	Buckling	Minimum value of Su $1.2Et \big/ (1+0.004\frac{E}{S_Y})D_m$
	Anchoring bolt	Tension	S_u or $2S_y$
Towers with Pier supports	Pier	Buckling	$\lambda \leq \Lambda : \frac{1.8}{\nu}\left\{1-0.4\left(\frac{\lambda}{\Lambda}\right)^2\right\}F$ $\lambda > \Lambda : \frac{0.5F}{\left(\frac{\lambda}{\Lambda}\right)^2}$
		Bending	1.1 S_u
		Combination	1.1 S_u
		$\sqrt{(\sigma_c+\sigma_b)^2+3\tau^2}$	

	Anchoring bolt	Tension	S_u
		Shear	$\frac{1}{\sqrt{3}}S_u$
		Combination $\frac{\sigma_t + 1.6\tau}{1.4}$	S_u
Towers with circular supports (Lug)	Adjusting anchor	Tension	S_u

Parameters are as follows:

S_u: Tension strength
S_{ee}: Yield point
E: Longitudinal elasticity module
t: Thickness of skirt plate
D_m: Average diameter of skirt
λ: Slenderness ratio
Λ : Limit slenderness ratio = $\sqrt{\frac{\pi^2 E}{0.6F}}$
l: Compression length of pier = $0.7H_l$
H_l: Length of pier
i: Minimum gyration radius
I: Minimum moment of inertia of pier
A: Cross sectional area of pier
F: Minimum value of S_y or $0.7S_u$ as standard strength

4-Detailed assessment

The tower and vessel which do not have simplified detailed assessment conditions should be assessed with design standard.

Retrofitted facilities are controlled and overviewed for overall damage state.

Retrofitting method for enhancing seismic strength is shown in figure 5-25.

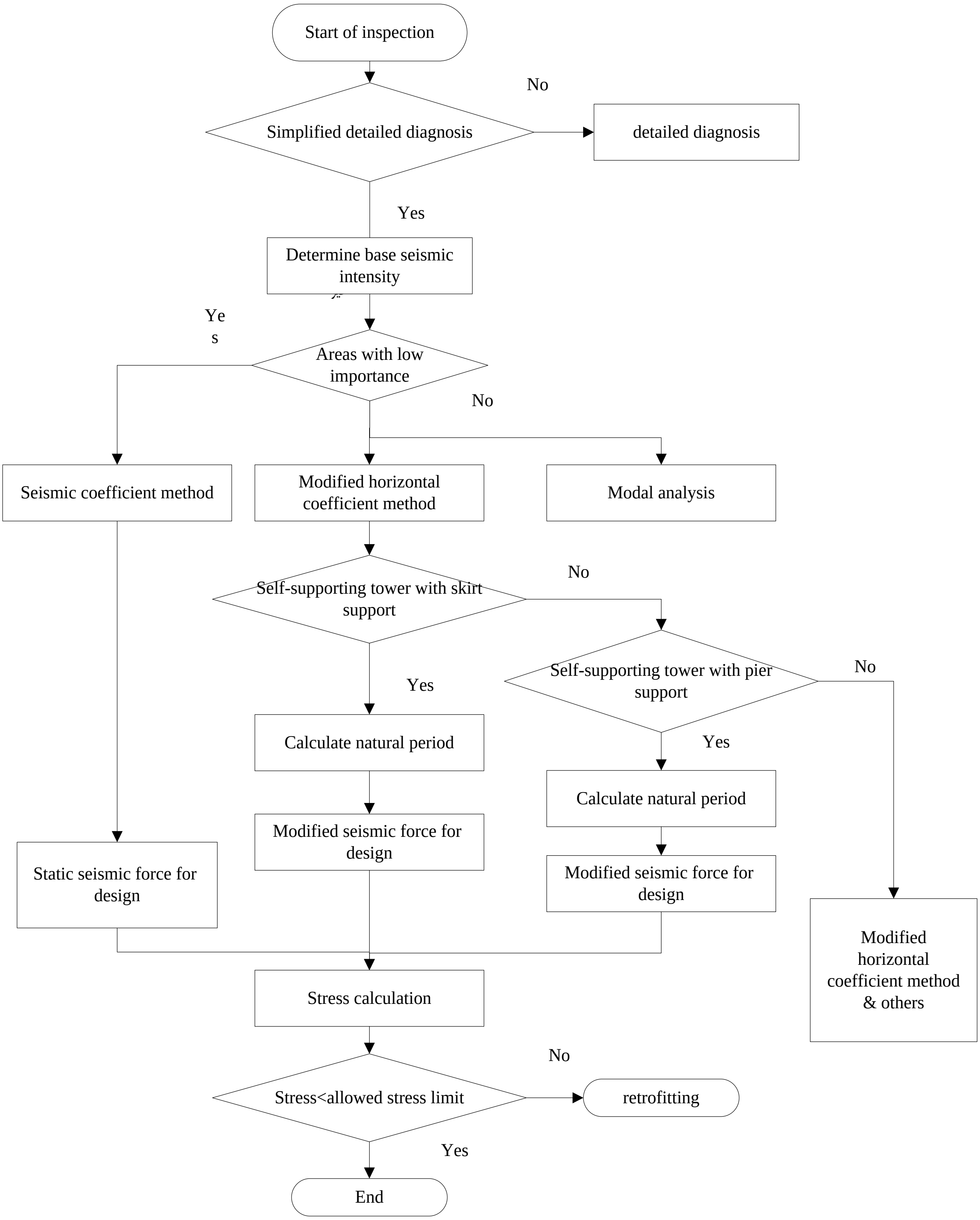


Figure 5-25 Flowchart of retrofitting plan for enhancing seismic strength

5-3-4-Retrofitting methods

Retrofitting measures for facilities detected as defected during local inspection, are simple and executable.

Seismic retrofitting measures in detailed assessment, basically includes items like shear strengthening of anchored bolts, release of compression stresses, strengthening of supports and vibration control method.

1-Concrete crack of foundation

a) When the cracks in concrete are small, resin injection will be used.

b) When there are relatively small cracks in fire-proof coverage, mortar will be used for repair.

2-Bolt corrosion

a) If there is severe corrosion in bolts, first the rusted part should be removed and then painting and oiling will be done.

b) Bolt and nut which could be separated easily should be replaced.

3-Damage and deformation of support

a) Damaged and deformed part of support should be repaired. In this case, new strength should not be less than initial strength.

4-Loosening of bolt and nut

a) When the bolt has curve and nut does not fasten completely to base plate, a washer could be used to fasten the nut to base plate.

5- A connected pipe and others

a) For gas shut off valve and stop valve which are installed beneath the tank and has support from ground side, a gap between valve and support should be considered to absorb vibration.

b) Nozzle should have sufficient strength against external forces exerted from connected pipes and pipes' flexibility should be taken into account.

c) During the local inspection, if the flexibility of pipes is judged as insufficient, necessary steps should be taken according to nozzle strength.

6-Apparatuses and peripheral connected devices

- Peripheral devices are fixed with secure connection to tower or vessel.
- Related devices are fixed in a platform and this platform is connected rigidly to tower or vessel.
- For peripheral devices which are fixed with an independent frame structure and has short connecting pipe to tower or vessel, it is recommended to consider the sliding possibility relative to framed structure of support.

6-1-seismic retrofitting measures based on detailed assessment

Retrofitting measures at least should increase absorbed energy with non-elastic deformation.

This is based on results of seismic test of a steel tower where by supplying proper non-elastic deformation for support structure, it could absorb a lot of energy.

The most important measures for seismic retrofitting are as follows.

a) Reduction of seismic force

If seismic force releases, stress on place under consideration will decrease and it may be possible to reduce stress to below allowed stress limit level.

To reduce seismic response, it is possible to dampen seismic force by use of oil or viscous-elastic damper.

b) Stress reduction by controlling seismic force of other sections

i) Although seismic force is calculated for skirt, pier and anchoring bolts of tower, but with distribution and allocating seismic force on different section of tower, it is possible to reduce induced stress in skirt, pier and anchoring bolt without direct retrofitting.

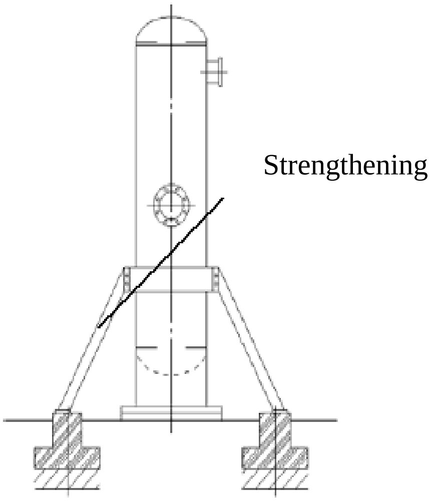
ii) Example of these measures are as follows:

- Strengthening the support
- Strengthening with framed structure
- Strengthening with cables

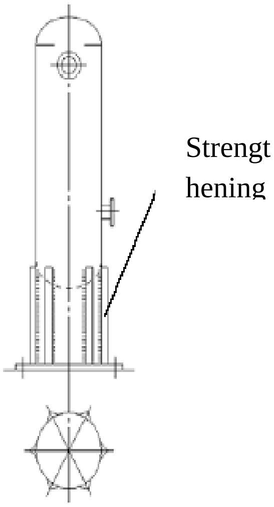
c) Strengthening of area under study

It is possible to reduce stress by increasing cross sectional area to less than allowed level. If tower's rigidity increases due to strengthening, it is necessary to recalculate response analysis.

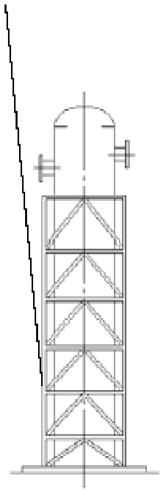
6-2- seismic retrofitting measures for tower



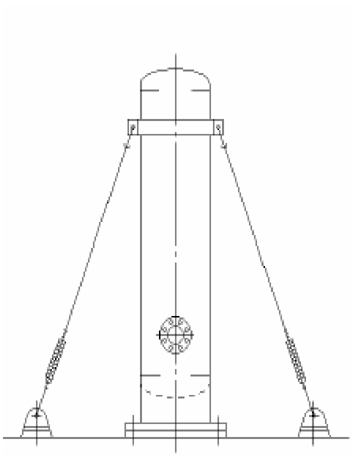
Strengthening with supporting structure



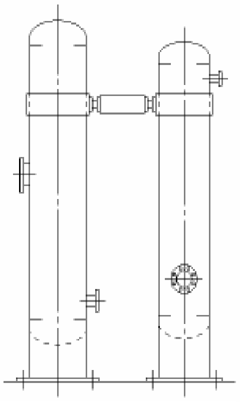
Strengthening inside & outside of skirt of vessel



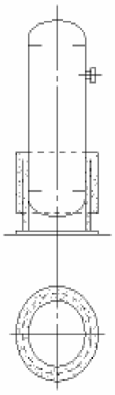
Strengthening with scaffold



Tower strengthening with cable



Seismic strengthening of two tanks with viscous damper



Strengthening with damper

5-3-5-Determine retrofitting method from safety and cost stand point of view

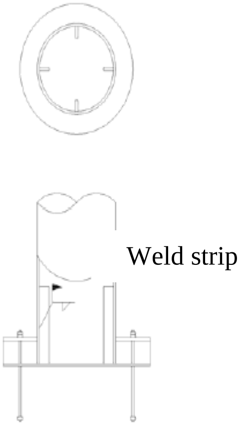
According to seismic retrofitting measures which are obtained by detailed assessment, necessary shapes and sizes will be determined based on simple design method or precise method together with details.

Then costs will be calculated and workability related to that location will be studied and execution procedure will start.

As retrofitting cost depends on cost of material, time and location, the selection of proper method usually depends on the case and location.

As a reference for list of real methods, for retrofitting plan and cost calculation, comparative charts for one of given methods is shown as follow.

Table 5-5 Comparison of retrofitting criteria

Facilities	**Method**	**General view of strengthening**	**Retrofitting criteria**				
			deformability	**Strength**	**cost**	**executable**	**Limitation in plan**
towers	Strengthening skirts by adding plate		○	●	Δ	Δ	Δ
	Note	In cases where skirt strength is low					
● shows the best effect, ○ good effect and Δ no clear effect							

Another method to decrease seismic force is to reduce liquid level in the tank.

5-4-Spherical tank

5-4-1-Damage modes

Damage modes and control criteria for spherical tanks are as follows:

a) Damage to rod of bracing
  - tension yielding

b) Damage to upper column
  - Compression buckling, yield or yield due to bending
  - Shear yield

  - Combination of compression yield, bending and shear

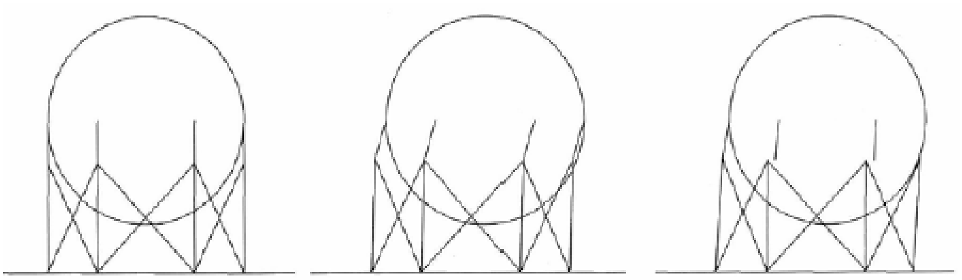
c) Damage to lower column
  - Combinational buckling, yield or buckling yield

d) Damage to anchoring rod
  - Tension yield
  - Shear yield
  - Combination of tension yield and shear

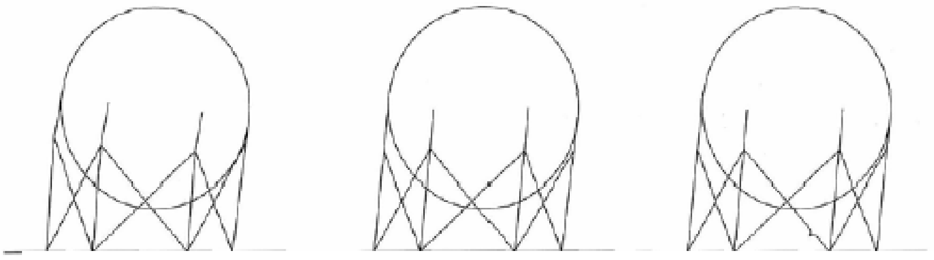
e) Damage of shear plate
  - Buckling yield
  - Shear yield
  - Combination of bending yield and shear

f) Damage to base plate
  - Bending yield due to pressure from foundation concrete
  - Bending yield due to tension force from bracing rod

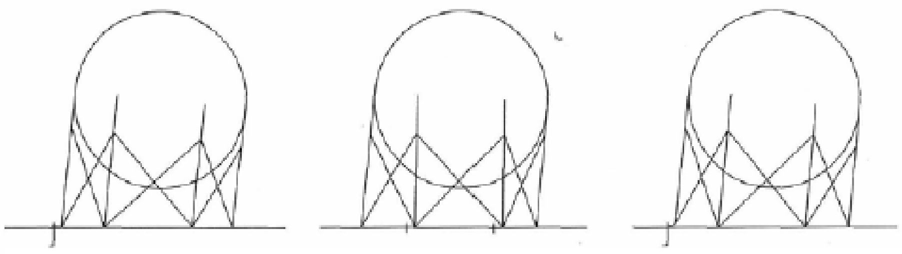
Schematic view of these damages is shown in figure 5-27.



Normal condition (1) Upper column (bending) (2) Upper column (Shear)



(3) Lower column (4) Brace (5) Brace (buckling)



(6) Anchor bolt (7) Shear plate (8) Base plate

5-4-2-seismic assessment procedure

Detailed assessment is done for each damage mode according to latest design standard. Retrofitting procedure based on allowed stress method according to new standard is shown in figure 5-28.

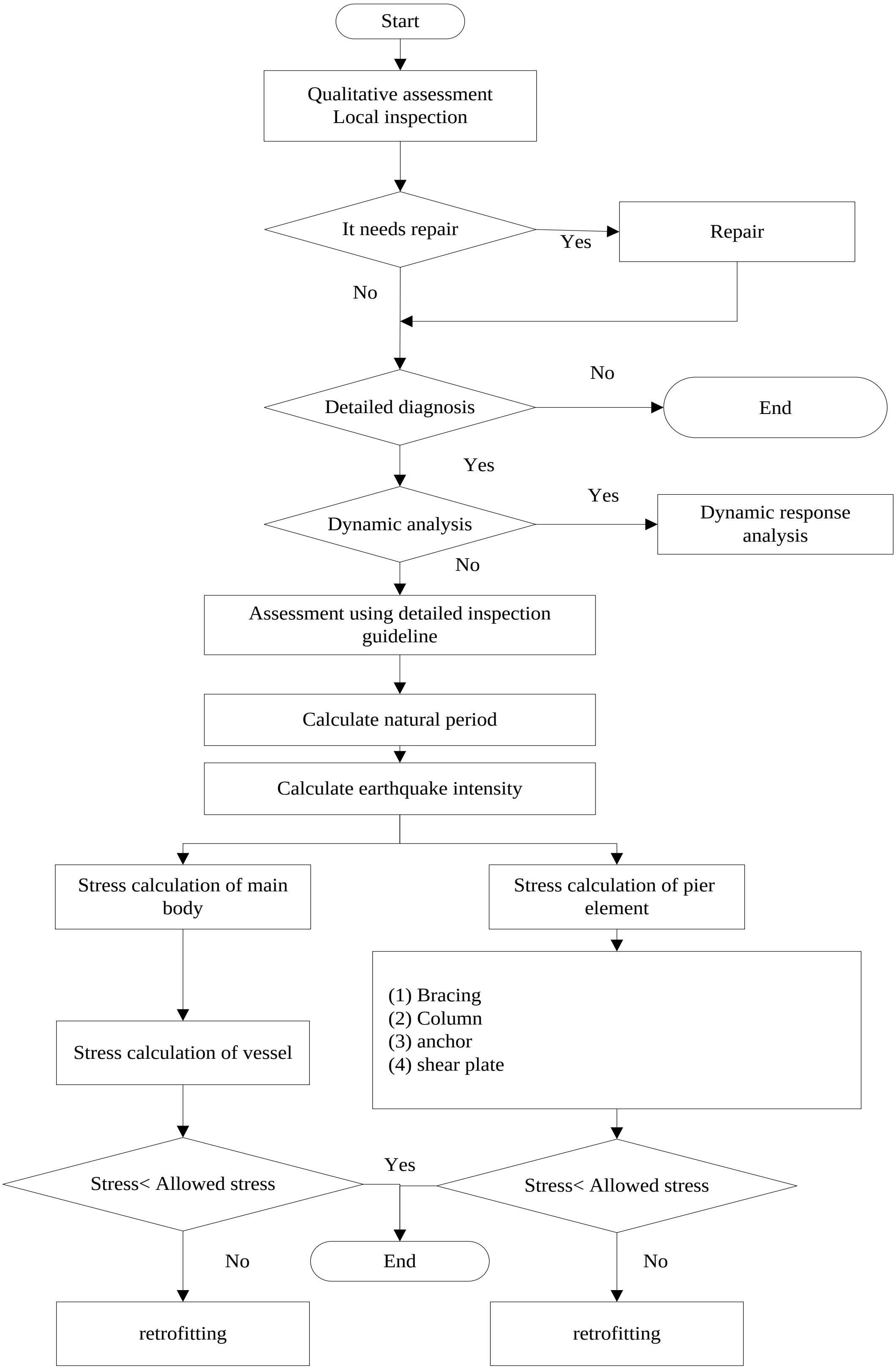


Figure 5-28 Assessment procedure for spherical tanks

Another simple method for simplification of model analysis and calculation is presented.

In this method, dominant damage and related items for easy assessment of facilities with different installation conditions is presented.

This method is used for stress calculation of materials in support structure and judging the facilities strength against earthquake and is based on allowed stress method.

If qualitative assessment method is used, its consistency with prerequisite of local inspection should be controlled with precise consideration of damage mode and allowed stress limit.

For those facilities which are not consistent with analysis prerequisites, detailed assessment including dynamic response analysis and precise modeling should be sued for assessment.

5-4-3-Retrofitting measures for spherical tanks

Priority for retrofitting measures of spherical tank is based on amount of damage to it during earthquake.

Usually retrofitting priority factor is based on degree of importance and is determined by site distance from borders, gas type and pipeline capacity.

Here pipeline capacity means volume of liquid which could hurt human if it is leaked.

Among other factors are economical and social factors. These factors could affect customers and reconstruction cost of buildings and etc.

Retrofitting priority for spherical tanks in each damage mode will be determined by the scale of its effects.

Simplified detailed evaluation is a method for reducing amplitude that is created easily.

Related factors should be determined for assigning retrofitting priorities.

Basics and method of retrofitting are as follows:

1-Retrofitting based on detailed assessment

For minor damage, works are limited to a daily inspection and a simple study and quantitative concept is determined for enhancing seismic strength.

For major damage, this study will be done by detailed assessment.

2- Points which should be considered in retrofitting plan.

2-1-

- Area under pressure should not be operated repeatedly like as before.
- Structural discontinuity and stress concentration should be avoided.
- Balance and harmony between all facilities like workability, dimensions and economic approach should be provided.
- Present and newly constructed structure should act as one unit.

2-2- The section which should be improved:

In this guideline, retrofitting measures to limit sections that are vulnerable to damage mode concentration in spherical tanks and easy seismic strength control of facilities and their installations are explained.

3- Simplified detailed assessment

3-1- Conditions to use simplified detailed assessment

- Following conditions should be met in order to be able to use simplified detailed assessment.
- All drawings, specifications, and conditions of spherical tanks should be studied thoroughly to be sure that the requested conditions are met.
- There should be no severe corrosion in tank, protecting structure and elements of foundation.
- Weight, shape and calculated sizes should be consistent with major structure.

- Piping and its piers should not have great effect on seismic behavior of main structure.
- Tank should be considered as one solid body.
- Spherical tank should not have torsion vibration.
- Foundation sits directly on the ground.
- Braces between column connections should be arranged as pairs.
- Column to foundation connection should be considered as hinge.

3-2-Damage modes and categorization of studies

Considering the damage mode of spherical tank body (toppling), tension strength and failure of support structures should be studied:

- ✓ Bracing
- ✓ Column
- ✓ Anchoring bolt
- ✓ Shear plate

3-3-Limit of allowed stress

- Allowed limit for tension stress for bracing is $3S_y$ for ordinary steel and high strength steel is (cable) $2S_y$. (S_y is yield stress)
- Allowed limit for tension stress for anchoring bolt is $(1/\sqrt{3})S_u$. S_u is ultimate strength.
- Simplified retrofitting plan for enhancing seismic strength is shown in figure 5-29.

4-Detailed assessment

Seismic performance of spherical tank, which does not have simplified detailed assessment conditions, should be studied and assessed by use of design standard including measured data and qualified assessment method.

Stress condition in improved facilities should be revised and controlled for total damage.

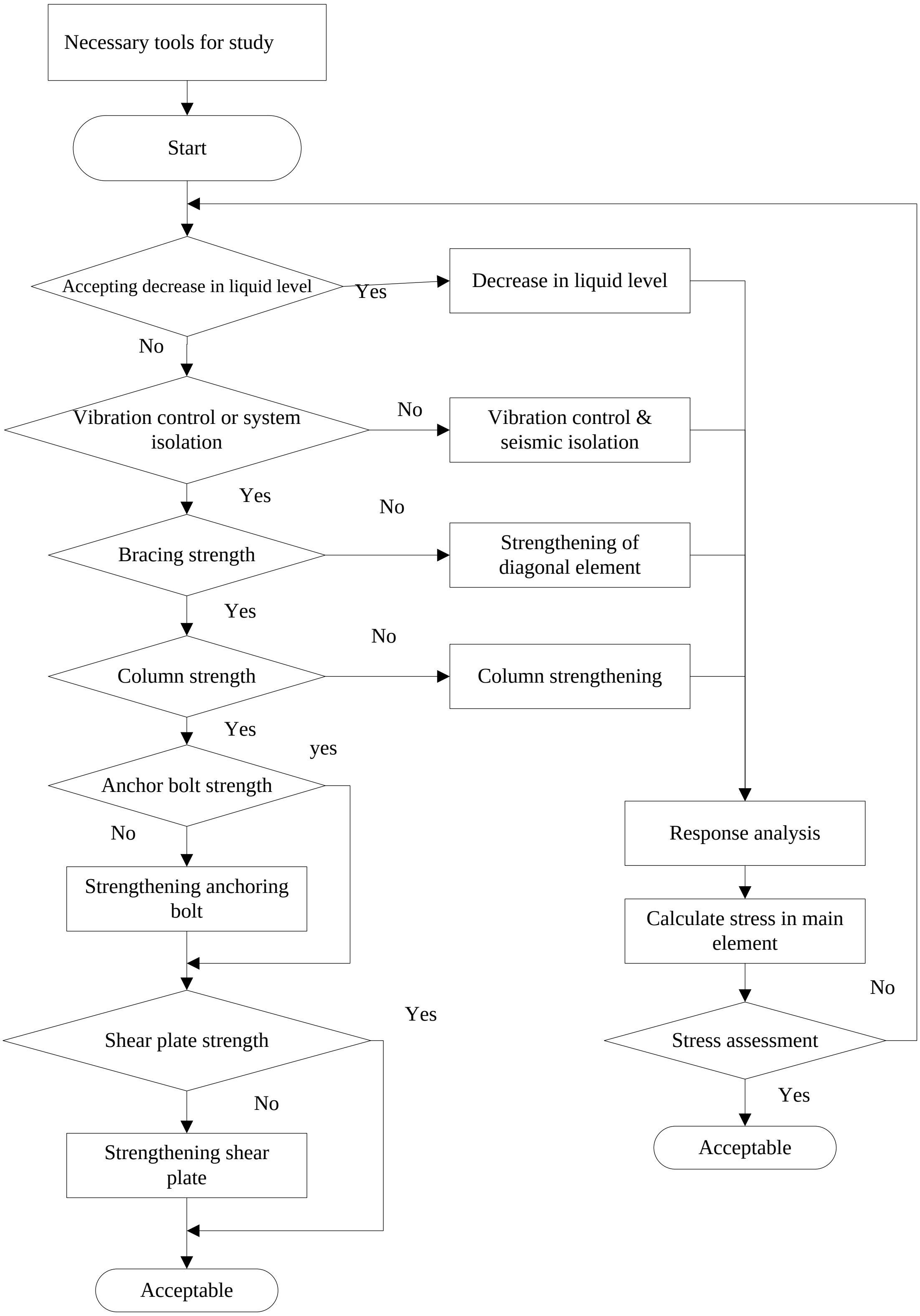


Figure 5-29 Simplified detailed assessment flowchart for retrofitting measures of spherical tank

5-4-4-List of retrofitting methods

Retrofitting measures for facilities, which are diagnosed as defected in local inspection (walking along the project line and assessing) are simple practical works.

Seismic retrofitting measures based on detailed detection method usually consists of shear strengthening of anchoring bolts, stress decrease in supports, strengthening of support structure and vibration control method.

1-Retrofitting measures based on results of field studies

Retrofitting measures for facilities, which are recognized defected during study, are as follows:

These works usually are simply doable.

Study of structure safety during construction and retrofitting effects should be done in advance.

1-1- Crack in foundation

If there is crack in foundation, resin will be injected, but crack sizes should be small relatively.

1-2-Corrosion

If there is serious threat to bolts, first the rust should be removed and then painting and oiling should be done.

1-3-Aging of bolts and nuts

Bolts will be threaded again and nuts will be replaced with new ones.

1-4-Loosening

a) If bolt is bent and nut is not placed properly in its place and does not sit completely on the base plate, it should be fixed by inserting washer between base plate and bolt.

b) Bolts are fastened steadily using special wrenches.

1-5-Adding pipe

a) It is recommended that adding place of pipe be anchored directly from tank side.

b) Stairs, corridors and … should be located beside main structure on the ground or inside the main structure.

c) Supporting pipes for measuring devices and valves should be short.

d) Valves and pipes should be connected to tank even if they are anchored with short pipes so they behave like a solid structure and have the same seismic characteristics.

e) It is recommended to consider a void space between valve and supports in exit valve and stop valve, which is connected beneath the tank and is protected by ground.

f) Pipe outlet has sufficient strength against exterior pressure and pipe flexibility also should be considered.

g) It is recommended that pipes connecting adjacent tanks have U-shaped and knee bend.

h) Pipes entering supporting walls of liquid tanks should have curves and direct pipe should be avoided.

i) It is recommended pipes which enter ground have bends in the beginning.

2-Seismic retrofitting measures based on detailed assessment

2-1-Strengthening of braces

When bracing strength is not sufficient, following retrofitting measures will be done.

If the brace is already strengthened, seismic performance considering total stiffness of retrofitting tank should be checked again.

a) Additional brace

In retrofitting measures, lateral plate should be connected with pinned connection.

As it is seen from following figure items (b) and (c), similar considerations is necessary.

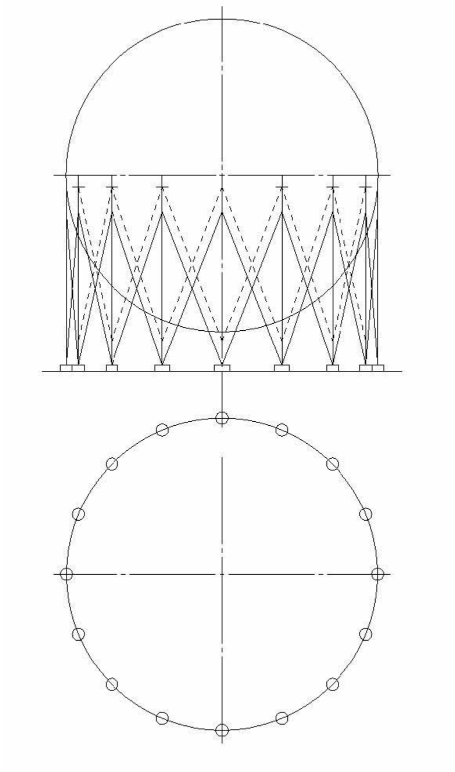


Figure 5-30 Strengthening by adding anchored bracing

b) Moving of anchoring rod

Instead of anchoring rods with small diameter, strong, stiff and big diameter rods should be used.

c) Increase steel bracing cross sectional area with circular cross section.

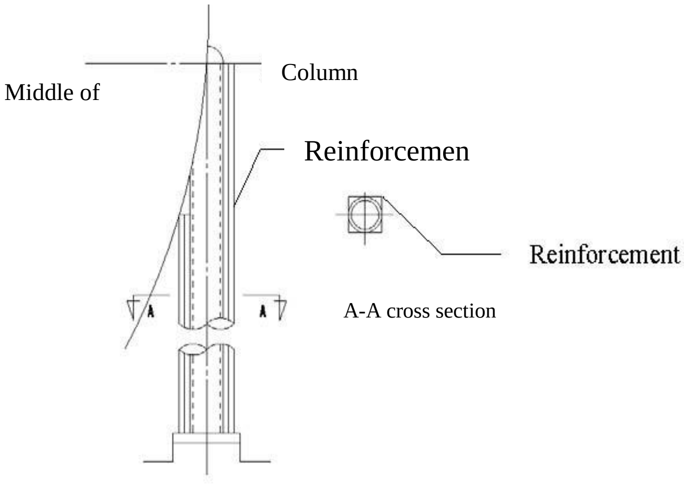
Cross section of circular brace will increase by welding of new angles.

2-2-Strengthening of column

Total stiffness of tank will be assessed considering strengthened column and bracing.

Figure 5-31 shows the strengthening by welding of angle to column.

When upper columns need retrofitting, lower columns also should be strengthened in similar way.



Column reinforcement

2-3-Reinforcing anchor

a) Reinforcing tension anchor

- Additional anchoring bolt (1)

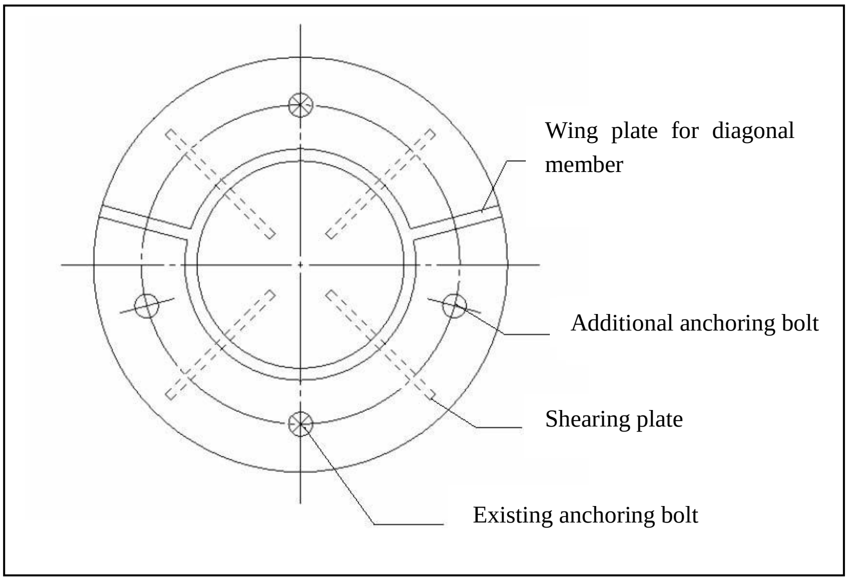


Figure 5-31 adding anchoring bolt (1)

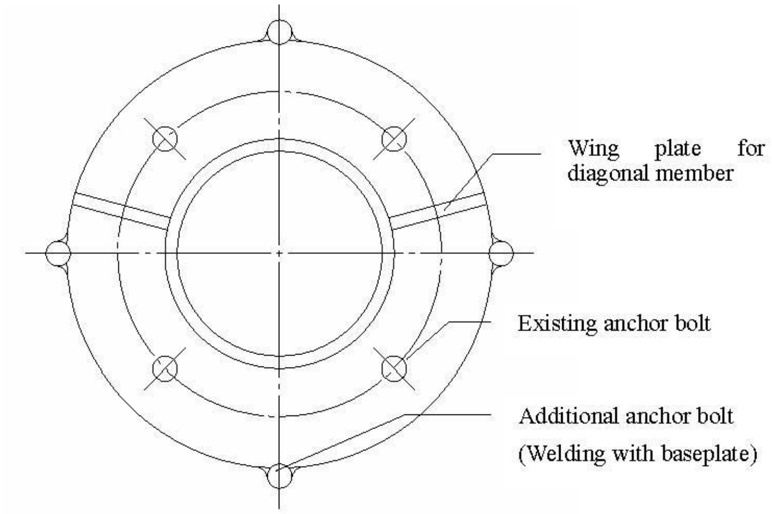


Figure 5-32 adding anchoring bolt (2)

b) Shear reinforcement of anchoring bolt

- Adding anchoring bolt
  - It is similar to above article
- Additional anchoring bolt (2)
  - It is similar to above article
- Reinforcement with shaped steel

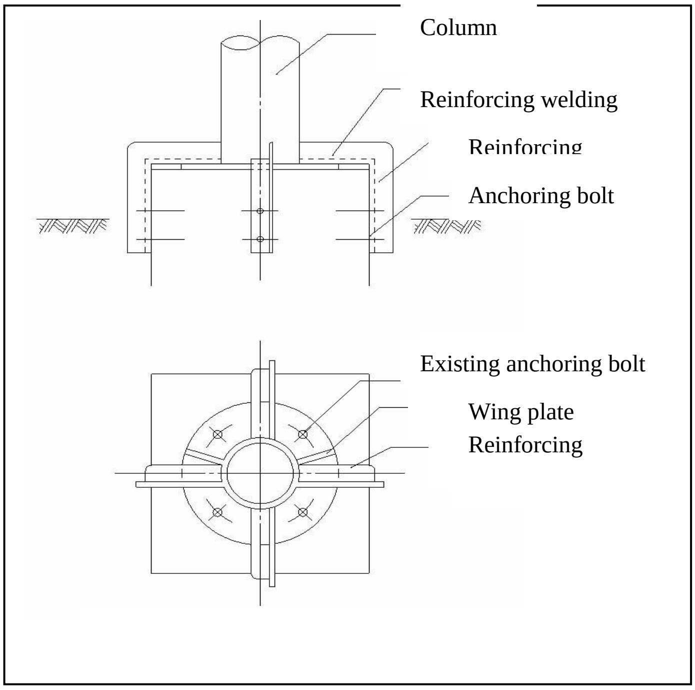


Figure 5-33 Reinforcement with shaped steel

2-4-Vibration control method and seismic separation

Vibration control is a method to increase damping in structure and decrease vibration reaction. Seismic separation is a method to decrease seismic reaction by modifying vibration mode and structure's period.

a) Vibration control using damper (figure 5-34 and 5-35)

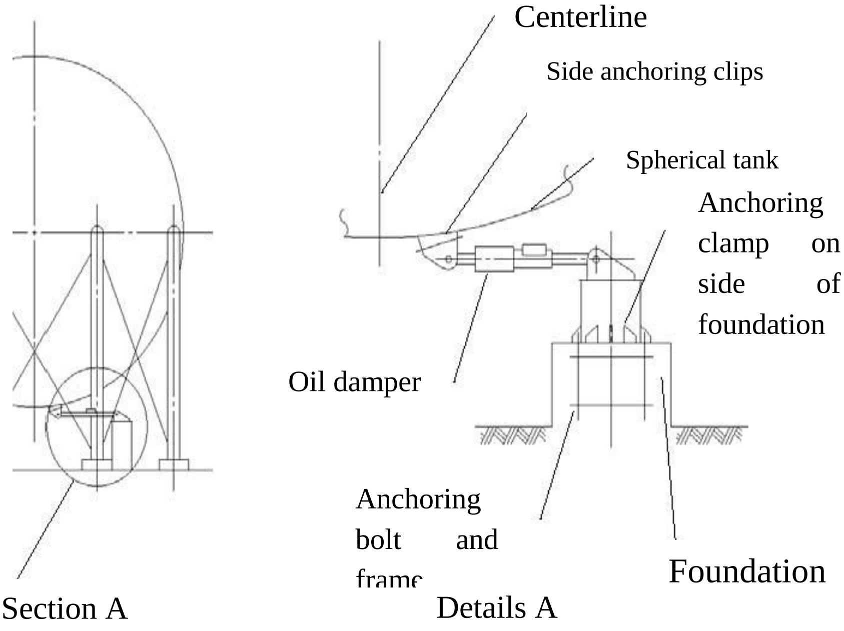


Figure 5-34 Vibration control with damper (standard type)

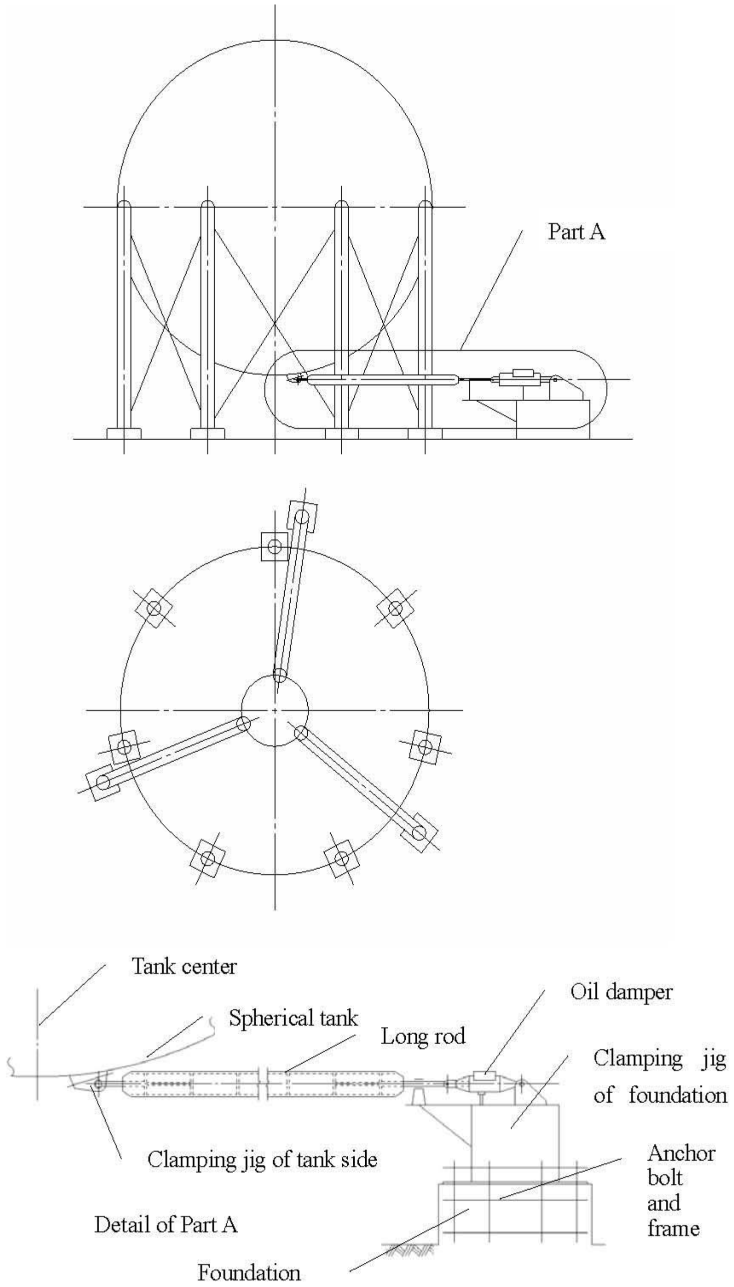


Figure 5-35 Vibration control using damper (long rod type)

b) An example of vibration control with viscous-elastic damper (figure 5-36)

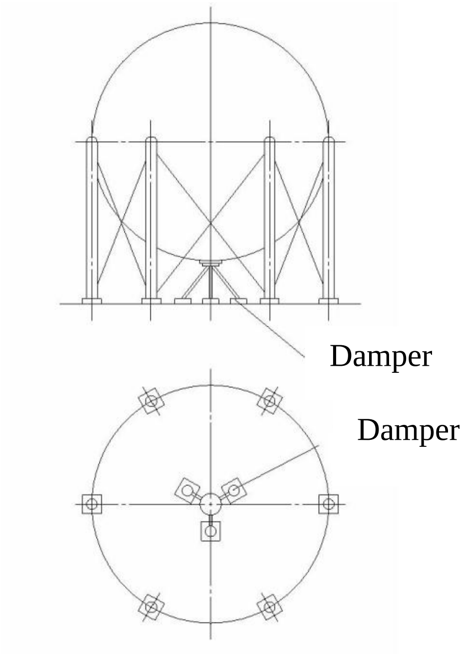


Figure 5-36 Vibration control using viscous-elastic damper

c) Example of seismic separation using inertia dampers including pendulum and rod (figure 5-37)

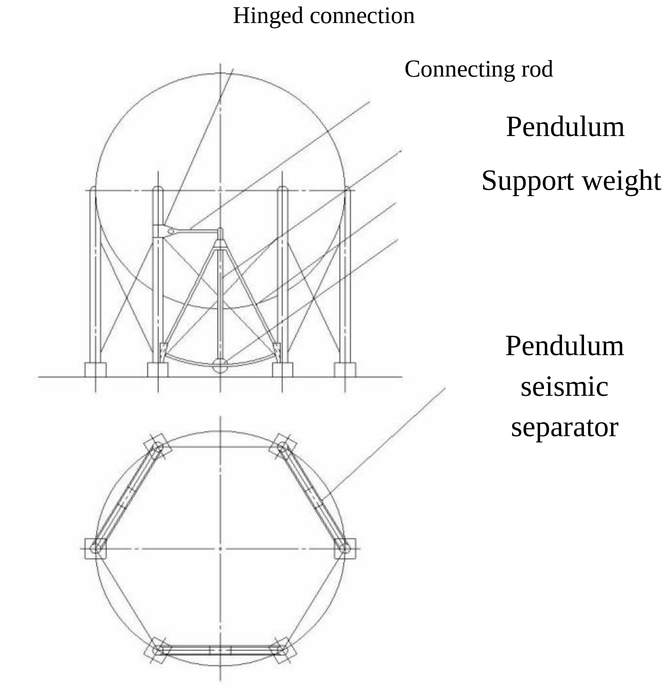


Figure 5-37 Example of seismic separator using inertia damper including pendulum and rod

5-4-5-determining retrofitting method from safety, workability and cost point of view

According to different seismic retrofitting measures, shapes and sizes of initial plan will be prepared.

After that, cost and workability at site will be compared and then construction of final retrofitting plan will start.

As the material cost will change by time, retrofitting type will be determined based on time and location. For each retrofitting method, a comparison table should be prepared including structure strength, cost, and workability and plan limitations.

Limiting liquid level in tank to reach safe conditions against earthquake, could cancel out the need for retrofitting.

1- Decreasing seismic input force by decreasing liquid level

Usually the behavior of tank against earthquake is determined when the liquid level in tank is 90%. Effect weight (W_b) will be determined according to natural period and modified horizontal earthquake force as follows:

$$F_{MH} = K_{MH} . W_b$$ 5-3

$$W_b = W_D + \alpha W_L$$ 5-4

Where

W_d: Tank dead weight (kgf)

W_L: Weight of liquid inside tank (upper limit weight after considering decreasing works) (kgf)

α: Effective rate for liquid weight

Liquid level will decrease earthquake force considerably.

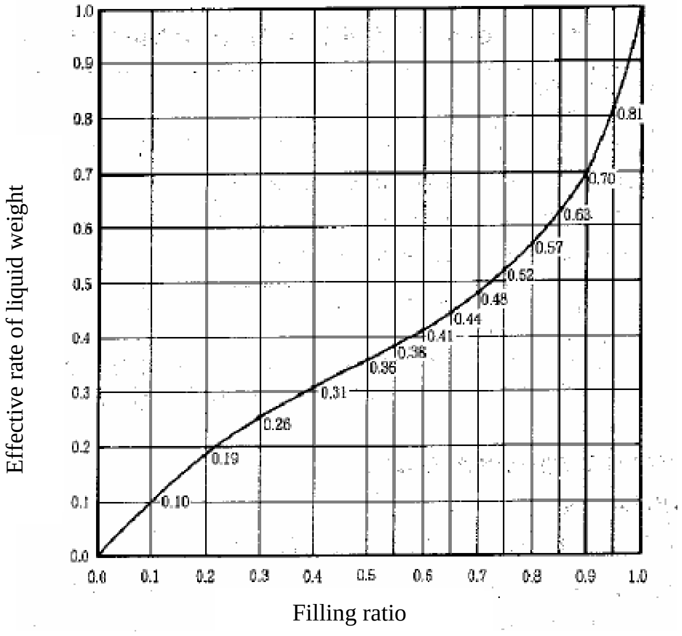


Figure 5-38 Effective rate for liquid weight

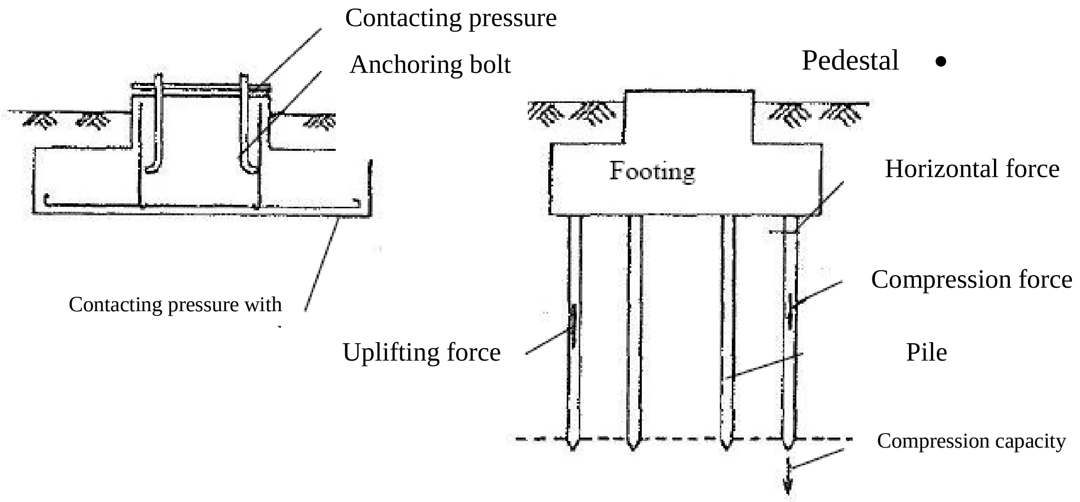
5-5-Foundation

5-5-1-damage modes

Necessary places for seismic studies are as follows:

- Anchoring bolts and anchoring plates
- Pedestal
- Footing
- Pile

Part of damaged foundation is shown in following figure (figure 5-39)



(a) Ordinary foundation (b) Pile foundation

Figure 5-39 Damage modes in foundation

Lateral movement damages due to liquefaction are as follows:

- Failure of piles (underground)
- Failure of pile cap due to earthquake movement
- Failure of pile cap due to reduction of lateral strength in liquefaction
- Failure of pile cap due to inertia force
- Deviation due to reduction of bearing capacity of ground in spread foundations.

5-5-2-assessment procedure

Assessment procedure for foundation of spherical tank is shown in figure 5-40.

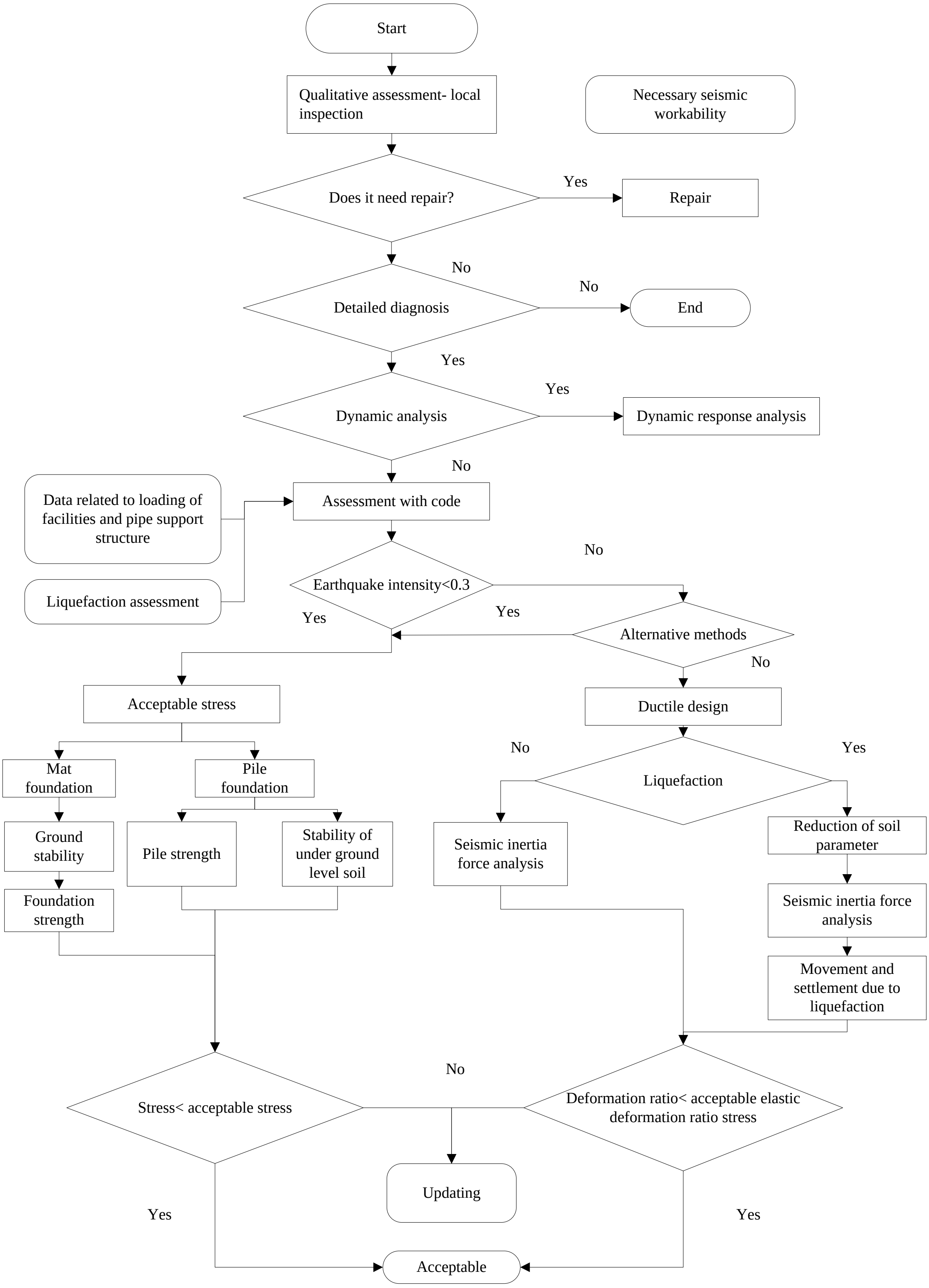


Figure 5-40 Foundation assessment flowcharts

5-5-3- Foundation retrofitting

Retrofitting priority will be determined based on damage intensity to damaged facilities due to earthquake.

Main factor to prioritize retrofitting measures and change of parts is their importance and it is calculated based on their distance from the site.

Also gas type and pipe capacity which is relate to human lives in case they leak. Another factor is the social and economic scale.

Of course, other factors like limitation on customer, reconstruction cost and etc are effective as well.

Damage points usually are concentrated in pier, foundation and piles and retrofitting measures are different depending on the location.

Retrofitting priority is considered with pressure intensity of facilities on foundation. In cases where the foundation is damaged those facilities which are closer to foundation have higher priority.

In the following cases, foundation should be retrofitting:

a) Strength and deformation capability of old foundations is low or for seismic reinforcement of facilities over foundation, yield strength of foundation is improper.
b) A foundation with low strength against liquefaction
c) Lateral spread due to liquefaction

In qualitative assessment, necessary data together with local inspection data should be collected.

In seismic retrofitting of old foundations, initial data like foundation type, shape, dimension and etc are unclear in most of the time.

Retrofitting design will be done by determining initial data like rebar's arrangement and etc.

Local excavation for investigation, uncovering part of cover concrete, non-destructive test or reverse analysis according to design standard during foundation construction, will be used for estimation of main or initial data.

Foundation detailed assessment should be based on detailed assessment of facilities located over the foundation.

Seismic retrofitting procedure of foundation is shown in figure 5-41 together with above-mentioned items.

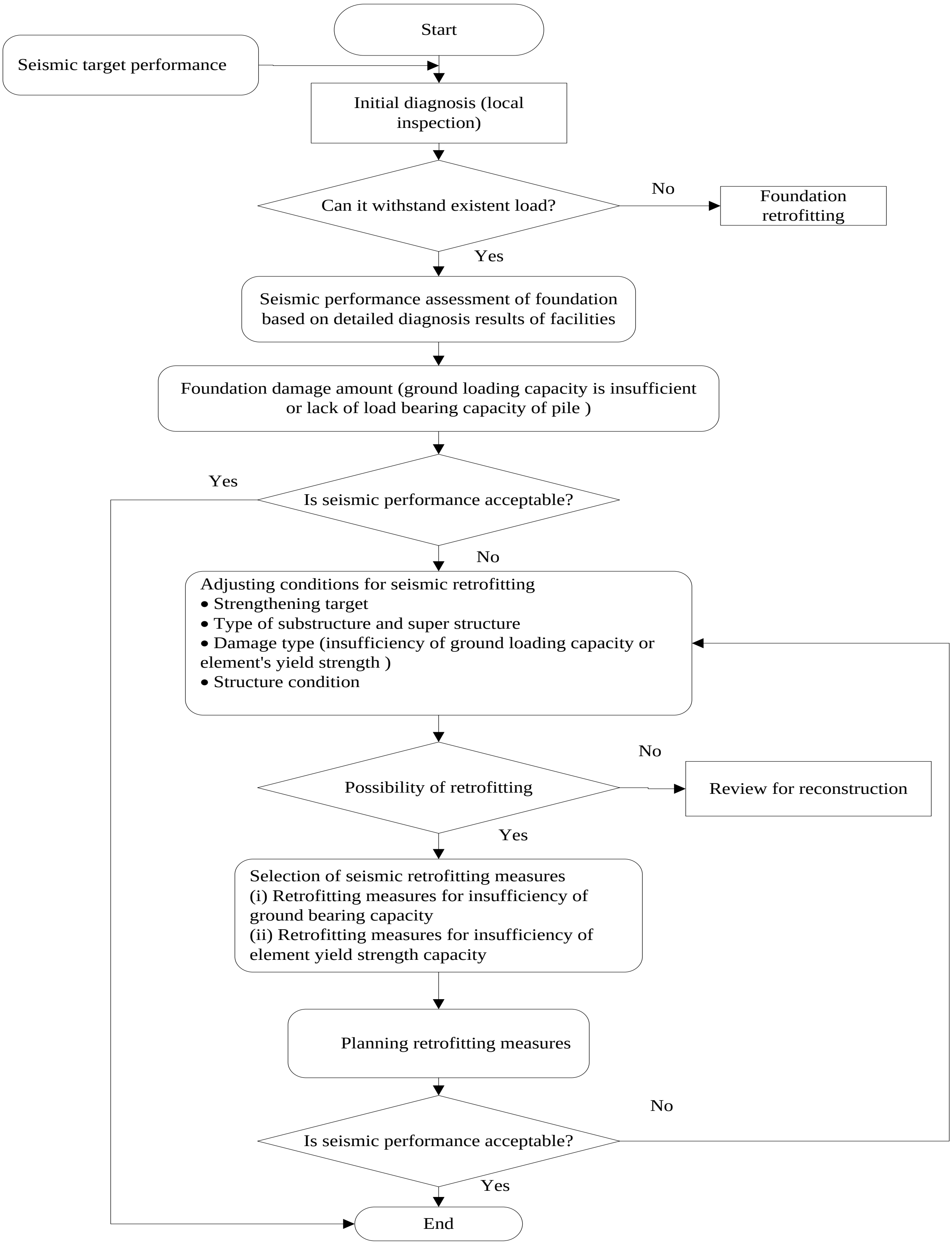


Figure 5-41 Foundation retrofitting plan flowcharts

5-5-4-List of retrofitting methods

Retrofitting measures for facilities, which are detected as defected during local inspection, are simple practical works. Seismic retrofitting measures based on detailed assessment usually include pier reinforcement and adding piles.

1-Retrofitting measures based on local inspection results

Relatively small cracks in pier and foundation will be filled with resin injection.

2-Retrofitting measures in detailed assessment

2-1-Pier reinforcement

This item will be done when shear and compression strength of pier is improper.

Reinforced concrete will be reinforced when its flexural capacity is improper.

Foundation weight will be increased when the foundation tension is improper. They are shown in table 5-6.

2-2-Different type of seismic reinforcement for foundation and ground

There is no precise definition for seismic retrofitting solely for foundation.

Retrofitting or seismic reinforcement is divided into two categories namely; seismic reinforcement due to lack of ground bearing capacity and second is to overcome the lack of material strength.

Summary for each case of seismic retrofitting is given in table 5-6.

Table 5-6 Different type of seismic reinforcement for foundation

Seismic reinforcement type **Foundation type**	**Seismic retrofitting for enhancing foundation stability**						**Seismic reinforcement when strength of foundation material decreases**					
	Foundation construction with excavation from bottom	Common load with other type of foundation	Increase dimensions of foundation	Additional pile	Soil stabilization	Load reduction	Adding concrete or steel plate coverage	Common load with other type of foundation	Increase dimensions of foundation (filling)	Load reduction	Post tensioning	Additional pile
Ordinary foundation	◦	◦	◦	◦	◦	◦	◦	–	◦	◦	◦	◦
Foundation on the pile	◦	◦	◦	◦	◦	◦	◦	◦	◦	◦	◦	◦
Large scale foundation (steel pipe, diaphragm wall)	–	–	–	–	◦	◦	–	–	◦	◦	–	-
Relative to ground motion	–	◦	–	Δ	◦	–	◦	◦	◦	–	Δ	Δ
Relative to inertia force	–	◦	–	◦	◦	◦	◦	◦	◦	◦	◦	◦

◦ Is a method, which is effective, Δ is a method, which is not very effective and – is not used at all.

2-3-Examples of adding piles

This method is used when load-bearing capacity of structure is improper.

Load bearing capacity will be strengthened by adding sections to existent structure.

Between added sections, adding pile is the most common method.

Another method is cast-in-place of diaphragm wall.

Adding piles with small sized diameters, which is called micro pile has developed recently.

Another method is connecting old and new foundation, which is done by increasing dimensions of existent foundation by adding pile to perimeter of foundation. It is shown in figure 5-42.

Load distribution among old and new piles depend on dimensions, structure type and construction conditions.

Vertical load except for seismic load of existent foundation will be beard by previous piles and horizontal load will be beard by both types of piles (old and new).

Special note should be given to integrity of news and old foundation.

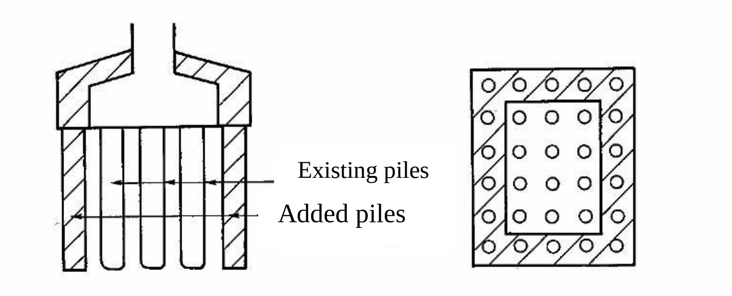


Figure 5-42 Examples for added piles

5-5-5-Determining retrofitting type based on safety, practicality and its cost

For execution of seismic retrofitting of foundation, after determining its degree in different damage modes, retrofitting measures, construction type and total degree of retrofitting should be specified considering foundation damage degree from its workability and assessment results.

Study of following items after determining retrofitting criteria is necessary:

1-Construction volume
2-Foundation type
3-Foundation damage type
4-Construction and ground conditions

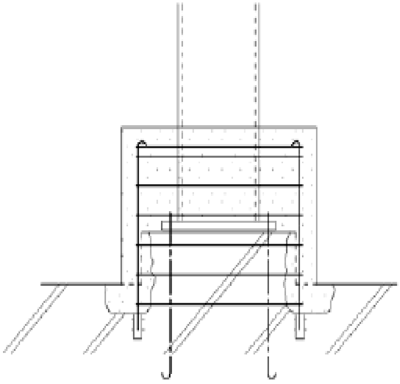
In design of seismic retrofitting of foundation facilities, shape and dimension will be determined by design standard.

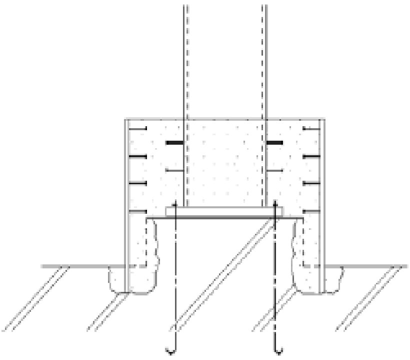
When the foundation strength is improper, foundation retrofitting and its type will be determined.

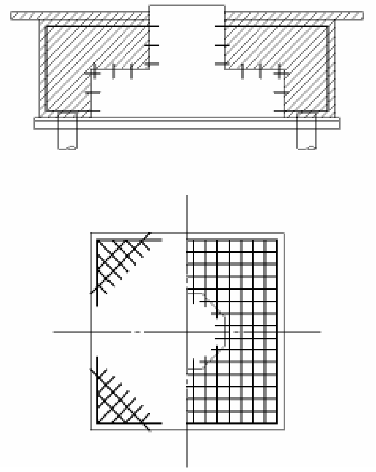
Estimated cost and comparative studies also will be done. As the material cost varies by time, retrofitting type will be determined by time and location.

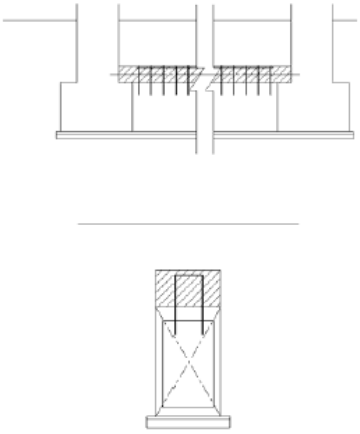
For the ease of engineers who study executable methods, above-mentioned items are compared in tables 5-7 in retrofitting planning based on cost, design type and its elements.

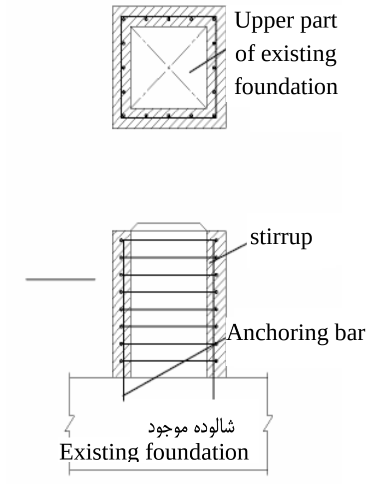
Table 5-7 comparison of retrofitting measures

Sections	Method	**General view of Reinforcement**	**Retrofitting measures type**				
			Deformability	Strength	Cost	Workability	Limitation in plan
Pedestal	Reinforced concrete		○	○	○	○	Δ
	Note	Flexural reinforcement					

Sections	Method	**General view of Reinforcement**	**Retrofitting measures type**				
			Deformability	Strength	Cost	Workability	Limitation in
Pedestal	Reinforced concrete		○	○	○	○	Δ
	Note	Shear reinforcement					

Sections	Method	**General view of Reinforcement**	**Retrofitting measures type**				
			Deformability	Strength	Cost	Workability	Limitation in plan
Foundation	Foundation reinforced by adding pile and broadening of cross section of foundation		○	●	Δ	Δ	Δ
	Note	For cases where yield strength of existent piles and pullout strength of present piles is insufficient					

Sections	Method	**General view of Reinforcement**	**Retrofitting measures type**				
			Deformability	Strength	Cost	Workability	Limitation in
Foundation	Concrete tie beam reinforced by broadening of cross section		○	●	Δ	○	○
	Note	For cases where yield strength of ground beams (connecting tie beams) is insufficient					

Sections	Method	**General view of Reinforcement**	**Retrofitting measures type**				
			Deformability	Strength	Cost	Workability	Limitation in
Foundation	Increase of cross section of pedestal		○	○	○	○	Δ
	Note	For cases where yield strength of pier is insufficient					

● Shows the high effect, ○ proper effect and Δ no clear effect

Chapter 6

Tanks retrofitting methods

6-1-Types of tank

Tanks with cylindrical shell and spherical or conical roofs are used for pressures less than 35 kPa. Floor of these tanks could be flat or like their roof and usually they need supporting structure of the shell.

For pressures more than 35 kPa usually semi spherical, spherical and network spherical tanks will be used. These types of tanks have valves for preventing pressure increase more than designed values. Tanks with simple spherical roof and network spherical roof are shown in figures 6-1 and 6-2. Figure 6-3 shows the cross section and figure 6-4 shows spherical floor with curved lump or soft change in shape in the common border of shell and upper part.

In semi spherical tanks elements with different radiuses are used which a flat shape is obtained. Networked semi spherical tanks are used for larger volumes and internal stirrups and supports will help for shell stress distribution.

Figure 6-1 simple half spherical tank

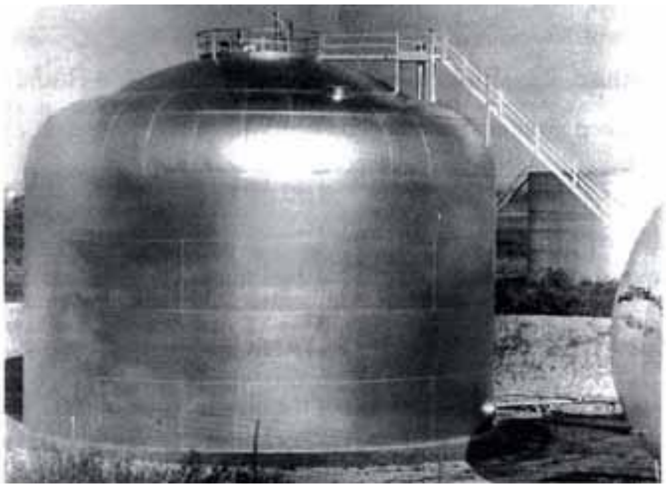


Figure 6-2 networked semi spherical tank

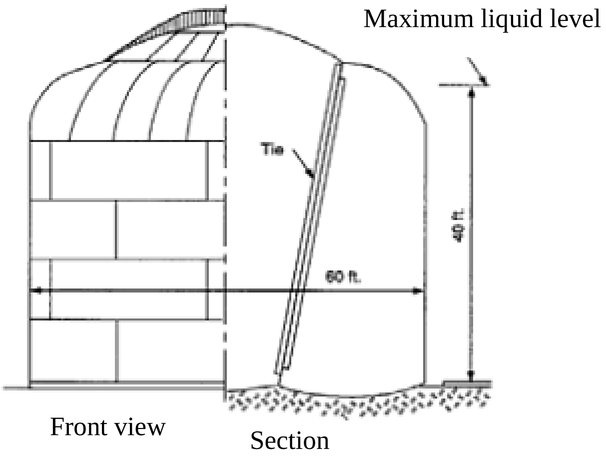


Figure 6-3 drawing of a semi sphere tank

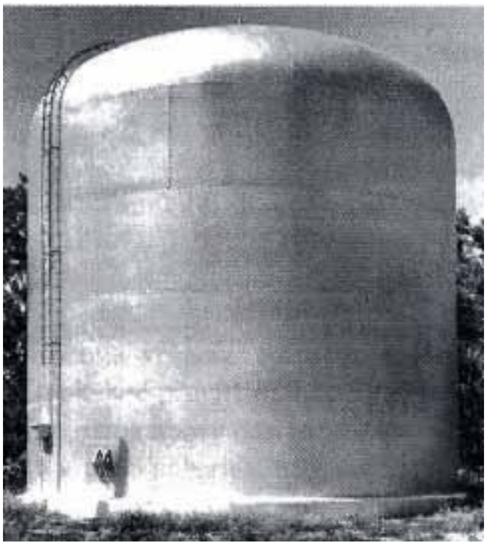


Figure 6-4 simple semi spherical tank with lumped curve

6-2-Retrofitting

Quantitative assessment and analysis of tanks could be done with numerical methods using three dimensional modeling. Loading and analysis method is similar to analysis and design of new tanks. Prioritization of tanks and components retrofitting should be done according to following parameters.

a) Age: Prioritization of tanks for seismic vulnerability will start from the simplest group. Those tanks which are constructed without seismic design consideration in high and very hazardous areas will be the first group to be assessed for seismic vulnerability. Second priority is those tanks constructed in medium and low hazardous areas.

b) Height to width ratio: Tall and slender tanks are more vulnerable compared to short and wide ones. Shells compression stresses increases, elephant foot buckling occurs and this increases possibility of total toppling. In addition, tall tanks displaced more than short ones.

c) Construction detail: Riveted tanks are more vulnerable comparing to welded ones.

It is possible in very old tanks that butt or lap weld with partial penetration was used. Damage to these connections in a severe earthquake is much more than structures which their connections have complete penetrated welds.

In old tanks sensitivity of steel to environment temperature is high which means rapid deformation due to seismic forces could lead to brittle fracture.

d) Attachment details: Most of the damage in seismic disasters is caused by break in piping, ladder, stage or other fixed facilities due to displacement in tank wall.

e) Anchored tanks: In anchored tanks compression tension of shell is considerably lower comparing to unanchored tanks. Also displacement due to uplift forces in anchors and fixed displacement of components and piping connected to tank will decrease.

f) Unanchored tanks: Major difference between seismic responses of anchored and unanchored tanks, is displacement due to uplift forces. This displacement is usually visible in the edges of unanchored tanks. This uplifting force will produce huge tension, compression and moment in the walls of tank and base plates and their intersections. Changes in execution details of tanks might amplify the effects of uplifting force in tanks. In many cases it is necessary to do retrofitting measures for these seismic vulnerable elements.

Damage priority in tanks is as follows:

- Complete toppling of tank
- Slide of whole tank
- Total buckling of tank shell due to pressure stresses or sloshing effects
- Uneven settlement and unstable supporting
- Uneven settlement and unstable soil beneath the foundation (landslide or liquefaction)
- Instability of floating roofs
- Damage to fixed or floating roofs
- Damage to connection and welds
- Stretch out of anchor bolts
- Overflow of liquid
- Other damages

6-3-1-Omission or replacement of shell plates

6-3-1-1-Minimum thickness for replacing plate of shell

1-Minimum thickness of replacing plate of shell should be determined by design standard. This thickness should not be more than the nominal thickness of the surrounding plates unless the surrounding plates are thickened.

2-Any change in major design conditions like specific weight, design pressure, liquid level and shell height should be considered.

3- Plates with same thickness should be used if only few plates are replaced.

4- If all shell plates are replaced, new plates could be thicker.

6-3-1-2-Minimum dimension of replaced shell plates

1- Minimum dimension of replaced shell plates is 300 mm or 12 times of replaced plate thickness which ever is greater. Replaced plate could be circular, rectangle, square with chamfered corners or rectangle with rounded corners unless when all shell plates are replaced. For acceptable details of replaced shell plates refer to figure 6-5.

2-When one or all shell plates or segments with same heights as shell plates are omitted or replaced, minimum space requirement for vertical welding should be obeyed. In omission or replacement, all shell plates or segments with same heights should be improved upon cutting and second welding along the horizontal welding connections. Before welding new vertical connections, existing horizontal welds should be cut so that at least 300 mm space up to new vertical connections remains. Vertical connections should be welded before horizontal connections.

3-When one or all shell plates or segments with same height as shell plates are omitted or replaced, minimum space requirements and welding length in last pitch should be obeyed.

6-3-1-3-Welding connection design

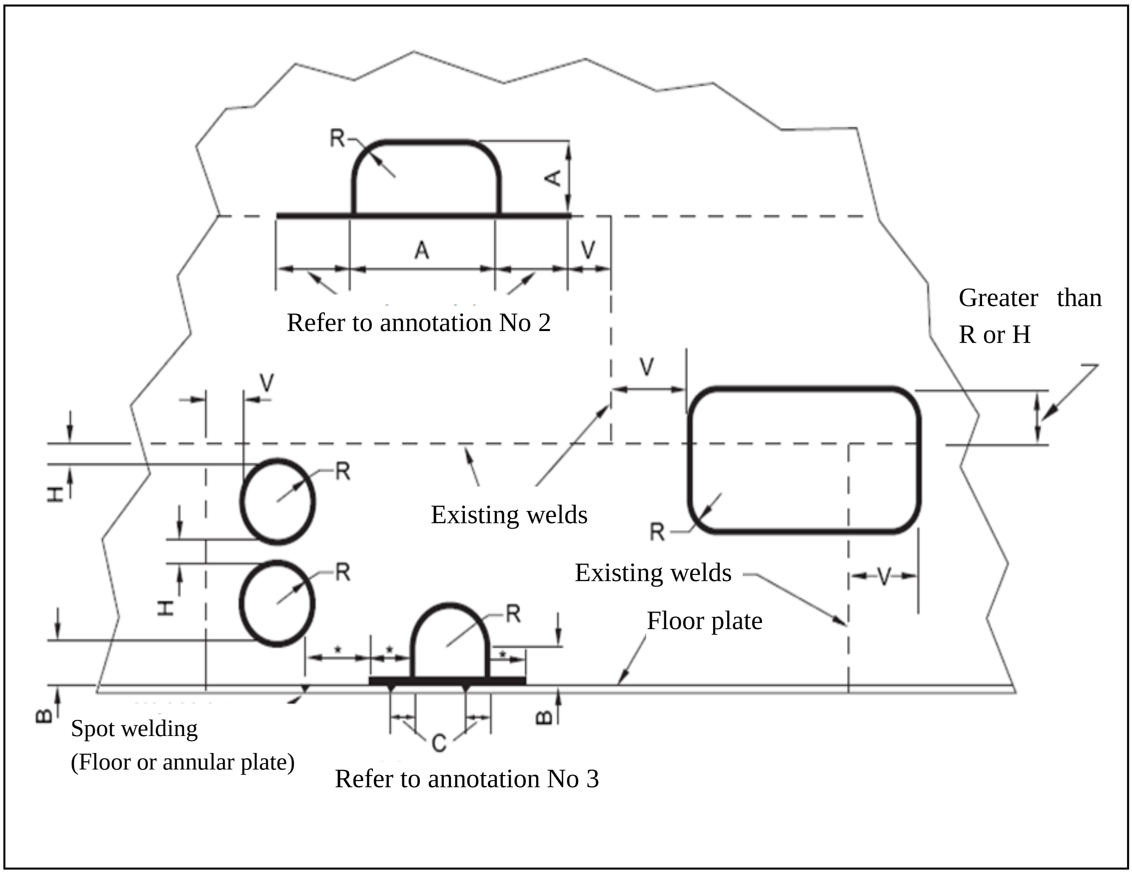
1- Residual strains due to welding of replaced plates could be much bigger comparing to newly built tanks and it is necessary that design should be done in a way to decrease these strains.

2- Shell replaced plates should be welded by butt method with complete penetration and melt unless covered connection should be allowed for shell repair.

3- Weld connection design for replaced shell plates should be done according to API STD 650. 3.1.5.11 to 3.1.5.3. Connections in shell tanks with lapped welds could be repaired with construction standard. Welding details should be according to API Std 650, 5.2

4- For existing shell plates with thickness more than 0.5 inch outer edge of butt weld connected to replaced shell plate should be at least 8 times weld thickness or 10 inch from outer edge of existing shell connection with lap weld, whichever is bigger. For existing shell plates with thickness 0.5 inch or less, distance could be decreased up to 6 inch from outer edge of vertical connection or 3 inch from outer edge of horizontal connection.

For existing shell plates with thickness greater than 0.5 inch, outer edge of butt weld connected to replaced shell plates should be at least 8 times weld or 10 inch from edge of strip weld connecting floor shell to floor, except when replaced shell plate is extended and plate connection to floor is almost 90 degree.



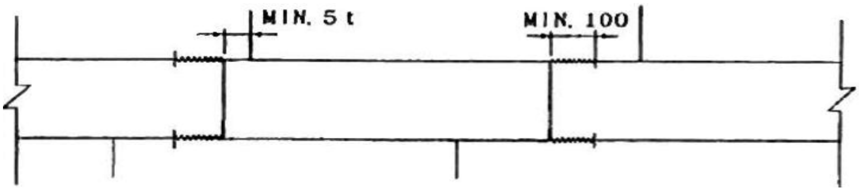
1-All weld junctions should be vertical or in other words 90 degree.

2-Before new vertical welding, existing horizontal welds should be removed for at least 12 inch from edge of vertical weld. Horizontal welding should be done at last.

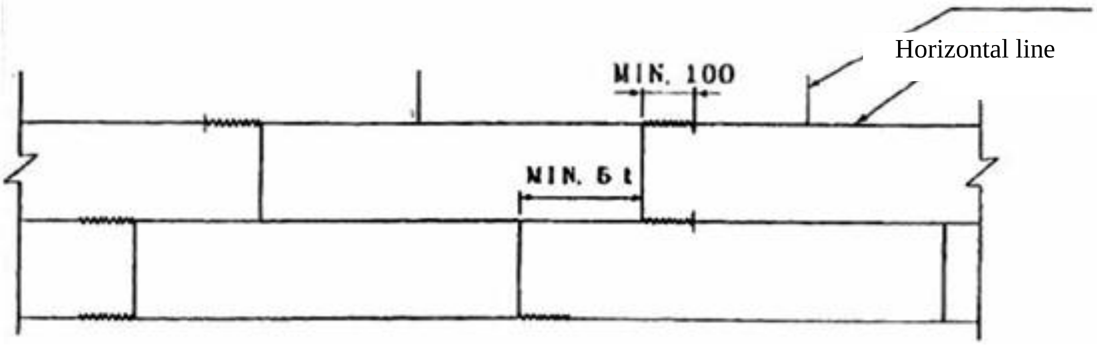
3-Before new vertical welding, plate weld to existing floor should be removed for at least 12 inch from edge of vertical weld. Weld removal should continue at least for 3 inch or 5t from cut of floor plate weld. Plate welding to the floor should be done at last.

4-Minimum distance from edge of welds to determine replacing plate's thickness, t

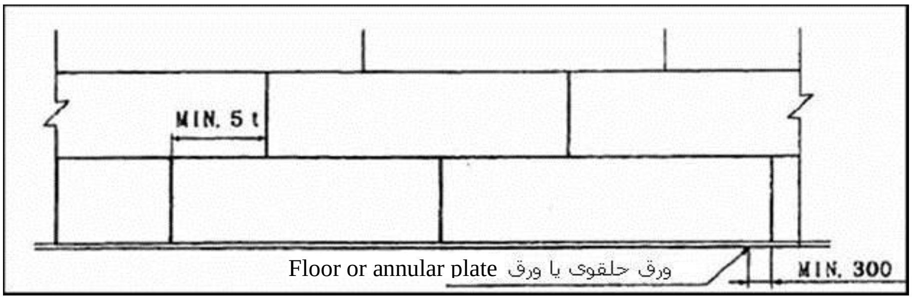
Dimension	≥0.5t inch	<0.5 t inch
R	6 inch	bigger than 6 inch or 6t
B	6 inch	bigger than 10 inch or 8t
H	3 inch	bigger than 10 inch or 8t
V	6 inch	bigger than 10 inch or 8t
A	12 inch	bigger than 12 inch or 12t
C		bigger than 3 inch or 5t



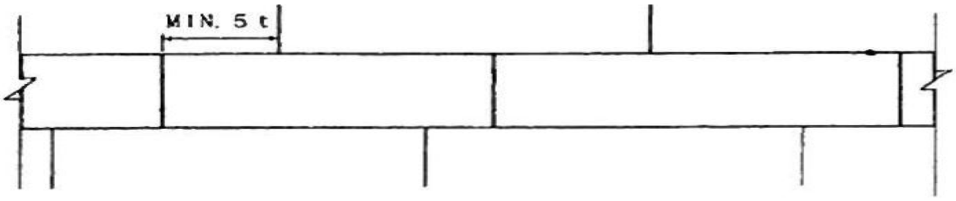
(A) Replacing of only one shell plate



(B) Replacing of several shell plates



(C) Replacing of shell plate at floor



(D) Replacing of middle shell plate

Figure 6-5 Details of plate replacement in steel tanks

t: shell plate thickness 〰 : welding in last step

Figure 6-6 Requirements for minimum distance and welding length in last step for replacing shell plates

For existing shell plates with thickness 0.5 inch or less, distance could be decreased to 6 inch for shell plates with unknown hardness where they have not satisfied criteria of figure 6-6. Edge of each vertical weld connection of a replacing plate should be 3 inch or 5 times thickness away from weld connection edge in floor annular ring or weld connection in floor plates beneath tanks shell. Minimum dimensions are given in figure 6-5.

5- In order to decrease distortion potential due to welding, heat, input flux and welding steps should be considered.

6-3-1-4-Reinforcing shell plates

1-Repairing of shells with covering connections is an acceptable repair method for riveted, lap and butt weld tanks. The aim of these repairs is permanent repairs related to inspection and continuous maintenance plans. These requirements are for assessment of shell repair with covering connection although it is not necessary to impose plate thickness limitations.

2-All repair materials should be provided according to this guideline requirements and API Std 653.

3-Above repairing method should not be used for shells (main construction) with thickness more than 0.5 inch or for replaced cap or shell plates.

4-Repair plate material should be 0.5 inch or the thickness of adjacent shell plate whichever is smaller and should not be less than 3.16 inch in any case.

5-Repair plate shape could be circle, four cornered, square or rectangle. All corners should be rounded with minimum 2 inch radius except for shell to floor connection. The shape of reinforcing plate of nozzle according to API STD 650 is also acceptable.

6-It is possible that repair plate passes through vertical or horizontal shell strips with butt weld in the same line as ground line but there should be at least 6 inch overlap between shell strips. Weld spacing requirements shown in figure 6-5 should be used as a base for locating repair plate's position in butt weld, fillet weld method and rivet strips and other repair plates.

7-If vertical faces have 90 degree angle with tank floor and the welding of floor to shell is not according to figure 6-5, it is possible that repair plates have extended to outer connection of plate to the floor. Repair plates inside shell should be located in a way that open gap of weld be at least 6 inch toe to toe up to floor to shell welding.

8-Maximum dimension of repair plate is 48 inch in vertical and 72 inch in horizontal. Minimum dimension for repair plate is 4 inch.

9-Openings in shell and their reinforcements should not be located in covering connections.

10-Before using covering connection on repair shell, those places which will be welded, should be inspected for defects and remaining thickness by ultrasonic methods.

11-Repair plates should not have over laps with welded shell strips, riveted places, other repair plates, places with distortion or cracks and unrepaired defected places.

12-Covered connection repair plates will be used for capping opening holes or places with high corrosion.

13-Welding should be continued to outside of repair plate region and inside perimeter of hole. Minimum diameter of hole is 2 inch and minimum corner radius for shell openings is also 2 inch.

14-Nozzle opening and reinforcing plates should be separated completely before connecting repair plate.

15-Welds of repair plate should be complete fillet type. Minimum shell plate dimension is 4 inch with minimum 1 inch over lap and maximum 8 times shell thickness over lap.

16-Repair plate thickness should not exceed adjacent plate nominal thickness.

17-Repair plates with covering connections could be used for reinforcing of those areas of shell plate which have damaged severely and doesn't have enough strength to bear service loads. These plates also could be used for shell plates which their thickness is insufficient and they have to comply with following additional requirements.

18-Thickness of repair plates will be selected based on approved design using API STD 653 and as-built standards and connection efficiency not more than 35%. Peripheral welding should be complete fillet type.

19-Repair plate thickness should not exceed 4/3 of shell plate thickness which is located on the perimeter of repair area, and it should not be more than 1/8 inch. Repair plate thickness should not exceed 1/2 inch.

20-Residual strength of the area which is damaged should not be considered for hydrostatic and service load bearing capacity in calculations.

21-Covered connection repair plate could be sued for repair of small shell leakage and if following requirements is satisfied the leakage potential from insulated scattered holes could reach to a minimum.

22-Existing shell thickness should be more than minimum acceptable thickness except for holes and cavities.

23-Repair plate should be designed in a way that assuming holes in shell and connection efficiency of 35%, it could bear the hydrostatic pressure between repair plate and shell.

24-Thickness of repair plate should not exceed 4/3 of peripheral shell plates' thickness and should not be more than 1/8 inch. Thickness of repair plate should be more than 3/16 inch and less than 1/2 inch and peripheral welding should be complete fillet type.

25-If the fillet type weld facing the products inside tank which causes corrosion cracks or there is the possibility of corrosion cell, then this repair method should be avoided.

26- If the product goes between shell plate and repair plate and prevents gas exhaust from tanks, this method should not be used for leakage repair of shell.

27-Shell plate under repair plate should be assessed on each inspection to satisfy requirements of clause (22). If shell plate thickness doesn't satisfy clause (22) or repair plate doesn't satisfy clauses (17) - (23), then that area should be repaired according to clauses (12) - (16)

28-Methods for seismic reinforcement of shell plates are based on buckling prevention by use of additional plates.

29-Figures 6-7 and 6-8 shows several ways to reinforcing of shell plate, using additional plates.

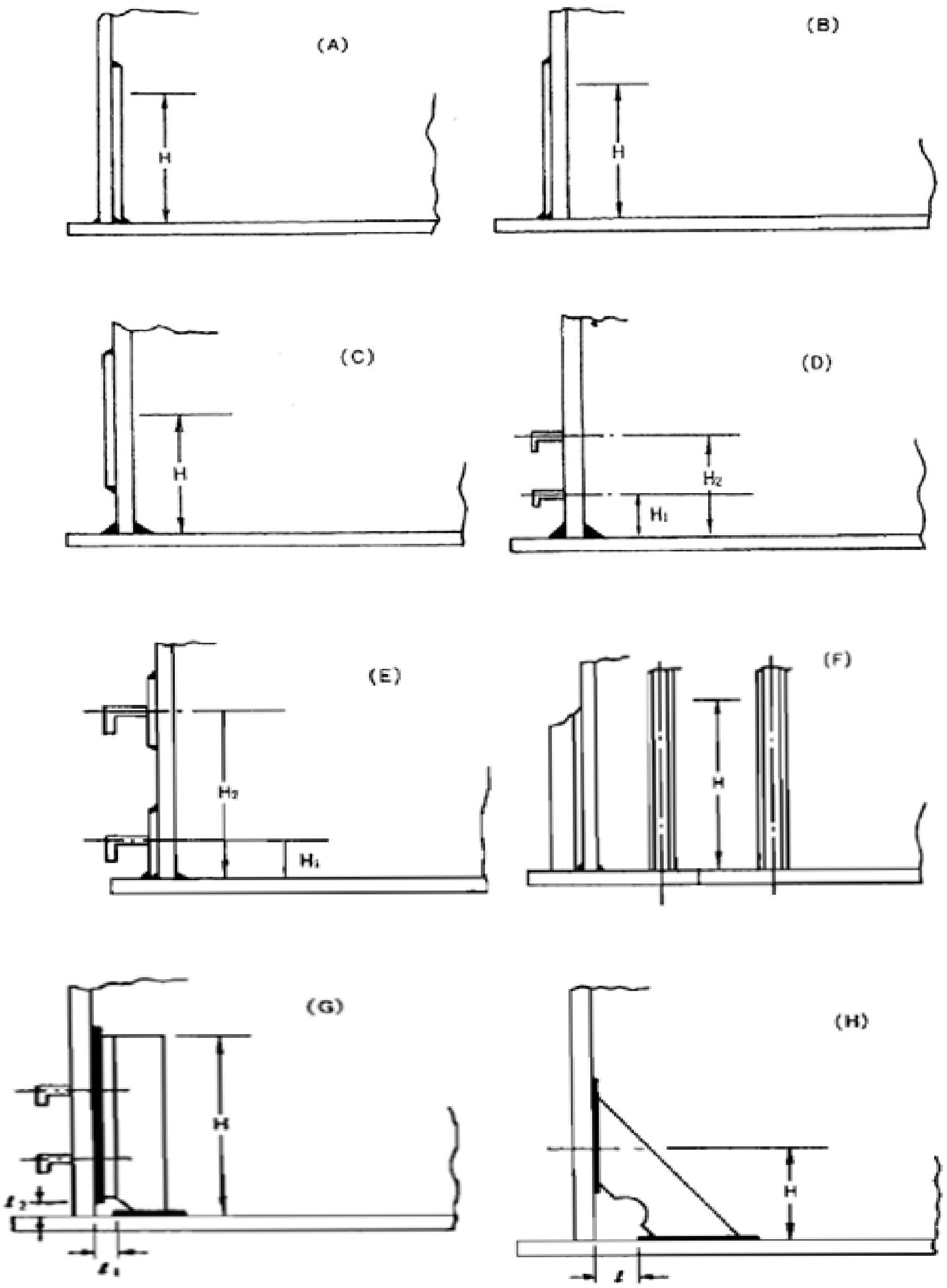


Figure 6-7 Shell plate reinforcement using additional plate

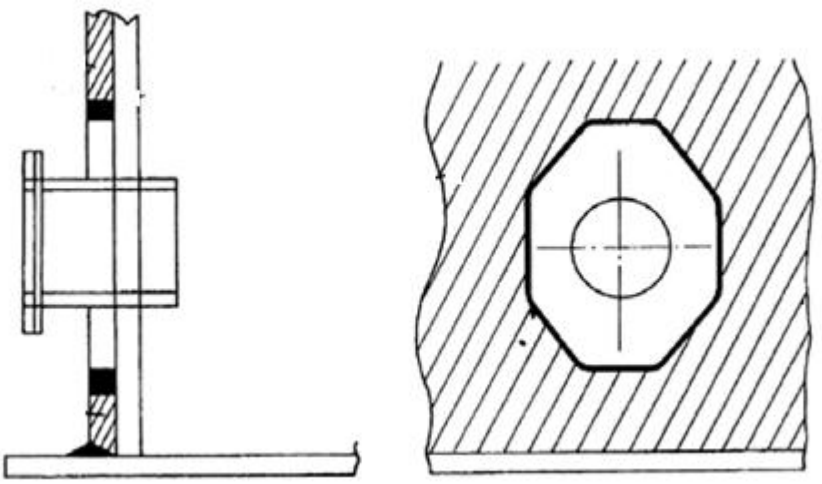


Figure 6-8 Shell plate reinforcement using additional plate around manhole, nozzle and visit gate

6-3-1-5-Dimension of added plate to side wall

1-Dimension of added plate to side wall (shell plate) should satisfy following provisions:

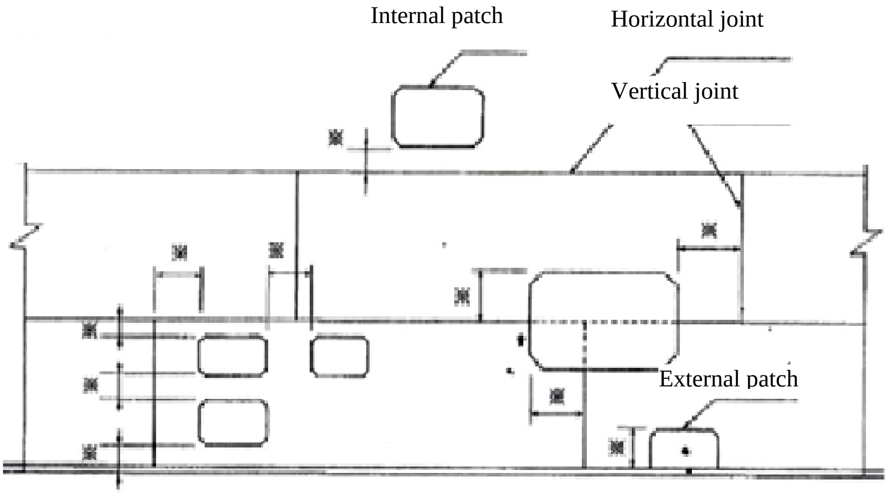
Dimension of added plate should not be so big to produce high residual strain due to weld heat.

Vertical dimension of added shell plate should not exceed 500 mm.

Area of a segment of an added plate should not exceed following values:

- 0.75 m^2
- 10% of area of side panel plate

2-Figure 6-9 shows minimum space between added plates for shell plate reinforcement.



Minimum marked spaces is 50 mm or 8t, where t is tank shell thickness.

Figure 6-9 Minimum space between added plates for shell plate reinforcement

6-3-1-6-Repairing the defects of shell plate material

Cases like cracks, break (sections which are left after picking up installments), scattered holes and corroded areas which need repair and are found during tank shell inspection, should be determined. In sections where shell plate thickness is more than design thickness, it is possible to obtain an even surface with grinding uneven surfaces up to a point where remained thickness is acceptable by design criterion. In cases where the surface grinding will decrease the shell thickness to below acceptable value, shell plate should be repaired with repair weld and rest of the tests should be carried out. If a larger area of shell plate needs repair, substituted shell plate with butt type weld or cover connecting plate should be used.

6-3-1-7-Replace of tank shells to change shell height

To increase tank shell height, it could be replaced with additional shells of new material. Modified height of shell should be standard and all loads like wind and seismic loads should be considered.

6-3-1-8- Repair of shell inlets (manhole, nozzle, visit gate and etc.)

With this repair, reinforced plates are added to no reinforced nozzles. Reinforced plate should have all requirements related to dimension and weld spacing of API STD 650.

6-3-2-Annular plates

1- Required thickness for annular plates should not exceed floor shell thickness.
2- Figure 6-10 shows methods for adding annular plate under tank floor shell.
3- Figure 6-11 shows external strengthening methods for annular plate.

6-3-2-1-Supporting plate

1-If compression stress under floor plate or annular plate under tank wall exceeds the limits, supporting plate under floor plate or annular plate could be used to increase loading capacity and stiffness of plates.
2-If compression stress transferred to top of foundation, exceeds allowable foundation bearing stress, supporting plate could be added to top of foundation and beneath floor plate or annular plate in order to decrease transferred stresses and increase tank shell stability.
3- Figure 6-12 show a sample of added supporting plate to top of foundation and beneath floor plate or annular plate.
4- If compression stress beneath floor plate or annular plate beneath tank wall exceeds allowable value, these plates will distort and cause rotation or plate displacement (figure 6-13). In these cases supporting plate will increase plates' stiffness.

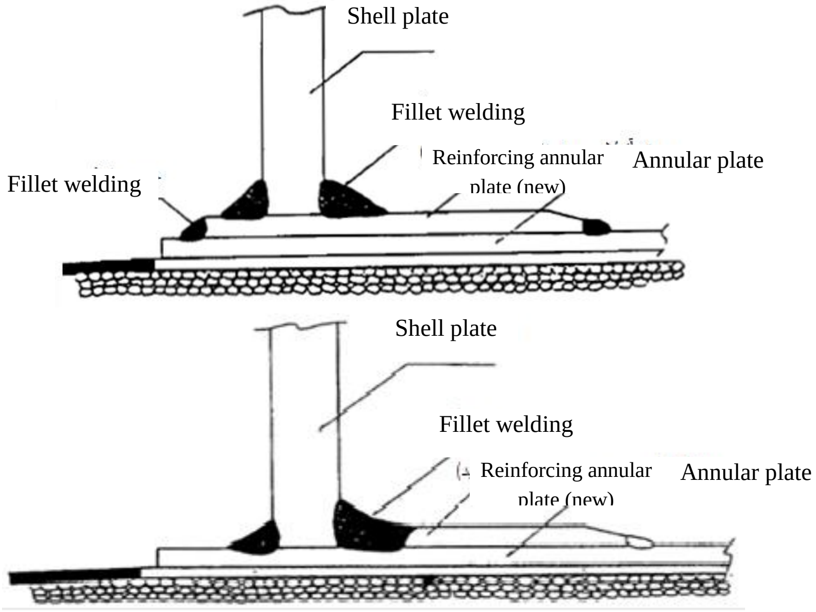


Figure 6-10 Methods for adding new annular plate under tank floor shell

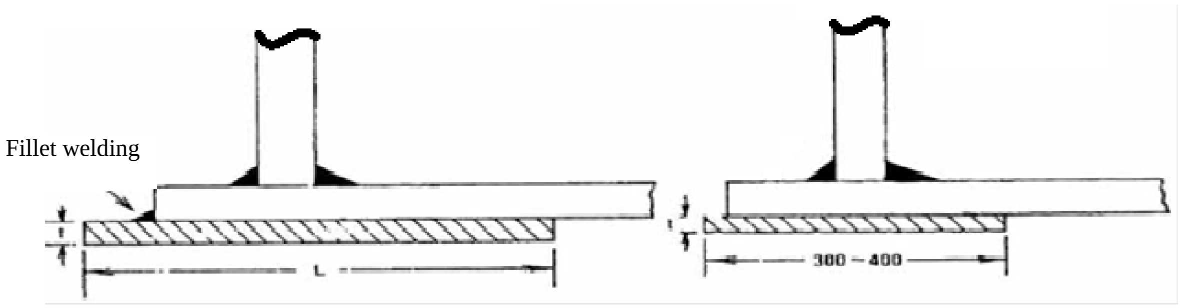


Figure 6-11 outside strengthening of annular plates

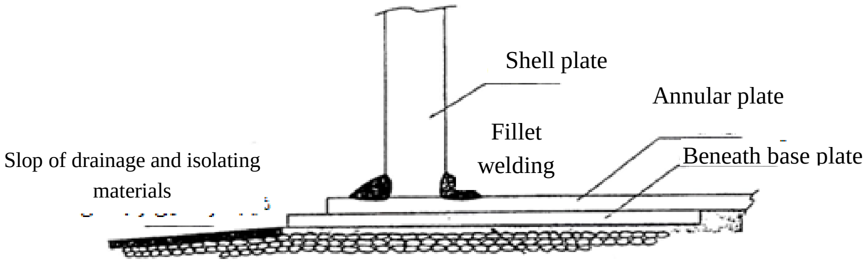


Figure 6-12 Sample of added supporting plate

5- If compression stress transferred to top of foundation exceeds the limits, supporting plate could be added to top of foundation and beneath floor plate or annular plate and decrease compression stress in foundation and increase tank stability.

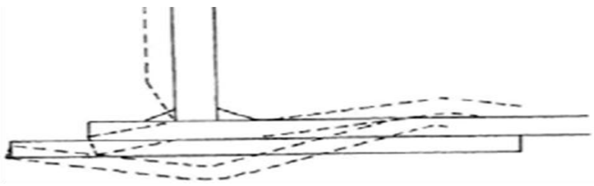
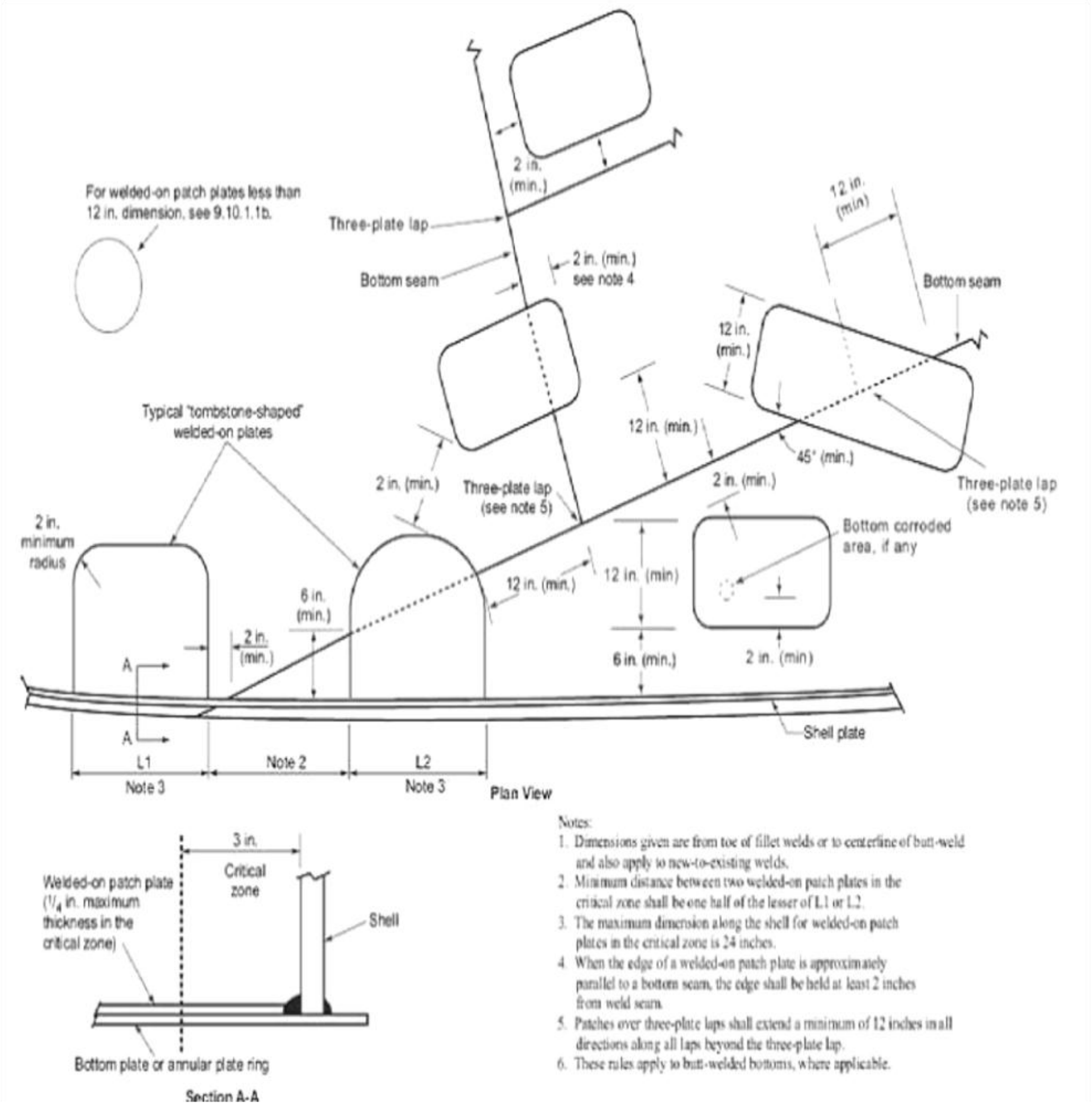


Figure 6-13 Supporting plate influence after seismic countermeasure



Notes:

1. Dimensions given are from toe of fillet welds or to centerline of butt-weld and also apply to new-to-existing welds.
2. Minimum distance between two welded-on patch plates in the critical zone shall be one half of the lesser of L1 or L2.
3. The maximum dimension along the shell for welded-on patch plates in the critical zone is 24 inches.
4. When the edge of a welded-on patch plate is approximately parallel to a bottom seam, the edge shall be held at least 2 inches from weld seam.
5. Patches over three-plate laps shall extend a minimum of 12 inches in all directions along all laps beyond the three-plate lap.
6. These rules apply to butt-welded bottoms, where applicable.

Figure 6-14 Welding connections plates in tank floor

6-3-3-Floor plate

Following limitations should be considered for repair of floor plate of tanks with uniform supports by use of welding plates:

1-Minimum plate dimension with weld connection which has overlaps between existing connection and floor longitudinal gap is equal to 12 inch. Weld connection plate could be circle, four cornered or multi cornered with rounded corners.

2-Weld connection plate smaller than 12 inch is allowed only when: its diameter is 6 inch or more, has no overlaps with floor longitudinal gap, is not located partially or completely over existing connection, if it has extended at least 2 inch more than floor corroded area.

3-Weld connection plates should not be located at portions of tank floor which has local or total exfoliation. If tank settlement is still continuing, it is not recommended to attach weld connection plate.

4-Weld connection plate is allowed to be used in mechanical dented or locally layered places if: Dimension of unsupported sections in any direction does not exceed 300 mm, thickness is at least 1/4 inch, minimum thickness is equal to existing floor thickness, longitudinal gaps does not have overlaps with other connections, except for tanks which are designed according to API Std 650, appendix M and weld connection plates should have minimum 3/8 inch thickness.

5-These repairs are permanent repairs and are subjects to inspection and maintenance plans.

6-3-3-1-Replacement of tank floor plates

1- Requirements for fixing replacement plate on floor plate are given in clauses (2) to (6).

2- Suitable and non corrosion shock absorbing materials like sand, gravel or concrete should be used between previous and new floor.

3-Shell should be cut continuous and horizontal to tank floor. Cut edge should be able to drainage all waste and particles produced during cut. As it is mentioned in API STD 650, new floor plate should be continued to outside shell. All provisions related to weld spacing also should be obeyed.

4- Void spaces inside foundation under old floor should be filled with sand, crushed lime stone, mortar or concrete.

5- Except for allowed cases in clause (12) all inlets in the shell should be raised, or if new floor level is not sufficient due to details of nozzle strengthening (refer to API 650, 3.7.2) or weld spacing requirements are not observed according to Std 650, 3.7.3, then supporting plates should be modified.

6-For tanks with floating roofs, new floor profile should keep roof level when it is located on its supports. Floor level could be changed with changing support piers length. In order to keep the main height above floor, it is possible to keep the support piers with their height or decrease their height equal to new floor plate thickness plus deprecated thickness.

7- New base plates should be installed for supporting piers of floating roofs and fixed roofs. For internal floating roofs with aluminum supports, new arsenic stainless metal or another acceptable non metal separator (for example Teflon) should be used to separate supports from carbon steel floors.

8-To separate shell from tank floor, one of the following methods will be used:

a) Cutting shell parallel to tank floor at least 50 mm above floor to shell weld

b) Separate all floor to shell weld including total penetration and heat effect area with proper method like abrasion all arc shape areas of floor to shell weld should be tested with magnetism particle and damaged areas should be repaired and tested again.

9- Installation of new floor after removing existing floor should be done according to API Std 650. Except for cases mentioned in clause (12) existing inlets in shell should be raised or if new floor level is not sufficient according to nozzle strengthening details (refer to API Std 650, 3.7.2) or weld spacing requirements is not fulfilled according to API Std 650, 3.7.3, supporting plates should be modified. For tanks where shell plate stiffness is unknown, new welds in floor or annular ring should be located in at least 3 inch distance or 5t, which ever is bigger from vertical welds of floor shell. Here t is floor shell thickness in inch.

10- Replacing parts of existing tank floor (integrated rectangle plates or big plates) which are not located in critical areas, will be done with provisions similar to provisions of installing new floor in construction of new tanks according to API Std 650.

11-For tanks with cathodic protection and under floor leakage detection system, following items should be considered:

  a) In tanks with catholic protection under the floor, whole floor should be removed and old shell will not be used for cathodic protection of new floor. Removal of old floor is important for prevention of galvanic corrosion (refer to API REPAIR PLATE 651). If it is possible, whole old floor except for unusable old shell and annular area with a diameter less than 18 inch of installed floor to shell should be removed.

  b) Leakage detection system should be installed under the floor to direct the leakage to a place which is visible from outside tank.

12- In tanks with material yield strength of 50000 lbf/in ^{2} or less if following conditions are met, then it is not necessary to raise inlet pipes in shell:

  a) For strengthened inlets including its lower type, there should be at least 100 mm between weld toe to floor and the closest connecting weld toe of inlet. (Peripheral weld of support plate or nozzle inlet weld to support plate of lower type and shell weld)

  b) For self-supported inlets 3 inch or 2.5 t which ever is bigger should be kept between toe weld of shell to floor and the closest toe weld of inlet.

  c) Floor weld to shell should be done using low hydrogen electrodes and a welding guideline which limits the distortion and residual stress should be used.

  d) Toe of welds should be uniform to minimize the stress concentration.

    i) For circular strengthening plates, uniforming of peripheral weld should be done from 4 o'clock position to 8 o'clock position. Grinding and uniforming of inside and outside weld to floor should be done for at least for one length of penetration diameter on both side of central penetration line.

    ii) For diamond shape strengthening plates, lower horizontal length of diamond will be grinded. Grinding of inside and outside shell weld to floor, should be done at least for one penetration diameter length in both side of center line of penetration.

    iii) For lower type inlets, uniforming of nozzle weld (support plate and shell) will be done from 4 o'clock position to 8 o'clock position. Grinding of inside and outside shell weld to floor, should be done at least for one penetration diameter length in both side of center line of penetration.

  e) Grinding length of clause D should be tested with magnetic particles, before and after hydrostatic test.

13- Figure 2 (1) shows the gap limitation between added plate and floor support plate.

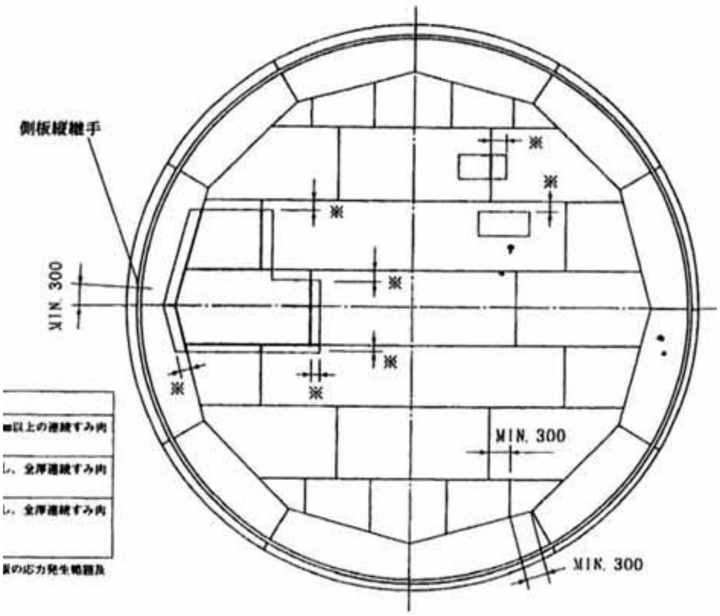


Figure 6-15 Gap limitation between added plate and floor support plate

14- If it become necessary to replace all floor plates, it is possible to enter the replacing plates from the groove which is made on floor shell or from the inlet and locate it in its groove from inside the tank. As it is shown in figure 60, when the new floor is installed in the groove, before cutting the next groove, each plate should be welded in its location or should be supported safely with upper part of shell plate. This will prevent shell buckling between grooves.

Peripheral layer should be from clean sand, metal mesh or a concrete layer should be installed beneath the new layer with a minimum 76 mm distance from it so that the shell will reside over the foundation and whole are of new floor. This method is called double floor method (API 575 9.2.3)

15- To replace floor in ordinary tanks using double floor method usually the segment beneath new floor is not designed for strength and is not connected to new floor and that part of tank which is located above. With increase of distance between previous and new floor majority of weight could be exerted to resist against overturning moment. It is important to consider necessary details to connect previous and new floors to each other with sufficient strength, because if the tank faces uplift not only new floor and its contents but also old floor and separating materials (usually concrete) should be moved. Concrete will increase floor section module and produce stiffness and will decrease the uplift. Again the soil supporting pressure should be controlled. This method will decrease the effective tank capacity because the new floor should be located at least 76mm (in special cases 300 mm) above the old floor to be effective.

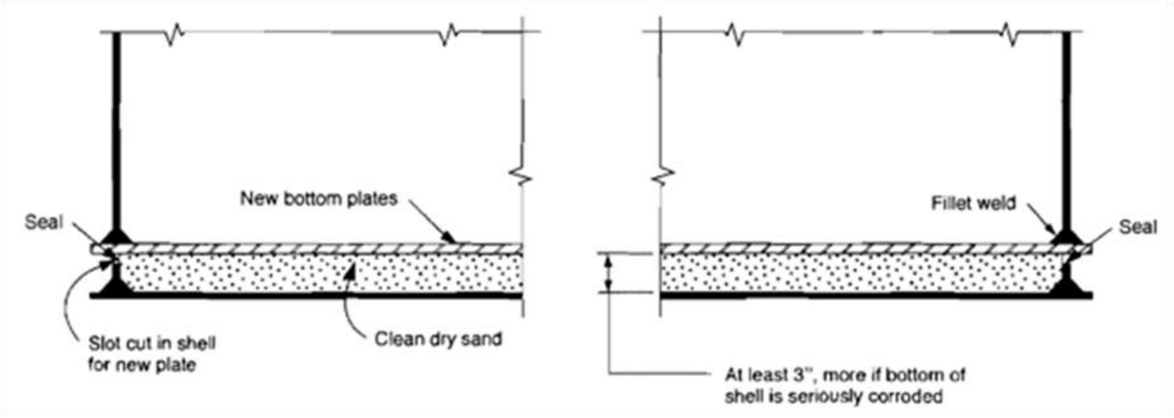


Figure 6-16 Tank floor repair using double floor method

16-Repair of floor plate in tanks with fixed roof

Step 1: If there is no suitable manhole in the roof, an entrance should be opened in the roof in order to separate floor plates. (Figure 6-17-a)

Step 2: Floor plates should be cut to a dimension to be discharged from manhole or entrance. (Figure 6-17-a)

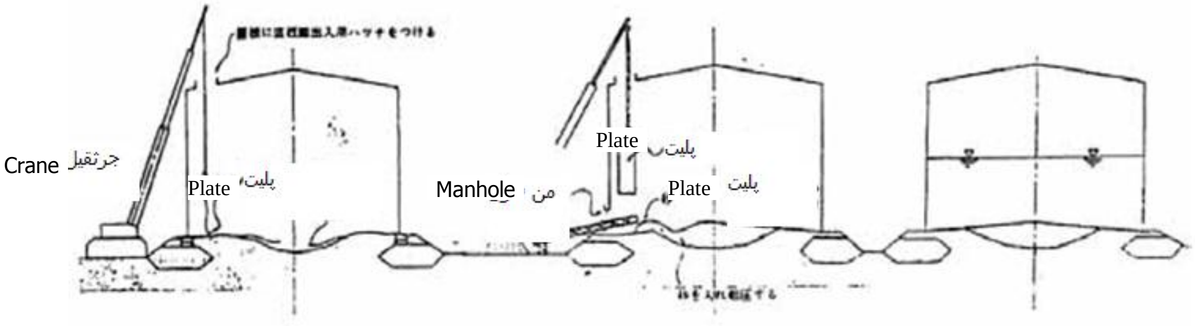
Step 3: Separation of floor plate (Figure 6-17-b)

Step 4: Separation of foundation material or soil which should be modified from lateral manhole (Figure 6-17-b)

Step 5: Foundation repair (Figure 6-17-b)

Step 6: Floor plate reconstruction (Figure 6-17-c)

Step 7: Tank leakage control (Figure 6-17-c)



(a),(b),(c)

Figure 6-17- Floor plate replacement method

6-3-3-2-Added weld plates

1- If other weld plates like separators and supporting plates are added to floor plates, they should be tested. For added weld plate if overlapped weld distance requirement of forth section of clause 6-12 are not obeyed, for that section of weld, where the minimum distance criteria are not obeyed, MT and PT tests should be carried out.

2- Those weld plates which are located in critical regions, should be installed according to all requirements.

6-3-4-Foundation

On-ground tanks will sit on compacted soil foundations or annular concrete walls or mats or a combination of them. Those tanks which are directly on the ground will sit on sand, gravel, asphalt, or crushed stone layer. Anchoring these tanks is difficult. There are three methods to anchor tanks with soil foundation.

i) In small and medium tanks, they should be lifted and construct a new foundation beneath them or build a new foundation with excavating the peripheral of the tank. In this method, anchoring bolt should be located in new foundation and anchors of retrofitted concrete should not be used. It is not necessary that soil bears the uplift forces like the foundation and anchorage are installed for this purpose. Allowed stresses should be controlled for earthquake and also anchoring loads like foundation ordinary design. Figures 6-18 and 6-19 show the method to lift the tank using jacks to repair the foundation settlement. Steps are as follows:

Step 1: Plating for jack (figure 6-18-a)
Step 2: Deformed floor plate will be removed using proper wires (figure 6-18-b)
Step 3: Lifting tank (figure 6-18-b)
Step 4: Repair of foundation settlement (figure 6-18-b)
Step 5: Locating flat floor plate on repaired foundation (figure 6-18-c)

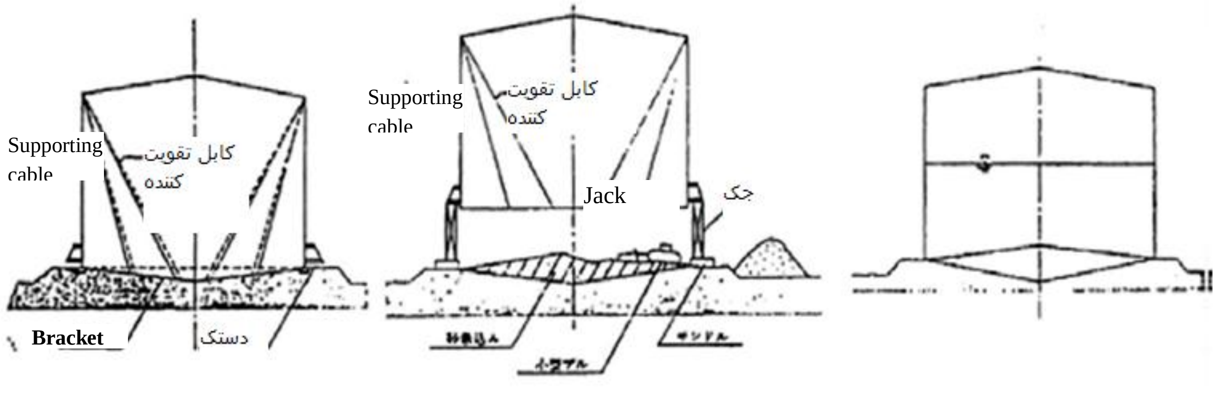


Figure 6-18-a-b-c Lifting all tank using jacks to repair foundation settlement

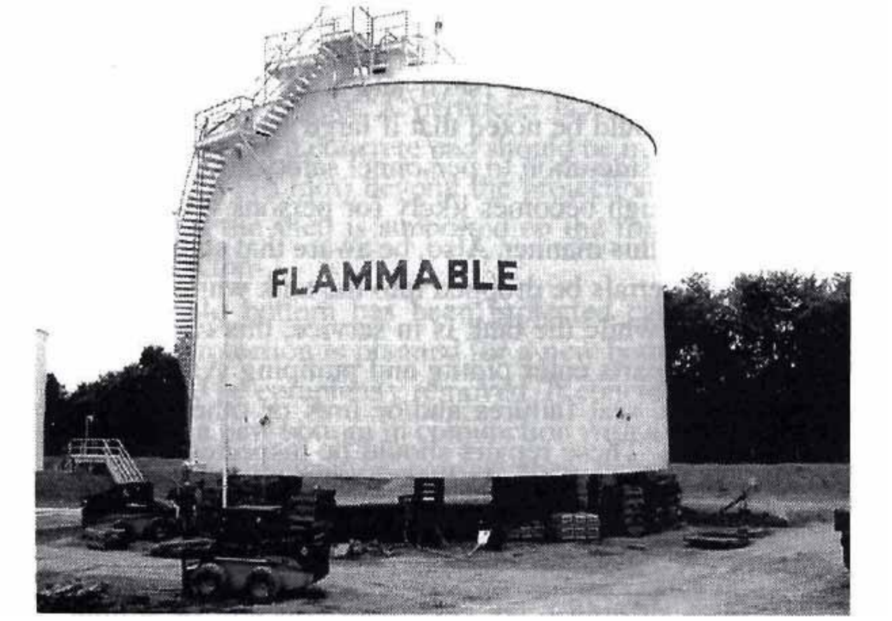


Figure 6-19 Lifted tank to repair below layer

ii) Moving bigger tanks without damage is more difficult and costs more.

- Although it provides retrofitting of annular wall beneath tank shell.
- In most case annular wall weight is not enough against uplifting force.
- Spiral piles and caissons are necessary for retrofitting.
- Figures 6-20 and 6-21 show two methods for reinforcement of tank foundation (annular wall)
- Seismic retrofitting will be done in connections by replacing tank floor.
- Floor replace will increase weight and therefore increase the resistance against uplift.

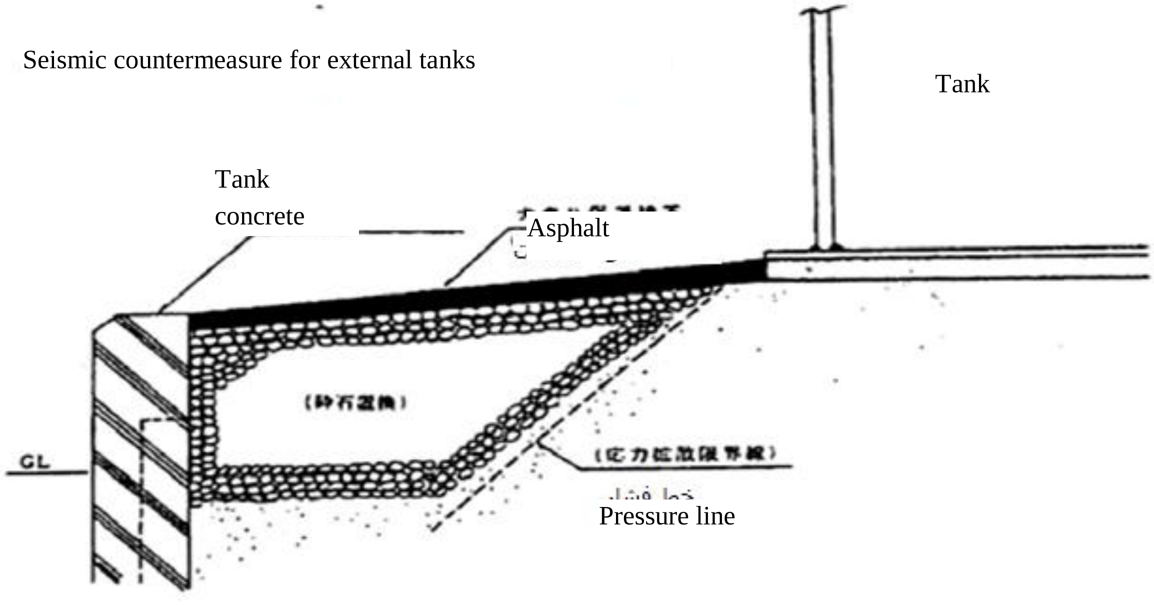


Figure 7-20 Reinforcement method of tank foundation

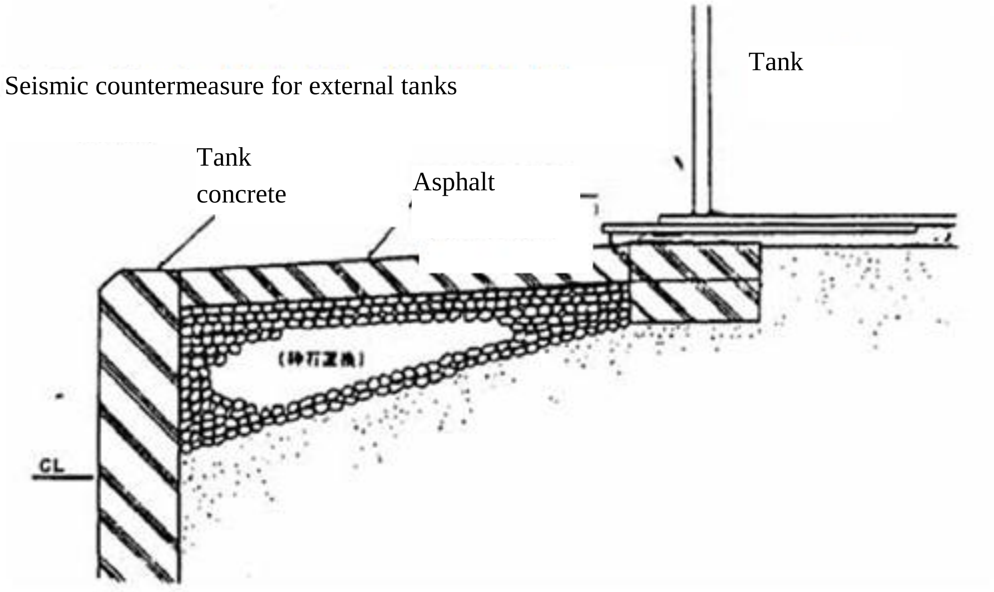


Figure 6-21 Reinforcement method of tank foundation

6-3-4-1-Slabs

Tanks with slabs beneath them need the minimum retrofitting.

Foundation without retrofitting does not have strength on toppling forces and should be controlled.

Tank could be anchored directly to slab but if there is not enough space between bolt and slab edge, the foundation should be extended in radial direction to accommodate anchorage bolts.

In thin slabs, the bolts should pass through the slab. In this case, washers or plates will be used beneath the slab to spread the bolt force in a wider area.

With all retrofitting, soil bearing capacity should be checked and approved for seismic toppling forces. Otherwise foundation may need other sort of retrofitting.

6-3-4-2-Annular walls

1-When a tank is anchored to annular walls, it should be designed for additional seismic forces, namely shear and moment due to anchorage.

2-Annular wall will be modeled as a continuous beam with supports on piles location.

3-Depending on location of annular wall and load direction, the moment could be positive or negative.

4-Load direction could be the tensile forces of bolts or compression stress from tank shell.

5-Eccentricity between bolts and piles could produce torsion in annular walls which should be considered in the design.

6-Piles should have connections to resists uplift due to uplift forces produced by seismic loads.

7-Piles added beneath the annular wall will take bigger portion of vertical loads comparing to center of tank which is sat on the soil.

8-If soil settlement continues, differential settlement between annular wall and tank center should be calculated.

9-For tanks with annular wall, the anchorage system will be connected to shell and shell will be anchored to annular wall. It may be necessary to improve annular wall against toppling forces.

10-One method of retrofitting is to extend the annular wall in radial direction and increase weight.

11-Usually it will become necessary to increase number of spiral piles and caissons.

6-3-4-3-Piles

1-In this section basic data will be given on spiral piles and will be compared with other types of piles but detailed design will not be covered. In order to resist against earthquake, tank should be able to transfer seismic forces to soil. Usually earthquake causes tank to uplift in a part of foundation and having piles in those area could produce sufficient strength against tension. Following piles can resist against tension forces:

- Driven piles
- Caissons (or drilled shaft foundations, deep piers)
- Spiral piles

2- Spiral plies are the best ones due to economical reasons. Spiral piles are big plates which twisted around the shaft in spiral manner. Usually they are put in their place with rotation. Equipments used for installing these pile are smaller comparing to other type of piles and usually they are put on trucks.

3- Resistance against pull out will be supplied by soil itself and in shallow soils damage in shear cone will occur from spiral plate upward. Less than 5 cycle of rotation of spiral plate is considered as shallow soil and more than that is deep soil. In deep soils damage surface is anchorage diameter. It is better to use deep anchoring system because has flexible damage mode. Anchorage diameter is between 8 to 14 inch. Spiral pile will be inside the foundation and therefore no pullout will take place. Figure 6-22 shows a sample of spiral pile. Its plate and concrete should be checked for following items:

- Support pressure of concrete beneath the plate
- Shear and bending stress in plate
- Pullout of support plate from concrete

4-When the spiral pile could be in tension or compression, all above three items should be checked in both directions.

5-When pile can not be anchored to rock, soil depth should be considered deep (five times diameter). When the spiral piles are fixed in their place, soil should not be highly compacted nor has big rocks.

6-Spacing considerations should be applied:

- Minimum spacing between piles is three times the diameter.
- Minimum spacing between adjacent structures is five times the diameter.

7- If it is impossible to impose above-mentioned limitations, other types of piles should be used.

8- Spiral piles' cost is less than caisson, but soil condition could be the main factor for economical selection.

9-It is necessary to investigate the under tank soil condition to ensure the safety of anchors.

10- Spiral pile age should be considered with estimated corrosion rate. It is possible to use cathodic protection system to extend the spiral anchor's age or select big enough anchors to pass the allowed corrosion limit.

11-If the soil is shallow or has low strength it might not resists pullout. In these cases it is economical to use piles or caisson and combination of seismic anchorage and floor replacement should be applied. In this method, tank's own weight will be used for anchoring and it could be applied for all types of foundation when soil loads are less than allowed loads. It might not be the best economical choice.

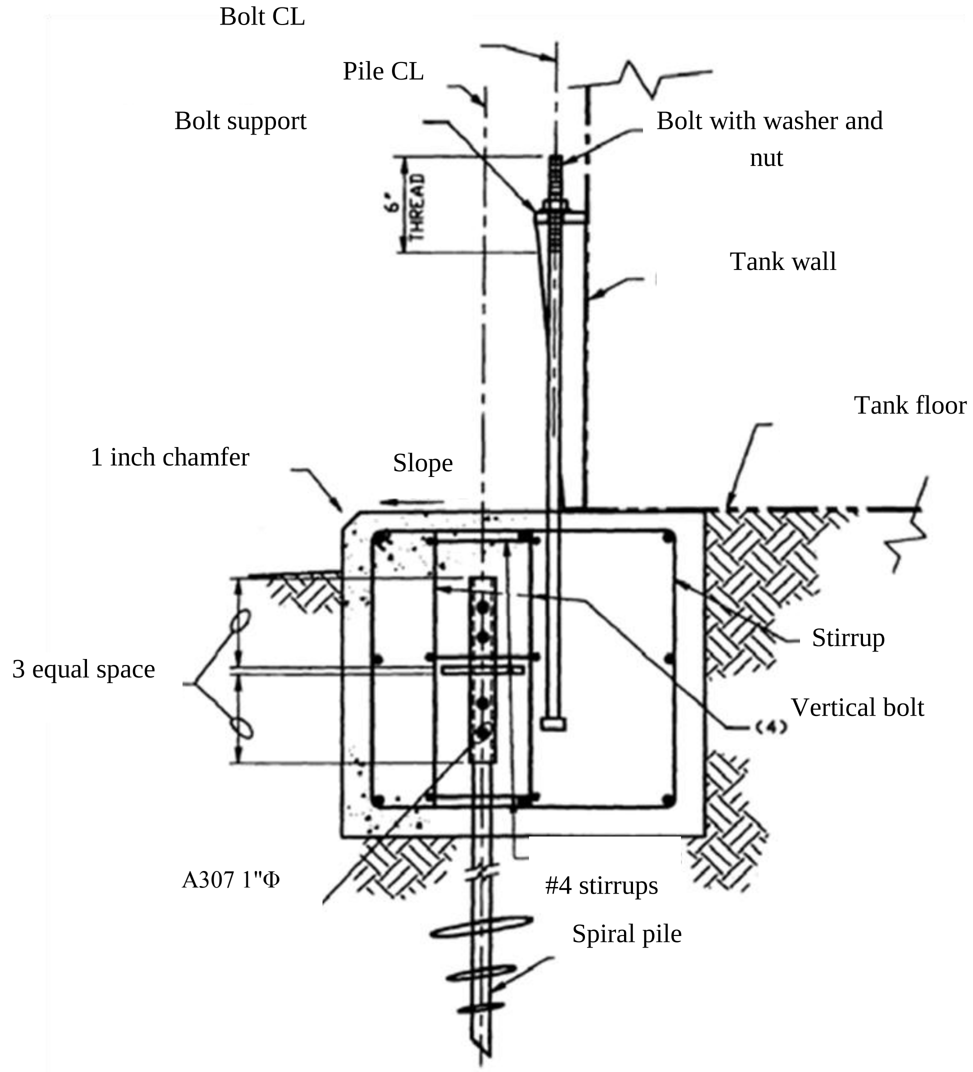


Figure 6-22 Spiral piles used with annular wall foundation

6-3-4-4-Drainage of rain water beneath the foundation

After retrofitting of foundation, annular wall, slab, annular plate & floor plate the upper part of rain water drainage should be protected with proper seal. Figure 6-24 shows the protection of rain water drainage using seals.

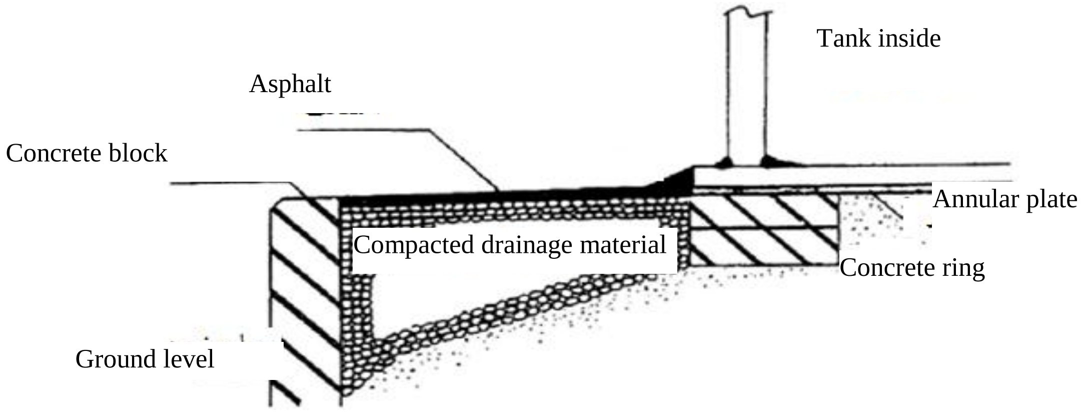


Figure 6-24 Protection of rain water drainage using seals

6-3-4-5-Anchoring bolts

If anchoring bolts have weak connections, then floor plate or tank shell might be torn.

Weak connections (figure 6-25) are those seats which are considerably short and can not transfer bolt force to tank shell or those connections where tank shell tears before bolt yields.

By replacing these connections with flexible ones, the dangers could decrease.

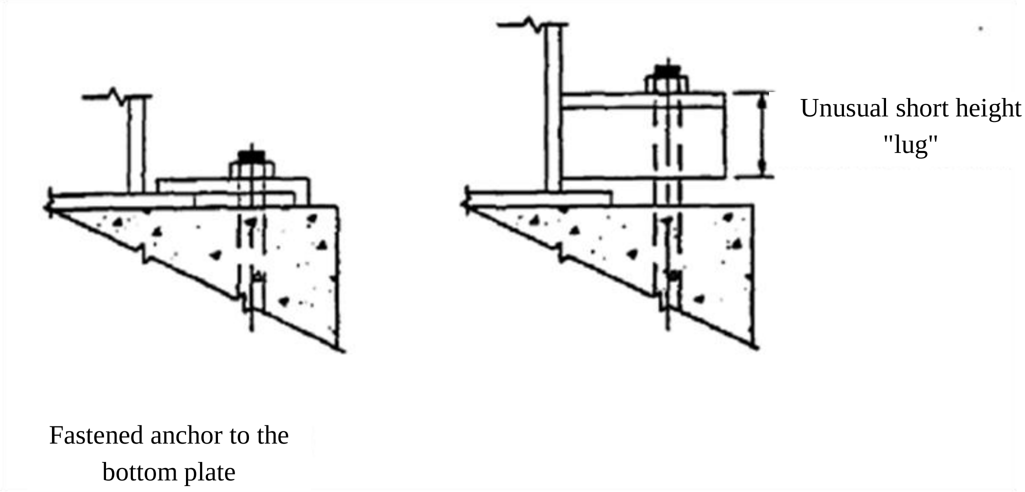


Figure 6-25 Weak connection details

1-In anchored tanks, it is important that anchor bolts face ductile damage before anchor seat, tank shell or other installments.

2-In order to develop ductility, steel component capacity should be less than concrete.

3-Detailed consideration for anchor edges is necessary so that concrete does not fail before calculated value.

4-Routine anchors used are as follows:

- a) Cast-in-place anchors
- b) Capsule anchors
- c) A-307 in-situ injected bolts
- d) Bolts which are located inside the foundation
- e) In situ anchors: This type is the best type because concrete will be poured around the anchor and makes the best connection. Its limitation is that it can be used only when there is new concreting.
- f) Capsule anchors: In this type of anchor, cohesive epoxies are used for better cohesion between bolt and concrete. This type needs less buried length and it could be located near the tank. For ductile design, it is necessary that epoxy strength should be more than bolt strength. Maker's recommendation should be considered as well. According to an estimated calculation, twice the minimum depth is necessary for ductile anchoring system. For foundation of hot tanks, epoxy's strength should be controlled. It will be assumed that anchor's and tank's temperature are equal. Otherwise detailed temperature analysis will be necessary to determine the worst case for fixed temperature of anchor in the deepest buried point.

g) A-307 injected bolts: When the above-mentioned conditions regarding spacing and distance from edge are not possible, this type of bolts will be used. The advantage of these bolts are as follows:

- Short distance from edge is required.
- Bolts could be placed in minimum depth of concrete.

Disadvantages are as follows:

- Bigger eccentricity will occur as they need bigger holes.
- They need bigger safety factor because of bigger ductility of concrete cone

h) Steel bolts: For those slabs and foundations which are not thick, those anchors could be used where they can penetrate in foundation. Stainless steel bolt is recommended when there is the possibility of corrosion to carbon steel bolts.

6-4-Attached equipments

One ordinary failure mode in tanks is the break of pipeline attached to tank due to relative movement between tank and nearest pipe support. If piping is stronger than tank wall or support plate which is connected to, then wall or support plate will break. Piping should never go directly or with less or no flexibility through shell, floor, concrete walls, pool and pumps which are connected rigidly to ground. Different types of damages explained above, are shown in figures 6-26(a) to 6-26(d) in detail.

In the first three cases pipeline flexibility should be provided using additional vertical and horizontal bends or attaching a flexible pipeline.

In four cases, piping should connect to tank center or if piping is flexible enough, concrete pool could be extended up to connection of pipe to tank.

1- As it is shown in figure 6-26 (E) damages are due to relative movement of two tanks connected by a rigid pipe. Piping flexibility as explained above should be applied.

2- Where the vertical pipe is connected rigidly to ground or foundation, and also it is fixed rigidly to wall of tank, minor damages as shown in figure 6-26 (F) may occur.

3- The case which has less risk but occurs frequently. is the support of wall tank and it has a big U-shaped bolt and has the freedom to move the pipe with tank upward and downward. It is possible that U-shaped bolt fixes to pipe and produce a rigid connection and cause the tear off of tank wall.

4- All rigid connections along the tank shell should be replaced with a connection close to intersection of shell and roof or connected to sliding connections or guides along the shell wall. In most cases it is sufficient to loose the nuts of U-shaped bolt.

5- Access to roof is possible through walkways located between tanks spans. A sample for walkways plans is shown in figure 70(G).

6- In both cases, relative movement between tanks may cause break or tear off of wall or roof. In lower walkways shown in figure 6-26(G) there might be minor damage to tank content. In upper walkways in the worst case it might damage the walkway itself or roof and therefore there will be no damage to tank content. The difference between two walkways is important because the lower walkway could cause the release of tank content but damage of upper walkway only releases the vapors and produces less economical damages. In both cases it is necessary to increase the flexibility of walkways.

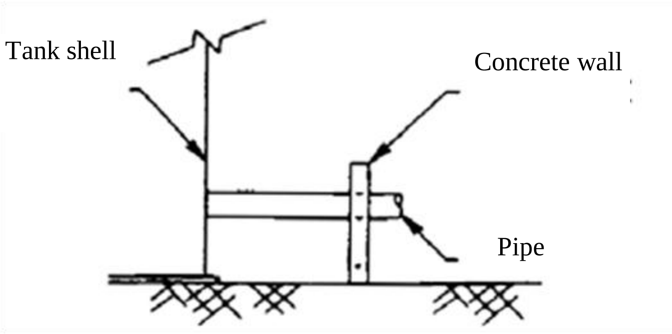
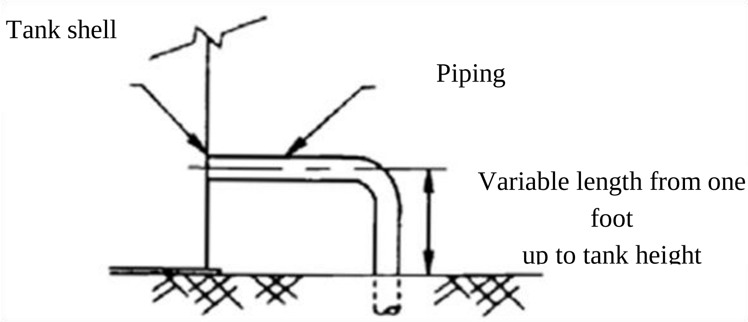
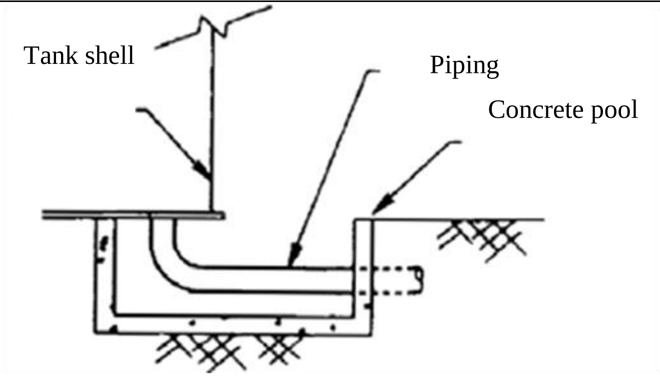
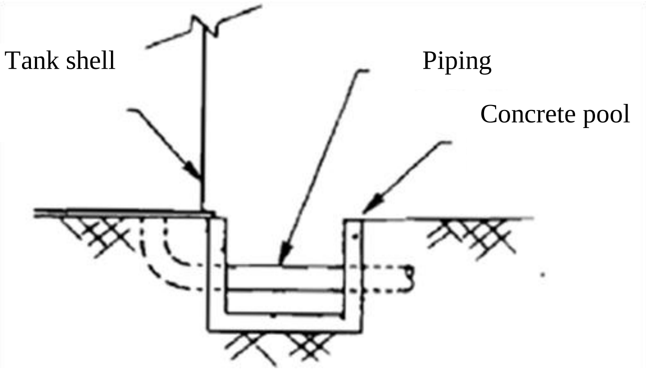
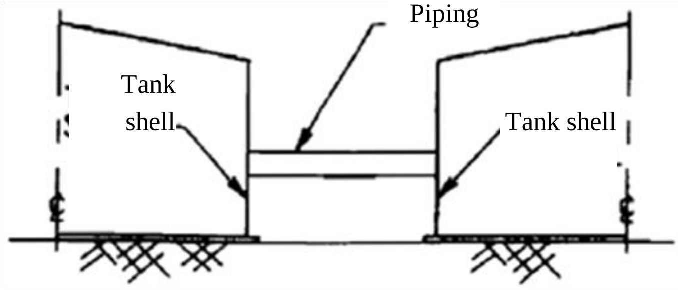
Also for tall tanks located in a crowded site and with high precision instruments, there is the risk of overturning. Walkways should be fixed by a secondary element like cable to tank in order to prevent its fall.

1-Stairs should not be connected both to foundation and tank shell (refer to figure 6-26(H)). Although in tanks with thin shells, these details may cause tank wall damages and damage to tank content. Therefore this case should be studied separately from tanks with thick shell because in the latter one, these details only cause damage to stairs itself. In both cases, it is possible to decrease the risk by connecting the stairs to tank shell or use other connections to decrease the vertical displacement of stairs.

2-As it is shown in figure 6-26 (I), tank piping is concentrated in one area and in-between walkways are supplied to access pipelines.

3-If walkway is fixed to ground rigidly and there is no enough space between piping and walkway, tank uplift might cause collision between piping and walkway and damage one of them.

4-In piping with small diameter or tanks with thin shell, tank content might damage as well. Otherwise damages will be limited to walkway itself. In both cases, by increasing pipeline flexibility, it is possible to decrease the damage risk. As it is mentioned in item (5) for stairs, another detail which has high seismic vulnerability is the case where walkway is attached to tank and foundation.

Retrofitting method	Weak details	
Adding flexible pipe		**A**
Adding flexible pipe		**B**
Adding flexible pipe		**C**
Connection of piping to tank center or extension of concrete pool wall up to pipe- tank connection		**D**
Increase flexibility or use of horizontal and vertical bends		**E**

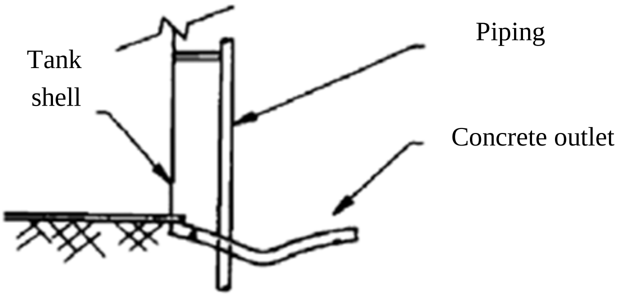
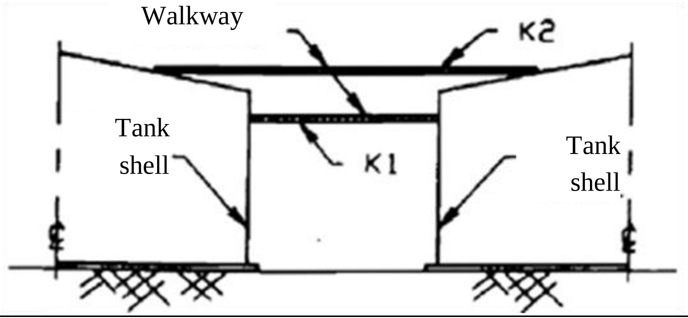
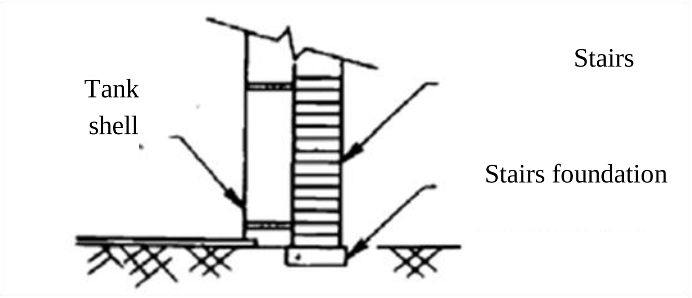
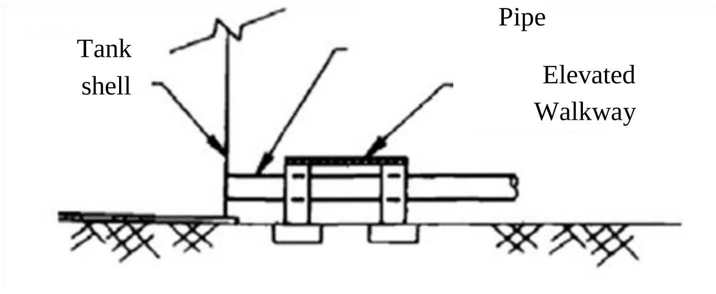
Fixing pipe in roof instead of fixing along the shell wall		**F**
Increase walkway flexibility as a counter measure for relative displacement		**G**
Fixing stairs only to tank shell		**H**
Increase piping flexibility, fixing walkway only to tank shell or more space for piping		**I**

Figure 6-26 Weak details of unanchored tanks and recommended retrofitting methods

For site inspection, experienced engineers familiar with seismic design and earthquake effects should be used so that he can reply to question: "How much flexibility is necessary?" Assumed tank uplift is critical to answer this question. In the past cases with 150 to 200 mm has occurred. Using 150 to 300 mm for vertical and 100 to 200 mm for horizontal displacement (at least for regions located in the highest seismic level) will be conservative. Real values depend on parameters like tank dimension, filled height, width to length ratio, seismic characteristics of area and soil type.

6-5-Special repair methods

When deep holes are not close to each other or they are not spread therefore they don't affect tank strength, they could be repaired or filled with different methods. According to tank content, they could be filled with epoxies cohesive to steel. For temporary repairs any natural-based mortars which will be hardened after drying could be used. These mortars in addition to making hard connection with steel plate should also resist against tank content. In all cases holes should be cleaned before filling.

Epoxy and other heat-based resins could be a good protection against corrosion of shell, floor, roof and floating bridge of tanks. Their combination with glass wool could be used for repair of floor, roof, floating bridge and also effective low stress elements. For more information on repair of covers, refer to API RP 652.

1-Leakage from ceil could be repaired with soft coverage connection without cut, weld, rivet or steel bolt. Soft connection could be plastic, neoprene, glass coverage, asphalt and mortar or epoxy sealing materials and the best selection depends on tank content and operation condition. The use of cover connection method is similar to its use on building ceil. If the safety points are obeyed, then this connection method could be used during operation period of tank as well. Figure 6-27 and 6-28 shows cover connection and complete cover method consequently.

2-If repair is done on a big area, there is the possibility of personnel fall down from roof and other personnel safety issues. In those tanks where repair is going on simultaneously with tank operation, materials may fall into tank and enter piping or pump and cause shut down, sealing damage, fire or other problems.

3-These types of repairs are done more than permanent repairs.

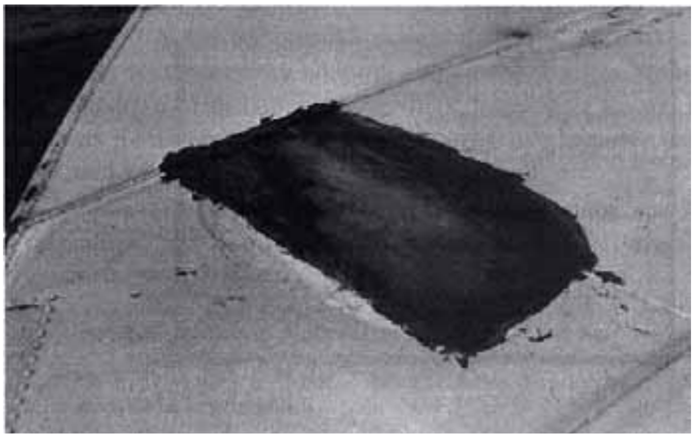


Figure 6-27 Temporary soft cover connection for sealing tank roof

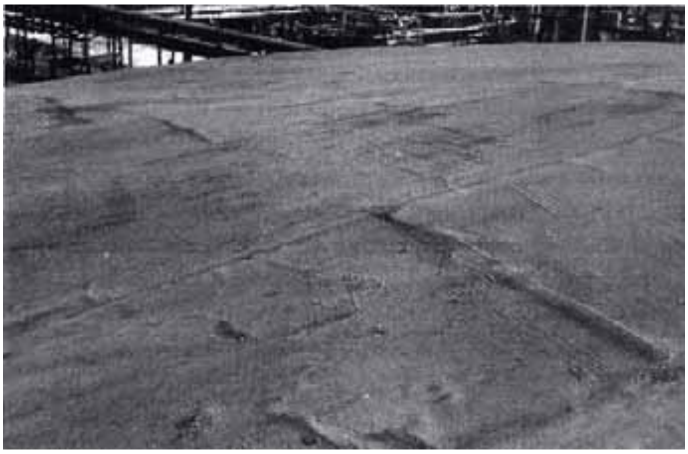


Figure 6-28 bitumen roof coverage

6-6-Retrofitting method from cost, applicability and safety point of view

In retrofitting works, cost, applicability and safety should be considered as well.

- Safety
  1-Retrofitting plan should be assessed from safety point of view

  2-Assessment includes inspection, transfer of liquid inside tank, separation of main materials, welding, cutting, built and secondary installation of plates and equipments.

  3-Before retrofitting starts, in order to prevent fire, all dangerous materials should be removed from tank.

  4-During retrofitting works, all firefighting equipments should be at site.

  5-During retrofitting works, structural instability is very important and it should be included in retrofitting planning phase.

  6-Stability of crane should be checked.
- Applicability
  1-Applicability of methods mentioned in this report for each case of tanks retrofitting works should be reviewed by an organization which has inspecting personnel and experienced engineers in tank design, erection, repair and inspection.

  2-To assess applicability of retrofitting plan, inspection time, retrofitting time, costs, retrofitting equipment's availability, erection and technical & safety personnel should be considered.
- Cost
  1-Seismic retrofitting initial cost including design, inspection and execution usually will be paid by owner.

  2-Extra costs are related to seismic risk reduction plans which are paid for develop and conduct plans like studies for investigation of high risk tanks, social-economic and environmental reports, educational and tank design control and inspection plans.

  3-Seismic retrofitting includes local requirements like omission of dangerous materials.

  4-Costs for strengthening of seismic performance of non structural elements also should be considered.

  5-Costs for temporary shutdown of tanks during retrofitting works also should be considered.

  6-If seismic retrofitting is the main goal, cost of other works that are not related to seismic retrofitting should be considered directly. On the other hand, if seismic retrofitting works are the main goal and it needs non seismic works as well, then these works should not be considered as seismic retrofitting.

7-If seismic retrofitting budget decreases, then the political and social costs might not be considered. Unfortunately in seismic retrofitting, there is a need for omission of vulnerable parts of structure of tank in most of the time.

8-Internal inspection costs: These costs are very important and could reach as much as millions of dollars for a petroleum company. Most of these costs are related to tank preparation for internal inspection and stop of operation. In this report and API Std 653 some methods have been introduced to lengthen the internal inspection period from few years to 20 years.

9-Costs according to findings of inspection: During assessment of operation there is a chance to conserve costs. For example a tank which has many deficiencies according to standards, could assessed to be updated without considering costs. Results of this assessment will tell us what works are necessary to be done to update tank and enhance its operation. Cost difference of these two methods could be considerable.

10-Cost of keeping information: Establish and keep a data collection system. One of the data collection system's goals is to reduce total cost of owner or operator through standardization and development.

6-7-Miscellaneous activities

Roof, shell and floor plates could be cut to small pieces and transferred to a new site for reconstruction.

6-7-1-Floors

1- Those floor plates which will be used again, should be cut at least in 2inch distance from previous welds except for sections where cuts will cross the weld strips.

2- If floor is useable, then one of the following methods is acceptable:

- a) Floor plate could be separated from shell along the A-A and B-B line as shown in figure 6-29, and floor plate & grinded welds are connected directly to shell.
- b) If all plates of floor are used again, then floor will be cut along the C-C line and separated from shell.
- c) If tank has annular ring with butt weld, this ring could remain connected to shell or cut along the B-B line or otherwise annular ring weld will be separated from shell.

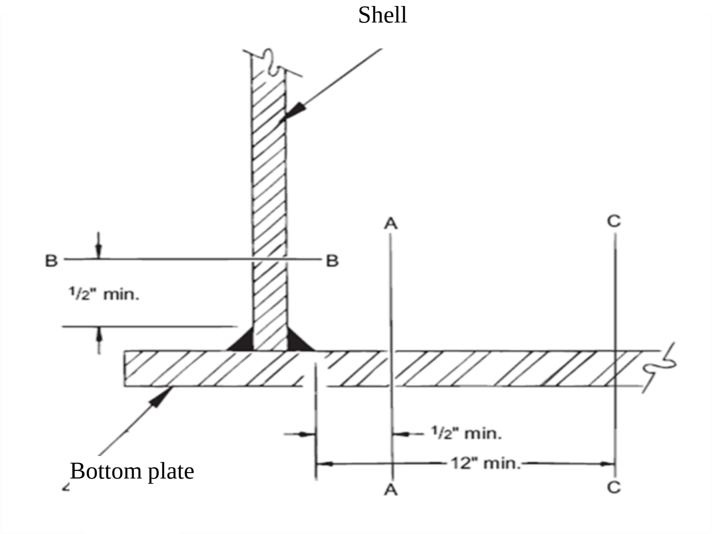


Figure 6-29 Cut line of floor and shell

6-7-2-Shells

1-Tank shell plates could be separated with one of the following methods:

a) All shell rings could be separated by cutting weld strip and heat affected zone (HAZ) of weld. Minimum HAZ value is the smallest value of 0.5 times the width of weld iron or one forth of inch in both side of weld.

b) If the thickness of shell ring is 1/2 inch or less, then it could be separated by weld cut without HAZ.

c) Shell rings could be separated with horizontal and/or vertical cuts in at least 6 inch distance from existing welds except for areas where cut lines cross existing weld.

2- Stiffening rings of shell including bracings could remain connected to shell plates or could be separated by cutting the connecting welds.

3- As it is seen from figure 6-29, floor plate connection to shell should be cut along B-B line. Floor weld to shell should not be used again except if whole floor is intact and will be used again.

6-7-3-Roofs

1- Roof plates should be cut using welding or cut along remaining welds in at least 5 mm distance from existing cut welds except for areas where cut lines cross welds.

2- Roof supporting structure should be separated by removing bolts or removing welds.

Chapter 7

Retrofitting of on ground pipelines

7-1-Target components

Main pipelines or transmission pipelines include pipes, valves and connections between pump room outlet main block valve and terminal input main line block valve.

On ground pipelines are divided into two categories depending on installation conditions.

1-On ground pipelines: On ground pipelines and its supports should be studied for corrosion, mechanical integrity, stability and aging of support's concrete.

2-On ground transmission pipelines: On ground pipelines should be studied for corrosion, mechanical integrity, ground stability. Inspection and periodic maintenance is necessary along the pipeline to prevent human losses.

3-Pipe bridges: Pipe-bridge will be used when it is impossible to pass underground and it will be used in junctions with natural barriers or roads. Pipe bridges should be designed according to structural standards with sufficient free gap to avoid probable damages due to traffic and access for repair and maintenance.

Interfere between catholic protection of pipeline and bridge structure should be considered.

7-2-Damage modes due to earthquake

Seismic risk which will effect on ground pipelines and bridges are as follows:

a) Fault movement

Pipeline which crosses fault will deform due to permanent ground displacement (PGD) and produces different damage modes like buckling due to compression force, tearing due to tension and shear failure.

b) Liquefaction risk

Liquefaction in sandy soils with high underground water level, especially in modified areas will cause large-scale ground displacement.

Lateral spread or settlement will cause severe damages to on ground structures.

c) Landslide

Landslides usually occur in steep slopes. In this case, if monitoring equipments are installed along the pipeline, they will be damaged.

Figure 7-1 Cracks and buckling in bent pipe

d) Pipe bridges

When the pier moves or rotates due to earthquake, it will damage not only the super structure but also the attached pipeline. Pier damage is due to large- scale ground displacement like liquefaction, fault movement and landslide. Following figure shows damage to bridge pier due to liquefaction. Pipeline has suffered considerable damages as well.

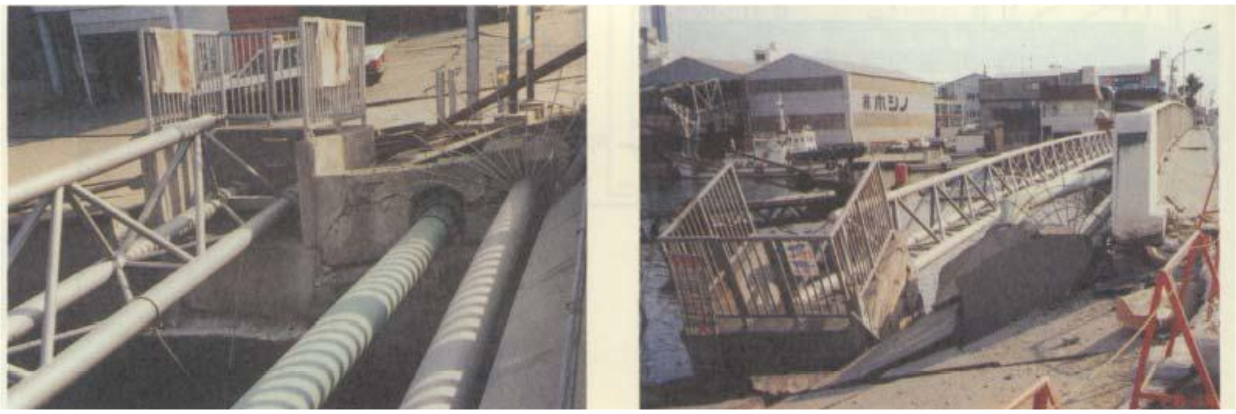


Figure 7-2 Damage to pipeline due to failure of bridge in spread liquefaction

According to above items, damage modes to pipeline are as follows:

1-Severe damage mode

Severe damage mode for a pipeline system is defined as a pipe in plastic state or ultimate limit with large movement or displacement and threats integrity of the pipeline.

2-Medium damage mode

Medium damage mode for a pipeline system is defined as a pipe in plastic state with considerable displacement and threats integrity of the pipeline but still operable.

3- Minor damage mode

Minor damage mode for a pipeline system is defined as a local damage with limited displacement and no threats to integrity of the pipeline.

Damage modes for each structural element are given in table 7-1. Damage mode for performance of each related element is also given in table 7-2.

Table 7-1 Damage modes from structural damage point of view

Structure	**Elements**	**Structural damage modes**		
		Minor	**Medium**	**Severe**
Structure	On ground pipeline	Minor damage	Case damage	Tear
	Pipe bridge	Small movement	Relative displacement	Collapse
	Pipe on bridge	Small movement	Large- scale displacement	Break
	Pier	Ignorable crack	Minor damages	Downfall
	Valve	Small movement	Considerable movement	Break
	Monitoring tools	Small movement	Considerable movement	Break
	Protection equipments against	Small	Considerable movement	Break

	corrosion	movement		
	Pipe connected to structural facilities	Small movement	Considerable movement	Break
	Transmission pipeline	Small damage	Damages in specific length	Tear
Pipeline system	Control center	Small damage	Considerable damage	Downfall
	Terminal facilities	Small damage	Considerable damage	Downfall

Table 7-2 Damage modes from performance point of view

Structure	**Elements**	**Structural damage modes**		
		Minor	**Medium**	**Severe**
Structure	On ground pipeline	Small settlement	Bearable settlement	Large- scale settlement
	Pipe bridge	Low hydraulic turbulence in transfer	Considerable hydraulic turbulence in transfer	Stop working
	Pipe on bridge	Small settlement	Bearable settlement	Large- scale settlement
	Pier	Low hydraulic turbulence in transfer	Considerable hydraulic turbulence in transfer	Stop working
	Valve	Almost intact	Usable but it should be controlled later	Defected & unusable
	Monitoring tools	Almost intact	Usable but it should be controlled later	Defected & unusable
	Protection equipments against corrosion	Almost intact	Usable but it should be controlled later	Defected & unusable
	Pipe connected to structural facilities	Small settlement	Bearable settlement	Large- scale settlement
	Transmission pipeline	Possible to operate with caution	Transmission with low pressure	Stop working
Pipeline system	Control center	Possible to operate with caution	Defect in part of system	Defected and unusable
	Terminal facilities	Possible to operate with caution	Defect in part of system	Defected and unusable

Those seismic levels which will be used like effects of seismic wave and ground permanent displacements should be categorized for risk assessment of pipeline system in damage modes as shown in table 7-3

Table 7-3 Seismic levels which are used for each damage mode

Earthquake		**Damage modes**		
		Minor	**Medium**	**Severe**
Wave effects	Risk level 1	o	**x**	x
Permanent ground displacements	Risk level 2	x	**o**	o
	Fault movement	x	**o**	o
	Lateral spread due to liquefaction	x	**o**	o
	Settlement due to liquefaction	x	**o**	o
	Landslide	x	**o**	o

7-3-Seismic assessment procedure

Seismic retrofitting and assessment steps for pipeline system are explained below and related flowcharts are shown in figures 7-3 and 7-4.

Step 1: Initial assessment

Step 2: Detailed assessment

Step 3: Presenting seismic retrofitting plan

Step 4: Check the adequacy of seismic retrofitting

Figure 7-3 shows few criteria for seismic retrofitting based on results of assessed inspection and figure 7-4 shows the inspection procedure and discussion about the necessity of first and second assessment and seismic assessment respectively.

1- Initial assessment

General and fast study of seismic performance of pipeline system should be done by walking along the line. This inspection is done to show the need for detailed assessment. Group or individual inspections should be prior to control inspection activities according to importance of existing pipeline system.

2-Detailed assessment

Target pipeline and its seismic performance should be selected and approved by client in the first step of detailed seismic assessment.

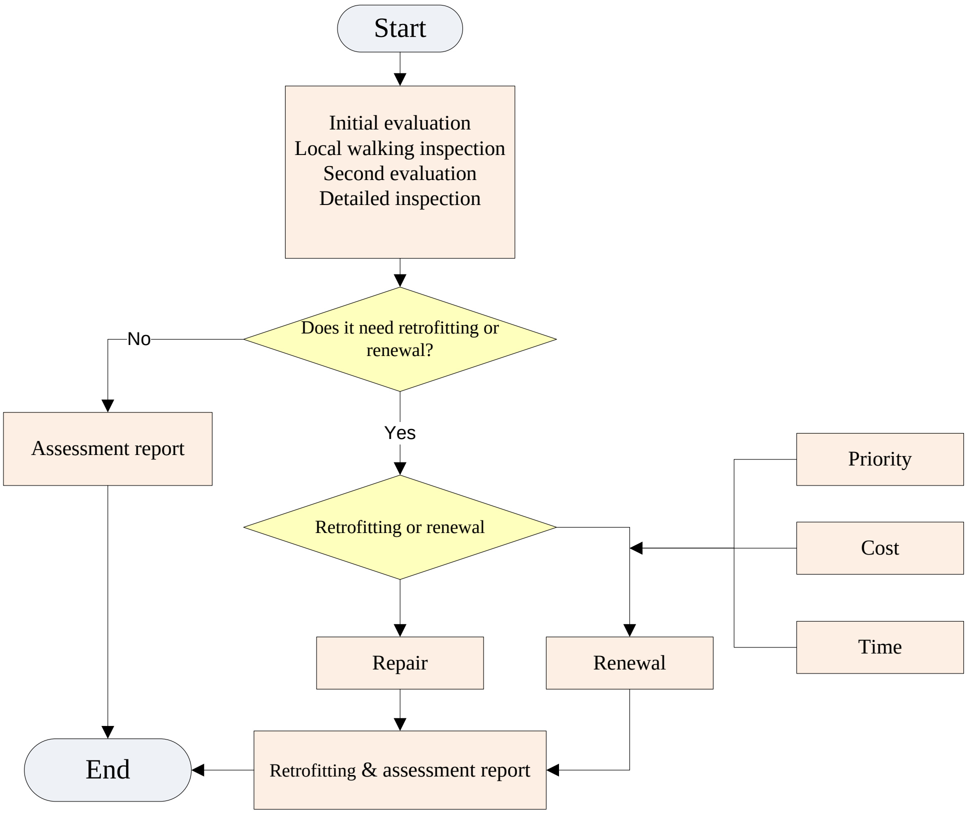


Figure 7-3 Seismic assessment flowchart for on ground pipeline and pipe bridge

3- Presenting seismic retrofitting plan

Based on detailed assessment report, proper seismic retrofitting measures for structural elements will be chosen in sequential order. If renewal measures are chosen, precise study on priority, time and cost should be done.

4- Control the adequacy of seismic retrofitting plan

Adequate control should be done on the adequacy of selected seismic retrofitting plan before execution.

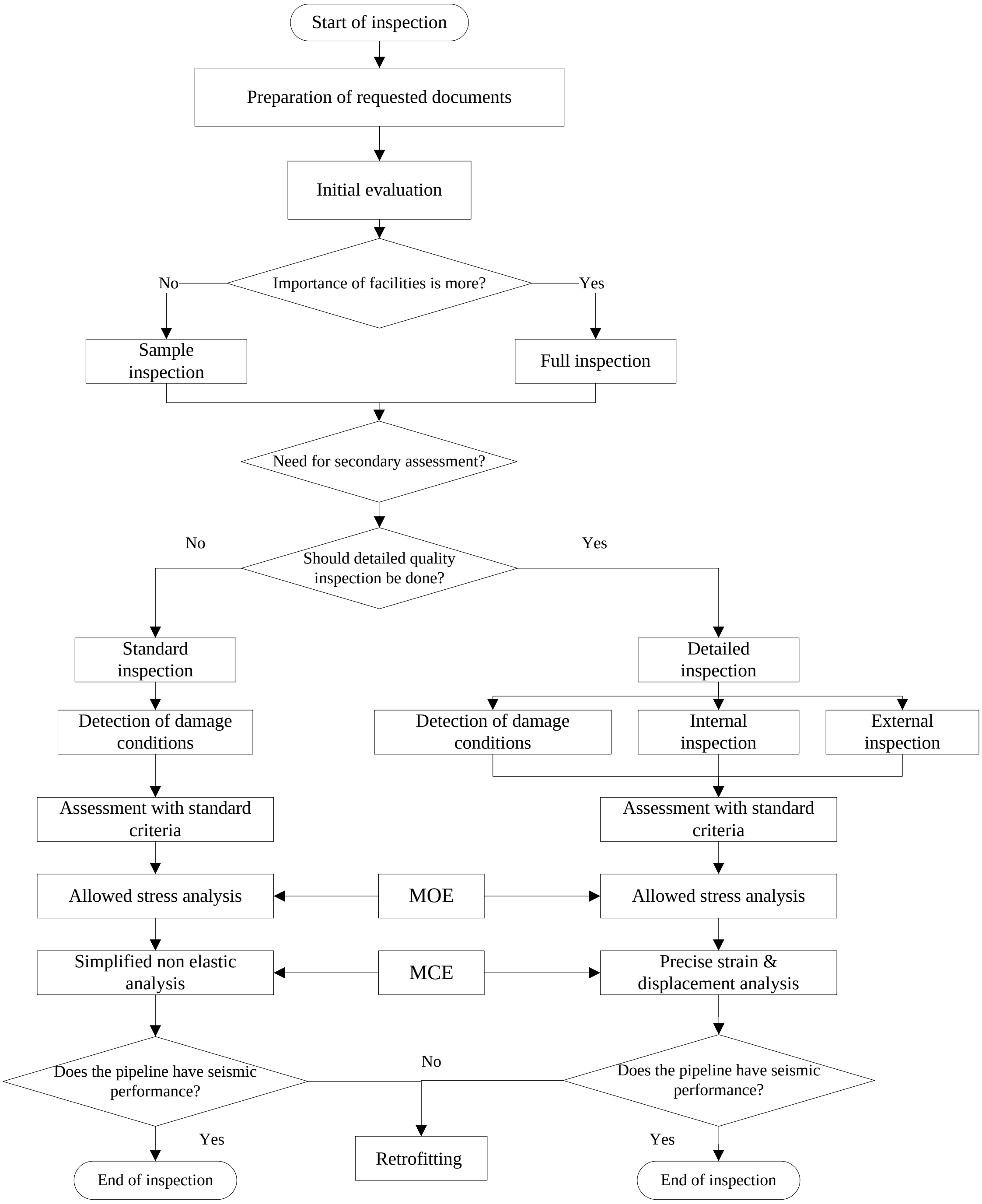


Figure 7-4 Seismic inspection flowchart for on ground pipeline and pipe bridge

7-4-Retrofitting

7-4-1-Prioritizing of retrofitting

Prioritizing retrofitting measures is based on following items:

1- To minimize live loss due to earthquake
2- Selection of pipeline in an area with the highest seismic risk
3- To minimize the social damages

4- Selection of the most important pipeline from risk and financial point of view

7-4-2-List of possible methods

Three methods are recommended for retrofitting as follows:

1- Retrofitting based on the result of inspection: Although the local inspection results are not adequate, but it is possible to use them to solve many defects in pipeline and related facilities. There are many ways for this method in pipeline system and some of them are shown in figure 7-4.

2- Retrofitting based on detailed assessment: It is possible to obtain more precise and reliable results in detailed assessment. In this step, based on reports, if leakage risk or damage and structural aging are diagnosed, the damaged part should be repaired or replaced rapidly.

3- Retrofitting based on repair and maintenance methods for pipeline system: These methods include following items:
   a) On ground pipeline and pipeline bridge
   b) Shut off valve
   c) Control valve

In table 7-5 examples of these retrofitting methods are given. Some of these methods are shown in figures 7-5 to 7-7 as sample.

Table 7-4 Protection methods against leakage for different damage modes

Retrofitting methods for protection against leakage		**Crack & break**		**corrosion**	**Loosening of connection**	
		Pipe	**Weld Connection**		**Mechanical connection of flexible cast iron**	**Flange connection**
Replace		○	○	○	○	○
Piping insert		○	○	○	○	○
Repair of connection	Steel plate coverage		○			
	Replace washer				○	○
	External coverage				○	○
Internal coverage		○	○		○	○
Catholic protection				○		

Note ○: is applicable

Table 7-5 Retrofitting method for pipeline system

Location	Defect	Retrofitting measures
On ground pipe	**Leakage**	**Repair or replace depending on conditions**
	Damage or aging of cover and anti corrosion materials	Repair
Expansion connection	Leakage & aging	Replace or installing additional expansion connection
Pipe's support structure	Non fixed or loose anchoring rods	Repair
	Instability of fixed pipes	Repair or replace
Support equipment	Crack, damage in equipment	Repair or replace
Pipe inside wall	Isolation performance	Repair
Pipe under wall	Settlement	Control of pipeline settlement, after that if it becomes necessary, reduce stress and replace pipe

Figure 7-5 U-shaped bolt

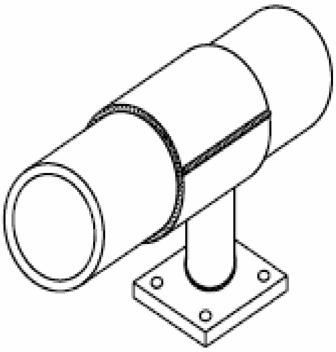


Figure 7-6 Anchoring steel pipe

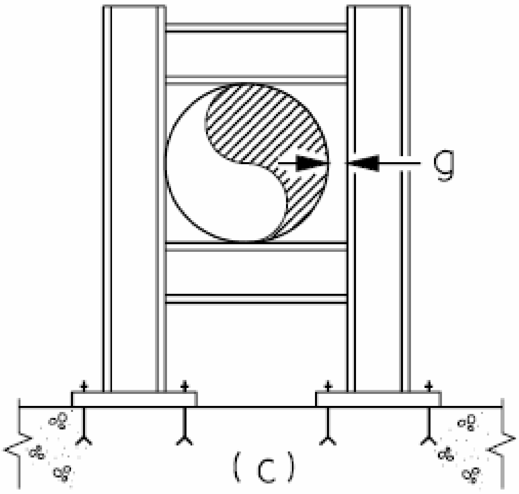


Figure 7-7 Solid frame as a seismic lateral support

Table 7-6 Retrofitting method for shut off valve

Location	**defect**	**Retrofitting measures**
shut off valve	leakage	1. Tighten of flange screw to stop the leakage 2. Repairing or replacement of valve body if it leaks
handle	Capacity of operating	1. oiling of handle 2. if necessary, separating and installing or replacing
Inside the hole	Waterproof performance	1. cleaning 2. if necessary, repair for waterproofing
Hole cover	Manhole cover closing performance	cleaning of connection part 2. if necessary, replacement after temporary repairing
Space between hole cover and road surface	Settlement	Alignment of manhole surface to road level

Table 7-7 Retrofitting method for control valve

Location	**Reasons**	**Retrofitting measures**
Pressure increase in pier	(1) weakness in valve body	Repair of damaged parts or adjusting installing conditions for main valve
	(2) Inadequate closure of lateral line	Complete closure of lateral line
	(3) improper performance of pipeline	Replace damaged parts
Pressure decrease in pier	(1) improper performance of control equipments	Replace damaged parts
	(2) improper performance of secondary pipeline	Cleaning secondary pipeline
	(3) pressure drop	Replace equipments, cleaning dust
	(4) closure by shut off valve	Opening shut off valve and inspect the reason for improper performance
Secondary effects due to big variation of pressure	(1) improper performance of control equipments	Replace damaged parts
	(2) Rapid change in pressure	Replace main valve with rapid response capability valve
	(3) Unbalance in flow pressure	Repair or replace of damaged parts
	(4) Short flow	Replace new valve with proper performance
Leakage	(1) Inadequate cover for connection part	Fastening or replace of bolts
	(2) improper performance of damage alarm system	Control installation conditions or replace it

7-4-3-Determine retrofitting method from safety, applicability and cost point of view

In pipelines, damage due to leakage in large scales should be avoided. It is not only natural hazards which cause considerable damages to pipeline and finally lead to leakage, but also human activities may cause this problem. The most usual reasons for damages include human threats, corrosion and aging effects, inadequate care of connecting bolts and finally damages due to earthquake. In table, 7-8 retrofitting methods for leakage due to different reasons are compared. Each method is studied from safety, applicability and cost point of view.

Table 7-8 comparison of retrofitting methods

Target	Necessary performance Conditions	Safety	Priority	Possibility	Cost
Protection against leakage due to crack and corrosion	(1) safety against leakage under crack and break (2) adequate strength to protect against break during long term operation	Structural analysis to obtain strength despite of observed defects	Priority is with big leakages in important pipelines	Replace if damage is considerable, otherwise repair	Medium
Protection against leakage due to corrosion	(1) safety against leakage from pipe & connections (2) Adequate strength to sustain geometry of the pipe	Repair should be done based on remaining age, corrosion speed and remaining thickness of pipe	Request for repair of corrosion protection system	Replace for mechanical damage and if soil conditions are changed, detailed inspection is necessary	Medium
Protection against leakage due to loose connection	(1) safety against leakage from connection	Control fastening conditions	Every damaged equipment should be repaired rapidly	Easy repair	Low
Protection against leakage due to seismic damages	(1) repair to satisfy seismic design guideline's requirement for ground deformations (2) Safety against leakage under crack & break (3) Adequate strength to protect against break under internal pressure during long operation	Damaged pipeline performance should be assessed for ground response and PGD	The most important pipe should be chosen for seismic retrofitting	Emergency shut off and rapid retrieval for large scale leakage from big-diameter pipe is necessary	High

7-4-4-Other measures

Supervision requirements for pressure, temperature, flow rate, physical specification of transferred liquid, data of pumps, compressors, separation units, contours and tank levels, danger alarming conditions like power source shut off, high temperature of electrical motors' coils and bearings of rotating devises, high level of vibration, low pressure of vacuum, request for high pressures, leakage from gaps, unusual temperatures and tracing fire and dangerous air should be determined and used in the design of system according to article 5 of pipeline system design ISO13623.

Data collection and supervision systems (SCADA) should be used for control of equipments.

Operation requirements from pipeline system like safety and environmental requirements should be used as a base to determine the needs of supervising and communication body.

1- Earthquake risk

Different types of remote controlled sensors could be used for lifelines especially to supervise seismic activities.

2- Review of leakage from pipelines

During operation, all parts of pipe should be checked routinely to be sure they don't leak. Personnel at site, people near the system and operational officers, find many leakages. Operational officers should pay especial attention to leakage reports and visual inspections. In addition, methods other than visual check should be considered as well.

In different steps of leakage detection, possibility and leakage results should be taken into account. Some of factors which operator should consider for type and period of inspections as low risk items are as follows:

2-1-Functionality: clean liquid, non corrosion and with low vapor pressure

2-2-Location: far from population, in an operator controlled place, far from non repairable places, far from rivers with commercial and leisure usage.

2-3-Construction: with materials with acceptable functionality below limit state

2-4-Operation type: operation in low stress level

2-5-Leakage history: shows the years with no leakage

Response time in a leakage or an emergency accident is another important factor which should be taken into account. Also inspection precision and avoiding faulty recognitions are among factors which could tolerate the reliability of selected inspection method.

Operators should choose the leakage method very carefully. Scheduled and routine inspections either aerial, land or marine ones, trapped pressure analysis, monitoring flow and pressure variation with reference to stable regime, volumetric balance or any other method which could detect leakage in time are among methods which could be used in systematic inspection. Inspection periods vary from continuous inspection by computers into daily and weekly visual inspections. If computerized supervision is going to be used, then the API RP 1130 standard should be used.

Whatever method is chosen, operational officers should inspect and analyze leakage behavior periodically and give necessary adjustments to decrease the leakage in the selected method.

3- Setup of redundant system as a network system

3-1-Functional concerns in design phase

When there is no need for especial design, design decisions should be based on requested functions. Three important characteristics of a system which could enhance the emergency functionality considerably are redundancy, use of standard elements and accessibility to major elements.

Redundancy is one of the main elements of a system for recovery from limited damages. For a big distribution system, usually the severe damage centers are recognizable and service to rest of customers could be continued. But as products passes through one pipe, in case of transmission systems it could not be acted as distribution systems. In other words redundancy of these systems is less than redundancy of distribution systems. Although in both systems it is possible to use redundancy like a pump or compressor to avoid service shut down in an emergency situation. Redundant elements are installed for backup purposes and also use them after damage in main system for repair or replacement of damaged parts.

In addition to considering redundancy in design, it is important to consider the shut down of system after earthquake, flood or landslide.

3-2-Emergency response system

The most risk is pointed toward those systems which are not designed for earthquake. These systems should be studied for different types of seismic damages by creating similar case and emergency response system should be installed if they become necessary.

Chapter 8

Retrofitting of buried pipeline

8-1-Damage modes in earthquake

Different risks and damages are as follows:

1-Seismic risk including landslide, liquefaction and fault movement
2-Structural damages
3-Valve damage

1-Seismic risk including landslide, liquefaction and fault movement

Usually earthquake causes large scale and permanent ground displacements like landslide, liquefaction and fault movement. Examples of damages due to these displacements are shown in figures 8-1 and 8-2.

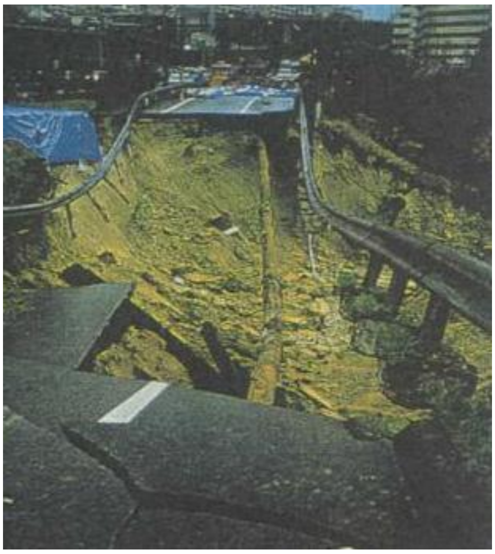


Figure 8-1 large scale ground movement due to landslide

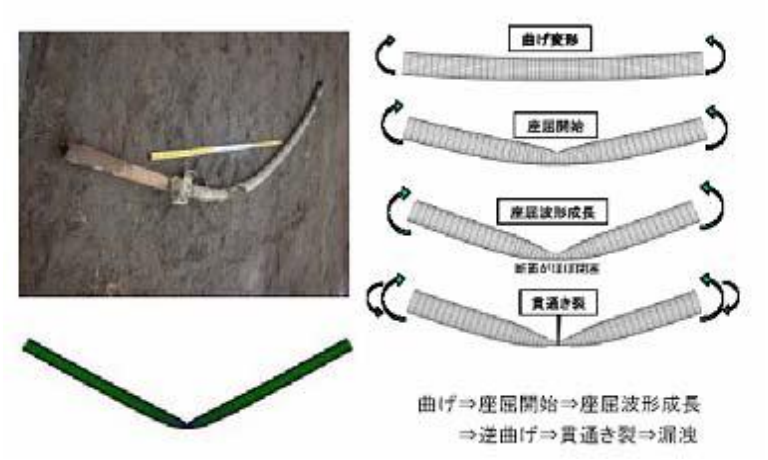


Figure 8-2 deformed pipe in landslide

2-Structural damages

Maximum considered earthquake (MCE) could produce huge tension strains in buried pipeline due to ground movement. If there is damage potential in weld connection, these strains could produce crack or damage in the connection.

3- Damage to valves

Buried valves usually are connected with sliding connections to pipe (figure 8-3). Because of loosening bolts in this connection, it will be vulnerable against ground movement.

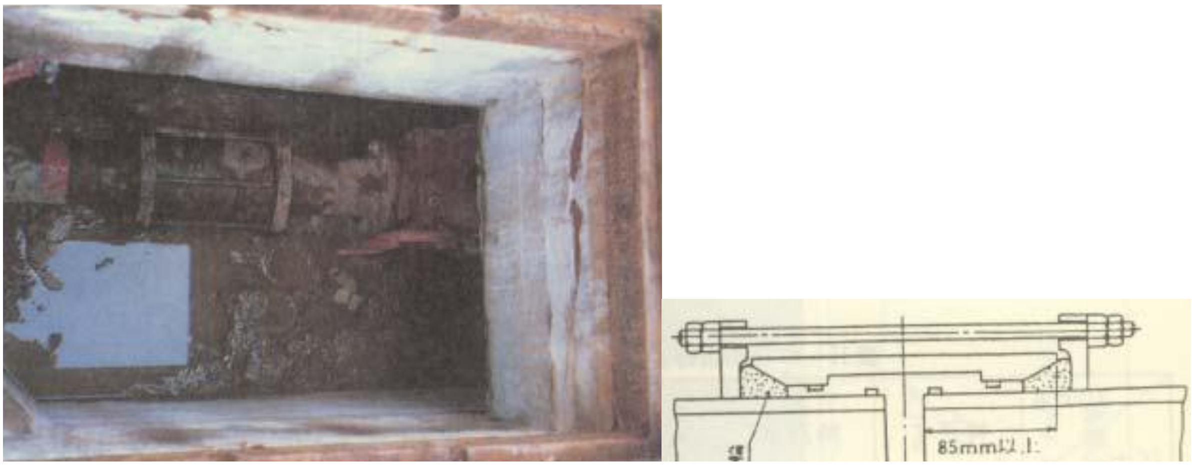


Figure 8-3 Sliding connection in buried valve

Therefore the damage modes in pipeline are as follows:

1- Severe damage mode

Severe damage mode for a pipeline is defined as plastic or ultimate limit state with large displacement and threat to integrity of pipeline.

2- Medium damage mode

Medium damage mode for a pipeline is defined as plastic state with considerable displacement and threat to pipe integrity for part of the pipe with possibility to operate.

3- Minor damage mode

Minor damage mode for a pipeline is defined as local damage and limited displacement and no threat to integrity of pipeline.

Structural damage mode for each structural element is given in table 8-1 and functional damage modes for relevant elements are given in table 8-2.

Table 8-1 Damage modes from structural damage point of view

Structure	**Elements**	**Structural damage modes**		
		Severe	**Medium**	**Minor**
Structure	**Buried pipeline**	**Little damage**	**Little damages**	**Tear**
	Valve	Small displacement	Relative deformation	Break
	Inspection elements like manholes and gates			
	Equipment for protection against corrosion			

	Pipe connected to structural facilities			
Pipeline system	Transmission pipeline	Little damage	Damages in specific distances	Tear
	Control center	Little damage	Relative damage	Collapse
	Terminal facilities			

Table 8-2 Damage modes from performance point of view

Structure	Elements	Structural damage modes		
		Severe	Medium	Minor
Structure	Buried pipeline	Considerable leakage	Relative leakage	Little leakage
	Valve	defected	Usable but should controlled for adequacy	Almost intact
	Inspection elements			
	Equipment for protection against corrosion			
	Pipe connected to structural equipment	Considerable leakage	Relative leakage	Low leakage
Pipeline system	Transmission pipeline	Stop working	Transmission with low pressure	Operable with caution
	Control center	defected	Problem in part of system	Operable with caution
	Terminal facilities			

Applicable seismic load including wave effects and permanent earth deformation must be categorized in order to hazard evaluation of pipeline system in this mode.

8-2-seismic assessment procedure

Seismic retrofitting and assessment steps for pipeline system are explained as follows and its flowcharts is given in figure 8-4 and 8-5

First step: Initial assessment
Second step: Detailed assessment
Third step: seismic retrofitting plan
Forth step: Study adequacy of seismic retrofitting plan

In figure 8-4, several retrofitting criteria are given base on inspection result. In figure 8-5, detail of inspection process and discuss about the necessity of first and second investigation and seismic evaluation is given.

1-Initial assessment

Rapid and general study of seismic performance of pipeline system should be done by local walking inspection. This inspection is necessary to show the need for study and detailed assessment. Individual or group inspection depends on the importance of pipeline system and should be controlled and selected prior to inspection.

2-Detailed assessment

Target pipeline and expected seismic performance should be determined on the first step of assessment and should be approved by the client.

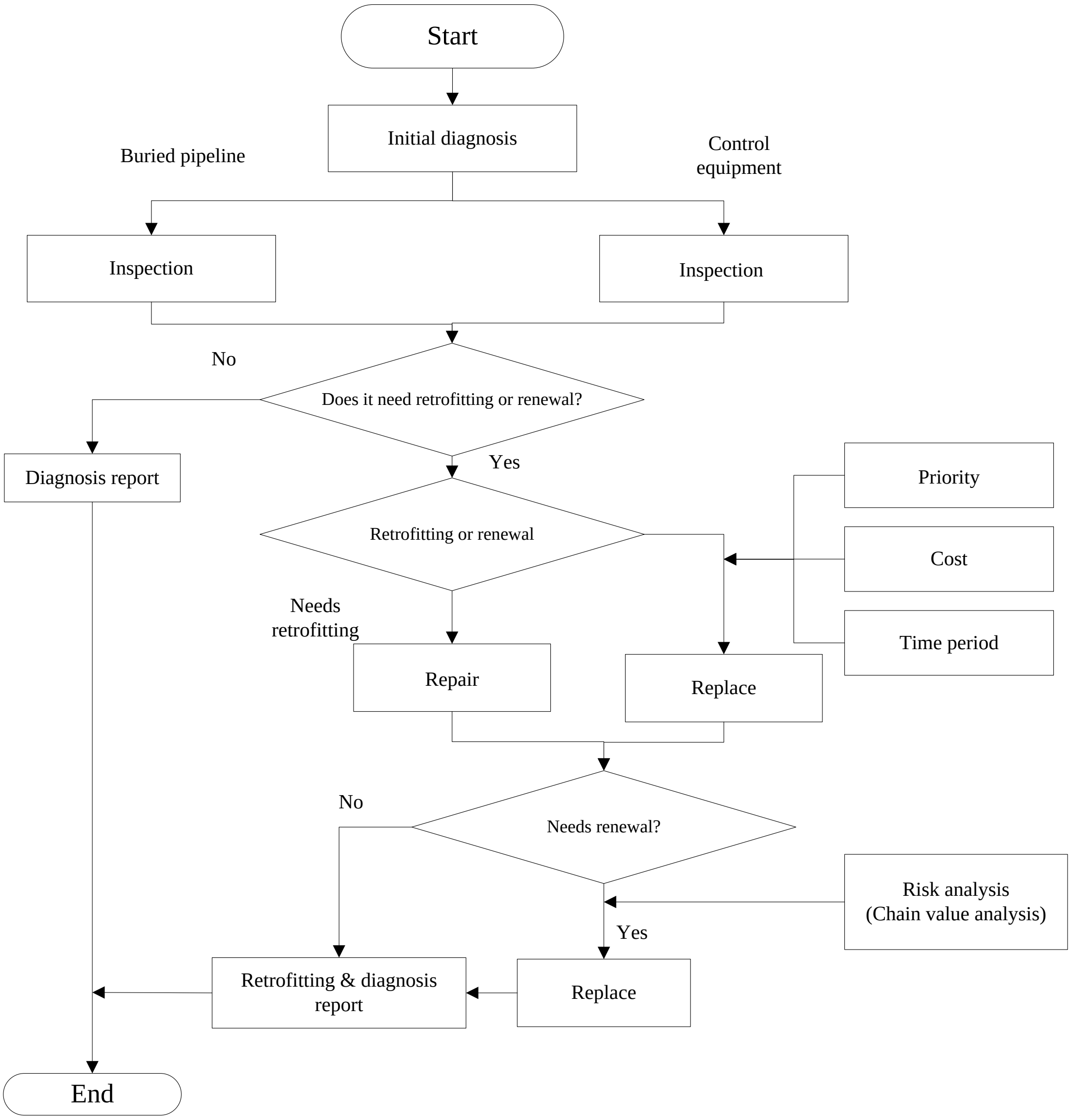


Figure 8-4 Flowcharts for seismic assessment of buried pipeline and control facilities

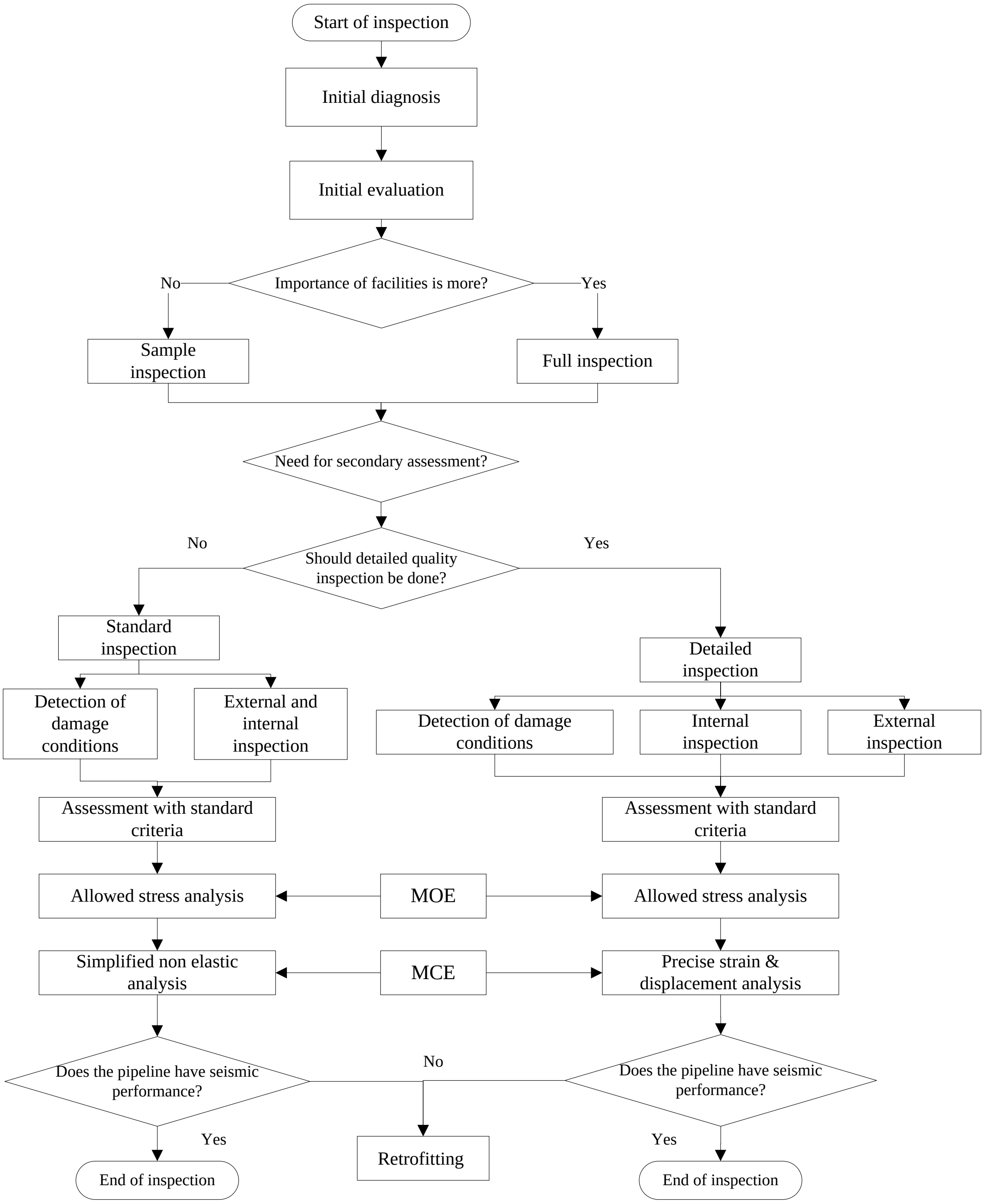


Figure 8-5 Flowcharts for seismic assessment of buried pipeline and its control facilities

8-3-Retrofitting

Retrofitting is done to obtain more effective and economical performance as well as a kind of damage prevention against earthquake. In the retrofitting of existing pipeline, it should be done without replacement or omission of buried pipeline as much as possible in order to use them as long as possible. Burying gas pipelines is a recognized method among execution works because it costs less comparing to replacement.

8-3-1-Priority in components of retrofitting works

Retrofitting works' priority is done based on following items:

1-To minimize human loss due to earthquake
2-Selecting the pipeline in area with the highest seismic risk
3-To minimize social damages
4-Selection of the most important pipe from risk & financial management point of view

Prioritizing retrofitting of pipe in different leakage conditions could be determined based on table 8-3.

Table 8-3 Items to be considered for Prioritizing Retrofitting Methods of Buried Pipeline in Different Leakage Conditions

Item		**Leakage cause**		
		Crack & break	**Corrosion**	**Loose connection**
Buried environment	Beneath road	○	x	○
	Natural ground	○	x	○
	Inside city	○	x	○
Result of pipeline inspection		x	○	x
Leakage history		○	○	○

(Note) ○: usable, x: unusable

8-3-2-List of Retrofitting Methods

There are different methods for retrofitting of buried pipeline and some of them are presented below:

1- Reinforcement of pipeline

Ground's distortion could exert considerable displacements on buried pipe. The common solution is to determine these places and replace those parts that have displaced. In some cases in order to release stress the pipeline will be cut. This work will release strains if the pipe material still is in elastic limit. But if displacement occurs in non elastic region of materials, residual strains will remain after pipe cut. During the cut big amount of strain energy may be released which is accumulated in pipeline. Also if the stress level in the pipe is high, sudden tear off may occur and pipe contents pour out. Relative movement of cut area could change from few centimeters to few meters. The workers doing this job should be alert of this risk and take necessary preventive measures to avoid damage due to fire and sudden pipe movement.

Acceptable methods for repair of pipes without buckling, crack and indent are shown in table 8-4. Acceptable methods for repair of pipes without buckling, crack, leakage and indent and other damages are shown in table 8-5.

Table 8-4 Acceptable Repair Methods (pipes without buckling, cracking and indentation)

Defect	Repair methods								
	1	2	3	4a	4b	5	6	7	8
	Replace	Removing by rubbing	Sedimentation of weld metal	Reinforcing circumferential cover (type a)	Pressurized circumferential cover (type b)	Composite layer	Mechanical bolts of clamp	Valve with high temperature	Brackets
External corrosion <0.8 t	Yes[1]	No	Limited[2]	Limited[5]	Yes	Limited[5]	Yes	Limited[3]	Limited[8]
External corrosion >0.8 t	Yes[1]	No	No	No	Yes	No	Yes	Limited[3]	Limited[8]
Internal corrosion <0.8 t	Yes[1]	No	No	Limited[5]	Yes	Limited[5]	Yes	Limited[3]	No
Internal corrosion >0.8 t	Yes[1]	No	No	No	Yes	No	Yes	Limited[3]	No
Groove or covering corrosion of joint in EFW & ERW welding	Yes[1]	No	No	No	Yes	No	Yes	Limited[3]	No
Gap, groove or arc burn	Yes[1]	Limited[7]	No	Limited[5,6]	Yes	Limited[5,6]	Yes	Limited[3]	Limited[6,8]
Crack	Yes[1]	Limited[7]	No	Limited[5,6]	Yes	Limited[5,6]	Yes	Limited[3]	No
Hot point	Yes[1]	No	No	Limited[5]	Yes	No	Yes	Limited[3]	No
Gas inclusion	Yes[1]	No	No	No	Yes	No	Yes	Limited[3]	No
fillet defected weld	Yes[1]	No	Limited[2]	No	Yes	No	Yes	No	No
Lamellar tearing	Yes[1]	No	No	No	Yes	No	Yes	No	No

Notes:

1-Replaced pipe should have a length at least half its diameter or 75 mm, whichever is bigger and also it should satisfy design requirements of main pipe.

2-Weld specification should be based on remaining wall thickness in repair area and also has highest internal pressure level.

3-The defect completely should be located in a place where the biggest amount of material could be taken.

4-It is usable only if internal corrosion is prevented.

5-In damage location, covers with hard connection or hard fillers like epoxy or polyester resin should be used to fill the voids.

6-It is usable only if the groove, gap, burned weld or crack has been removed completely and this point is approved by visual inspection, magnetic particles and penetration liquid (plus scraping in arc burn).

7-Groove, gap, burned weld or crack should be removed completely without penetration to more 40% of wall thickness. Allowed length of metal for removal is based on standard ASME B31.4 article 451.6.2(a)2. Removal of groove, gap, burned weld or crack should be approved by visual inspection, magnetic particles and penetration liquid (plus usage of aquafortis in arc burn).

8-Defect should be located completely under bracket and bracket size should not be 75 mm more than pipe nominal size.

Table 8-5 Acceptable Methods for Repair of Pipe for Indentation, Buckling, Cracks, Advancing Leakage and Previous Incomplete Repairs

Defect	**Repair methods**					
	1	**2**	**4a**	**4b**	**5**	**6**
	Replace	Removing by rubbing	Reinforcing circumferential cover (type a)	Pressurized circumferential cover (type b)	Composite layer	Mechanical bolts of clamp
Indentation <6% of pipe diameter with groove or fillet weld	Yes[1]	No	Limited[2]	Yes	Limited[2]	Yes
Indentation <6% of pipe diameter with groove gap or crack	Yes[1]	Limited[4]	Limited[2,3]	Yes	Limited[2,3]	Yes
Indentation <6% of pipe diameter with external corrosion with depth more than 12.5% of wall thickness	Yes[1]	No	Limited[2]	Yes	Limited[2]	Yes
Indentation exceeding 6% of pipe diameter	Yes[1]	No	Limited[2]	Yes	Limited[2,3]	Yes
Buckling and corrosion	Yes[1]	No	Limited[2]	Yes	No	Yes
Advancing leakage	Yes[1]	No	No	Yes	No	Yes
Surface defect from previous repair	Yes[1]	No	No	Yes	No	Yes

Notes:

1-Replaced pipe should have a length at least half its diameter or 75 mm, which ever is bigger and also it should satisfy design requirements of main pipe.

2-In damage location, covers with hard connection or hard fillers like epoxy or polyester resin should be used to fill the voids or annular space between pipe and repairing cover.

3-It is usable only if the groove, gap, burned weld or crack has been removed completely and this point is approved by visual inspection, magnetic particles and penetration liquid (plus usage of aquafortis in arc burn).

4-It is usable only if crack, stress concentration point or other defects has been removed completely and this point is approved by visual inspection, magnetic particles and penetration liquid (plus usage of aquafortis in arc burn). Also wall remaining thickness should not be less than 87.5% of pipe nominal thickness.

2- Anchoring of equipments

Large equipments have to be fixed by anchor rod and frame structures to prevent sliding, slipping and overturning.

3- Mechanical connections

Movement (rotation and displacements) and loads (forces and moments) should be limited to values specified by connection manufacturer.

4- Seismic constraints

Seismic force exerted on seismic constraints and its connections into building structures and anchorage in concrete should be determined by static and dynamics analyses. Seismic strength of seismic constraints and its connections should be determined based on design standards for support components like MSS-SP-69, AISC or AISI for steel elements and ACI for concrete anchors.

5- Anchor movement

In order to prevent vibration or damp them out in pipeline and its equipments, there should be ample supports and anchors.

- Seismic movement of anchor

Seismic anchor movement (SAM) is the movement difference between connecting points of pipe to support (for example, supports connected to higher stories vibrate with amplitude larger than the supports connected to lower altitudes) or it is the movement difference between nozzle connections and pipe supports. Seismic inputs for anchor are displacement (transfer or rotation) in connections of support or in equipments' nozzle. Stresses and forces of pipeline system will be combined with stresses and inertial forces (pipe vibration due to earthquake force) by squared root of sum of squares (SRSS) method.

Branch connection of pipelines on the ground should be protected with consolidated embankment or sufficient flexibility should be provided.

If openings are used in consolidated embankment for connecting new branches to existent pipe on the ground, a footing should be provided for main pipeline and new branch to prevent vertical and lateral movement.

Anchors and dampers will be considered to prevent vibration of pipeline in the main line.

All attachments should be designed to minimize stresses in the pipeline. Welding of attachments should comply with standard structural execution.

Structural supports, anchors and braces should not weld directly to a pipeline which is designed to operate in a circular stress 50% or higher. Instead should be reinforced with elements with complete coverage.

In places where supports like anchor is necessary, attached elements should weld to covering element. Pipe connection to covering element should be done with continuous fillet welds instead of consecutive welds.

Supports which are weld to pipeline should be designed in a way to be accessible during inspection.

- Design of anchors

In design of anchor blocks to prevent axial movement of pipeline, forces due to pipeline expansion and any kind of friction between pipe and soil should be taken into account.

In design of covering element, combination of functional stresses, environment stresses, construction stresses and random loads should be taken into account. Connection of covering element attachments could be done using strong brackets or continuous welds.

Axial force, F which the bracket should sustain in the pipeline will be obtained from the following equation:

$$F = A\left[E\alpha(T_2 - T_1) - v\sigma hp\right] \quad 8\text{-}1$$

A: Pipe cross section

E: Elastic module

α: Linear expansion coefficient

T_1: Installation temperature

T_2: Metal minimum or maximum temperature during operation

σ_{hp}: hoop stress due to internal pressure based on wall thickness

ν: Poisson coefficient

Considerable residual forces during the installation also should be taken into account in calculation of axial forces of pipeline.

- Seismic support's requirements

Supports and foundations need to control with a view to seismic requirement.

6- Cathodic protection method

It is possible to protect the pipeline from corrosion completely by design and installing proper covers and cathodic protection system.

- Covers

Cover for intercity pipeline is different from piping in factories. Buried pipeline in factories are ordered with covers and installed but for intercity pipeline, it is covered at site.

This difference prevents use of some sort of covers for pipeline in factories.

- Cathodic protection system

Cathodic protection system is not just flow of electricity in the pipeline. To execute this method, some requirements like proper covers and conductible cables are necessary.

- Cathodic interference

There are two types of cathodic interference, current interference and voltage interference

Current interference:

Figure 8-6 shows a cathodic protection system, rectifier and ground level. Usually this type of setup will transfer few amperes from soil to protected pipeline.

Voltage interference:

Figure 8-7 simulates the case where voltage interference is produced as high voltage passes between external pipeline and surrounding soil. High voltage and high density of current could make soil alkali.

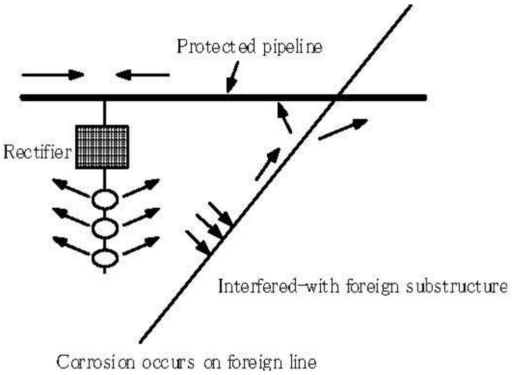


Figure 8-6 Current interference

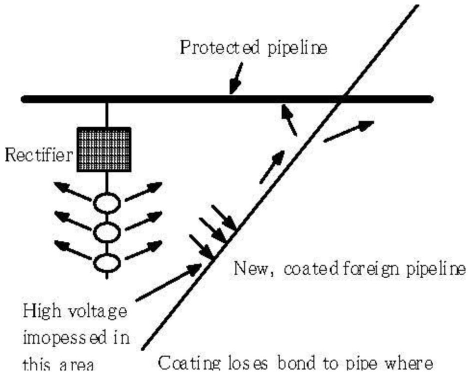


Figure 8-7 Voltage interference

Chapter 9

Retrofitting methods for internal equipments

9-1-Target component

Seismic retrofitting of internal equipments is divided into four groups as follows:

- 1-Air conditioning facilities
- 2-Building internal piping facilities
- 3-Building internal cabling and electricity facilities
- 4-Footing of equipments and support for piping

Details of these four groups are as follows:

- 1-Air conditioning facilities
  - 1-1-Heating equipments
    - a) Heating source
    - b) Cooling source
    - c) Equipments depending on heating source
    - d) Equipments depending on cooling source
    - e) Energy equipments
  - 1-2-Air conditioning
    - a) Equipments installed on the floor
    - b) Equipments installed on the ceiling
  - 1-3-Piping for air conditioning
    - a) Piping
    - b) Valves
    - c) Measuring devices
  - 1-4-Duct equipment
    - a) Duct
    - b) Dampers
    - c) Air controlling gates
    - d) Air controlling canals
  - 1-5-Automatic controlling equipments
    - a) Automatic control panel
  - 1-6-Exhaust gas fan
    - a) Exhaust gas fan installed on floor
    - b) Exhaust gas fan installed on ceiling
  - 1-7-Exhaust gas duct
    - a) Exhaust gas duct
    - b) Dampers
    - c) Exhaust gas gates
    - d) Exhaust gas canal
- 2-Building internal piping facilities
  - 2-1-Water system
    - a) Piping
    - b) Gauges
    - c) Tap water valve
    - d) Water valve
    - e) Measuring devices
    - f) Pump

    - g) Water tank
    - h) Electricity panel
  - 2-2-Hot water devices
    - a) Piping
    - b) Tap water mixing valve
    - c) Valves & expansion valves
    - d) Measuring devices
    - e) Hot water tank & pump
    - f) Hot water cylinder
    - g) Electricity panel
  - 2-3-Sewage equipments
    - a) Piping
    - b) Pumps
    - c) Sewage tank
    - d) Electricity panel
  - 2-4-Sanitary equipments
    - a) Rest room facilities
    - b) Hand wash basin
    - c) Bathroom facilities
    - d) Kitchen facilities
    - e) Service facilities
  - 2-5-Gas facilities
    - a) Gas piping
    - b) Measuring devices
    - c) Heat source facilities
    - d) Other equipments
  - 2-6-Sewage tank equipments
    - a) Piping
    - b) Sewage tank
    - c) Electricity panel
- 3-Building internal cabling and electricity facilities
  - 3-1-Supply wiring and change
    - a) Internal electricity wiring
    - b) Equipments
    - c) Footing
    - d) Internal situation
  - 3-2-Private electricity facilities
    - a) Equipments
    - b) Footing
    - c) Internal situation
  - 3-3-Battery facilities
    - a) Equipments
    - b) Footing
    - c) Internal situation

- 3-4-Trunk line
  - a) Metal tube
  - b) Cable rack
  - c) Metal duct
  - d) bus duct
- 3-5-Electrical Equipments
  - a) Equipments
  - b) Internal situation
- 3-6-Lighting instruments
  - a) Equipments
- 3-7-Automatic fire risk alerting alarm equipments
  - a) equipments
- 3-8-Lightning rod
  - a) Lightning rod

4-Footing of equipments and support of piping
- 4-1-Footing
- 4-2-Piping

9-2-Seismic damage modes

Seismic damage of equipments is mostly due to aging, loosening of anchoring nuts and defects in supports. These sections are vulnerable to seismic forces, displacement between different parts of footings and displacement between ground & building.

Figures 9-1 to 9-8 shows damage modes to equipments in past earthquakes.

9-3-Seismic assessment

Assessment of building equipments should be done based on requested seismic performance after the earthquake, regardless it is being architectural equipments or piping. Flowchart for seismic assessment of internal equipments is shown in figure 9-9. In master seismic plans for assessment of important equipments, following points should be considered:

- Necessary measures to secure human safety
- Necessary measures to prevent secondary disasters
- Maintaining required functionality after earthquake without need for extensive retrofitting works

Regarding other equipments, assessment should be done considering actions necessary to secure the human lives and preventing secondary disasters. In seismic assessment, required functionality for equipments in order to secure human lives and preventing secondary disasters, should be determined.

Fig. 9-2 Damage to cooling tower. No slide is reported due to existence of fillers (structures).

Fig. 9-1 Damage to pipe connection due to footing independent displacement

Fig. 9-4 Piping in the building inlet

Fig. 9-3 Damage to piping of water cooling system (Due to lateral seismic force, the welded part of pipe has damaged)

Fig. 9-6 Movement of room unit

Fig. 9-5 Damage to sound-proof element

Fig. 9-8 Damage to transformer and its elements

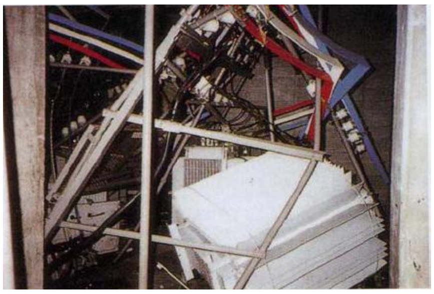


Fig. 9-7 Transformer has over turned in open air electric facilities' site

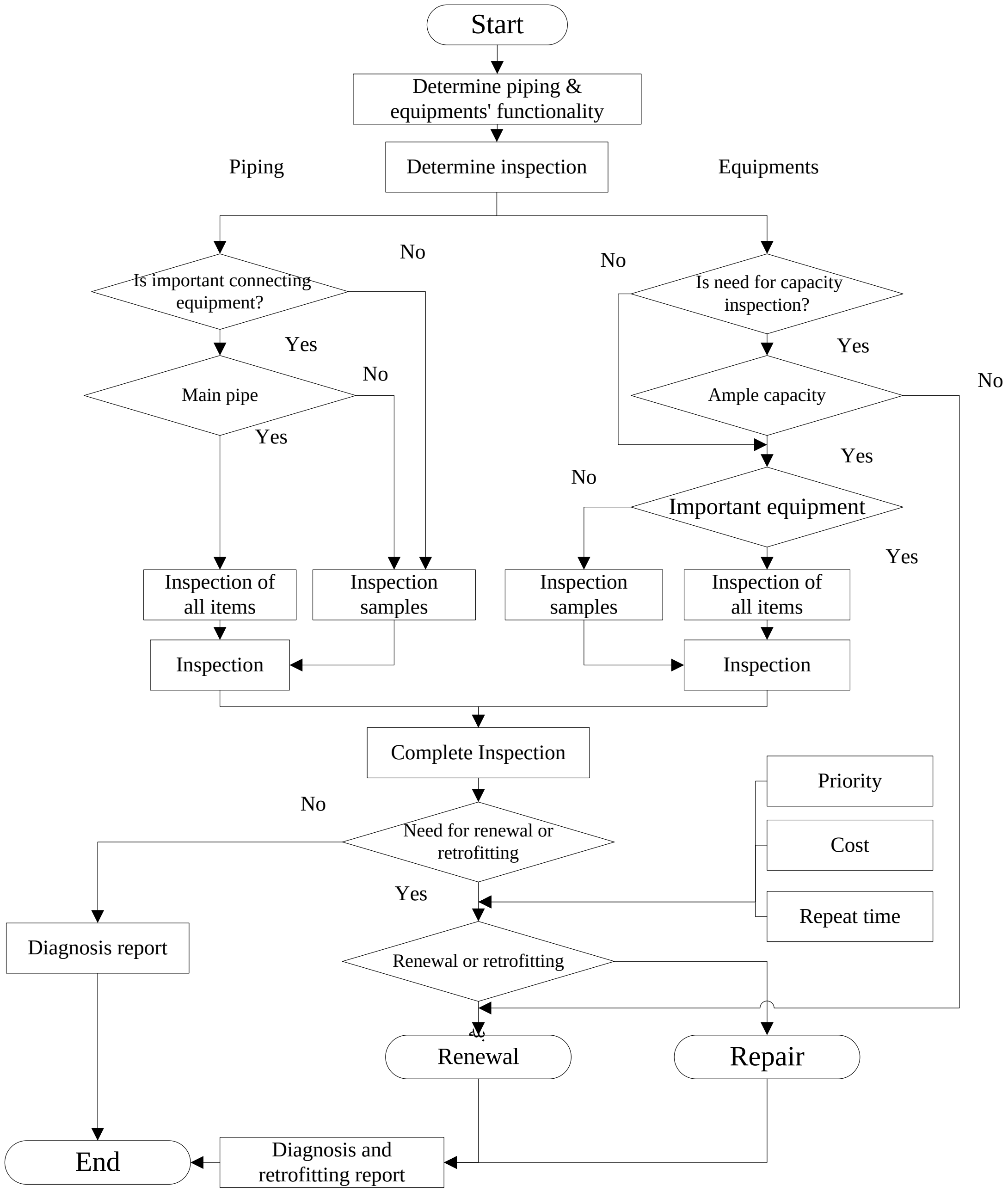


Figure 9-9 Flowchart for seismic assessment of internal equipments

9-4-Selection of Retrofitting Method as for Safety, Practicability and Cost

In selecting the retrofitting method for facilities, safety, practicability, cost and execution priority should be considered. Method type could be determined using guidelines mentioned in clause 4-1. Usually retrofitting methods are determined by considering that during seismic retrofitting of equipments other parts of building or facilities are serviceable.

Economical concerns in this regard are method's cost and effects of execution conditions.

Chapter 10

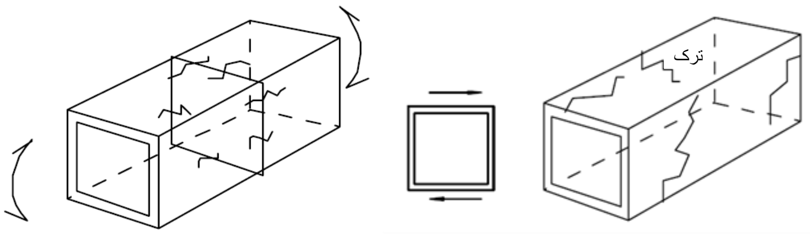
Retrofitting methods for other non-building structures

10-1-Target components

In this chapter seismic retrofitting and assessment of usual and vulnerable non-building structures in gas supply system is presented. These structures namely are culverts for passage of facilities and walls or dikes around the tanks.

1-Culverts

Culvert's cross section is rectangular and with tow-sided placing mechanism is connected. As it is shown in figure 10-1 common break mode in culvert in earthquake is shear curvature of cross section or connection break due to axial displacement or flexural deformation.



Cracks in connection due to flexural deformation

Cracks due to torsion deformation in longitudinal direction

Fig 10-1 Usual break modes in culvert

2- Walls and dikes

In this guideline, dike is a structure that will prevent tank liquid leakage during earthquake. Dike is not considered a fuel facility but is a mean to produce safety during break of fuel facilities. Therefore, during an earthquake the dike which is designed for seismic performance of the tank, should stay stable.

dike structure is a reinforced concrete wall or soil depot.

10-2- Culvert

10-2-1- Seismic damages

In an earthquake, seismic damages to culvert are shown in figure 10-2 and are concentrated in the connections and gaps of the structure.

Fig 10-2. The gap in the culvert with square cross section due to earthquake

1-Severe damage mode

In main damage mode one pipe element will be in ultimate limit state.

2-Medium damage mode

In medium damage mode, no pipe element is located in ultimate limit state but there some minor interruptions in serviceability.

3-Minor damage mode

In minor damage mode, minor damages will occur and operation will continue with caution.

Structural damage modes related to structural components are summarized in table 10-2

Table 10-1 Structural damage modes

Section	Damage mode	Damage level		
		Minor	**Medium**	**Severe**
Culvert	Corrosion	Without need for repair of rebar	In more damages, repair of defected element is not permitted, if other reducing effects could eliminate risk of an acceptable level.	Repair of rebar inside concrete due to high corrosion
	Crack	Without need for repair of non structural cracks		
	Indentation	Without need for repair of shallow indentation		Repair of defects bigger than allowed limit
	Deformation	Without need for repair of small displacements		
Connection to abutment	Soil settlement	Without need for repair of small displacements	In more damages, repair of defected element is not permitted, if other reducing effects could eliminate risk of an acceptable level.	Repair of defects bigger than allowed limit
	Soil slide			
Gap	Gap distance			

10-2-2-Assessment

There are many difficulties in culverts and some the major ones are as follows:

- Cracks of solid culverts
- Eluviations and loss of structural supports
- Water loss of culverts due to corrosion or abrasion
- Extra bending and displacement of flexible culverts
- Stress cracks in plastic culverts
- Increase of culvert gap due the earthquake
- Settlement and Increase of gap due to permanent displacement of ground which is caused by fault displacement or liquefaction

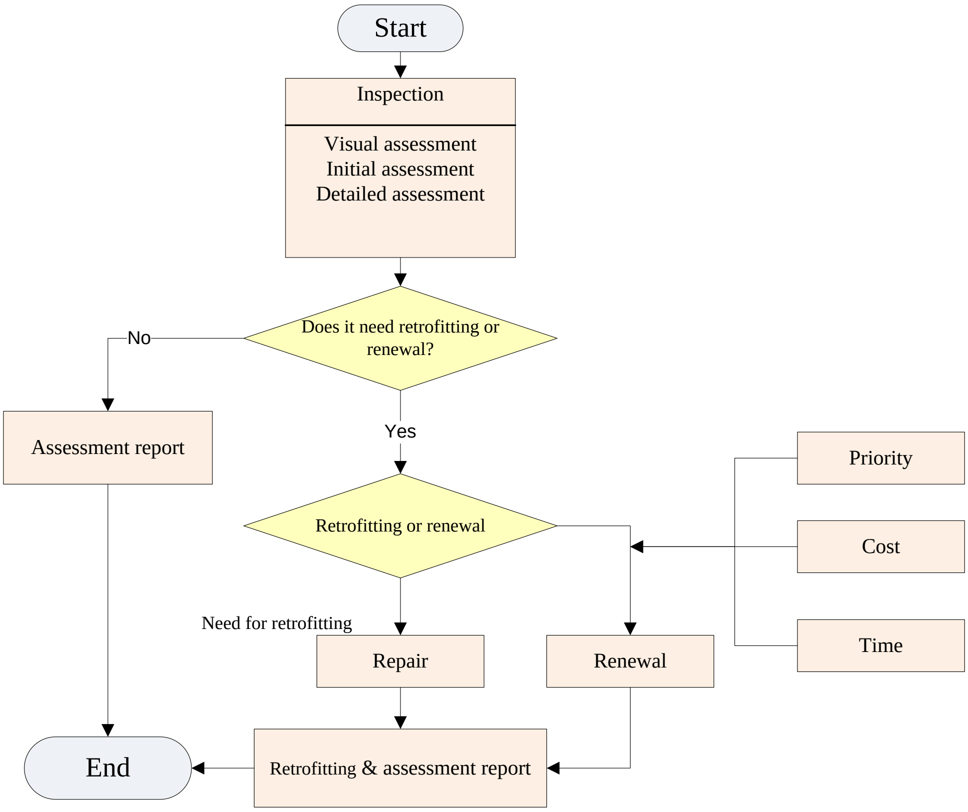


Figure 10-3 Flowchart for seismic assessment and retrofitting of culvert

10-2-3-Retrofitting

10-2-3-1-Notes

In design of culverts it is recommended to consider requirements for maintenance period. Although structural conditions are one of important functions of culverts, but problems related to durability, is the most cause of damages. Usually culverts age rather than face a structural break. Durability is under two mechanisms: corrosion and abrasion.

10-2-3-2-Determining retrofitting method from safety, practicability and cost point of view

1-Safety

Safety of personnel should be considered during construction, maintenance, repair and renewal of culverts. Designer should recognize the least possibility of repeat of risk in the construction of special type of structures as much as he can.

Repair, maintenance and inspection personnel should be aware of bad weather conditions, chemical and poisonous containment, animals and collapse potential of unstable structures.

2- Practicability

Culverts are built with reinforce concrete, wave-shape plates and recently with filled walls, profile walls and reinforced plastic. Strength and physical specification of material depends on chemical specification and interaction of included material. Metals and plastic are homogeneous and isotropic material where concrete and masonry materials are mix or combination of materials.

The way materials are interconnected to each other considerably affects material's strength in structural operation.

3- Cost

For design of new culverts and major repair of culvert, economical analysis usually considers factors like, construction cost, estimated service life, maintenance cost, replacement cost, fail risk and financial risk. Long and short term costs should be considered in main design and repairs or replacements.

10-2-3-3-Selection of retrofitting methods considering culvert material

1-Concrete

Culvert may be built with pre-cast concrete or cast-in-place concrete. Pre-cast sections are uniform in shape and dimension and are built in sections to be easy for transportation and installation. It is possible that pre-cast concrete culvert is built with high-strengthened concrete, but in cast-in-place concrete culvert, special rebar arrangement is used in critical positions in order to sustain high forces and stresses.

2- Wave-shaped steel

Steel plates and pipes of this type of culverts are built in the factory. But big wave-shaped culverts are installed at site.

3- Culvert material cover

Different types of covers are used alone or in combination of different layers, to protect culverts against corrosion or chemical materials. Covers vary on types depending on type of culvert material, type of aging and or possibility of their occurrence.

4-Cover of metal culverts

Wave-shaped steel culverts are protected with a layer of tin (galvanized) or aluminum protection covers for metal culverts include tar covers, tar flooring, tar-fibered covers, polymer, concrete flooring and concrete covers. Protective covers together with metallic covers are used a lot if there is corrosion or abrasion.

5- Cover for concrete culverts

Concrete culverts are seldom covered during construction. But if they are installed in places with chemical attack, they will be covered with epoxy resins or special concrete with high density and low porosity. These concretes have high strength against chemical and chemical effects.

Most of culverts will last until their useful life. In many cases culverts are built under heavy slopes and under roads with heavy traffics. Replacement of these culverts has very high cost and also will cut off traffic.

10-2-3-4-Works other than Retrofitting

In dikes and walls, usually settlement occurs due to earthquake. Monitoring system to diagnose damage place will be very helpful for assessment and retrofitting of these structures.

10-3-Wall and Dike

10-3-1-Seismic assessment and retrofitting procedure

Retrofitting plan is defined with following flowchart.

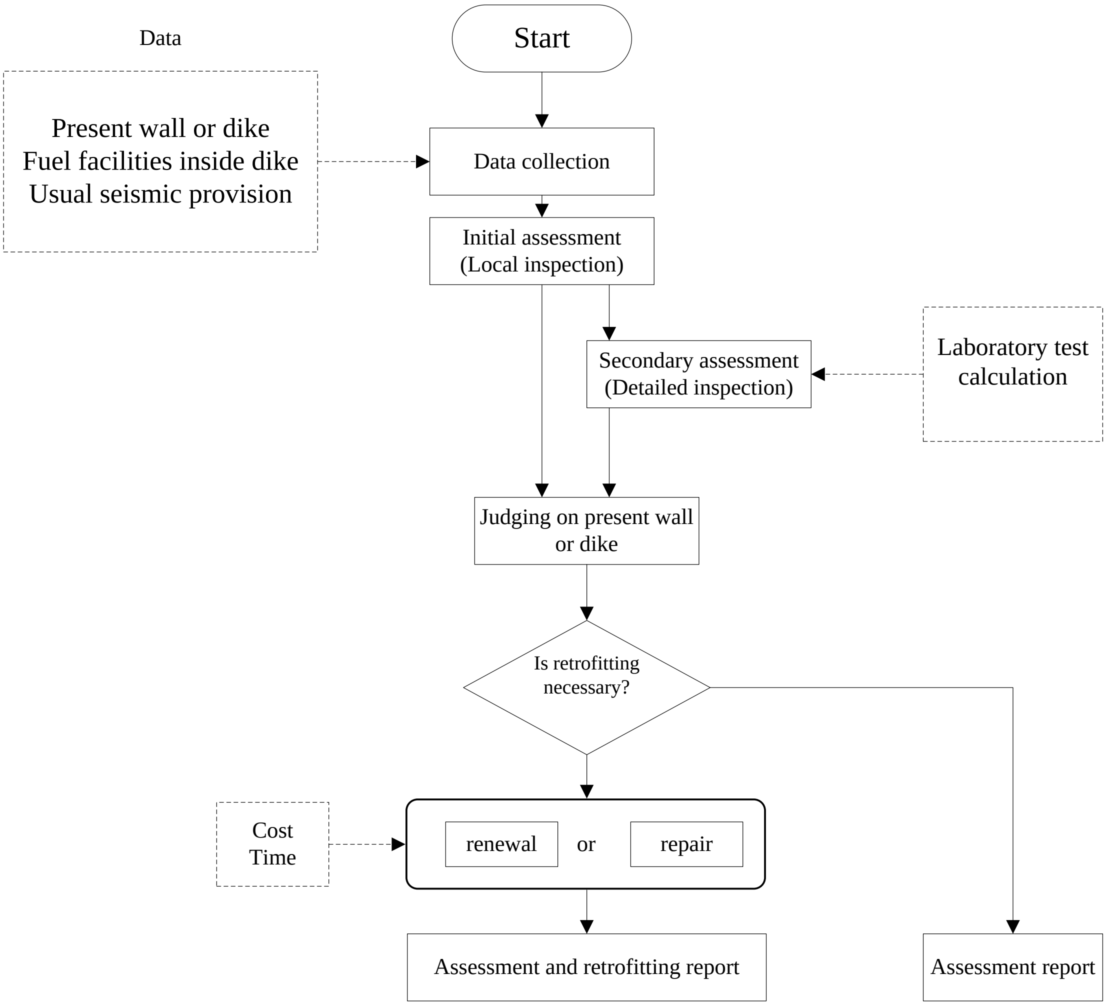


Figure 10-4 Flowchart for seismic assessment of dike

10-3-2-Retrofitting method

First priority for inspection should be sections like, connection, opening in pipe, provided gap, water discharging devise, main body and gate of the dike. Second priority is related to attach parts to main body of dike like stairs or firefighting chemical foam or ready gravel bag in dike.

First priority is also for ground to prevent ground break like liquefaction.

Regarding retrofitting of main body of dike, selection of the best method like tank or culvert footing from safety, practicability and cost point of view, should be done as mentioned in previous chapter. Regarding connection or pipe hole, selection of practical methods is limited and usually is repaired as the initial condition. If newly installed elements or devises are accessible, this method is usable after considering safety, applicability and cost.

Regarding wall gap, plastic and stainless flexible material is used instead of old connections with waterproof plate. Figure 10-5 shows example of gap cross section where flexible material is added. Figure 10-6 shows the real gap installed in concrete wall.

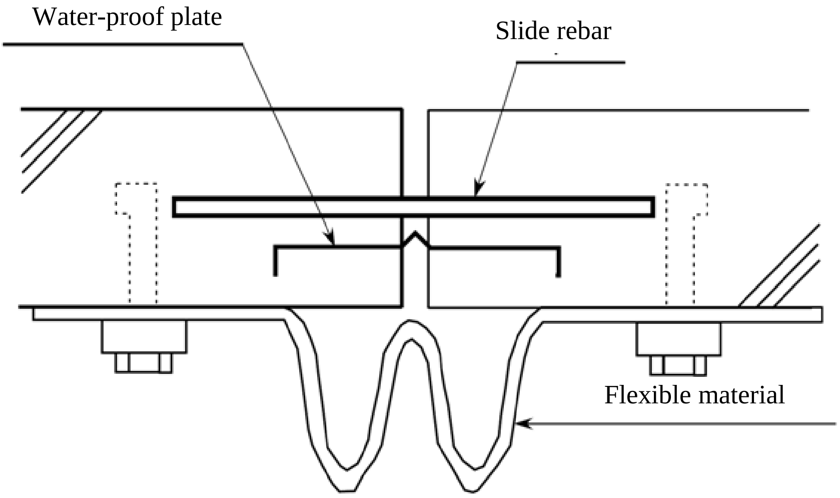


Figure 10-5 Gap cross section where flexible material is added to it

Figure 10-6 Gap with flexible material

Appendix

Appendix 1-Classification of subscribers of power transmission network

In this guideline, types of intended subscribers involve home utilization, public utilizations, agricultural utilizations, industrial utilization, commercial utilizations, lighting and special subscribers. In following, above-mentioned subscribers are described summarily.

Power branching for home utilizations is applied for a branch that merely established for operation of ordinary home apparatus and equipments in residential units.

Power branching for public utilization is applied to a branch that is used for public services. Types of public subscribers can be classified as following.

- ministries and their subsidiary offices, the Legislative, the Judiciary, Foundation of Martyrs and Veterans Affair,Foundation of the Oppressed and Disabled, Foundation of the 15 Khordad, municipalities and all governmental firms and organizations that aren’t administered as company (such as Organization of Hajj, Endowment and Benevolent Affairs, Organization of Management and Planning, Environment Protection Organization, Agricultural-Jihad organizations of provinces, customs, Port & Maritime Administration, I.R. Iran Civil Aviation Organization), Joint consumptions of non-residential building complexes, mausoleums, cemeteries and ghasalkhanehs.
- all qualified research institutions and research centers with valid licenses from formal authorities, Sale positions of petroleum products, Governmental sanitary and remedial centers such as hospitals, clinics, Centers of medical recognition, Medical centers, all beneficence institutions and centers, of Red Crescent and Imam Khomeini Relief Committee, residential complexes and towns, gardens, green areas of cities and consumptions related to beautification of cities.
- cultural centers (such as libraries, museums, registered historical sites), Broadcasting, cinemas, education and upbringing centers (such as kindergartens, preschools, schools, universities, educational hospitals, Career and Technical Education centers, schools, seminaries) student dormitories, student camps, Islamic Development Organization, mosques, Hoseiniehes, tombs of martyrs, shrine monuments and holy places of recognized religious minorities, sport centers, Disabled welfare and patronization centers, peoples with disabilities and elders, baths and clubs.
- military and police garrisons and centers
- rural and urban drinking water pumpage and refineries, sewage collection refineries and networks, drainage wells related to water and sewage centers, jungle parks and non-traditional bakeries
- small sanitary and medical centers such as medic recognition, medication centers, medical centers and physician clinics
- traditional bakeries

Agricultural power branching is applied for branching that uses power for pumpage of surfacial and underground waters or further pumpage of water for production of crops and also have operation licenses from Regional Water corps. Agricultural subscribers can be divided in two groups including water pumpage for irrigation (agriculture, further pumpage, pressurized and gravity irrigation) and water pumpage for production of crops (gardening, animal husbandry, reproduction and culture of aquatic in internal waters).

Industrial power branching is applied for branching that is used for operation of big industries and plants (such as production of mushroom, fishery, culture of caterpillar, reproduction and culture of aquatic in internal waters, poultries and animal husbandries) and small industries and production guilds.

Commercial power branching is applied for branching that is used generally for market places in non-production centers and also all supply centers. According to International Standard Industrial Classification of All Economic Activities (ISIC), various types of commercial subscribers can be presented as following:

- Wholesales such as wholesale of all products such as foods, home appliances, office supplies, etc.
- retails such as retailing of all products such as groceries, carnages, supermarkets, bookstores, boutiques, drugstores and cosmetics stores

Table 1-Classification of special subscribers

	Subscriber Type	Inclusive organizations	definition of activity
1	staff	province general governors governments municipalities crisis management organizations unexpected accidents and disaster staff Presidency of The Islamic Republic of Iran communication and information systems	planning and dispatching of received forces and supplies from various sources, procurement and collection of reliefs, suitable maintenance and distribution of facilities to relief forces and people, planning and coordination for supplying facilities to inhabit people and for damaged regions on the basis of precedence, supplying required communications for relief organizations and institutions, supplying required communications for damaged people
2	power support	Regional Electric Companies power transmission companies	supplying power to damaged regions to endure relief operation day and night and prevent horror of damaged people from darkness, detection of damaged electrical facilities, technical inspection of all supply lines, equipment and connections related to subscribers in damaged regions and try to reestablish power transmission system
3	political and military	Organizations and administrations of information and security General Command of Armed Forces of the Islamic Republic of Iran military and police centers centers of aerial and armed forces	
4	auxiliary	hospitals, emergency centers and clinics, Red Crescent populations, organizations of firefighting and safety services of cities, Road & Transportation offices, Relief committees	specialized search to find individuals, required actions to bring out damaged peoples, performing basic critical actions in incident places, remedial actions, supplying sanitary forces in provisional places and sanitary controlling of damaged areas, halting and quenching fire, supplying required safety for relievers, recognition and debris removing of relieve paths, supply and distribution of transportation machines to relief and remove debris
5	critical services	The National Iranian Oil Products Refining& Distribution gas companies water and sewage organizations Fruits, Vegetable and Agricultural Products Wholesale Markets Organizations	performing basic critical actions with coordination of emergency teams, compulsive housing and providing necessities and primary utensils of damaged people, supply and distribute fuel and oil products, water for drinking and other consumption and also food