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Guideline for seismic evaluation and rehabilitation of telecommunication systems

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Chapter 1

General

1-General

Communication lifelines play critical role in the time after earthquake. Radio, television, telephone and telegraph and other communication advices must be capable to compensate interruption of communications that sometimes occur in people's day life. Obviously, communication is generally needed for emergency and necessary reliefs, coordinating rescue operations and medical measures, collection information regarding damages inflicted on facilities and apparatus, supporting urgent actions to renovate facilities and informing people. Impacts of damages due to earthquake may be aggravated if sufficient seismic rehabilitation isn't exercised and there is no idea about vulnerability to provide needful strength and safety that coupled with inability for appropriate control of emergency conditions may lead to catastrophic event and occurrence of critical circumstances.

1-1- Objectives

The objective of seismic evaluation and rehabilitation if telecommunication systems are to acknowledge their seismic safety and then minimizing the consequences resulted from earthquake on these systems and components. Maintaining the integrity and safe performance of this system ensures lack of unacceptable risks for human lives and their properties as well as the environment. The main objectives in preparing this guideline are:

- Defining and determining the general criteria of seismic vulnerability evaluation for current telecommunication systems which are applied nationwide uniformly and in concert with each other.
- Presenting seismic rehabilitation approaches for telecommunication systems components to manage hazard reduction and contingent emergency and critical conditions.

1-2-Scope

This guideline is applicable for all communication lifeline components. Contents of this guideline pave the ground for improvement of engineering knowledge regarding seismic safety but its proper interpretation and application is of the user responsibility. Text of this guideline is undergone revision over time so users must apply its latest version. Seismic evaluation against other natural and artificial factors and their related considerations isn't in the scope of this guideline and must be examined additionally if needed. Requirements of this guideline are the same for permanent and provisional facilities.

1-3-Objective components

Objective components of this guideline are divided into two essential sections:

- Stationary components such as buildings, non-building structures, equipments and non-structural components
- Linear components (main communication lines) and network components (urban distribution of communication)

- Table 1-1 presents examined components from communication system in this guideline for seismic evaluation and improvement.

Table 1-1-Objective components in this guideline

component	type
Data centers and switching stations	stationary
Aerial transmission lines	linear
Microwave antenna and masts	stationary
kiosks	stationary
Underground transmission lines, conduits and tunnels	linear
manholes	stationary
Subscriber branches	stationary

Since all communication equipment are installed predominately in the indoor of communication buildings (communication centers), strength of these structures against earthquake is the first important issue that the investigation of vulnerability and improvement of other communication facilities and equipment can be discussed only after its achievement. Another component of communication system is its equipment power supply system. In order to achieve function of communication equipment, their required power must be supplied from power network and supporting source.

1-4-Related regulations

The regulations and codes as well as guidelines related to this collection are as follows:

- Latest revision of Iran 2800 standard, building designing against earthquakes, Ministry of Housing and Urban Development
- Instructions for seismic rehabilitation of buildings, issue #360, President deputy of strategic planning and control
- Instructions of buildings fast evaluation, issue #346, President's deputy of strategic planning and control
- Instructions of seismic vulnerability and rehabilitation of current unarmed monumental buildings, Ministry of Housing and Urban Development
- Instructions of seismic evaluation of power plants installations, issue #512, President's deputy of strategic planning and control
- Instructions of seismic evaluation of electricity substations installations, issue #513, President's deputy of strategic planning and control
- Iranian National Building Code, Ministry of Housing and Urban Development

Using other guidelines and criteria which could be needed in special projects is permissible, provided their general compliance with the contents of this guideline and satisfying the minimum criteria.

1-5-Structure of guideline

The current guideline consists of the following chapters and appendices:

Chapter one: Generalities

Chapter two: Seismic evaluation procedure
Chapter three: Seismic evaluation methods
Chapter four: Seismic rehabilitation procedure
Chapter five: seismic rehabilitation methods
Appendix 1: Classification of subscribers
Appendix two: Preventive list of resources and references

In chapter two of the guideline, the general seismic evaluation procedure of telecom systems is presented. This procedure defines the seismic evaluation studies through two general sections, namely pre-evaluation and evaluation. The pre-evaluation procedure is presented in this chapter while the evaluation procedure is in the next chapter. The seismic pre-evaluation is presented in this chapter for the general seismic vulnerability prediction of components, and using this, the primary screening of vulnerable components could be performed. Also, considering the different evaluation requests based on employers' objectives, the general level of studies and outputs could be determined.

In order to perform pre-evaluation, the effective factors in evaluation are introduced in this chapter, and based on this, the evaluation level index is determined and the evaluation level is selected. Next in this chapter, based on the selected levels, the suggested titles for planning the evaluation studies and also the stages for continuing studies following the completion of pre-evaluation are presented in order to prepare the description of evaluation's necessary services.

In chapter 3, the vulnerability evaluation methods are suggested as matrices for various components in three categories, fast, qualitative, and detailed, for the different evaluation levels presented in chapter 2, following introduction of target components in a telecom system. For each method and component, the codes related to determining the methods' details are listed, while introducing the factors important in evaluation.

For fast and qualitative evaluations, the important points to consider in preparation and completion of worksheets used in this section are presented through chapter 3, according to the importance of technical control in this two methods.

The details of the detailed methods for different components, such as load combinations and calculation of seismic capacity, and acceptance criteria in addition to items mentioned in chapter 3, are a function of seismic design methods of each component, and it could be referred to the related codes presented in this chapter for each component in order to determine them.

The fourth and fifth chapters discuss the procedures and methods of rehabilitation, respectively. The rehabilitation procedure include introduction of effective factors on prioritizing the rehabilitation design presentation and rehabilitation design preparation steps. The different rehabilitation methods for different components separately and detailed are the pre-requirements for the topic of the fifth chapter of this guideline.

Chapter 2

Seismic evaluation procedure

2-1- Seismic evaluation approaches

The seismic evaluation is defined through two stages in this guideline. The first stage is the pre-evaluation which by fast examination of vital artery state, the studies level is signified while determining the need or lack of need for evaluation. Then, in the evaluation stage, the activities are defined in primary or detailed evaluations, as follows. The roadmap of seismic performance evaluation is shown in the following figure.

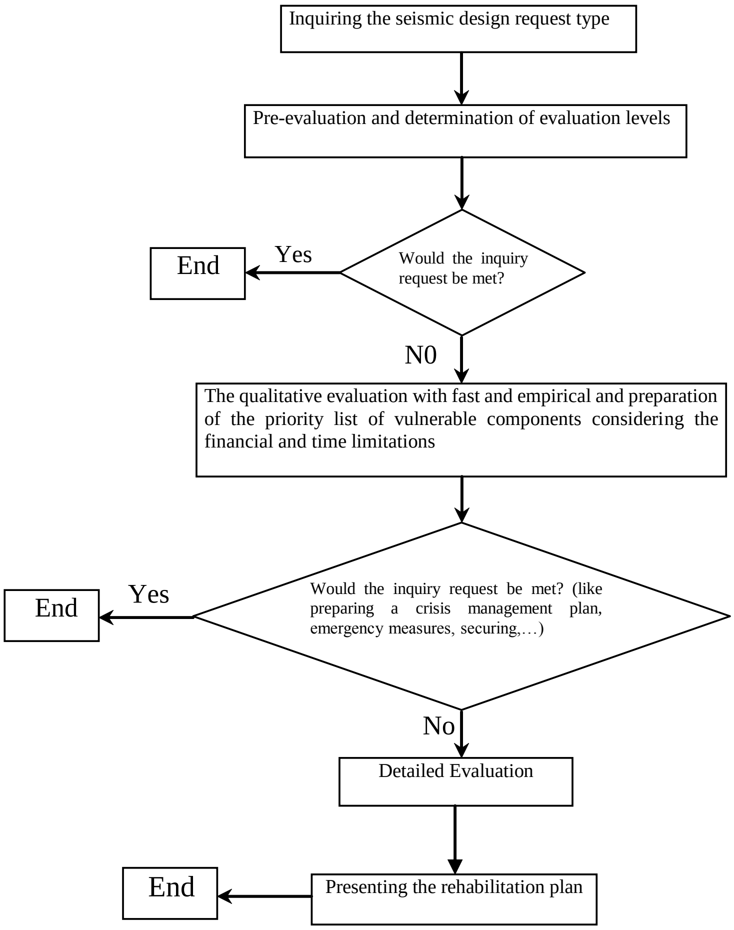


Figure-2-1: Performance evaluation roadmap

- The primary evaluation includes the empirical and qualitative methods. This evaluation is relatively fast and it requires the detailed evaluation in order to determine the vulnerable or safe components. Generally, the primary evaluation methods of this guideline are based on primary evaluation worksheets with qualitative or quantitative scoring.
- The detailed evaluation includes two empirical and analytic approaches. The empirical methods are based on damage mode and stats and history of damages in the past earthquakes. The analytic methods are based on modeling and numerical calculation analyses. Often, the empirical methods are used for seismic evaluation of networks with large number of

components. Generally, these empirical methods are based on empirical and possibility damage diagrams of different components in different modes. More details on damage diagrams are presented in appendix 1 of this guideline. The analytic method has also two levels. The first level is similar to simplified design methods and is mostly static-equivalent method. The second level is used for components with special conditions or more complex behavior and includes dynamic and non-linear methods.

2-2- Pre-evaluation

The system operator must be always sufficiently aware and certain about the proper seismic safety and performance of his/her installations. Otherwise, the request for performance evaluation of power installations is the submitted. The required level and details of evaluation depend on the requester's needed knowledge level. Before initiating the evaluation, the pre-evaluation stage is preformed for the following objectives which could be carried out by the operator engineer:

- Hazard's intensity identification and general vulnerability evaluation against it in order to determine the required level for detailed evaluation
- Assuring the availability of resources and sufficient, proper expertise for evaluation
- Determining the proper level of studies based on the request, available resources, and schedule.

2-2-1- Types of evaluation requests

The evaluation requests could be in one of the following three approaches:

- Technical approach (usually aimed to promote safety by performing rehabilitation practices)
- Financial approach (usually aimed for budget planning and/or capital loss, return, and risk assessments)
- Management approach (usually with goals such as crisis management planning, planning for immediate and emergency measures, increased-safety planning with software or non-rehabilitation and risk management plans)

The components which should be evaluated are largely dependent on the request and target's performance. Based on this, the director of installations should decide which components to be evaluated. The reliability in this instruction is measured based on the amount of power cuts and the duration of power cuts.

This request may not be submitted for the whole network, and be based on the crisis management priorities. In this case, the measurement of service delivery reliability initiates with the priority of more important subscribers which play more significant roles in controlling and management at the time crisis. Preparing a list and how the important subscribers in a network are selected is carried out based on the guides in appendix 1.

2-2-2-Factors effective on performance evaluation

The main factors in a performance evaluation are:

- Hazard (H)

The seismic hazard includes primary and secondary hazards. The primary hazards are vibrations and ground intense shakes and deformation caused by them, such as liquefaction, slope slip, and faulting. The secondary hazards include explosion, fire, environmental pollution, and likes of them which are resulted from occurrence of primary damages of earthquake.

- Vulnerability (V):

The vulnerability includes the potential of life losses and physical damages in relation to equipments, installations, buildings, operational and control systems, environment, industrial, office, financial and business activities, security of installations, capitals, society, and cultural heritage.

- System performance (S):

The performance of power supply vital artery during earthquake hazard is evaluated and judged based on outputs, operational objectives, safety defects, and performance disturbance. The major operational objectives of a power supply system are:

- Safety of people’s and personnel’s life
- Continuation of electric current and reliability on system
- Preventing damages
- Preventing environmental damages

2-2-3-Identification of seismic hazard

The primary seismic hazards including vibrations permanent ground deformations are measured based on intensity, acceleration, and ground’s intense movements. The most common measurement criterion of vibrations is the peak ground acceleration (PGA) which could be obtained from zonation maps or on-site studies. In order to investigate the level of permanent ground deformations, including liquefaction, landslip, and faulting, could also be performed using the zonation maps. The information of this map is approximate and conservative, to some extent. For example, a province might be placed in the high hazard classification against earthquake, only because a small portion of this province is on instable slopes.

The seismic secondary hazards, such as explosion, fire, environmental pollution, and likes of them, should be examined case-specific and local. Table (2.1) shows the hazard levels classification criterion.

Table-2-1: Criteria used in determining the relative hazard levels (H status)

Seismic hazard level	Seismic peak acceleration range
Low (L)	PGA>0.15 g
Medium (M)	0.15g ≤ PGA≤ 0.5 g
High (H)	PGA > 0.5g

2-2-4- Identification of seismic vulnerability

Regarding records of pervious earthquakes, damage potential in various parts of communication system against various seismic hazards is variable. Sliding and overturning equipment are the most important damages inflicted on communication equipments in pervious earthquakes. Switch racks fail due to overturning or cutting its connecting cables. Other types of equipment such as batteries fracture or fail due to overturning. An example of these failures occurred obviously in the Bam earthquake and the primitive call center of Bam was totally damaged due to overturning switches. Table 2-2 presents general classification of this subject into three categories of high (H), moderate (M) and low (L). If one component or system is located in the interior of building, vulnerability of building and that component must be considered simultaneously. For example, in a place that there is probability of building collapse or its compulsory evacuation, types of equipment in the interior of building are at risk.

Table 2-2-Vulnerability degree of components against earthquake damage (situation V)

Seismic hazards	Vulnerability degree								
	Computer equipment for commercial operations and activities	headquarters ،repair building, operation building	manholes	Underground distribution lines and conduits	kiosks	Communication antenna and masts	Aerial lines	Switching building	Protection and control system
Earthquake vibrations	M	H	M	M	M	M	L	H	M
Permanent ground displacements due to earthquake (Fault fracturing, liquefaction, landslide)	L	H	H	H	M	M	H	M	L

2-2-5-Seismic performance

The seismic performance depends on the following factors:

- Intensity and amount of hazard
- Vulnerability of system of component
- Consequences caused by life or financial damages, service cut, environmental impacts, and other effects.
- Permanent redundancy amount of the evaluated system (High redundancy, redundant, or no-redundancy)
- System size

In pre-evaluation, the performance is defined by the layer index, IL, as the product of H, V, and S:

$$I_L = H \times V \times \max\left(C_{LS}, C_{FL}, C_{SD}, C_{EI}\right) \qquad (2.1)$$

H: degree of hazard (low = 1, medium = 2, high = 3, according to table 2.1)

V: degree of vulnerability (low = 1, medium = 2, high = 3, according to table 2.2)

S: degree of system performance (maximum of CLS, CFL, CSD, and CEI)

CLS: degree of life safety consequences, varies between 1 and 3 (According to table 2.3)

CFL: degree of financial loss consequences, varies between 0.5 and 6 (According to table 2.3)

CSD: degree of service cut consequences, varies between 0.5 and 6 (According to table 2.3)

CEI: degree of environmental impacts consequences, varies between 1 and 3 (According to table 2.3)

In table (2.3) a redundancy correction factor (RC) is used to determine CFL and CSD. Indeed, using this correction factor justifies the decrease in consequences due to system redundancy.

The redundancy correction factor provides the possibility of flexibility in weighting differently some of the performance special conditions, provided the availability of the alternative resources.

For example, for one establishment, the redundancy factor might be determined equal to 2 (no-redundancy) due to lack of knowledge about a proper alternative for servicing an important subscriber. While, the subscriber himself might consider this factor equal to 0.5 due to existence of a proper alternative; therefore, the CSD could vary depending on the nature and characteristics of request and who is performing the evaluation. There are similar considerations when applying the redundancy correction factor to CFL. The redundancy correction factor is equal to 1, for normal cases.

Table-2-3: Degrees of system performance disturbance consequences (S status)

Consequence	**Intensity of Consequence**		
	Low (Normal)	Medium (Non-critical)	High (Critical)
Life safety CLS	Minimum impact on life safety; without any important or significant effect on personnel or people around facilities CLS = 1	The damage or cut could inflict injuries to personnel or people around facilities CLS = 2	The damage or cut could bring significant life threats for personnel or people around facilities CLS = 3
Financial loss CFL	No or low effects CFL = RC	The damage or power cut could inflict high financial losses, but these losses have no or low effects on facility economic status CFL = 2RC	The damage or power cut has significant effect on economic status of facility and/or a number of main subscribers CFL = 3RC
Service cut CSD	No or low effects on population under its coverage CSD = RC	Power cut: - affects a small portion of covered population (less than 10%) - lasts less than one day and has no specific effect on any important subscriber CSD = 2RC	Power cut would lead to one the following: 1) Affects a considerable portion of covered population (more than 10%) 2) Has the potential to affect a population more than 100 thousand people 3) Includes a broad area and lasts more than one day 4) Affects the performance and operation of an important and vital facility CSD = 3RC
Environmental impacts CEI	No or low effects on the environment CEI = 1	The damage or power cut might cause limited environmental impacts CEI = 2	The damage or power cut might cause large environmental damages (i.e. neutralizing its effects might take months or years) CEI = 3

RC is equal to 0.5 for high redundancy (member damages do not reduce system's performance); for medium redundancy equals to 1 (member damages reduce system's performance); and for no-redundancy is equal to 2 (the task performed by that member only and no other alternatives would do the same). The scoring system is approximate and replacing decimal values instead of 1 for low, 2 for medium, and 3 for high is not considered.

The final step in the scoring operations is to compare the layer index, IL, with a set of pre-determined ranges which defines the recommended base level for performance evaluation. Based on all the possible combinations of input parameters, the layer index could vary from 0.5 to 54. The performance evaluation base level could be determined using the ranges presented in table (2.4). The base level is used as a starting point for evaluation and later more complete evaluations could be felt. Sometimes the inquirer might request a specific level of studies based on his/her requirements.

Table-2-4: Selection of evaluation levels

Layer Index	Base Level for Performance Evaluation
$I_L \le 6$	No need for seismic evaluation
$7 \le I_L < 17$	Generally, the primary evaluation is sufficient (level 1)
$17 \le I_L < 35$	Primary and detailed evaluations using empirical and common calculative methods (level 2)
$I_L \ge 35$	Primary and detailed evaluations using accurate calculative methods (level 3)

2-2-6-Evaluation studies planning

The required information for seismic evaluation and the type of studies differ based on the different seismic levels. In addition to the guides presented by the chapter's tables, also issues such as cost and schedule as well as numerous hazards must be included in planning of evaluation studies type.

Table -2-5: Hazard evaluation matrix for power supply system

Hazard/Measure		H1	H2	H3
1-1	Earthquake hazard – surface failure of fault			
1-1-1	Reviewing the regional earthquake's history and active faults hazards maps, if available	♦	♦	♦
1-1-2	Reviewing topographic maps	♦	♦	♦
1-1-3	Reviewing aerial maps, if available	♦	♦	
1-1-4	Performing identification and site visits (by an expert geologist)	♦	♦	
1-1-5	Highlighting active faults by excavating trenches	♦		
1-1-6	Estimating fault's displacements using empirical methods	♦	♦	
1-1-7	Determining fault's displacements and their occurrence possibility by excavating bores, sampling, age determination, and analysis	♦		

Hazard/Measure		H1	H2	H3
1-2	Earthquake hazard – liquefaction			
1-2-1	Reviewing documentations concerning regional vibrations (seismic-risk)	♦	♦	♦
1-2-2	Probability evaluating of earthquake hazard throughout the whole system	♦	♦	
1-2-3	Reviewing topographic maps	♦	♦	♦
1-2-4	Reviewing ground surface geological maps	♦	♦	♦
1-2-5	Reviewing the current geotechnical data	♦	♦	♦
1-2-6	Performing minimum excavation and soil boring, standard penetration tests and/or cone penetration		♦	
1-2-7	Performing extensive excavation and soil boring, standard penetration tests and/or cone penetration	♦		
1-2-8	Performing preliminary visits and site detection (desert) (by an expert geologist)	♦	♦	
1-2-9	Identifying soil mines with liquefaction potential by judgment	♦	♦	♦
1-2-10	Identifying soil mines with liquefaction potential by engineering analysis of sail data	♦	♦	
1-2-11	Estimating the amount of lateral displacement spreading by empirical methods	♦	♦	
1-2-12	Estimating the liquefaction potential using liquefaction capability maps	♦	♦	
1-2-13	Applying detailed analysis using analytical tools, estimating liquefaction possibility, and lateral displacements spreading.	♦		

Hazard/Measure		H1	H2	H3
1-3	Earthquake hazard – ground intense vibrations			
1-3-1	Reviewing documentations concerning regional vibrations (seismic-risk)	♦	♦	♦
1-3-2	Reviewing regional seismic hazards, if available	♦	♦	♦
1-3-3	Reviewing ground surface geological maps	♦	♦	♦
1-3-4	Determining and developing factors amplifying ground shakes	♦	♦	
1-3-5	Estimating levels and elevation of ground shakes using judgment and current maps	♦	♦	♦
1-3-6	Estimating levels and elevation of ground shakes using empirical methods	♦	♦	
1-3-7	Estimating levels and elevation of ground shakes using analytical methods and tools	♦		
1-3-8	Applying PSHA to the whole system	♦		

Hazard/Measure		H1	H2	H3
1-4	Earthquake hazard – landslip			
1-4-1	Reviewing geological maps of earth surface	♦	♦	♦
1-4-2	Reviewing topological maps	♦	♦	♦
1-4-3	Reviewing aerial maps, if available	♦	♦	
1-4-4	Reviewing regional precipitation maps	♦	♦	♦
1-4-5	Performing site visits and identification (desert) (by an expert geologist)	♦	♦	
1-4-6	Reviewing current regional ground shakes maps	♦	♦	♦
1-4-7	Evaluating the potential of landslip by expert judgment	♦	♦	♦
1-4-8	Evaluating the potential of landslip by slope stability maps	♦	♦	
1-4-9	Evaluating the potential of landslip by statistical or empirical analysis	♦	♦	
1-4-10	Evaluating the potential of landslip by analytical methods	♦		

Hazard/Measure		H 1	H 2	H 3
1-5	Earthquake hazard – Tsunami			
1-5-1	Determining the location of facilities in a 20km range from shore	♦	♦	♦
1-5-2	Reviewing topographic maps of shore areas	♦	♦	♦
1-5-3	Reviewing bathymetric maps of boundary areas (close to shore)	♦	♦	
1-5-4	Reviewing records by local wave/tide gauges	♦	♦	♦
1-5-5	Estimating potential of tsunami water overflow using expert judgment	♦	♦	♦
1-5-6	Estimating potential of tsunami water overflow using judgment and evaluating the tsunami possibility sources	♦	♦	
1-5-7	Analyzing regional flooding	♦	♦	♦

Table-2-6: Vulnerability evaluation matrix

Component/Measure		V1	V2	V3
1	Damage evaluation of power system facilities			
1-2	Collecting information by interviewing facilities designers, site engineers, and executive managers. Obtaining performance evaluation (estimates, heuristic estimates), and every performance data (statistical) which should be informed about.	♦	♦	♦
1-2	Collecting information by examining the site for local conditions evaluation and information related to the total vulnerability of components.	♦	♦	
1-3	Collecting information by examining the site for parallel hazards resulted from external sources, structures, and neighboring facilities.	♦	♦	
1-4	Collecting information by reviewing maps and calculations of critical and important issues of facilities.	♦	♦	
1-5	Collecting information by visiting location and determining the installation details of critical items in facilities.	♦	♦	
1-6	Performing structural calculations for examining and determining the sufficiency of installation details of critical and important items in facilities and matching with characteristics based on performance.	♦		
1-7	Evaluation of equipments' fragility using location data, heuristic estimates, empirical data from previous events (statistical) with minimum local collected data.	♦	♦	♦
1-8	Evaluation of equipments' fragility using location data obtained from (1.2) to (1.5), more accurate and more detailed data of loads, and equipments' sufficiency, and fragility tests	♦	♦	
1-9	Evaluation of equipments' fragility using actual in-place data (according to steps (1.2) to (1.6)) and selected equipments' structural analysis results	♦		

Component/Measure		V1	V2	V3
2	Damage evaluation of critical and important buildings			
2-1	Collecting information through interviewing executive managers of facilities and maintenance personnel of building	♦	♦	♦
2-2	Determining critical performances inside buildings and damages which have defected or stopped these performances	♦	♦	♦
2-3	Paying general visits to sites for evaluation of local conditions and collecting information about buildings’ general vulnerability, their contents, and each facility near them and their supports	♦	♦	
2-4	Paying general visits too sites for evaluation of parallel hazards from external sources and structures and neighboring equipments	♦	♦	
2-5	Performance evaluation of buildings and support equipments using judgment (estimates, heuristic estimates) and/or empirical data (statistical) from past events and/or using empirical evaluation of damages with minimum local collected information	♦	♦	♦
2-6	Reviewing architectural and structural maps, design calculations, foundation evaluation reports, and also past structural evaluation reports for evaluating buildings’ capacity.	♦	♦	
2-7	Performing independent structural calculations for building capacity evaluation.	♦	♦	
2-8	Performing independent structural calculations for building response evaluation	♦		

Table-2-7: Performance evaluation matrix

Measure		S1	S2	S3
1	System performance evaluation			
1-1	Reviewing system maps	♦	♦	♦
1-2	Reviewing system performance against natural hazards/previous events	♦	♦	♦
1-3	System’s critical performance model	♦	♦	
1-4	Matching system model on maps of various hazards (GIS performance)	♦	♦	
1-5	Estimating system’s performance using expert judgment	♦	♦	♦
1-6	System analysis for limited scenarios (minimum 3)	♦	♦	
1-7	Probability analysis and system reliability	♦		

Table-2-8: Minimum necessary effort for evaluation of hazard, vulnerability, and system's performance in different levels

				Vulnerability Evaluation		
1 to 15 man-hour [white] 3 to 10 man-hour [grey] 3 to 9 man-hour [black]				V1	V2	V3
Evaluation levels of system performance	S1	Hazard evaluation	H1	[white]	[white]	[grey]
			H2	[grey]	[grey]	[grey]
			H3	[black]	[black]	[grey]
	S2	Hazard evaluation	H1	[grey]	[grey]	[grey]
			H2	[grey]	[grey]	[grey]
			H3	[black]	[black]	[black]
	S3	Hazard evaluation	H1	[black]	[grey]	[grey]
			H2	[black]	[black]	[grey]
			H3	[black]	[black]	[black]

2-3-Seismic Evaluation Stages

After performing pre-evaluation and determining the level of studies, it would be necessary for seismic emulation to determine the seismic vulnerability, seismic hazard, and seismic performance level of the target. These parameters, which determine the volume of necessary activities for evaluation of each component, are listed in the evaluation stages according to the following order:

1-Level of importance and system general value
2-Calculating seismic hazard of different elevations
3-Determining component/system performance levels
4-Selecting the primary seismic evaluation method
5-Determining the primary vulnerability
6-Selecting the detailed seismic evaluation method
7-Determining the detailed vulnerability

2-3-1-Determining importance of component or system

The first step in seismic evaluation is to determine the importance and role of the system in a network which is carried out according to table (2.3). After systems' classification, the subsystems and internal components are classified based on their relative importance and role in power supplying, according to table (2.9). Table (2.10) indicates how the role combination of internal components and the entire system in seismic evaluation.

Table 2-9-Classification of internal subsystems or components

type	definition	Damage effect in function
primary	Direct role in system function	Interruption of communication
auxiliary	Supporting or redundancy role in system function	Disorder in communication
secondary	Main or supporting role in system function	invisible

Table-2-10: Determining the importance with combination of internal components and entire system

Subsystem or internal component / Entire system or set	Main	Auxiliary	Subordinate
Up	Very high	High	Medium
Middle	High	Medium	Low
Down	Medium	Low	Low

Also, the obtained importance level could be obtained as following:

1-Very high: inflicting damages to these components would lead to critical conditions and cause several casualties and financial losses.

2-High: inflicting damages to these components results in power- and service delivery-cut as well as financial losses.

3-Medium: inflicting damages to such components would cause disturbance in currents.

4-Low: inflicting damages to such components has no effect on the system.

2-3-2-Earthquake hazard level

Three earthquake hazard elevations are defined for evaluation:

- Hazard level-1: Maximum Operational earthquake (MOE)
- Hazard level-2: Maximum Design Earthquake (MDE)
- Hazard level-3: Maximum Considered/Credible Earthquake (MCE)

These hazard levels are equivalent to the following safety levels which their precise definition is presented in table (2.12) for different importance levels:

- Operational safety: In this level, the possible imposed damages should not create any disturbance in power supplying.
- Design safety: In this level, the possible imposed damages might create temporary and short-term disturbance in power supplying but should not lead to major damages, collapses, fire, explosion, network instability, and so forth.

- Safety from crisis: In this level, high operational damages might occur but no system damages should be inflicted; therefore, it is necessary to consider required measure to minimize secondary effects.

Table-2-11: earthquake seismic hazard levels

Seismic Level	Probability of emergence in 50 years (earthquake return period in years)	Safety Level
Hazard level-1 (MOE)	99.5% (75 years)	Operational safety
Hazard level-2 (MDE)	10% (475 years)	Design safety
Hazard level-3 (MCE)	2% (2475 years)	Safety from crisis

2-3-3-Performance levels of system components

The definition of performance levels based on hazard level and importance classification of vital arteries' equipments is presented in table (2.12).

Table -2-12: Definition of seismic performance levels based on earthquake hazard level and importance classification

	Seismic elevation (Performance level)		
Importance level	Earthquake hazard level-1 (operational safety)	Earthquake hazard level-2 (design safety)	Earthquake hazard level-3 (safety from crisis)
Very high	Without any damage and performance disturbance	No life damages. Equipments receive minor damages but they would be still operational.	No life damage. Equipments are damages, but the system still maintains its performance and critical conditions do not occur.
High	Without any damage and performance disturbance	No life damages. Equipments are damaged but they would maintain their performance.	No life damages. The equipments are damaged with possible temporary disturbance in system performance but the critical conditions do not occur.
Medium	No life damages. Equipments receive minor damages but they would maintain their performance.	No life damages. The equipments are damaged with possible disturbance in system performance	No life damages. The equipments are damaged with major disturbances in equipment and system performance however repairable and recoverable in an acceptable time
Low	No life damages. The equipments receive minor damages but the system maintains its performance	No life damages. The equipments are damaged with major disturbance in the equipment and system performance however repairable and recoverable in an acceptable time	Not necessary

Chapter 3

Methods of seismic evaluation

3-1-Objective components

Objective components of this guideline are introduced in table 3-1 with general classification of linear and stationary components. Regarding seismic function evaluation, this classification is performed in two types of individual function of each component and systematic function of several components consisting one system.

Table 3-1-Classification of component members

type	topic	function	members
stationary	Communication centers	Individual components	equipment
			non-building structure
			building
			False floors and non-structural members
		systems	Cable communication system and power system
	Masts and antenna	Individual components	equipment
			Non-building structure
			foundation
		systems	
Linear (network)	aerial	Individual components	branches
			bases
			Electrical and connections
		systems	
	Underground and conduits	Individual components	kiosks
			Input and output structures and branches
			manholes
			Handles and non-structural members
		systems	

3-2-General approach in determination of vulnerability

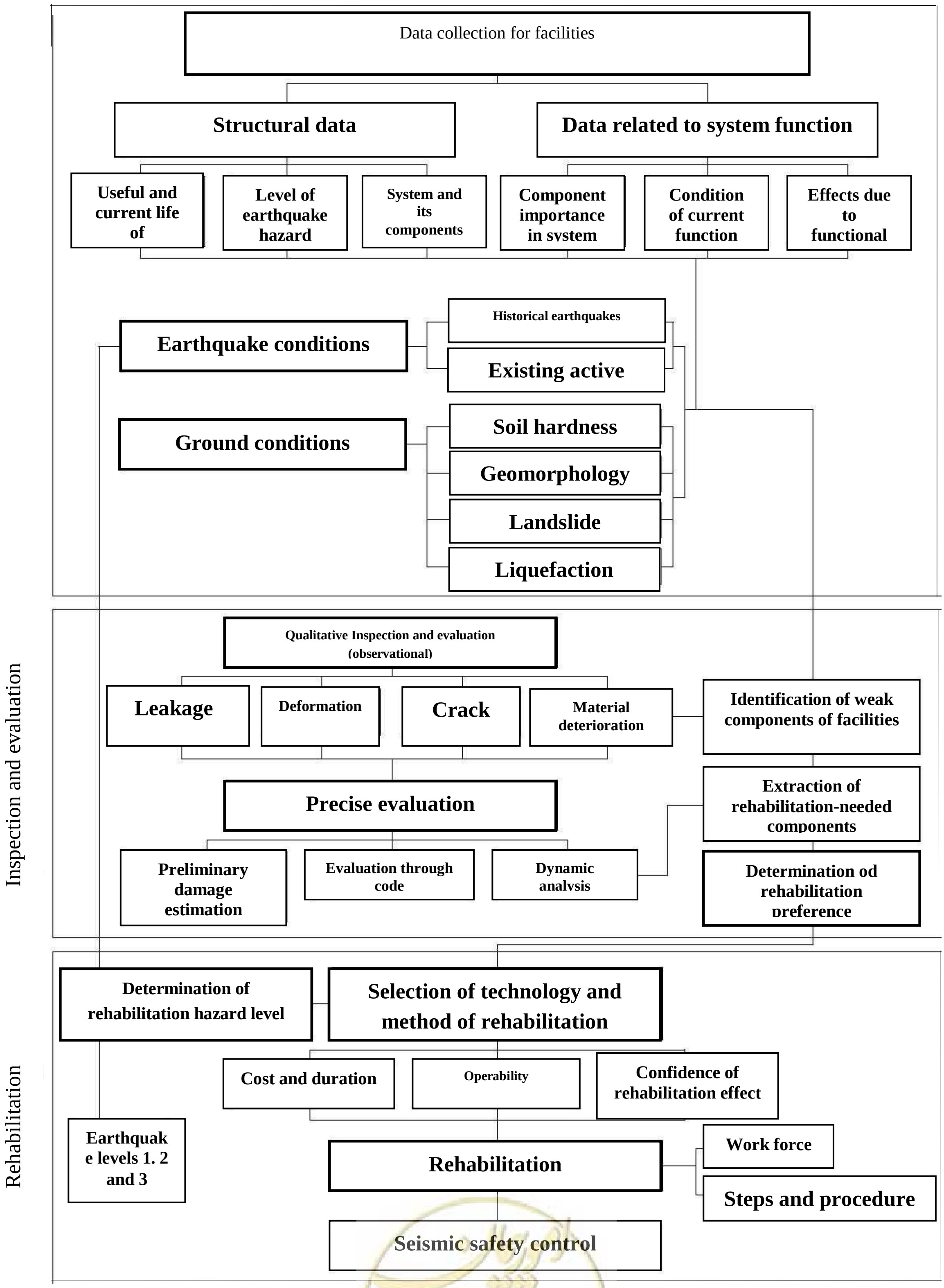
Figure 3-1 shows general approach in determination of seismic vulnerability and improvement of lifelines. This approach involves four following activities:

1-Information collection of structures, facilities and equipment involving information related to individual components and systems regarding function and process

2-Investigation geotechnical and seismicity issues involving soil specifications and secondary effects such as sliding, liquefaction, faulting and examination of seismicity history and active faults

3-Examination of seismic vulnerability

4-Seismic improvement if required


Data collection for facilities
Structural data
Data related to system function
Useful and current life of
Level of earthquake hazard
System and its components
Component importance in system
Condition of current function
Effects due to functional
Earthquake conditions
Historical earthquakes
Existing active
Ground conditions
Soil hardness
Geomorphology
Landslide
Liquefaction
Inspection and evaluation
Qualitative Inspection and evaluation (observational)
Leakage
Deformation
Crack
Material deterioration
Identification of weak components of facilities
Precise evaluation
Extraction of rehabilitation-needed components
Preliminary damage estimation
Evaluation through code
Dynamic analysis
Determination od rehabilitation preference
Rehabilitation
Determination of rehabilitation hazard level
Selection of technology and method of rehabilitation
Cost and duration
Operability
Confidence of rehabilitation effect
Earthquake levels 1. 2 and 3
Rehabilitation
Work force
Steps and procedure
Seismic safety control

3-3-Seismic evaluation methods of components

The primary and details seismic evaluation methods for stationary structures, including buildings, non-building structures, equipments, and non-structural and structural line and network components for different evaluation levels are as shown in table (3.2). In addition to the suggested cases in this table, also the laboratory methods could be used especially for non-structural equipments and components.

Table-3-2: seismic evaluation methods of components in different evaluation levels

Component's name	**Level-1 evaluation methods**	**Level-2 evaluation methods**	**Level-2 evaluation methods**
Building structures	Fast evaluation instructions	Fast evaluation instructions	Detailed evaluation using seismic rehabilitation instructions
Non-building structures	Evaluation using qualitative evaluation worksheets or using scoring methods	Controlling seismic behavior by reviewing primary design documents and using simple and static-equivalent (pseudo-static) methods of code	Software and numerical modeling and pseudo-dynamic, dynamic, and interactive behavior analysis
Outdoor equipments	Evaluation using qualitative evaluation worksheets or using scoring methods	Controlling general seismic stability by reviewing design documents and using: - Code's simple and static-equivalent methods - Empirical methods based on damage curves - Vulnerability spectrum method - using empirical screening	Software and numerical modeling and pseudo-dynamic, dynamic, and interactive behavior analysis
Non-structural components and indoor equipments	Evaluation using qualitative evaluation worksheets	Qualitative evaluation worksheets	Controlling general stability using static-equivalent methods or empirical methods
Aerial and underground transmission and distribution lines	Evaluation with qualitative evaluation worksheets or using scoring methods	Controlling seismic general stability under geotechnical hazards (slippage, faulting, liquefaction, etc.) and interactive effect of neighboring structures	Dynamic behavior analysis under geotechnical hazards (slippage, faulting, liquefaction, etc.) and interactive effect of neighboring structures

		by reviewing design documents and using simple and empirical methods	and analytic and numerical modeling

3-3-1-Buildings seismic evaluation

In addition to the issues addressed in determining the evaluation parameters, the key factors in evaluating the buildings' performance are as follows:

- Structure's economic value and years left from its operation life.
- Building's application including number of people inside the building exposed to danger and structural damage factors which would lead to releasing of dangerous materials and casualties outside the building.
- Structure's performance and economic and social effects in case of damages to its servicing in result of earthquake.
- Historical significance of the structure and effects of seismic rehabilitation on cultural and heritage sources.
- Site-specific seismic hazard.
- Relative costs of rehabilitation compared to its revenue.

The primary seismic evaluation in levels 1 and 2 of concrete and steel and monumental buildings is performed based on the President's Deputy of Strategic Planning and Control's instructions #364, namely Visual Fast Evaluation Method for Steel and Reinforced concrete Buildings.

The primary seismic evaluation in levels 1 and 2 of monumental buildings is performed based on the fast qualitative evaluation method presented in the President's Deputy of Strategic Planning and Control's instructions #364 for building with monumental materials.

The level-3 detailed evaluation of concrete and steel buildings is performed using the service descriptions presented in issue #251, titled Descriptions of Evaluation and Rehabilitation Services of Buildings and issue #360 of President's Deputy of Strategic Planning and Control, Buildings' Seismic Rehabilitation Instructions.

The detailed evaluation of current monumental buildings is performed using Seismic Vulnerability and Rehabilitation Instructions for Current Monumental Unarmed Buildings (Buildings Deputy of Ministry of Housing and Urban Development).

3-3-2-Non-building structures seismic evaluation

The primary seismic evaluation of non-building structures in levels 1 and 2, which is performed as component, could be carried out using the following methods:

- Reviewing the structure's primary seismic design documents considering the status like construction and current conditions, if the documents are available
- Inspection by preparing and using seismic worksheets considering the type of each structure and evaluation using qualitative scoring method
- Using models and simple and static-equivalent methods and seismic general stability control

Usually, in the primary seismic evaluation of non-building structures, the system inspection would not be performed. If the components are vulnerable in this stage, then the detailed evaluation is performed using both component and system approaches.

The level 3 detailed evaluation of non-building structures using numerical modeling and analysis. This inspection includes studying the dynamic and interactive behavior of the structure. Using the detailed method for complex structures or with unknown dynamic behavior or with considerable interaction with environment or other structures is mandatory.

3-3-3-Seismic evaluation of non-structural components and internal equipment

Seismic evaluation of architectural members and internal equipments of buildings such as walls, racks, false floors and internal facilities such as plumbing, canals and cables is performed in single step as following regulations and guidelines:

- Appendixes of communication lifeline seismic design guideline
- Directive of seismic improvement of buildings, issue 360
- Appendixes of issues 512 and 513
- Other valid and introduced references in this guideline

3-3-4-Network and lines seismic evaluation

The seismic evaluation of lines and network is carried out in two stages, component-stage for determining the vulnerability of each network's component, and system-stage for determining the vulnerability of the entire line or network range.

The primary evaluation of lines and network components in leve-1 performed through following methods:

- Reviewing network's seismic design documents, if available
- Preparing and using seismic worksheets according to the type of network components and using qualitative scoring method
- Using simple and static-equivalent method of code and seismic general stability control of line and network components
- Using current vulnerability curves of components

Lines and network system primary evaluation in level-1 could be performed using vulnerability combination formulation based on the reliability method.

The level-3 component detailed evaluation of lines and network could be carried out by the analytical method using calculation and numerical model.

The level-3 component detailed evaluation of lines and network could be performed using vulnerability combination formulation based on the reliability method.

The combination formulation could be performed based on the reliability method using guides from appendices of issues #512 and #513.

3-4-Inspection in Qualitative Evaluation

The inspection and completion of components' qualitative evaluation forms is one of the main stages of seismic evaluation in levels 1 and 2. The result of this activity, which leads to preparation of vulnerable components primary list and their vulnerability qualitative level, has a large effect on type and volume of studies. The local inspection and concluding their results should be performed by a qualified and legitimate engineer or a group of engineers.

Usually, the general steps of this activity are as follows:

- Holding sessions with employers, technicians, standard supervisors, safety engineers, and other stakeholders to discuss the inspection's goals and provide the inspection group with the necessary possibilities
- Identification and preparing the list of considered equipments, structures, and other components
- Categorization of vulnerability modes of considered components
- Preparing and completion of inspection worksheets
- Settling required coordination with process and operation safety team
- Collecting local data such as seismic hazard, faults location, current holes in soil and other geotechnical related issues.
- Local inspection of components and filling up the worksheets and documentation of obtained observations and information
- Reviewing maps, in necessary, in order to control the sufficiency of reinforced concrete structures, determining bracing details and/or determining items which are undetectable by visual inspection due to limitations such as fireproof coverings, isolations, and so forth.
- Listing weak and suspicious components for employers and/or standard supervisors including sufficient explanations
- Identification of consequences caused by components damage

During a destructive earthquake, there is the possibility of damaging outdoor facilities and their long-term destruction. In such cases, preparing items, such as support power generator equipments and water reserves, sounds reasonable in seismic evaluation and rehabilitation. The local inspection team should highlight the existence of other emergency systems effective on system performance in order to minimize earthquake effects. Especially, the necessity of fire alert and extinguish system, communication and preventive systems for non-stop performance after earthquake, should be emphasized.

The general technical considerations in an inspection are:

- Ground's seismic hazard level: in regions with low seismic hazard, the structures might be designed considering non-seismic lateral loads, such as wind, and are also resistant against earthquake but nonetheless the destructive displacements might also occur in seismic low levels.
- Secondary hazards intensity (faulting, soil displacement, and landslip): the inspection team should pay special attention to faults near site. Locations with the possibility of displacement and damage to buried lines and equipments relying on structural systems should be considered. When faults pass through site, the evaluation of the inspection team must be completed by performing additional geotechnical studies or other studies.
- Codes applied during construction: the applied codes and design methods might undergo major changes relative to the time of designing.
- For the evaluation of older facilities, more attention must be paid to current damages caused by structural age such as steel dent, damaged concrete, corrosion, etc.

- If the general quality of maintenance is not suitable, the local inspection team must consider and inspect details, such as number of lost bolts, unrepaired damages, changes and field modification, etc., through the structure's load transmission course as well as in connections.
- The process safety engineers and employers must be informed and assured of the safety primary inspection, pollution, or economic consequences and environmental impacts, through local inspectors.
- The local inspection team must always be aware of places susceptible to corrosion. These areas are especially associated to places with corrosive materials like acids and also amassed water places. Other cases in which the corrosion might become a problem are where the concrete covering is detached and rebar is exposed to environmental conditions.
- During inspection, the engineers could inspect installed facilities which have problems. These problems might be observed in welds, or installation of expansion anchor-bolts. For example, if the length of expansion anchors is not sufficient, they might not be as resistant as their design tensile capacity allows them.
- A piece from system, structure, storage cabinets, furniture, and storage equipments might move during earthquake. Due to this movement and consequently hitting a system or component, damages might be inflicted to that component or system which is called seismic interaction. Local inspections about possible interactions are one of the best items of component performance verification. Often, when there is not enough distance between two components, these interactions occur. Also, it might be due to slippage of non-braced facilities, movement of hanging pipes and/or cable trays, deflection of electric board and collision with adjacent boards, walls or structural member. Another example includes the hazard related to passageways with sharp supports. Another case of interaction could be the structural failure and overturn when different components fall due to anchor's lack sufficiency and hit other tools.
- For inspectors, the local asymmetric displacement is more important in case of facilities attached to different structural systems. Engineers must be aware of facilities' possible displacement states. These states include items such as connection pipes, ducts, canals, tubes, etc. In such cases, facilities must have enough flexibility against movement. Flexibility is a key characteristic to resist against vulnerability. It would be of special significance when using different foundations for equipments, when they are non-braced.
- One of the notable issues is the automatic fire alert and extinguishing system. The performance of water-sensitive electric equipments might be disturbed when placed under the sprinkler heads.
- Inspecting the current buildings' vulnerability adjacent to distribution network components and risk of their collision with network components, in case of destruction, must be evaluated. Therefore, first those building close enough to distribution network components must be highlighted which might collide network components in case of complete or partial destruction. After signifying the risky building adjacent to networks, the mentioned buildings must be evaluated against earthquake during the next step. The evaluation of building adjacent to distribution network for each case must be carried out according to the respective instructions (instructions #360 and # 364 of President's Deputy of Strategic Planning and Control, for buildings with reinforced concrete or steel structures, and instruction #376 for building with monumental materials) and using quantitative methods, as far as possible. The desired

performance level in evaluation of such buildings, for the design's hazard level according to these instructions, should be considered equal to collapsing threshold and for components with high importance, equal to life safety. If it is impossible to perform quantitative evaluation for the expected building, it is mandatory to carry out complementary qualitative evaluations based on the mentioned instructions.

3-5-Collecting Required Information in Detailed Evaluation

Collecting required information of quantitative evaluation should be performed through a planned process. The current references for determining and collecting required information include:

1-Documents available during different designing, operation, and periodic maintenance stages: the available documents must be visually compared with the current condition of the network and updated, if necessary.

2-Vesting and collecting information using visual methods and required measurements: in doing so, boring and destruction of coverings and upper layers should be performed (without imposing any weakness or disturbance to components' performance or behavior) and the required characteristics and parameters should be determined.

3-Performing required tests: if necessary and lack of required information based on current documents or catalogues, the information must be prepared and collected using experimental methods. The main application of test methods is for determining required properties of soil, site, and materials' mechanical properties. Totally, the nondestructive tests are preferred. If it is necessary to perform tests on connecting tools such as bolts, it would be better to be replaced with their identical item. Anyway, during boring or testing, inflicting damages or weaknesses to each current component of the network should be avoided.

3-5-1-Collecting documents of design and operation

At the beginning of seismic evaluation studies, the structural documents of facilities, such as buildings, non-building structures, and equipments, should be collected and reviewed as far as possible. Also, the executive maps should be matched with what has been implemented and be updated if not consistent. Also, it is necessary to collect information on changes, possible repairs, and influential events on facilities' behavior.

Materials and soil test information as well as hazard analysis studies should be collected and reviewed as far as possible.

3-5-2-Visual inspection and extracting visible and effective problems

In this stage of data collection, study and reviews are performed to record the visible and effective problems which create a specific and obvious weakness in facilities' seismic behavior. Comparing executive maps, like construction and installation, with the available facilities is mandatory in this stage.

3-5-3-Performing materials and soil tests and hazard analysis studies

Based on the assessment of the consulting engineering, if there was not sufficient documents and information for primary or detailed evaluations from the previous reviews, this stage of data collection must be performed following the employer's approval.

Conditions which require materials and soil tests and tests' levels are presented in table (3.3). The definition of standard and comprehensive tests for buildings is in accordance with the Buildings Seismic Rehabilitation Instruction (issue #360). In this guideline, no specific definition is presented for non-building structures and equipments for tests, and the required tests' level in these cases should be determined by the consulting engineer's assessment and employer's approval.

Table-3-3: Required tests of materials and soil

System's Relative Importance	Materials and Soil Information	Required Test Level for Materials and Soil
Very high	Available	Standard
	Not Available	Comprehensive
High	Available	-
	Not Available	Standard
Medium	Available	-
	Not Available	Standard
Low	Available	-
	Not Available	-

3-6-Seismic Evaluation Using Structure's Modeling and Numerical Analysis

The modeling and numerical analysis methods of structures are based on determining and comparing seismic demand-capacity of equipments, structures, and their joints. Modeling and numerical analysis methods of structures include the following two major aspects.

- Preparing a proper model according to the equipment's mechanical and dynamic properties
- Prepared seismic loading and numerical analysis of structure's model

For equipments, the applied damping and mass in modeling and numerical analysis of equipment structures are considered equal to contents of manufacturers' catalogues, test sheets, and/or based on results from analytic methods. In case information is missing, the 2% damping is suggested.

The numerical analysis methods of structures suggested by this guideline are as follows:

- Equivalent static method
- Spectrum method
- Time-history method

3-6-1-Equivalent static method

In seismic analysis of equipments in which the vibration first mode is accepted as the dominant mode, the equivalent static method is suggested similar to the section of non-building structures regulations of Standard 2800.

For equipments with natural period smaller than 0.03s, applying the force, obtained from multiplying acceleration by different parts' mass, to their center of mass, without any resonance factor, is acceptable.

3-6-2-Spectrum method

For more complex equipments with numerous vibration modes which are sufficiently far from each other, using the spectrum analysis in accordance with the regulations of non-building structures of standard 2800 is suggested.

3-6-3-Time-history method

For seismic evaluation of complex equipments with close vibration modes, using the time-history analysis in accordance with the regulations of non-building structures of standard 2800 is suggested.

3-7-Considering the Systems Seismic Interaction Effect

The systems seismic interaction is a set of effects on seismic behavior and intensifying consequences of earthquake. Undesired changes in dynamic properties from adjacent systems structural interaction, collision, falling, and relative displacement of adjacent systems and changes in environmental and operational conditions which lead to disturbance in systems' or personnel's performance, are some of the cases which cause seismic interaction.

The regular reasons of interaction in power plants are categorized as follows:

1-Adjacency: any effect which leads to malfunctioning caused by systems adjacency including: collision, relative deformation, and structural interaction

2-Failure and fall down: any effect which leads to malfunctioning caused by damage, failure, and fall down

3-Sprinkler: effects of pipes failures or performance of fire extinguishing sprinklers which might lead to short circuit or inaccessibility to power plant components.

4-Inundation: effects caused by systems flooding and their inaccessibility

5-Fire: effects caused by fire like smoke spreading and systems destruction

Each of power plant systems which are in the verge of negative effects of above mentioned interactions is "target of interaction" and systems which their malfunctioning would lead to these interactions are "source of interaction". If the interaction causes damages or malfunctioning of the system, it would be called "considerable interaction" and if the negative effect is negligible, then it would be "inconsiderable interaction".

Considering the seismic interaction effects in evaluation of "target of interaction" systems could be performed using one of the following four approaches:

1-Neglecting the interaction effects (inconsiderable interaction)

2-Modification of "source of interaction" systems in order to eliminate the interaction effects (considerable interaction)

3-Elevating the relative importance of "source of interaction" systems to the limit of "target of interaction" systems (considerable interaction)

4-Using performance modification parameter for "target of interaction" equipments in the scoring method (considerable interaction) unless the "source of interaction" equipments are evaluated assuming the relative importance equal to the importance of "target of interaction" equipments (approach 3).

3-8-Acceptance Criteria

If the effects from imposed loads to electric devices consistent with the following loading combination are larger than the equipment's components seismic capacity, the equipment would be considered as vulnerable. It is noteworthy that, in case of electric devices, the potential of short circuit, which is a source for one of the considerable imposed loads, might be intensified during earthquake occurrence:

Operational load impact + short circuit load impact + dead weight load impact + earthquake impact

In regards to the type of available buildings in a distribution network, the acceptance criteria presented in the applied instructions should be used.

In regards to other components (non-building structures and equipments) in a distribution network, they would be whether accepted or not based on comparing seismic effects (resulted from their seismic analysis under loads combinations) with seismic capacity of each of them. In regards to aerial line posts, their displacement must also be examined, in addition to the seismic capacity, in order to prevent overturn.

3-8-1-Combination of applied loads

Combination of required loads for seismic vulnerability evaluation of non-building component is generally as following:

Dead loads + loads during operation + horizontal earthquake load (in two directions, independently) + vertical earthquake load (in two directions, independently)

3-8-2-Structural components' strength and capacity

The capacity and strength of different components based on type of materials is obtained as follows using the respective standards:

- The seismic capacity of parts made of ceramic and porcelain, such as insulators, is considered according to the respective standards and catalogues and/or equal to 85% of ultimate strength of their materials. The above mentioned capacity should be considered in every hazard level.
- The seismic capacity of steel components for hazard level-2 or design should be considered equal to 1/7 of allowable stresses (and/or ultimate strengths) and for hazard level-1 or operation should be equal to allowable stresses according to section 10 of National Building Code (NBC).
- The seismic capacity of reinforced concrete components for hazard level-2 should be considered equal to the nominal strength of components (with material's strength reduction factor) and for operational hazard level should be equal to the strength equivalent to the cracking limit according to section 9 of NBC.

- The seismic capacity of aerial lines wooden posts for design and operational hazard level are assessed based on their standard category, based on ultimate strengths (for design level) and cracking limit (for operational hazard level) related to each class.
- The seismic capacity of aerial lines wires for design hazard level should be considered equal to yield tensile strength and for operational hazard level should be equal to allowable tensile stress according to section 10 of NBC.
- The seismic capacity of ground line cables for design hazard level should be considered equal to the longitudinal strain equivalent to the cable’s failure limit and for operational hazard level should be equal to longitudinal hazard level equivalent to the allowable tensile stress.

3-8-3-Controls related to displacement and overturn

In regards to non-braced parts and equipments as well as aerial lines, in addition to examining the seismic demands and capacity in terms of strength, it would be necessary to control overturn, slippage, and displacement, which are performed as follows:

- Non-braced equipments and pieced must be controlled against imposed seismic forces, in regards to overturn and slippage. The minimum values of required reliability for overturn and slippage in both hazard levels are 1.75 and 1.5, respectively.
- The escape value of aerial line posts (ratio of difference between displacements of both ends of post to its height or post’s rotation angle) for design hazard level is limited to 0.02 and for operation hazard level to 0.01.

3-8-4-Equipments bracing strength and capacity

In braced equipments and parts in concrete or other materials, the capacity of bracings should be determined based on the third chapter of issue #512.

3-8-5-Acceptance criteria in nonlinear dynamic methods

Totally, in nonlinear dynamic methods, evaluation and acceptance of different components are performed using criteria composed of force and displacement combination. In telecom distribution networks, considering the expected performance of equipments and network components, the stresses and internal forces created in non-ductile components (controlled by force) should be controlled similar to linear methods (presented in previous paragraphs), in case of performing nonlinear analyses. In ductile components which enter the nonlinear range, created displacements and rotations should be to the extent that does not disturb the evaluated component’s expected performance. Identifying these items should be performed based on equipments’ technical properties and experts’ judgment

Chapter 4

Seismic Rehabilitation Procedure

4-1-Rehabilitation Prioritization

The rehabilitation prioritization is carried out based on the following indices:

- Layer index, IL
- Changing expected performance level
- Rehabilitation cost
- Feasibility of rehabilitation method

The general method to determine the rehabilitation priority is based on risk analysis. In order to perform this analysis it is necessary to determine the consequences of not rehabilitating based on vulnerability studies' results and to decide on this basis. The consequences of not rehabilitating are verified in five categories, namely casualties, possibility of social and political crises according to time of power-cut, direct financial damages to facilities, economic damage caused by vital artery power-cut, environmental damages. In fact, these criteria determine the general safety of structure or equipment.

The highest rehabilitation priority is designated to the first two categories. In other cases, comparing the rehabilitation cost and predicted damage costs, the risk of not rehabilitating is determined and is decided on this basis. In risk analysis, different damage modes and also rehabilitation levels could be compared with each other.

4-2-Seismic Rehabilitation Procedure

The seismic rehabilitation of structures and equipments is a error and trial method and is performed following ensuring the vulnerability of the structure and based on the following steps:

- Choosing the rehabilitation methods based on damage mode of equipments, structures, and their required performance
- Applying changes caused by each rehabilitation method in structural model and reexamining vulnerability to obtain the expected suitable performance
- Comparing acceptable rehabilitation methods based on cost, time, and executive feasibility as value engineering, prioritizing each structure's and equipment's rehabilitation methods

Seismic rehabilitation prioritization of system components based on paragraph 4.1

Chapter 5

Methods of seismic improvement

5-1-Rehabilitation Method Selection Approach

The structures and equipments seismic consequences reduction methods could be divided into two general groups:

- Hardware methods as structural rehabilitation and modification and finally renovation
- Software methods as changing operation schedule, changing expected performance level, and increasing safety and reducing secondary incidents occurrence possibility

The seismic rehabilitation method depends on the dominant damage mode of structures and equipments. Thus, selecting a proper rehabilitation method has direct relation with the vulnerability evaluation results validity. In these studies, the damage mode and damage amount should be signified. Indeed, depending on the hazard level, the damage mode could differ, which this should be considered during selecting the rehabilitation method so that it would be possible to control all possible damage modes by performing proportionate rehabilitation exercises.

In reviewing damage modes and presenting rehabilitation methods, all primary and secondary damage modes must be taken into account. The secondary damage modes include permanent ground deformations, fire, fire, explosion, structures collision, destruction rubble fall-down of other components on them, and other cases.

5-2-Type of improvement methods

Public training about usage of communication systems during and after earthquake occurrence is as important as protection of equipment against earthquake. Network occupancy or traffic is a usual and common issue after earthquake occurrence. Unless cases related to emergency and rescue operations, people must be trained in the field of appropriate usage of communication systems in the emergency occasions that make lines to be free for emergency calls and rescue services.

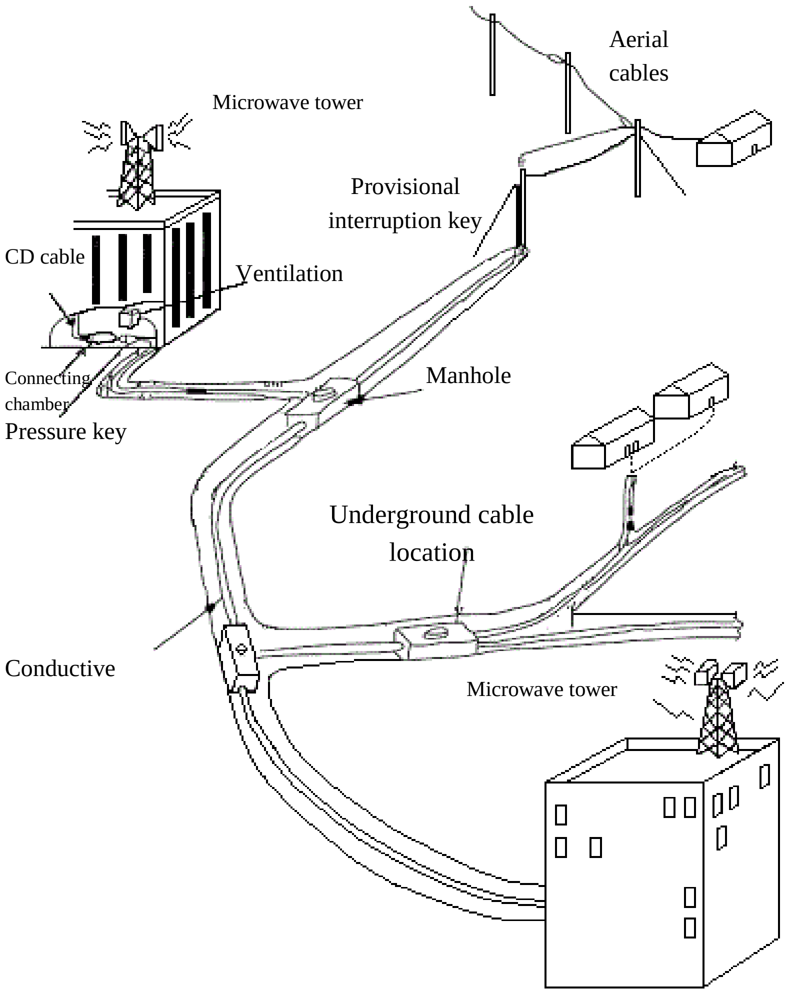


Figure 5-1-Schematics of communication network

In this section, general methods of seismic improvement and communication equipment are proposed on the basis of observed failure modes in pervious earthquake.

5-2-1-Switching centers

One of the main elements of maintaining communication connections are switching centers that disruption of connection in them lead to disruption of call connection in its undercover area and disorder in communication network. Obviously if this disorder happens in main centers of network such as international switching or each Subscriber Trunk Dialing (STD), connection with other countries or connection of vast area of the country with other area is disrupted. So it is necessary that these structures and equipment to be adjusted against earthquake occurrence and its likely effects. Switching equipment maintains two important tasks:

1-Connecting one subscriber to another subscriber

2-Give access permission of many lines from low numbers of main branch

In a communication center, there are numerous row types of switching equipment that maintain two above-mentioned tasks, permanently. Switching system involves local switching that performs path-finding calls in system and also access to another switching systems and remote switching that allows path-finding to remote lines.

There is a cable system and a power supply in each communication center to support switching equipment. In a communication center, cables pass usually from above of equipment. Cables involve connecting cables, supply cable and external network cables. A supporting structure is used for maintenance of cable sets. Cable trays are installed on horizontal members of truss studs. Cables that go from one story to another are supported by cable ladders.

5-2-1-1-Non-building structures

Non-building structures have numerous and various failure modes. These structures can be classified into three major classes:

1-Special structures such as towers and antenna

2-Connecting structures such as channels and underground conduits, shunts and racks

3-Secondary structures inside and outside of the buildings such as separating walls, buttresses and load-bearing floors

Table 5-1 presents list of all types of these structures with introduction of observed and likely seismic failure modes, common causes of these failure modes, damages and general methods of their improvement in terms of mode and related failure.

Seismic failure modes of non-structural buildings aren’t confined to items mentioned in this table and consultant must investigate appropriately occurrence probability of other seismic failure modes in terms of site condition and results of vulnerability studies.

Table 5-1-Guideline of seismic improvement of non-building structures

component	Probable failure mode	Improvement method	Failure cause
Underground channel	Collapse of wall and entrance of soil into the building Cracking channel wall and opening of traction joints Fall of ceiling caps into channel Damaging cables on studs	Reinforcement of concrete wall of channel from outside or by internal anchorage Adding joints or longitudinal reinforcement for removing joint Imbedding minimum 10 cm of supporting surface in each side or imbedding brake Removing edge of seating stud of cable with substation or improvement of stud	Insufficient resistance capacity of wall concrete to endure lateral pressure of soil Hugh ground deformation and improper design of joints Insufficiency of cap supporting surface on support Shape edge of seating stud of cable
False floor	Collapse of supporting pillars or anchorage them to floor	Imbedding anchorage in bases, reinforcing base braces, installation of heavy equipment on separately reinforced seating	Lack of sufficient lateral strength, weakness of base anchorage to floor, installation of heavy equipment on floor and lack of separate reinforced seating
Walls	Surfacial or deep-seated diametrical shear cracking in body and surrounding of openings Vertical crack in connection point with pillar overturning	External reinforcement of wall to endure lateral load, imbedding internal or external hasping with metallic belts or FRP or FRP sheets or concrete spraying with three-dimensional reinforcing mesh or panel or injecting or mechanical anchor bars, improvement of connection to frame Improvement of connection to frame, imbedding internal or external hasping Reinforcing connection with frame, imbedding internal or external hasping	Insufficient shear capacity, non-reinforcement, non-controlled connection to frame, lack of sufficient and suitable hasping Non-controlled connection to frame, lack of sufficient and proper hasping, improper and non-reinforced connection to frame, lack of sufficient and proper hasping

5-2-1-1-1-Towers and antennas

Antennas are steel structures that usually are installed on the ceiling of communicating centers and used as part of high capacity telecommunication system for servicing remote areas. At least two dish antennas are installed on the top of each tower pointed in different directions to transmit and receive used signal. In urban and congested areas, some towers are installed on the top of high commercial buildings.

Cell antennas are of new equipment of external network. These types of network use radio signals instead of wire to communicate with call center. Antennas are usually installed on the same towers of microwave towers. Two types of antenna are usually used:

-Bi-pole (Omni-directional) antenna

-120 degrees sectorized trans-receiver antenna

Structures of microwave towers must be designed in a manner that resist against wind load that is generally more than earthquake load so these towers are resistant against damages due to earthquake. However, controlling ground deformations against earthquake must be performed individually. Moreover, towers are analyzed for four special loading mode involving wind, environmental, ice and earthquake load.

Towers and antennas are in various types involving different configurations of trussed bases, telescopic metallic bases and anchored frame or trussed bases that trussed type in the most common among them. These bases don't have considerable failure record under earthquake vibration due to lightness and their main failures in earthquakes were happened due to ground deformations, collapse of buildings or landfall.

Table 5-2 presents lists of various observed likely seismic failure modes, common causes of these failure modes, damages and general methods of improvement in terms of related failure mode and cause. Seismic failure modes of towers aren't confined to items mentioned in this table and consultant must investigate appropriately occurrence probability of other seismic failure modes in terms of site condition and results of vulnerability studies.

Table 5-2- Guideline of seismic improvement of towers and antennas

Component	Probable failure mode	Failure cause	Improvement method
Trussed bases	Overturning, sliding and tilting	Hugh ground settlement due to liquefaction or lateral extension Hugh ground displacement due to slope sliding Hugh ground displacement due to faulting in intersection with fault Collapse of mountain and surrounding structures Overturning adjacent towers Lift of tower parts and weakening structures	Ground consolidation with injection or compaction Reinforcing foundation or imbedding pile or micro-pile or conversion to flattened foundation Slope consolidation or tower anchorage against sliding or reinforcement of foundation or using tendon or building buttress wall in the feet of tower Displacement of towers located in faulting area Consolidation of slumping with concrete-spraying and mesh or using cable mesh traps Sliding rocks or structural barriers in the upper part of tower for anchorage sliding parts Physical protection by anti-robbery bars
Telescopic metallic bases	Overturning, sliding and tilting	Hugh ground settlement due to liquefaction or lateral extension Hugh ground displacement due to slope sliding Hugh ground displacement due to faulting in intersection with fault Collapse of mountain and surrounding structures Interaction with building	Ground consolidation with injection or compaction Reinforcing foundation or imbedding pile or micro-pile or conversion to flattened foundation or increase burial depth Slope consolidation or base anchorage against sliding or reinforcement of foundation or using tendon or building buttress wall in the feet of tower Displacement of towers located in faulting area Consolidation of slumping with concrete-spraying and mesh or using cable mesh traps Sliding rocks or structural barriers in the upper part of tower for anchorage sliding parts
Braced framed or trussed bases	Overturning, sliding and tilting	Hugh ground settlement due to liquefaction or lateral extension Hugh ground displacement due to slope sliding Hugh ground displacement due to faulting in intersection with fault Collapse of mountain and	Ground consolidation with injection or compaction Reinforcing foundation or imbedding pile or micro-pile or conversion to flattened foundation or increase burial depth Slope consolidation or base anchorage against sliding or reinforcement of

Component	Probable failure mode	Failure cause	Improvement method
		surrounding structures Overturning adjacent towers Low tensile capacity of anchorage Displacement of anchorage support	foundation or using tendon or building buttress wall in the feet of tower Displacement of towers located in faulting area Consolidation of slumping with concrete-spraying and mesh or using cable mesh traps Sliding rocks, structural barriers in the upper part of tower for anchorage sliding parts Replacement or addition of anchor Consolidation of anchor support
Cables, conductors and optic fiber	Cable rapture, damage of cable due to frictional girth of cable trays	Overturning or tilting pillar Vibration and resonance in cable	Base consolidation Removing vibration mode of cable resonance with changing its vibration characteristics, changing tension inside cable, change in array of cable separators

5-2-1-1-2-Connecting structures

In the case of connecting structures, safe connection with floor (structural floor) is of the prime importance to assure non-occurrence of sliding and overturning equipment. If in special occasion, apparatus must be installed on the false floor, equipment must be installed on separator base and on structural floor and base must be connected to base using suitable bolts to prevent its displacement in horizontal and vertical sliding.

Cable trays and ladders must be connected to structural ceiling through suitable braces (vertical and tilted). In the case of connection of cable tray to wall, it must be earthquake-resistant that must be installed by special chute that is screwed to floor and wall.

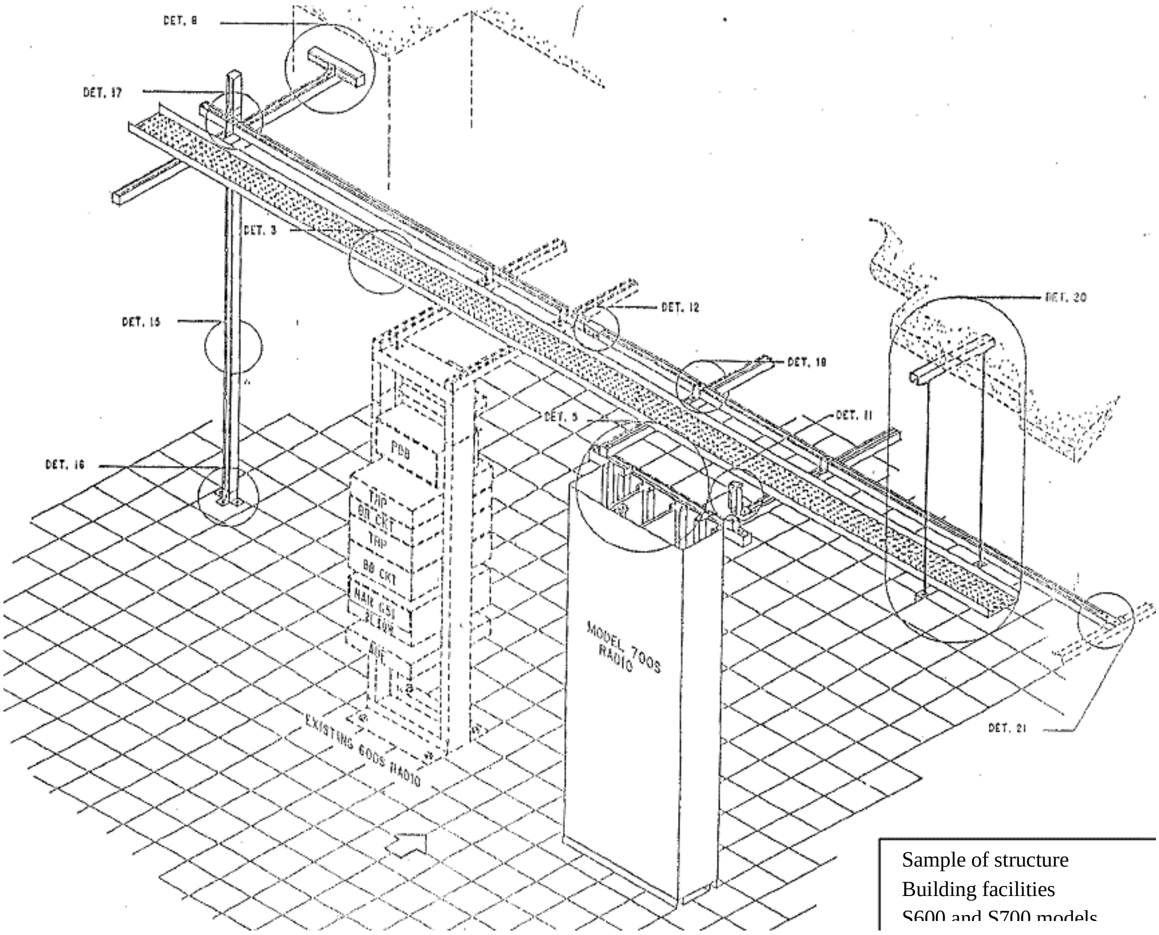


Figure 5-2-Stabilizing radio equipment to floor and walls

5-2-1-2-Equipment

Equipment can be investigated in two following classes:

1-main equipment of communication switch

2-control and support equipment inside buildings such as control panels, battery rack, lightening and power system, fire fighting system, computer equipment and display and racks.

Table 5-3 present lists of various types of these equipments together with observed and likely seismic failure modes; common causes these failure modes, damages and general methods of their improvement in terms of related failure mode and cause. Seismic failure modes of powerhouse equipment aren't confined to items of this table and consultant must investigate appropriately occurrence probability of other seismic failure modes in terms of site condition and results of vulnerability studies.

Table 5-3- Guideline of seismic improvement of equipment

component	Probable failure mode	Failure cause	Improvement method
Transformer	Overturning and sliding Fracture or oil leaking from bushing Separation of radiator Separation of oil tank	Uncontrolled sliding due to lack of proper lateral brace or its position on wheel and rail Uncontrolled bushing vibration Lack of lateral anchorage system Lack of lateral anchorage system	Replacement of wheel with anchored seating Connection with foundation through anchorage bar Lateral metallic supporter connected with foundation Replacement of porcelain bushing with composite Reinforcement of cap connection against leaking Imbedding proper lateral anchorage in base Imbedding proper lateral anchorage in transformer body Imbedding proper lateral anchorage in base
Battery rack	Overturning	Lack of lateral anchorage system	Imbedding lateral anchorage for battery-bearing rack
Control panel	Overturning	Lack of lateral anchorage system	Connection to floor through anchorage bar Lateral connection to wall Connection to ceiling Connection of panel together
Shunt	Separation and fracture of connections	Uncontrolled relative displacement	Replacement of pipe aluminum shunt with cable through imbedding sufficient looseness and freedom Using opening and closing mechanical parts in shunt connection
Condenser, fan, chiller, ventilator	Overturning	Lack of lateral anchorage system	Connection with floor through anchorage bar Lateral connection to wall Imbedding seismic separator in base
Lightening system	Cable rupture and disruption of communication cable	Uncontrolled relative displacement	Imbedding sufficient freedom of cable
Fire fighting system	Overturning	Lack of lateral anchorage system	Connection with floor through anchorage bar Lateral connection to wall
Computer equipment and display	Overturning	Lack of lateral anchorage system	Connection with bolt or glue to anchored table Connection together Connection to wall by bolt
racks	Overturning	Lack of lateral anchorage system	Connection with floor through anchorage bar Lateral connection to wall Connection to ceiling Connection of racks together
Communic	Overturning	Lack of lateral anchorage	Connection with bolt or glue to anchored table

component	Probable failure mode	Failure cause	Improvement method
ation equipment		system	Connection together Connection to wall by bolt

5-2-1-2-1-Switch equipment

There are numerous methods to reduce damages of equipment in communication centers. All equipment of communication centers must be anchored. Heavy, thin and tall equipment of electromechanical switches are anchored to ceiling from top. Equipment height is variable from 2.7 to 3.45 m. Ceiling height of most of communication centers are variable between 4.8 and 6 m; so anchorage these equipment from top is a suitable solution. Top member of equipment rack is connected to frame or ceiling through u-shaped bolts. All types of equipment are anchored together.

New electronically equipment has smaller dimensions and their height is varied between 1.8 to 2.1m. So it isn’t possible to brace them from top in building with high ceiling. There are methods for protection of these apparatus against overturning and fall, involve:

- Diametrical anchorage in which every row of ironwork is a truss that is located under ceiling in all over the surface
- Lateral stabilizing of one row of equipment that positioned next to each other. This is performed by steel pillars that are located in two ends of one row of equipment. These pillars are connected to floor and ceiling of gallery. Outfit is connected to these pillars and prevents equipment overturning.
- Horizontal cable anchorage system uses steel cables that are connected to building pillars. One net of ironwork that is stables over equipment frame is connected to cable in several points.
- Self-resting outfit

All of these methods require anchorage outfit to floor as well. Outfit anchorage from top leads to reduction of applied force to floor anchorage against force due to earthquake.

Self-resting is applied to equipment that require no external anchorage if it is bolted to floor. Second generation of digital equipment is designed and manufactured in such a way that to be self-resting. Two following approaches are used in self-resting design of these types of equipment:

- Using structural frame in each row of equipment
- Stabilizing equipment

These approaches are based on increment of natural frequency of system up to 10 Hz in order to keep away natural frequency of outfit from range of 2 to 5 Hz of earthquake vibrations that prevent form resonance of vibration with building, as well. New electronic equipment has numerous merits against olden systems, i.e. their gravity center is lower, their weight is lower and their support width is higher. Development of self-resting system is possible with advance of anchorage systems.

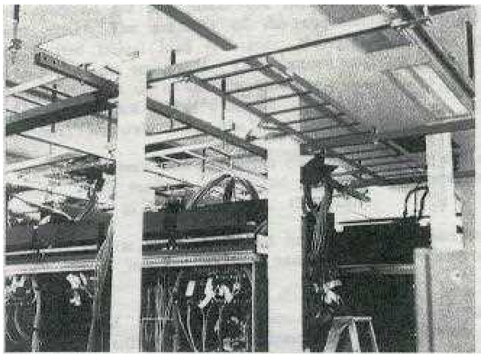


Figure 5-3-lateral stabilizing of equipment rows

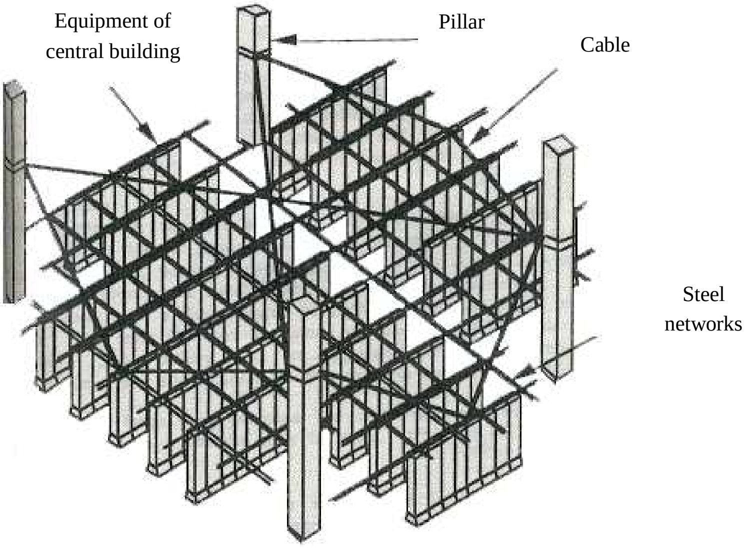


Figure 5-4-Horizontal cable anchorage system

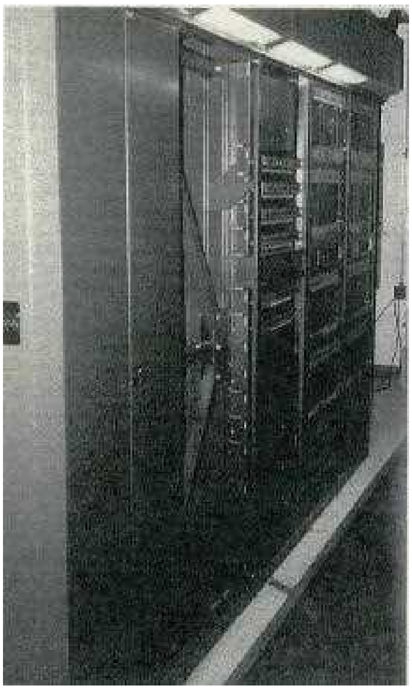


Figure 5-5-Mechanical anchorage frame

Using false floor in switching centers is a rational approach. Available computers in switching center require controlled environment for proper functioning. Cables that pass over equipment are located under floor away from eyesight if false floor is used and maintenance of cables is easier. Most of available false floor in market have general resistance against lateral loads.

There are various approaches for reinforcement of equipment on floors against lateral loads that involve:

- Bolting outfit to structural floor
- Imbedding lateral pillars in two ends of each row
- Imbedding structural pedestals under equipment

Bolting is done to connect frame base of outfit to structural floor through crossing false floor. This method is designed to prevent from overturning equipment but allows movement to depreciate energy.

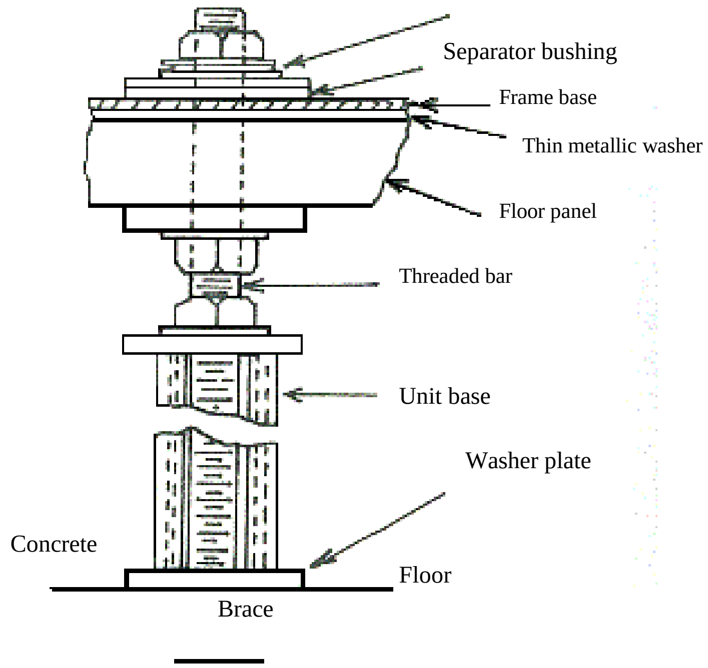


Figure 5-6-anchorage bolt that passes from false floor

Method of lateral pillars is similar with method of anchorage equipment from top that was discussed before. The difference is that one metallic member is embedded under false floor to connect with outfit. Structural pedestals under equipment are constructed to convey their load to false floor. In this case, structure must be harder than outfit to prevent from resonance.

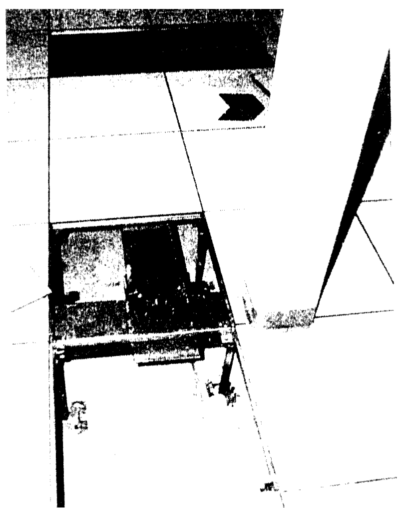


Figure 5-7-Application of anchorage through lateral pillar in false floor

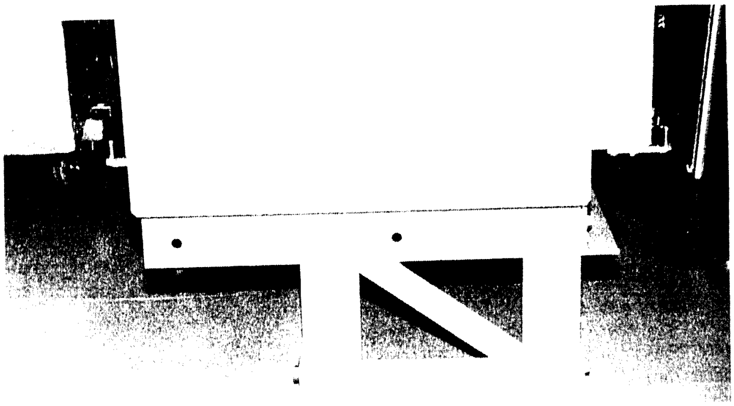


Figure 5-8-Using structural pedestals in false floor

In total, following important points must be observed regarding improvement of switch equipment:

a) Racks must be completely and reliably connected to floor altogether. To this end, details about rack installation on floor (directly) and rack installations on supporters (installation of rack on false floor) are given by manufacturing companies. Supporters are connected to structural floor by roll bolt. In addition to connection with floor, racks are connected with each other in top that maintain distance between racks. It is recommended that false floor to be used in apparatus halls of high-capacity centers because it facilitates installation of separator equipment and direction of connecting cables from floor.

b) In the case of using roof ladders to transit connecting cables, it is required that load to be properly distributed on ladders and bases to be used that connect to roof (tilted bases to prevent from displacement during earthquake).

c) Building walls must not be used for installation of supports as long as possible, because brick walls aren’t usually earthquake-resistant and are damaged locally or totally. So only concrete walls and pillars must be used for installation of supporter.

d) Card-maintain locks must be used to prevent card movement in rack shelves and quaking during card displacement.

e) Connecting cables in connection point to switch equipment must be capable of displacement and flexibility to prevent cable disruption during probable rack quaking.

5-2-1-2-2-Electrical equipment

Required electrical energy of communication system is supplied by electrical equipment so disorder in these equipments disrupts communication. Therefore it is essential that power supply equipments to be improved against non-natural and natural (such as earthquake) factors. Power supply systems are classified into two classes: main power system and reserve power system (emergency). This system usually is located in a separate room or a separate story.

Usually beneath part of communication center buildings is considered for installation of power system. In the most cases, this system is installed in the underground of building. Main power system involves control system, rectifiers and batteries and emergency system involves diesel generator. Input current (civil power) is used after transmission from a series of keys and rectifiers to balance direct current (DC) to charge batteries that supply power of switching equipments. In the case of interruption of civil power current, required current of switching equipments is supplied from batteries without any impression of power interruption. Batteries can supply up to 8 hours of required power of switching system. Emergency power producers are considered to supply required power after interruption of civil power, as well.

Installation place of power equipments must be in such a way that interaction between these equipment and non-electrical facilities such as gas and water pipes and also heating and chilling facilities to be prevented. Power equipments involve following items:

5-2-1-2-2-1-Batteries

Batteries as storing device of electrical energy play a major and important role in incessant power supply of communication systems. Pervious earthquakes have shown that batteries are one of the most sensitive electrical equipment during earthquake. Overturning and rupture of wall of batteries leads to outgoing their acid water and pull out them from operation mode.

All battery houses must be connected to structural floor by roll bolt and space between battery cells and metallic house must be filled with suitable separator (compacted rubber) to prevent from loosening batteries.

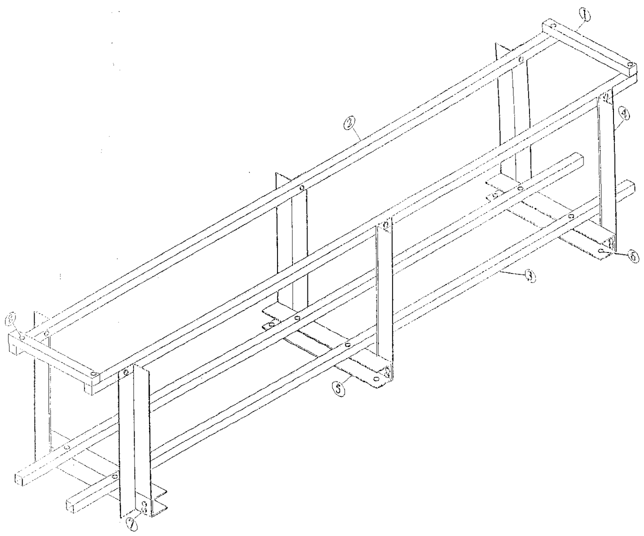


Figure 5-11-An example of battery houses

Usually each rack involves two tall drawer made of steel or metallic pipe. Cells of each drawer are the maintenance place of each battery and they are separated from each other by wax parts to prevent from vibrate motion of batteries during earthquake.

Cells in mid-elevation of each drawer have a rail that prevents batteries from fall due to earthquake motions. Some of battery racks involve diametrical anchorage but most of them aren’t. All battery racks are connected to structural floor. Very heavy and big batteries are installed on structural floor without placing against each other. A steel frame is used for maintenance of batteries.

Figure 5-12-rack of batteries

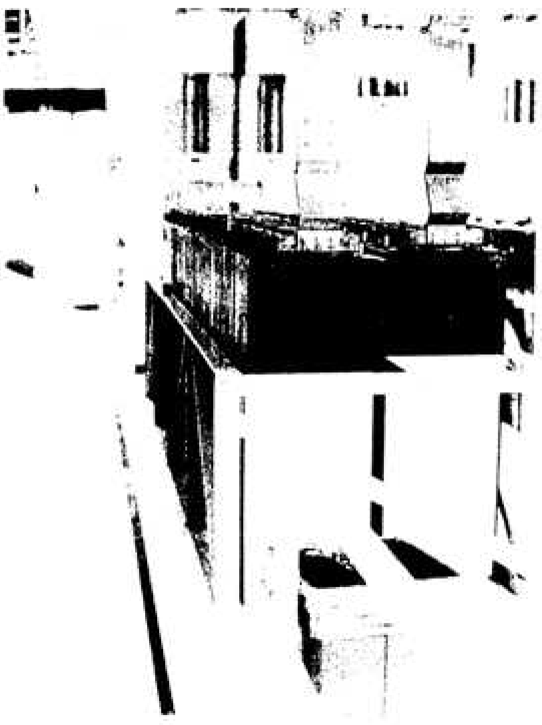


Figure 5-13-installed batteries on floor

5-2-1-2-2-2-Power supply and panels

Often there are proprietary transformers in communication centers and stations. Since movement of transformers (sliding or overturning) and disruption of their electrical connections is the most important failure mode of transformers, required preparation to prevent their movement is essential. In the case that transformer is connected to framework by bolt, sufficiency of bolt under earthquake loading must be assured and if transformer is reliant on wheel, it is required that wheels must be improved with proper stabilizer against movement.

Power panel and supply that are positioned as standup cells (unidirectioners, UPS system, DC/DC cells, AC/DC inverter and distribution panels) must be connected to structural floor from at least four points by means of roll bolt or bolt and roll plaque. In the case of false floor in the installation point of cells, it is essential that proper base (frame) must be prepared and base must be connected to structural floor through proper roll bolt.

Where panel is connected directly on floor, channel width under cells (where the direction of cable passage is prepared) must be equal to maximum half of cell width.

Regarding panels that are connected to wall, it is essential that the mentioned panels to be installed on main pillar or on shear walls.

5-2-1-2-2-3-Tracks and ladders bearing power supply cables

In the centers involve false floor, it is essential that space under false floor to be used for cabling. Where cable ladders or trays are used for cable maintenance, proper maintainer must be considered on structural wall or ceiling. Cable ladders or trays must be connected to ceiling by means of vertical or tilted braces to withstand against displacement during earthquake.

5-2-1-2-2-4-Diesel generators

Diesel generator is used in most of communication center as support of network power. Three main following points must be considered in improving diesel generators:

a) Proper connection of diesel to foundation
b) Improving tank of diesel fuel
c) Proper connection of power panels of diesel generator

It is recommended that alarming systems of firefighting to be installed in diesel generator rooms as far as possible. According to the pervious experiences, diesel is relatively resistant against earthquake but its accessory equipments, especially daily fuel tank must be improved properly against earthquake. Installation of daily fuel tank must be performed as standup. Tank bases must be anchored and bases must be tightened to ground by suitable roll bolt (minimum 10 mm). However, it is essential for ingoing and outgoing fuel pipes of daily tank (from main fuel tank and diesel generator to daily fuel tank) to be of flexible type.

5-2-1-3-Buildings

Seismic improving of building is performed according to seismic improving guideline (issue 360, deputy of presidential strategic planning and control)

5-2-2-Communication lines

Communication network must involve additional redundancy and good expansion. This merit is decreasing gradually with increment of capacity and speed of signal transmission and interpretation that is caused by using optic fiber cables. Since available cable is decreasing due to using optic fibers, damage reduction is regarded as one of the main factors of network integrity.

5-2-2-1-Arial lines

High voltage lines are usually associated with communication optic fiber cables so failure of these lines is depended on failure of power transmission lines. Other types of aerial lines are as communication cables on bases that behave like power bases. Non-building structures of this network involve predominately usual and pre-stressed concrete, metallic and wooden bases, studs and their accessories.

Table 5-4 presents lists of various types of these equipments together with observed and likely seismic failure modes, common cause these failure modes, damages and general methods of their improvement in terms of related failure mode and cause. Seismic failure modes of these structures aren't confined to items of table 5-4 and consultant must investigate appropriately occurrence probability of other seismic failure modes in terms of site condition and results of vulnerability studies.

Table 5-4- Guideline of seismic improvement of non-building structure of communication aerial lines

component	**Probable failure mode**	**Failure cause**	**Improvement method**
Usual reinforced concrete beams	Overturning and sliding Tilting Bending shear fracture	Hugh ground settlement due to liquefaction and lateral extension Hugh ground displacement due to slope sliding Hugh ground displacement due to faulting in the intersection with fault collapse of debris and surrounding structures overturning surrounding beams insufficient shear and bending strength of material	Ground consolidation through injection or compaction Reinforcement of foundation or increment of burial depth Slope consolidation or base anchorage against sliding through reinforcement of foundation or building buttress wall on its feet Displacement of bases located on faulting area Consolidation of weak adjacent structures Base displacement from risk of building or debris collapse adding shear and bending strength through confining it with FRP and using its belts adding shear and bending strength through confining it with reinforced concrete adding shear and bending strength through reinforcement with steel belts using Surfacial metallic net stabilizer in the intersection with ground
Pre-stressed concrete beams	Overturning and sliding Tilting Bending shear fracture	Hugh ground settlement due to liquefaction and lateral extension Hugh ground displacement due to slope sliding Hugh ground displacement due to faulting in the intersection with fault collapse of debris and surrounding structures overturning surrounding beams Insufficient shear strength	Ground consolidation through injection or compaction Reinforcement of foundation or increment of burial depth Slope consolidation or base anchorage against sliding through reinforcement of foundation or building buttress wall on its feet Displacement of bases located on faulting area Consolidation of weak adjacent structures Base displacement from risk of building or debris collapse adding shear and bending strength through confining it with FRP and using its belts adding shear strength through reinforcement with steel convoluted belts using Surfacial metallic net stabilizer in the intersection with ground
Wooden beams	Overturning and sliding Tilting Bending shear fracture	Hugh ground settlement due to liquefaction and lateral extension Hugh ground displacement due to slope sliding Hugh ground displacement due to faulting in the intersection with fault collapse of debris and surrounding structures overturning surrounding beams Insufficient shear strength bending strength of material	Ground consolidation through injection or compaction Reinforcement of foundation or increment of burial depth Slope consolidation or base anchorage against sliding through reinforcement of foundation or building buttress wall on its feet Displacement of bases located on faulting area Consolidation of weak adjacent structures Base displacement from risk of building or debris collapse adding shear and bending strength through reinforcement with steel belts base replacement Using Surfacial metallic net stabilizer in the intersection with ground

component	Probable failure mode	Failure cause	Improvement method
Metallic beams	Overturning and sliding Tilting shear fracture	Hugh ground settlement due to liquefaction and lateral extension Hugh ground displacement due to slope sliding Hugh ground displacement due to faulting in the intersection with fault collapse of debris and surrounding structures overturning surrounding beams Insufficient bending strength of material	Ground consolidation through injection or compaction Reinforcement of foundation or increment of burial depth Slope consolidation or base anchorage against sliding through reinforcement of foundation or building buttress wall on its feet Displacement of bases located on faulting area Consolidation of weak adjacent structures Base displacement from risk of building or debris collapse adding shear and bending strength through reinforcement with steel belts Using Surfacial metallic net stabilizer in the intersection with ground
Aerial cables and conductors	Cable rupture	Overturning or tilting base Vibration or resonance in cable	Base consolidation Removing vibrative mode of cable resonance with changing its vibrative characteristics or changing extension inside cable or change in array of cable separators
Accessories and connections	Fracture of accessories and connections	Overturning or tilting base Vibration or resonance in cable	Reinforcement of accessories connections and using high strength bolt Replacement of accessories with resistant type
Insulators	Separation from accessories	Overturning or tilting base Vibration or resonance in cable	Reinforcement of insulator connections and using high strength bolt Inserting sufficient looseness in insulator connection cables
Branches of subscribers	Rupture of connection cable	Insufficient looseness for depreciation of relative displacement of building and cable connected to network	Inserting sufficient looseness for depreciation of relative displacement of building and cable connected to network

Aerial cables must have sufficient flexibility in connection with bases and branches. Figure 5-13 shows an example of making flexibility.

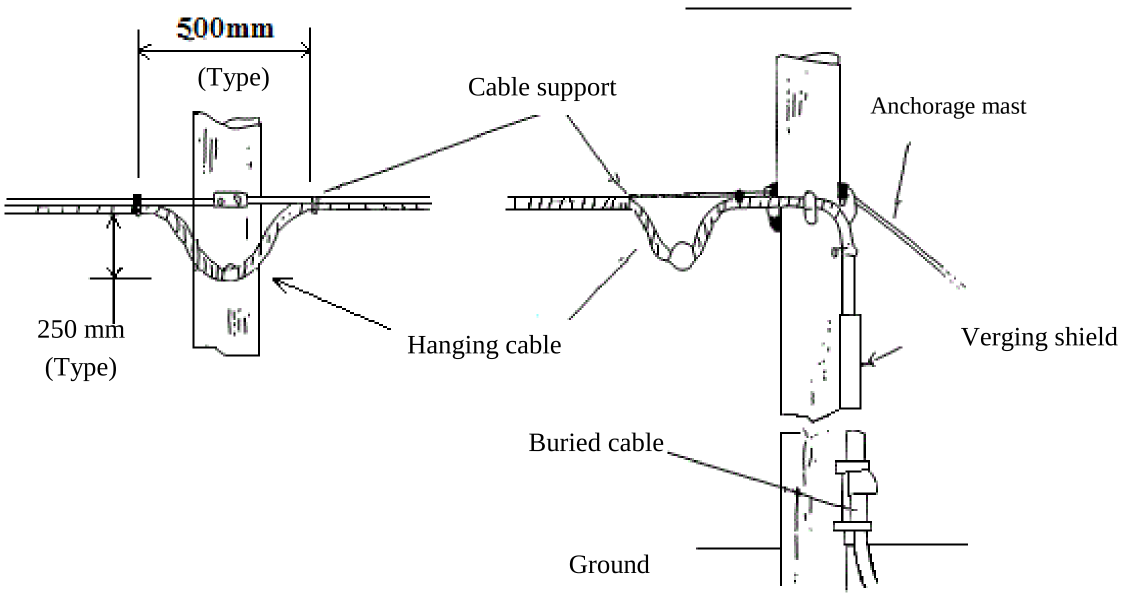
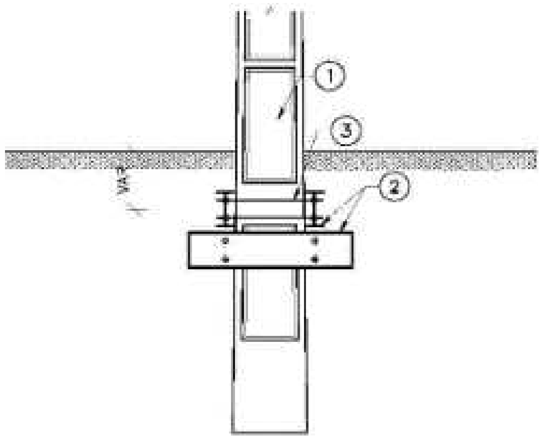
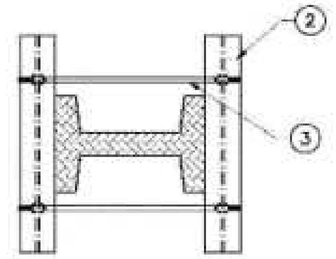


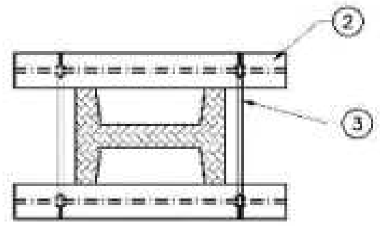
Figure 5-14-Connection flexibility of aerial cable

Required burial depth for hard and rocky ground in moderate, high and very high seismicity condition is at least 2.4 m and for low seismicity in above-mentioned soil is 1.7m. Reinforcing steel members with characteristics according to following figure or reinforcement of the soil surrounding to beam can be performed to adjust beams that are buried in low depths.



Reinforcement of foundation in the ground level through installation of accessory steel parts





Connection technique of iron beam to pillar **Connection technique of iron beam to pillar**

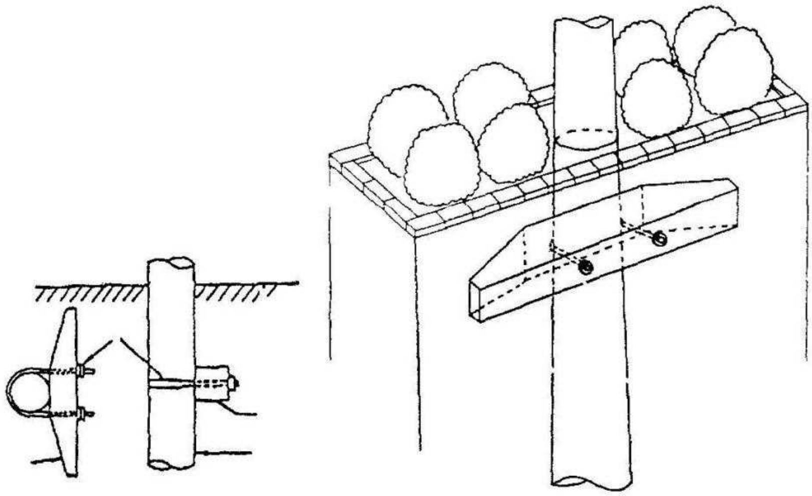


Figure 5-15-Details of improvement of communication aerial line bases

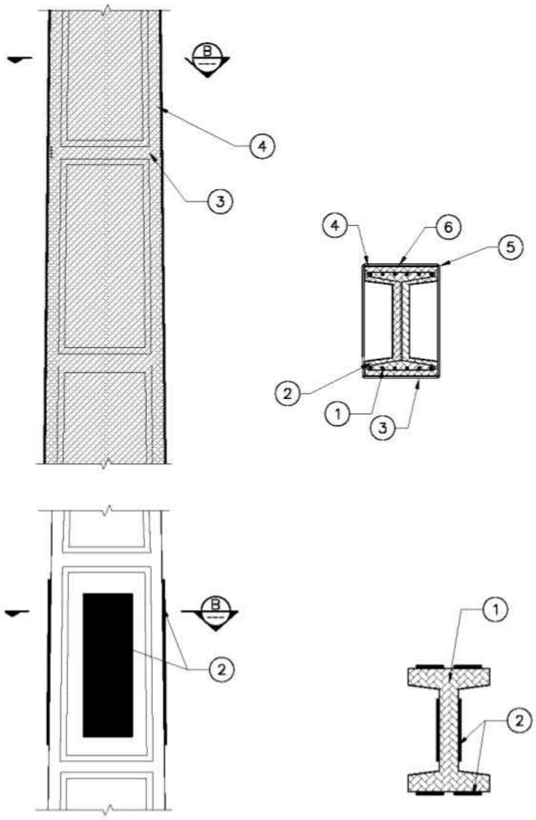


Figure 5-16-Details of improvement of communication aerial line bases with metallic jacket or belt

5-2-2-1-Undeground lines

Underground communication lines involving buried cables, cables inside PVC or metallic pipes, cables inside concrete conduits and cables inside tunnels and their maximum sensitivity against earthquake is related to permanent ground displacements. Accessory structures of these lines include manholes and their branches and connections with buildings. Variations of dynamic specifications of structure in the site of accessory structures usually lead to concentration of earthquake failure in these locations.

Table 5-5- Guideline of seismic improvement of non-building structure of Underground communication lines

component	Probable failure mode	Failure cause	improvement method
Underground tunnels and conduits	Collapse of wall and entrance of soil into the building Cracking conduit wall and opening of traction joints Fall of ceiling caps into channel Damaging cables on studs	Insufficient resistance capacity of wall concrete to endure lateral pressure of soil Hugh ground deformation due liquefaction or faulting or slope movement and improper design of joints Shape edge of seating stud of cable	Reinforcement of concrete wall of channel from outside or by internal anchorage Adding joints or longitudinal Ground consolidation Making ground flexible with replacement of surrounding soil of conduit Using seismic joint in the intersection with fault Removing edge of seating stud of cable with substation or improvement of stud
Underground cabling	Separation of cables from structures or its rupture in connection with building or channel or other equipments Failure of cable joint and connections	Hugh relative deformation between cable and structure or manhole due to excess displacement of structure or lack of freedom of cable connection with structure Hugh ground deformation due liquefaction or faulting or slope movement Fragility and insufficient strength of joints	Imbedding sufficient freedom and flexibility in connection of cable with structure or manhole using proper pipe sheath without sharpness, preparation of slight excess length and bend in cable or using cable of higher strength in required areas or in the intersection with fault Replacement or modification or removing joints, changing force distribution in cable through making cable surrounding soil flexible Using sheath pipe
Manhole	Shear fracture tilting	Lack of sufficient shear strength liquefaction	Internal shear reinforcement using convoluted belts Consolidation of manhole surrounding soil

Cable burial trenches are usually S-shaped to protect cables against ground deformation. Cable transit conduits are also connected to manholes to distribute shear force resulted from ground movement. More looseness must be considered for optic fiber cables and bend radius of these cables mustn’t be less than 10 cm.

Underground distribution lines must have sufficient flexibility and mobility so above-mentioned items can be considered with following details as an approach involving pipes with high flexibility in transition path.

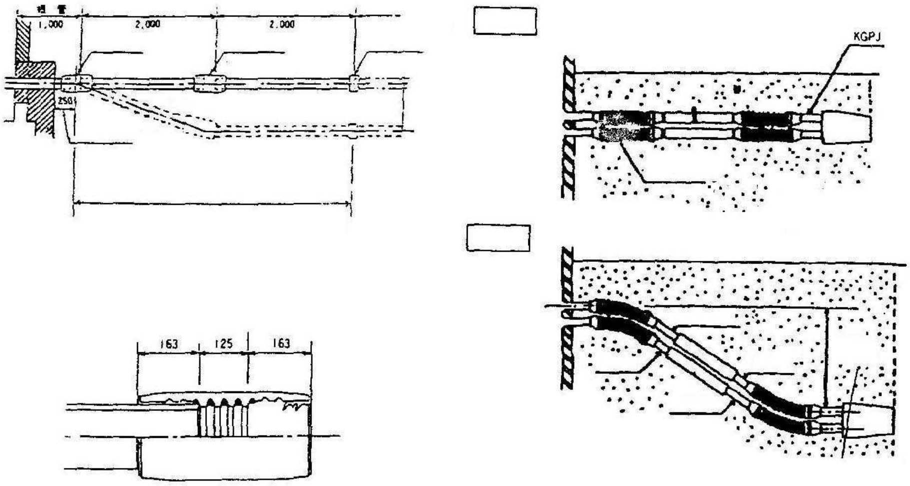


Figure 5-17-using smooth connection in underground communication lines

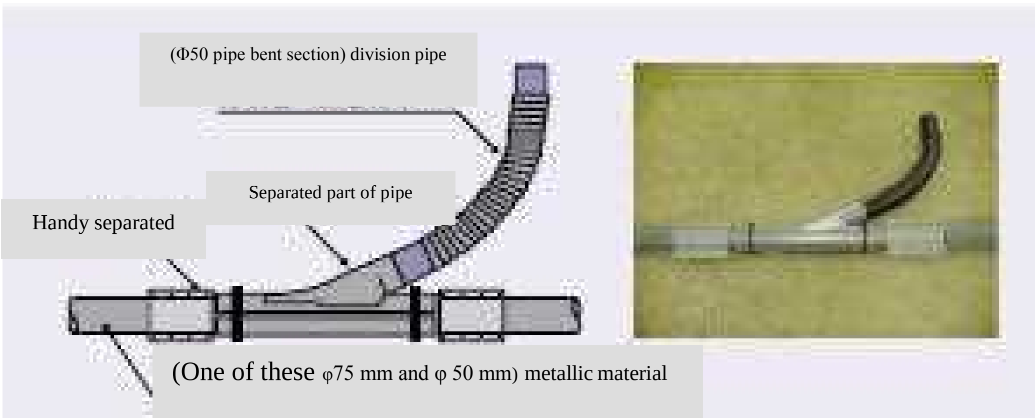


Figure 5-18-Flexible branch from main conduit

One of effective factors on pipe behavior is its material and function of its connection against earthquake so pipe type and its connection can be variable according to ground condition and pipe transition path. Table 5-6 shows pipe classification according to their seismic strength.

Table 5-6-Pipe material based on seismic strength

Sliding sheath Baton Sleeve	Adsorption of relative displacement of connection conduit of cables and manhole with expansion and traction
Adjustable connecting tube Differential fitting tube	Steel or cast iron pipe that has sufficient strength for displacements due to earthquake and can tolerate deformations of bends (arcs) up to several degrees. Hard vinyl pipes that adsorb movements of surrounding ground with increment and decrement of length
Connection preventing from separation	Pipe that can move with deformations due to surrounding soil movement, especially in big deformations such as liquefaction

Cable tunnel is a strong and earthquake resistant structure due to its construction in depth, big section and high hardness. Table 5-7 present generally weaknesses and counter-measures against earthquake regarding cable tunnels.

Table 5-7-general counter-measures against earthquakes in cable tunnels

Tunnel with reinforced concrete wall where ground mechanical characteristics changes abruptly	Reinforced concrete is used to endure excess stress in part of tunnel that is exposed against anisotropic ground displacement
Using sliding (telescopic) connection in connection of cable tunnel to vertical shaft	Sliding connection is inserted to absorb relative movement between cable tunnels and shaft
Sealing wall and fire-resistant	Separating walls are built to prevent entering flood or fire on cable tunnels into building

Conduits of moderate diameter are equipments of high reliability. Since diameters of optic fiber cables are lower, these conduits fulfill transition of these cables. Optic fiber cables can response to various communication needs due to digital technology and conduits of moderate diameter have reliability of structures equal to cable tunnel using Fleece Pace connections that their application has started recently.

Using conduits of moderate diameter leads to cost-saving in maintenance as well as its manufacture and installation. Design is performed on the basis of over-covered manufacture method (non-open), soil type, pipe material and manufacture method. The objective of design must be minimizing excess soil production in order to fulfill increasing environmental considerations.

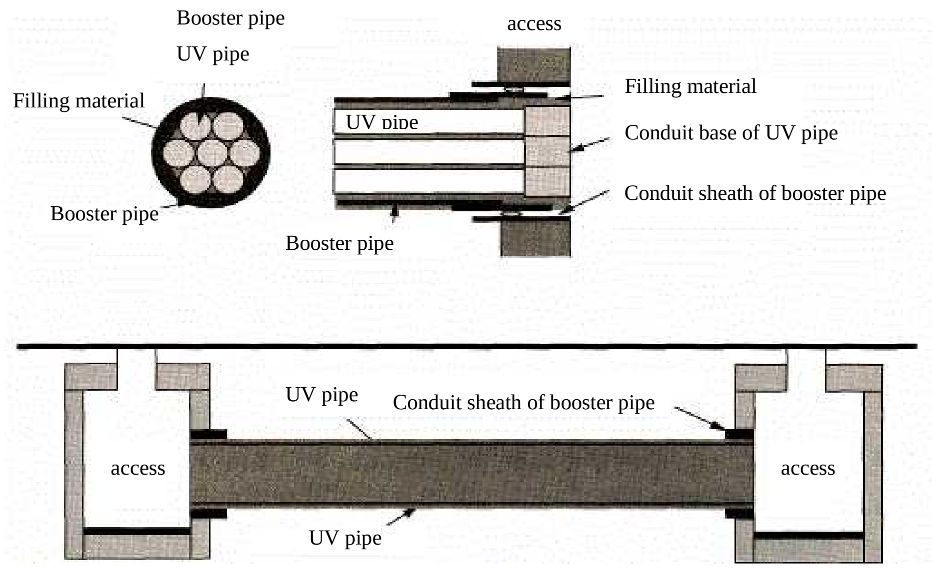


Figure 5-19-olden operation method of cable transition conduit

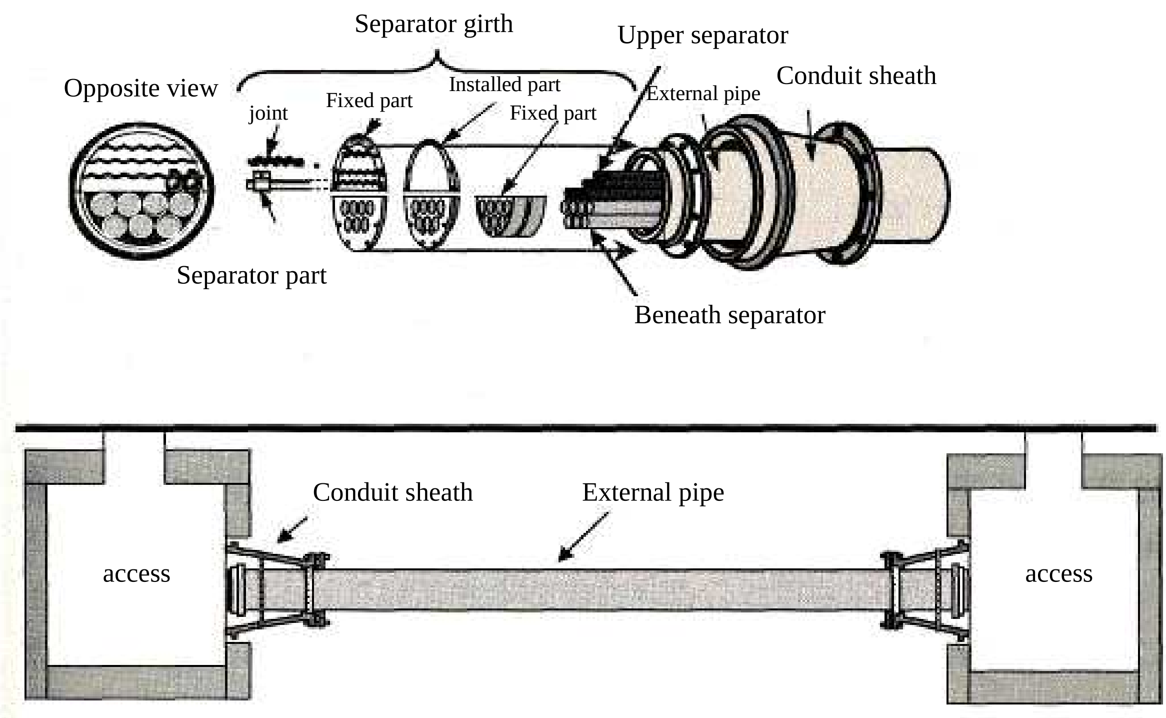


Figure 5-20-New operation method of cable transition conduit

Manholes and cable pools are of underground structures of external network that are used for connection and distribution of underground cables from one place to another. These structures usually have sufficient strength and are made from reinforced concrete. Recently reinforced composite material with fiber is used for construction of these structures. In some cases, cable pools that have controlled environment are used as transition, switching and supporting batteries room. This strength can be fulfilled by reinforcement of this connection similar to figure 5-20.

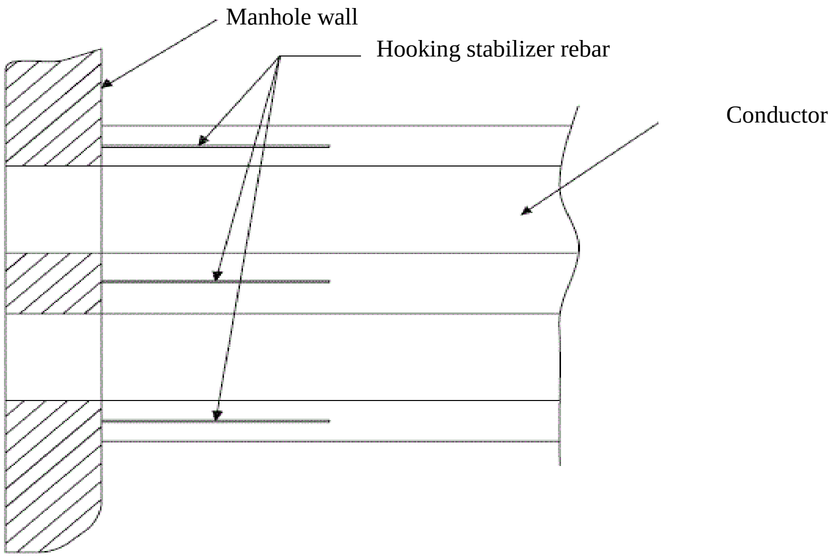


Figure 5-21-Reinforcement of connection of cable transition conduit with manhole

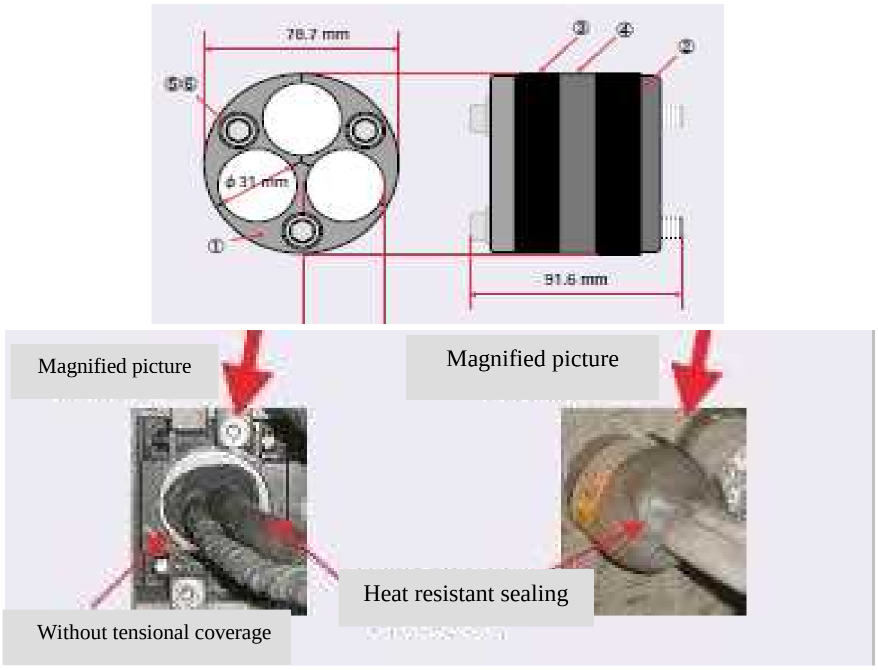


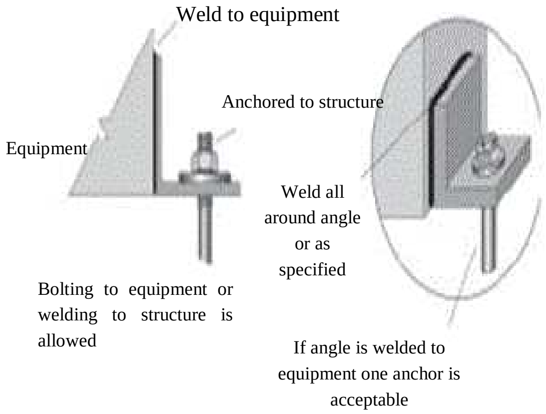
Figure 5-22-Sealing of connection of cable transition conduit

5-2-2-3-Euipment

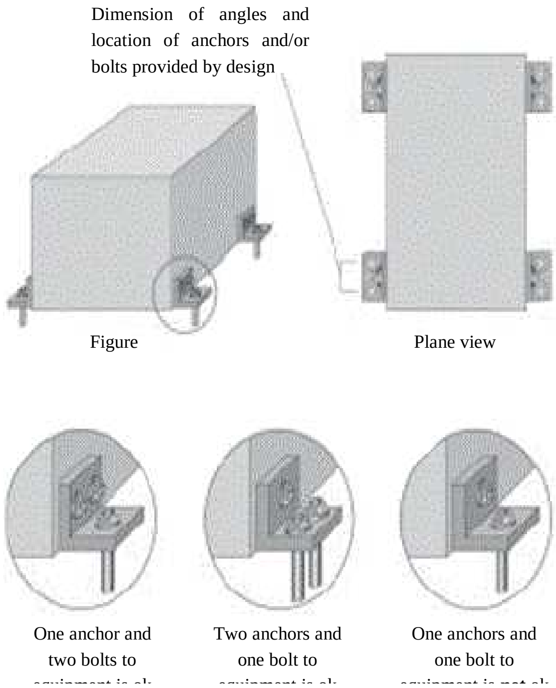
Equipments of communication network involve kiosks and panels. Table 5-8 presents lists of various types of these equipments together with observed and likely seismic failure modes, common cause these failure modes, damages and general methods of their improvement in terms of related failure mode and cause. Seismic failure modes of these equipments aren't confined to items of table 5-8 and consultant must investigate appropriately occurrence probability of other seismic failure modes in terms of site condition and results of vulnerability studies.

Table 5-8- Guideline of seismic improvement of communication network equipment

component	Probable failure mode	Failure cause	Improvement method
kiosks and panels	Overturning	Lack of accessory anchorage system	Connection to floor or ground through anchorage bar Lateral connection to wall or base Connection to ceiling or connecting beams of bases Connecting panels together



Four or more angles welded to equipment and bolted to floor/pad



Four or more angles welded used to attach the equipment to the building

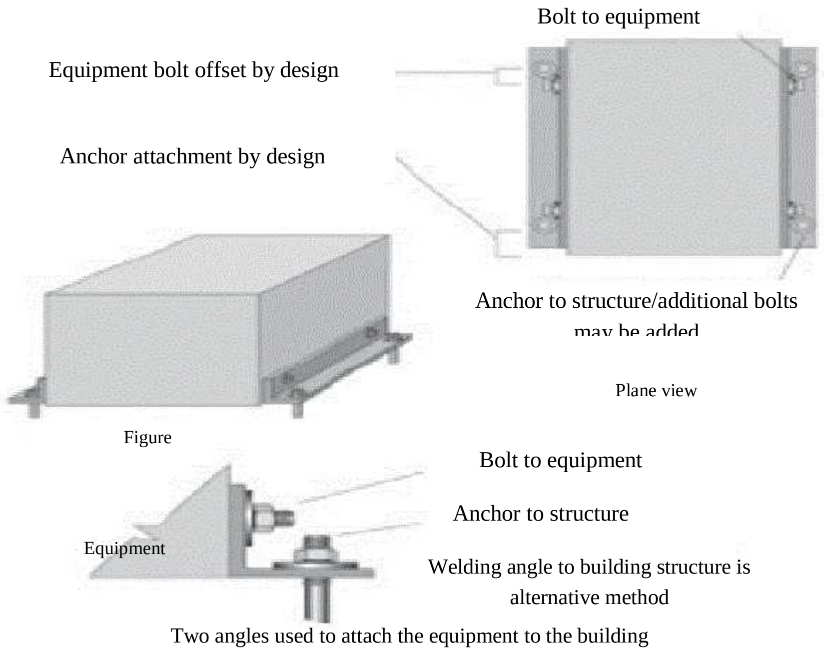


Figure 5-23-an example of improvement details of anchoring panels and kiosks

Remote structures are considered to imbed equipments to be used in network that can be one small switching unit as well as its supporting batteries. In remote areas, this station can be self-controlling communication center. These buildings can be used for establishment of facilities, as well.