Nepal Health Sector Support Programme III (NHSSP – III)

OVERVIEW AND REPORT RECOMMENDED RETROFITTING STANDARDS FOR HEALTH INFRASTRUCTURE FACILITIES

Disclaimer

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Content

List of Tables

List of Figures

EXECUTIVE SUMMARY

Health infrastructure- and its associated health services - are paramount for lifesaving responses to earthquakes. However, earthquakes often result in devastating damage to health facilities. In Nepal, this was the case with the 2015 earthquake; 446 public health facilities were destroyed, while a further 765 health facilities were partially damaged.

While the National Building Code Seismic Design of Building in Nepal (NBC105:1994) requires that all “essential facilities should remain functional after an earthquake”, currently, there is limited or only outdated guidance on evaluating and setting standards for the seismic resilience of health facilities.

The Nepal Health Sector Support Programme (NHSSP) aims to retrofit least two health facilities to a high standard – with the aim that this would represent good practice examples to guide a rollout by the Ministry of Health and other external development partners across the country. These example facilities would be resilient to cope with future earthquakes or other hazards.

This report sets out a process for review, assessment and retrofitting of hospital facilities. It shows an algorithm developed by the NHSSP Infrastructure Team to assist the prioritisation, selection and order of hospital buildings for retrofitting.

The report recommends taking a holistic approach to the retrofitting of facilities, taking account of performance requirements, design standards and risk mitigation strategies. It provides a framework for a generic standard for evaluation and improvement of health facilities in relation to seismic resiliency. The standard isbased on the investigation of major weaknesses, knowledge gaps, and areas for improvement required for the current Nepal codes and practices in comparison to codes and standards of other countries.

Finally, the report also recommends a basis for seismic evaluation and design loading for retrofitting of existing facilities.

ACRONYMS

DFID	UK Department for International Development
DG	Damage Grade
DoHS	Department of Health Services
DUDBC	Department of Urban Development and Building Control
EMS	European Macro-seismic Scale
FEMA	US Federal Emergency Management Agency
GI	Galvanised Iron
GoN	Government of Nepal
GPS	Global Positioning System
HVAC	Heating Ventilation & Air Conditioning
LFRS	Lateral Force Resisting System
MoH	Ministry of Health
MoHA	Ministry of Home Affairs
Mw	Magnitude
NBC	Nepal Building Code
NHSSP	Nepal Health Sector Support Programme
NGO	Non-Governmental Organisation
PGA	Peak Ground Acceleration
RC	Reinforced Concrete
URM	Unreinforced Masonry

1 Introduction

1.1 Earthquakes and health facilities

Health infrastructure plays a critical role in the response stage after an earthquake. The general public expectation is that healthcare facilities and hospitals will remain functional after earthquakes, providing the following essential services:

- Continuous provision of care for in-patients
- Triage and health services to earthquake casualties
- Acting as a communication point to disseminate information tothe public alarmed by earthquake
- Acting as a centre for the emergency response team
- Serving as a logistics hub and distribution point for relief supplies.

Accordingly, it is important to ensure that the healthcare facilities have sufficient resilience against earthquakes.

1.2 Purpose and scope

The purpose and scope of this report is three fold:

1. Thereport proposesa basis for assessment of health facilities and recommends taking a holistic approach, to include performance requirements of the facilities, design loads for the evaluations, risk mitigation strategies, and other options.

2. The report provides a framework for a generic standard for evaluation and improvement of health facilities in relation to seismic resiliency. The standard is based on the investigation of major weaknesses, knowledge gaps, and areas for improvement required for the current Nepal codes and practices in comparison to codes and standards of other countries.

3. The report also recommends a basis for seismic evaluation and design loading for retrofitting of existing facilities. The current seismic design loading standard of Nepal dates from 1994,and it has not been updated since its formulation. While the Department of Urban Development and Building Construction (DUDBC) has initiated a programme to update this criterion,this report provides an interim recommendationuntil the new standard is available.

2 Global perspective on seismic performance of hospital facilities

2.1 Overview

Past earthquakes have shown the vulnerability of hospital facilitiesto seismic damage, making them dysfunctional when health servicesare needed most. For example, the 1971 San Fernando Earthquake caused significant damage to a number of health facilities in greater Los Angeles, including the collapse of two hospitals (Figure 1).

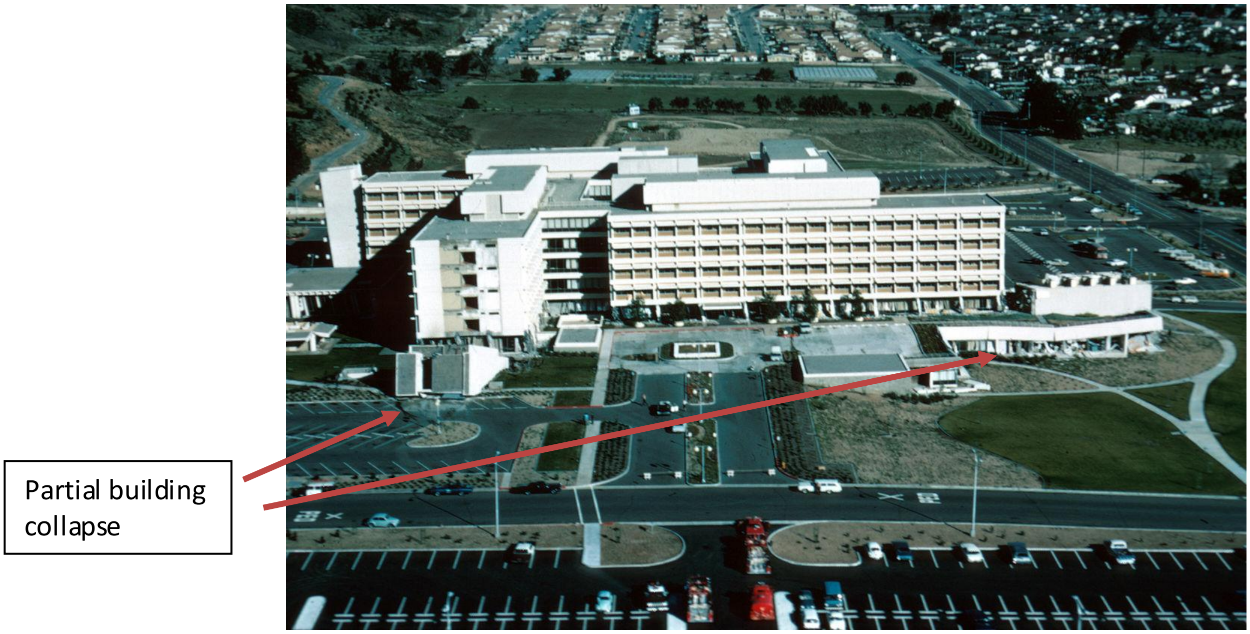


Figure 1. Partial collapse of the Olive View Hospital

When not properly designed, heath facilities have performed poorly in Asian earthquakes resulting in the damage and destruction of hospital buildings. This includes the 2001 Bhuj earthquake in Gujarat, India (ADRC, 2001) and the 2005 Kashmir Earthquake (EERI 2006). Similarly, during the 2008 Sichuan Earthquake, a number of hospitals collapsed resulting in thousands of fatalities (Miyamoto et al 2008).

2.2 Improved design requirements for health facilities

Following major recent earthquakes, health facility performance requirements in the US, Japan, Turkey and New Zealand have been upgraded to to a higher standard. Examples of these responses include:

- **Special consideration for health buildings**: For example, in the US, the building code defines health buildings as risk category IV (highest) and requires an importance factor of 1.5 to be used in their design. The 'importance factor' is an additional weighting to ensure design standard calculations are at a higher level for health facilities. In New Zealand, the health facilities are categorised as emergency medical, and post-disaster facilities. The earthquake emergency medical facilities and post-disaster facilities are designed for importance factors of 1.3 (earthquake return period 1,000years) and 1.8 (earthquake return period 2,500years) respectively. In the Nepal and Indian building codes, hospital infrastructures are designed for importance factors of 1.5.

- **Modification to the national / state building codes:** Certain provisions of building codes (such as importance factors and performance levels)include enhanced requirements for health facilities to ensure higher performance is obtained.
- **Provisions for non-structural components:** For example, seismic certification is required for hospital equipment such as generators and control panels. Engineering calculations for bracing and anchorage are also required for items such as pipes, ducts and ceilings, water supply lines and system, oxygen supply lines, vacuum lines, and other gas supplies, cylinders and heavy equipment such as autoclaves and generators.
- **Detail plan review and quality assurance**: All existing hospitals in California are required to undergo seismic risk assessment and be retrofitted if they are deemed insufficient. For all new construction, structural plans and calculations are peer-reviewed by registered and experienced structural engineers. During construction, extensive quality assurance (QA) takes place, including sampling of material, supervision of construction, documentation of concrete pours, and record keeping of all construction activities. Similar provisions apply to health facilities inNew Zealand.
- **Programme implementation:**Programmes of improvements to health facilitiesare implemented as practical programmes of retrofitting and refurbishment. For example, in Istanbul34 hospitals were seismically retrofittedas a part of a multi-year assessment and retrofit programme. In addition, newly constructed larger hospitals in Istanbul use seismic protection devices. In Japan, the Mw 9.1 Tohoku Earthquake resulted in major damage, however the hospital facility - designed according to the provisions of the modern code - performed exceptionally well.

The implementation of these provisions has reduced the vulnerability of hospital facilities in these countries. Notably, these responses are developed according to best comparable practice, in addition to respond to the local situation and needs. It suggests that for Nepal a programmatic approach to retrofitting, and new-build construction to high seismic resilience standards, is essential to raise the anticipated post-earthquake performance of the country’s health facilities.

3 Seismic performance of hospital facility in Nepal

3.1 Damage during the 2015 earthquake

At the time of the 2015 earthquake, Nepal was divided into14 administrative zones and 75 districts. The 2015 Nepal Earthquake had a devastating impact onhospital facilities - 19% and 23% of total health facilities were located in high or moderate-affected districts, respectively. According to the Ministry of Home Affairs (2017):

A total of 446 public health facilities including administrative building (consisting 5 hospitals, 12 Primary Health Care Centres and 417 Health Posts, 12 others) and 16 private facilities werecompletely destroyed while a total of 765 health facility or administrative structures (701 public and 64 private) werepartially damaged. Nearly 84% (375 out of 446) of the completely damaged health facilities are from the 14 most affected districts.

The Nepal Health Sector Support Programme, (2017) conducted a damage assessment report of hospital facilities in 17 districts with 2,085 building blocks. Of these structures, 27 (1.2%) of the buildings had collapsed, 242 (11.6%) were damaged beyond repair, and 124 (6%) were damaged but repairable. In other words, the earthquake affectednearly 19% of hospital facilities. A survey by Ministry of Health (2015) assessed 665 health facilities in 2015. Of the 1,141 buildings at these facilities, 620 buildings (54%) had sustained damage (Figure 2).

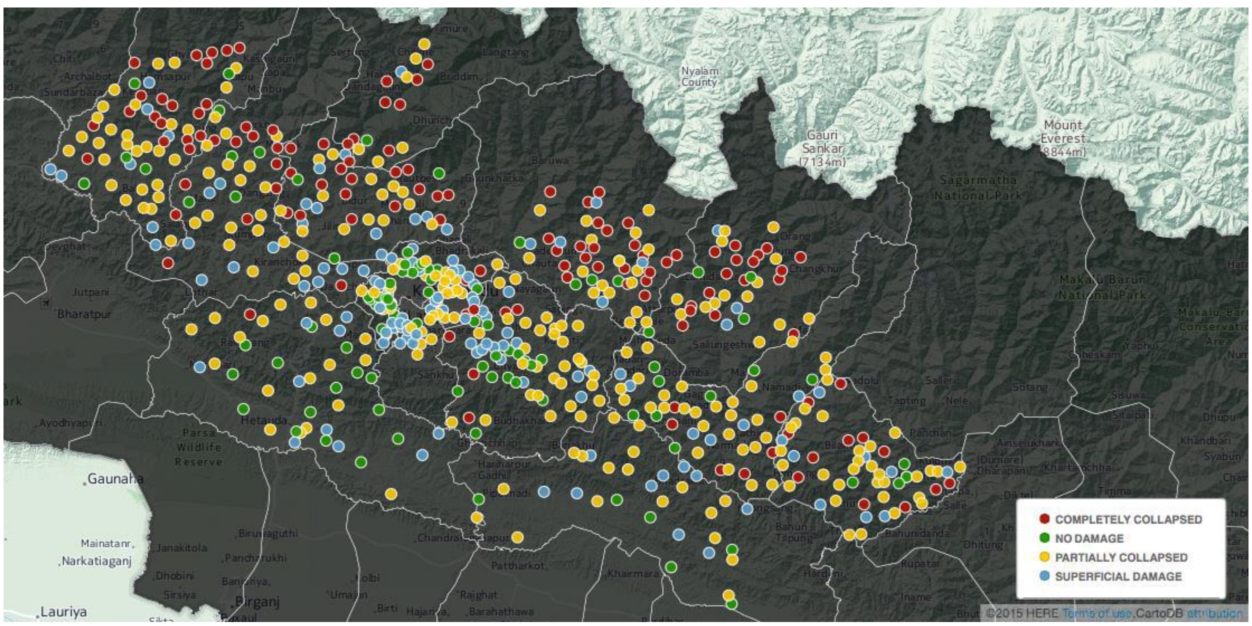


Figure 2. Damage assessment of hospital facilities (Source: NHSSP/MoH)

3.2 Current practice in Nepal

Currently, there are no standards/ guidelines or any code provisions in Nepal requiring design of a whole hospital facility. Nepal has its own set of standards for design of building, largely drawn from Indian Standards. The National Building Code Seismic Design of Building in Nepal (NBC105:1994) requires that all “essential facilities should remain functional after an earthquake.” Hospitals are to be designed for an importance factor of 1.5, i.e.design for one and half times the seismic load for a similar residential building.

It is common practice to use Indian Standards in Nepal, which has also similar provisions for hospital buildings. However, these standards do not have any explicit requirement for the design of secondary elements such as partition or parapet walls, and anchorage of non-structural elements such as ducting, ceilings, contents and equipment.Hence, these elements are often ignored during planning and design stages. In addition, many health facilities in Nepal are constructed by international official aid organisations and international NGOs. Building design standards are likely to vary, depending on whether they are based on the requirements of the home country. Smaller NGOs and charities have also constructed small-scale facilities in partnership with local communities. In such cases, the facility may not comply with any official standards and could be very similar to local residential buildings.

4 Hospital facilities in Nepal

4.1 Overview

The Department of Health Services (DoHS) is in-charge of hospital facilities in Nepal. It is divided into five (5) regional levels, administrating 10 health centres, 75 district health offices, and 83 district hospitals. The district hospitals in-turn oversee 700 health posts and 3,158 sub-health posts (serving villages).

4.2 Building typologies

A survey of the health facilities in the earthquake prone regions has identified a number of hospital building types depending on the lateral force resisting system (LFRS) (Table 1 and Figure 3). The unreinforced masonry (URM)and non-ductile reinforced concrete (RC)frame buildings are the most common building typologies in Nepal. These building typologies are seismically vulnerable' experiencing collapse and fatalities in past earthquakes. The newer reinforced concrete moment frame or reinforced concrete shear wall buildings are expected to perform better.

LFRS	Type
Unreinforced masonry (URM) load bearing wall*	Stone masonry with no mortar (dry stone masonry) with flexible floor and roof
	Stone masonry with mud mortar with flexible floor and roof
	Stone masonry with mud mortar with RC floor and roof
	Stone masonry with cement (lime) mortar with flexible floor and roof
	Stone masonry with cement (lime) mortar with RC floor and roof
	Brick masonry with mud mortar with flexible
	Brick masonry with mud mortar RC floor and roof
	Brick masonry with cement (lime) mortar with RC floor and roof
Concrete building1	Concrete frame with masonry infill Concrete moment frame Concrete shear wall

Table 1. Common existing building typologies for hospital facilities in Nepal

The scale of the challenge in retrofitting and improving functionality in health facilities across the country has yet to be quantified with precision. While some partial data exists for certain facilities (based on previous DFID-supported surveys of hospital buildings and earthquake damage over the period 2013-2015), the MoH will need a comprehensive assessment of each facility and details of building typologies on site. This data could be matched to criteria of risk and need in order to identify facilities to be prioritized for interventions. This is line with the intention of the NHSSP retrofitting workstream, which is to create at least two high standard, high profile retrofitting projects to be adopted as good practice examples. The experience from these hospital retrofitting projects can then be used to guide a roll-out by the MoH and other external development partners across the country.

* The concrete or masonry buildings could have upper stories with light roof.

Work done under the Detailed Engineering Assessment post the Gorkha earthquake in 17 districts identified 1,762 facilities with typologies broken down as follows:

- 3 % mud mortar brick/adobe masonry buildings
- 32% stone masonry with mud mortar
- 17% brick masonry with cement mortar
- 15 % stone masonry with cement mortar and
- 28 % RC framed buildings.

This kind of analysis will form the basis of a costed and programmatic approach to retrofitting and seismic strengthening of facilities across the country.

Dry stone masonry

Stone masonry and mud mortar (with cement pointing)

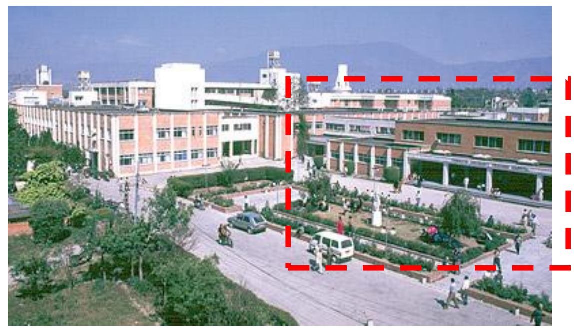
Stone masonry and cement mortar

Brick masonry with mud mortar

Brick masonry with cement mortar (note top story. Unlikely to be part of the original design)

Concrete frame with masonry infill

Concrete frame building



Concrete structural wall building

Figure 3. Building types

4.3 Seismic vulnerability

4.3.1 Global perspective

The expected damage to a given building typology is defined by fragility curves that identify the probability of exceeding a given Damage Grade (DG). For example, the USFederal Emergency Management Agency(FEMA) defines the following DGsfor reinforced concrete frame buildings with masonry infill (FEMA 2003):

- DG1: Diagonal hairline cracks on most infill walls; cracks at frame-infill interfaces.
- DG2: Most infill wall surfaces exhibit larger diagonal or horizontal cracks; some walls exhibit crushing of brick around beam-column connections. Diagonal shear cracks in concrete beams or columns.
- DG3: Most infill walls exhibit large cracks; some bricks may dislodge and fall; some infill walls may bulge out-of-plane; few walls may fall partially or fully; few concrete columns or beams may fail in shear resulting in partial collapse. Structure may exhibit permanent lateral deformation.
- DG4: Structure has collapsed or is in imminent danger of collapse, due to a combination of total failure of the infill walls and non-ductile failure of the concrete beams and/or columns.

For vulnerable health infrastructure buildings in Nepal, the DG4 levelis likely to result in a collapse of a large portion of the building inventory, in particular for bearing wall systems or deficient RC frame buildings. Damage assessment in the aftermath of the 2015 earthquake indicated that the dry masonry buildings and the brick or stone masonry buildings with mud mortar were the most vulnerable type of construction(MoHA, 2017).

Building vulnerability can be understood by examining the probability of major damage or collapse in the event of a strong earthquake, according to the building type (i.e. materials used). As shown in Figure 4, the stone/brick bearing wall buildings with mud (or no) mortar are the most vulnerable. On the other hand, the newer reinforced concrete frame or shear wall structures are less susceptible, and could likely survive a strong earthquake, albeit while experiencing damage.

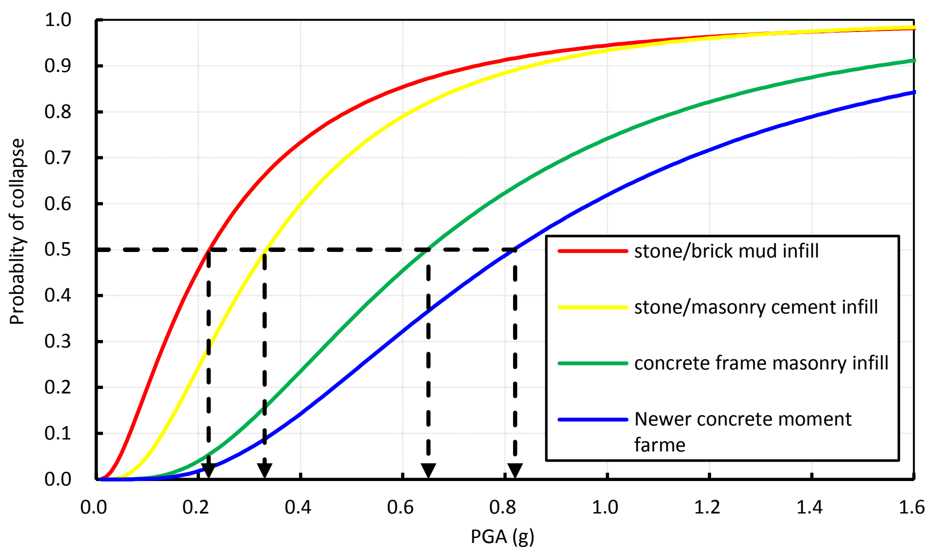


Figure 4. Probability of collapse or severe damage (FEMA 2003)

PGA (g): Peak Ground Acceleration

Thus, the building typology is an important consideration when assessing the key health facility buildings for retrofitting. Other important factors to be considered by decision makers include the number of people using the health facility, the importance of the building, whether it has to remain operational and /or be used as shelter in the event of an earthquake, and the proximity of other facilities that can be used as substitutes in an emergency.

4.3.2 Application to Nepal hospital facilities

The European Macro-seismic Scale (EMS 98) defies various DGs due to earthquake shaking applicable to buildings. As an example, various damage grades for a reinforced concrete frame building are reproduced in Figure 5.

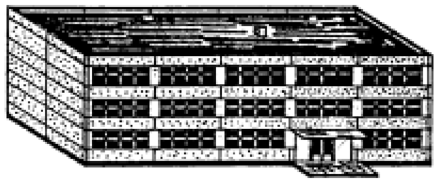
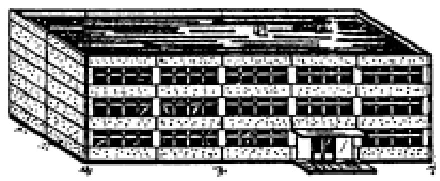
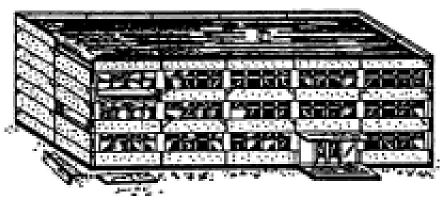
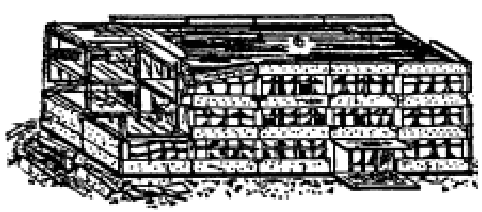
Classification of damage to buildings of reinforced concrete	
	**Grade 1: Negligible to slight damage** **(no structural damage,** **slight non-structural damage)** Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
	**Grade 2: Moderate damage** **(slight structural damage,** **moderate non-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	**Grade 3: Substantial to heavy damage** **(moderate structural damage,** **heavy non-structural damage)** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	**Grade 4: Very heavy damage** **(heavy structural damage,** **very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	**Grade 5: Destruction** **(very heavy structural damage)** Collapse of ground floor or parts (e. g. wings) of buildings.

Figure 5. European Macroseismic Scale 1998 (Grunthal, 1998)

For vulnerable hospital facility buildings in Nepal, the DG5 will result in a collapse of a large portion of building, in particular for bearing wall systems. Figure 6 presents vulnerability functions for typical Nepali building typologies (NBCDP 1994)

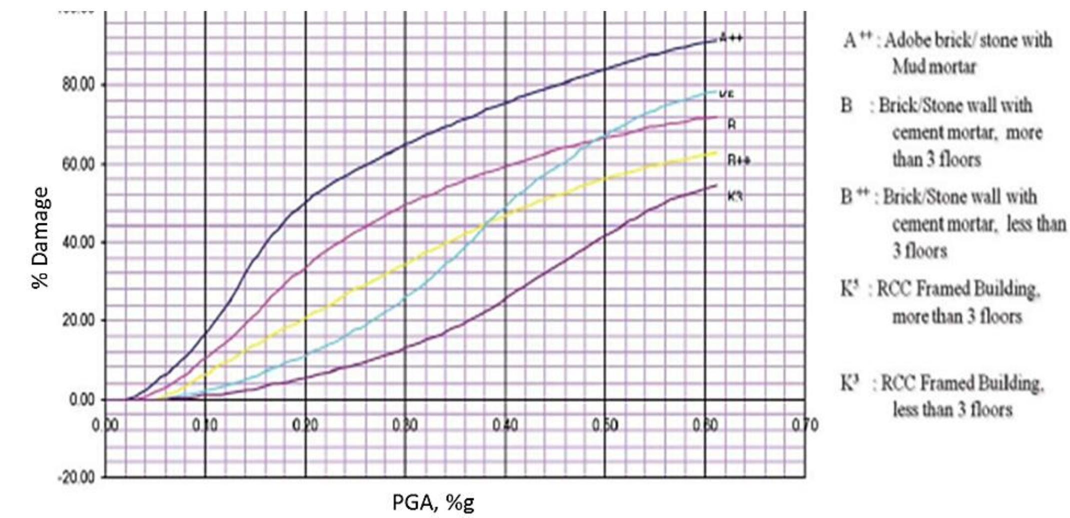


Figure 6. Probability of collapse(NBCDP, 1994)Note: PGA : Peak Ground Acceleration

4.4 Factors contributing to the seismic vulnerability of buildings

Several factors contributed to the damage to the different types of buildings (Dmytro et al, 2016). These are equally applicable to health facility buildings. These factors include:

4.4.1 Load bearing wall buildings

- Use of weak mud (no) mortar
- Irregularity of masonry units in case of stone masonry construction or weak masonry units
- Poorly integrated multi-leaf stone and adobe walls
- Lack of out-of-plane resisting mechanism for bearing walls
- Rocking and shear (in-plane failure) at the corner of bearing walls due to lack of integration with floor and roof diaphragm.
- Large and injudiciously placed openings, particularly in new buildings
- Separation of front façade and return wall due to poor connection of return walls
- Movement of diaphragm with respect to the load bearing walls due to lack of anchorage between horizontal and vertical elements
- Flexible and unrestrained floor and / or roof, unable to provide any effective diaphragm effect
- Lack of maintenance leading to structural degradation.

4.4.2 Concrete frame buildings with masonry infill

- Plan irregularity due to structural framing or injudiciously placed infill cladding and partition walls triggering torsional effects
- Vertical irregularities (geometric, mass) triggering weak or soft storey
- Over-turning of building
- Captive (short) columns due to stairways or partial height infill masonry
- Out-of-plane toppling of infills
- In-plane failure of infills
- Foundation settlement
- Poor quality of concrete and/or workmanship in construction
- Poor and non-ductile detailing of reinforcementmembers including beams, columns, beam-column joints, and connection between horizontal and vertical components,
- Lack of maintenance leading to structural degradation

4.4.3 Geotechnical hazards

- Liquefaction of soil
- Rock slide and / or land slide
- Ground settlement

These deficiencies contribute to the seismic vulnerability of buildings and need to be addressed as part of the intervention programme.

4.5 Factors contributing to the seismic vulnerability of non-structural elements

The key factors contributing to the vulnerability of non-structural components in hospital facilities are:

- Inadequate anchorage of components, resulting in sliding or overturning of the units
- Lack of bracing for ducts and pipes that can result in excessive movement of these units
- Use of rigid sprinkler connections that fail due to differential movement

4.6 Factors contributing to the seismic vulnerability of contents and equipment

- Improper design of the anchors for medical equipment or unrestrained equipment/ content
- Lack of support and restraining for cases, bookshelves, monitors and other equipment

5 Defining seismic requirements

5.1 Overview

This section provides a general discussion relating to the seismic retrofitting of hospital facilitiesin Nepal. The first step in such programme is the definition of a selection criteria and performance objectives.

5.2 Performance objectives for health facilities

5.2.1 Definition of performance levels

Five structural performance levels are considered in this document. These performance levels relate to damage states for elements of lateral-force-resisting systems.

- **Operational (O)**state isdefined as no permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. All systems important to normal operation are functional.
- **Immediate Occupancy (IO**)limit state is defined as only limited structural damage has occurred. The basic vertical-and lateral-force-resisting systems of the building retain nearly all of their pre-earthquake strength and stiffness. The risk of life-threatening injury because of structural damage is very low. Although minor structural repairs may be appropriate, these would generally not be required prior to preoccupancy.
- **Life Safety (LS)** damage state is defined by significant damage to the structure, but some margin against either partial or total structural collapse remains. Some structural elements and components are severely damaged, but this has not resulted in large falling debris hazards, either within or outside the building. Injuries may occur during the earthquake. However, the overall risk of life-threatening injury because of structural damage is low. It should be possible to repair the structure. However, this may not be economically feasible. While the damaged structure is not an imminent collapse risk, it would be prudent to implement structural repairs or install temporary bracing prior to re-occupancy.
- **Collapse Prevention (CP)** performance level means the post-earthquake damage state in which the building is on the verge of partial or total collapse. Substantial damage to the structure has occurred, potentially including significant degradation of the stiffness and strength of the lateral-force-resisting system. There is permanent offset due to the large permanent lateral deformation of the vertical components, and there is limited degradation in the vertical-load-carrying capacity. However, all significant components of the gravity-load-resisting system continue to carry their load. Significant risk of injury due to falling hazards from structural debris may exist. The structure would not be practical to repair and is not safe for re-occupancy, as aftershock activity could induce collapse.
- **Not Considered (**NC)some owners may desire to address certain non-structural vulnerabilities in a rehabilitation programme—for example, bracing parapets, or anchoring hazardous materials storage containers—without addressing the performance of the structure itself. Such rehabilitation programmes are sometimes attractive because they can permit a significant reduction in seismic risk at relatively low cost.

Furthermore, the non-structural performance level of a building should be assessed. Components addressed in this document include architectural (partitions, exterior cladding, and ceilings), mechanical and electrical (Heating, Ventilation and Air condition (HVAC) system, plumbing, fire suppression, and lighting) and medical equipment (floor, wall, and ceiling mounted). Occupant contents and furnishings (inventory and computers) are not discussed.

5.2.2. Importance criteria

It is important to define "importance/ occupancy" level of a building or a facility before its assessment and retrofitting design as the seismic force on a building depends upon the following factors:

- Importance of facility or intended functionality of the facility
- Importance of the facility for continual operation of the system

From importance/ occupancy point of view, hospital buildings can be classified into four groups (**Error! Reference source not found.**).

Risk Category	Importance/ Occupancy	Description	Examples	
1	Low	Low consequence for loss of human life, small or moderate environmental consequences	Minor structures, garage	Increased Occupancy
2	Ordinary	All buildings and other structures except those listed in Risk Categories 1,3, and 4	Residential houses, ambulance garage, small health posts	
3	High	Emergency medical and other emergency facilities not designated as post-disaster facility Health care facilities with a capacity of 50 or more resident patients but not having surgery or emergency treatment facilities	Normal hospital buildings Halls with capacity greater than 500	
4	Very high	Designated as post-disaster facility buildings or facilities Medical emergency or surgical facilities Utilities or emergency supplies or installations required as backup for buildings and facilities	Designated buildings or facility at national/ regional hospitals	

Table 2. Building importance

The Very High Importance / Occupancy category is determined by the significance of the facility in providing services in the post-disaster period. These hospitals are essential components of a health facility referral network, as well as providing the widest range of services themselves. They are typically the disaster 'Hub' hospitals, designed by the Government of Nepal with Health Cluster stakeholders (including the WHO). The Hub hospitals are essential elements in the implementation of the Guidelines on Emergency Preparedness Planning & Disaster Management for Hospitals (2002). The national Health Sector Emergency Preparedness and Disaster Response plan 2003 strengthened coordination across the health sector, and formulated the network linkages between key hospitals and support facilities. The importance of these facilities at individual district and local level is reflected in the respective contingency plans. The Hub hospitals are linked to the Health Emergency Operations Centre, which serves as the main disaster coordination and information management centre for major disasters. (More information on the legislative and implementation framework relating to health facility disaster preparedness planning is contained in the NHSSP Report Earthquake Performance Appraisal September 2017).

5.3 Earthquake intensity

The following levels of earthquake are defined for assessment.

- Level 4: This level has an intensity of 150% than of Level 2 and corresponds to a very rare event
- Level 3: This level has an intensity of 125% than of Level 2 and corresponds to a rare event
- Level 2: The design earthquake (DE) which is the earthquake implied in the Nepal Building Code. There is no definite return period assigned to this level of shaking but it approximately corresponds to a 300-year event in case of NBC105:1994 (Seismic Design of Buildings in Nepal).
- Level 1: This level has an intensity of 50% of Level 2.

The criteria setout above may have to be amended once updated the Nepal seismic standard is finalised.

5.4 Seismic Performance Objectives

The performance objectives for the hospital facility depend on the building category and level of seismicity (Table 3).

Building category	**Earthquake intensity level**				**Earthquake performance**
	1 (low)	**2**	**3**	**4 (highest)**	
1	--	CP			Building will not collapse in design earthquake
2	--	LS	CP		Building will preserve life and will not collapse; however, it will experience significant damage and will require extensive repair or replacement after an earthquake.
3	O	IO	LS	CP	Building will be inspected and it will only have sustained moderate and repairable structural damage
4	O	O/IO	IO	LS	Building will be operable and continues its normal function and only non-structural repairs would be needed

Table 3. Performance objectives

Table 3 demonstrates the relationship the Hospital Building risk category, the Design Earthquake intensity and the Performance Objective towards which the retrofitting solution would be chosen and applied. To illustrate:

- A low importance building (Category 1, minor structure) would be designed to survive a Level 2 earthquake at Collapse Prevention level (CP). Designing a minor structure to perform at a higher standard would not be cost-effective.
- An ordinary importance building (Category 2, garage, residential or small health post) would be designed to survive a Level 2 earthquake at Life Safety level. However, it would be exposed to

more intense forces in a Level 3 earthquake, where its performance objective would fall to Collapse Prevention (CP) grade.

- A high importance building (Category 3, normal hospital medical services and facilities, large meeting halls) would be designed to survive a Level 2 earthquake at Immediate Occupancy Level and Level 1 earthquake atOccupancy Level (which is the highest performance level). However, it would be subject to increasingly greater impacts as earthquake intensity levels increase through categories 2 to 4. As a result, the building's performance objective would slip consecutively to Immediate Occupancy, Life Safety and Collapse Prevention.
- A very high importance building (Category 4, buildings of national and regional significance) would be designed to survive a Level 3 earthquake at Immediate Occupancy Level, and a Level 2 event at an intermediate Occupancy / Immediate Occupancy performance objective. Subjected to a Level 3 earthquake, the building would perform at Immediate Occupancy level. In the event of a Level 4 earthquake, the building would continue to function at a Life Safety standard

Definition seismic force

The seismic design standard of Nepal (NBC105) was prepared in 1994 and has not been updated since. The standard is based on an old format (provides design spectra) and provides spectra for Equivalent Static Method (ESM) only.It is understood that the DUDBC has initiated a process for updating NBC105.

In the interim, it is recommended to use seismic design provisions setout ina recently revised Indian Seismic design Code(IS1893: Part 1 2016) until updated Nepal standard becomes available.

Taking into account economic considerations in the context of assessment and retrofitting of existing buildings, the seismic design forces could be reduced because of the limited remaining useful life of the building. Hence, based on the seismic retrofitting Indian Code, it is recommended to strengthen all health buildings and facilities to a minimum of $2/3^{rd}$ of seismic force of what is required for a similar new building, if practicable within the bounds of the budget and considering the degree of intervention within the building spaces and functions.

Strengthening shall address all building components including secondary and non-structural components that have an earthquake strength less than $2/3^{rd}$ of what is required for similar new building, noting that existing assessment reports may only report the strength of the weakest structural component.

Strengthening shall address any critical structural weaknesses (CSW) such as plan or vertical irregularity. Any proposed strengthening should not alter the load distribution such that other elements become critical at less than $2/3^{rd}$seismic capacity of the building or other CSWs are introduced.

6 Selection criteria for ranking of the buildings

6.1 Overview

The NHSSP Infrastructure team has developed a simplified prioritization algorithm to assist stakeholders in prioritising the selection and order of hospital building retrofitting. In this algorithm, prioritisation criteria, weight factor, classification, and classification-score are identified. The retrofit prioritisation score (i.e. weighted sum classification-score) is calculated for each building. The higher the score for a building corresponds to a higher seismic vulnerability for the building.

It is noted that the score presented in this section are recommendations only, and final determination of the classification score and weight function remains the responsibility of the GoN with relevant stakeholders.

6.2 Prioritisation criteria

In the algorithm, the five prioritisation criteria are the critical factors affecting the seismic performance of buildings.

Criteria 1 and 2 relate directly to the seismic vulnerability of building and, thus correlate to the anticipated fatality ratios. Criterion 3 affects the anticipated number of fatalities. The last factor is to be determined by the local officials and relates to the relative importance of a given hospital facility to the community. Note the construction date is not included as one of the criteria because many of the modern buildings are not code compliant.

6.3 Criterion 1: Building construction type

Building construction material and framing have a significant effect on the performance of the building in earthquakes. Non-ductile concrete and unreinforced masonry buildings have performed poorly in the past earthquakes. By contrast, well-designed concrete frames or wall buildings perform well in earthquakes and thus experience low fatalities. The classification scores of Table 4 are recommended.

Construction type	Classification score
Dry stone bearing wall	100
Stone masonry with mud mortar bearing wall	100
Stone masonry with cement (lime) mortar bearing wall	100
Brick masonry with mud mortar bearing wall	80
Brick masonry with cement (lime) mortar bearing wall	80
Concrete frame with masonry infill	60
Reinforced concrete moment frame	20
Reinforced concrete shearwall	20

Table 4. Classification score for building construction type

6.4 Criterion 2: Level of seismicity

Nepal does not have a uniform seismic intensity contour. Hence, hospital facilities are located indifferent seismic zones. Table 5is used to account for the site seismicity in three categories.

Seismicity	Classification score
High	100
Moderate	40
None/slight	0

Table 5. Classification score for building existing damage

6.5 Criterion 3: Number of occupants of each building

Although this criterion does not relate to the building vulnerability, it directly correlates to the expected fatalities, which is the most critical seismic risk factor for hospital buildings. The buildings with large number of users are more critical as collapse of such building could result in a large number of lost lives.In this criterion, the classification score for the largest number (to be determined during the surveys) will be 100 and the score of the rest of buildings reduced proportionally.

6.6 Criterion 4: Building category

This is factor indicative of the category of a given building. The classification scores of Table 6 are used for building importance. The stakeholders such as DoPH will determine this factor.

Building category	Classification score
4	100
3	60
2	30
1	0

Table 6. Classification score for building importance

6.7 Weight factors

For each of the five selected criteria a weight factor is assigned correlating to the relative importance of that criterion for the prioritisation process. By definition, the sum of all weight factors would equal unity. In typical applications, various stakeholders and policy makers such as, government officials, medical officials, doctors, nurses, emergency officials, and citizens at large would be responsible for developing of the weight factors. Engineering judgement and weight factors used in similar types of assessment in the developing countries were used to determine the factors for this project. Table 7presents a suggested weight factor option.

Criterion	Weight factor
1Building construction type	25%
2Level of seismicity	10%
3Number of occupants of each building	30%
4 Building category	35%
Aggregate	100%

Table 7. Weight factors for each prioritisation criterion

6.8 Prioritisation Score

6.8.1 Process

The prioritisation score is calculated as the weighed sum score by applying the classification score and weight factor. Table 8 presents the procedure used to calculate this score.

Prioritisation criteria	Classification	Classification-score, s_i	Weight factor, w_i	Weighted score
Construction type	Dry stone bearing wall	100	25%	(s_1) * (w_1)
	Stone masonry with mud mortar bearing wall	100		
	Stone masonry with cement (lime) mortar bearing wall	80		
	Brick masonry with mud mortar bearing wall	100		
	Brick masonry with cement (lime) mortar bearing wall	80		
	Concrete frame with masonry infill	60		
	Reinforced concrete moment frame	20		
	Reinforced concrete shearwall	20		
Level of seismicity	High	100	10%	(s_3) * (w_3)
	Moderate	40		
	Low	0		
Number of occupants	Occupants of each building (relative scoring by Max. value)	0 – 100 (= 100 * Each./Max.)	30%	(s_4) x (w_4)
Building importance	4	100	35%	(s_5) * (w_5)
	3	60		
	2	30		
	1	0		
Prioritization score				$\sum [(s_i) * (w_i)]$

Table 8. Simple prioritisation algorithm

6.8.2 Example

As an example, consider a hospital building with the following characteristics:

- One storey stone masonry with mud mortar bearing wall
- Constructed in 1985
- High seismic zone
- Number of users is 50% of the building in the group with the most occupants
- The facility is one of many in the district and has no special importance

Then the prioritisation score for this building is calculated as:

Score=(100*0.25)+(100*0.10)+(50*0.3)+(0*.35)=50

This procedure is then repeated for all the buildings in the group and the buildings are ranked in the descending order. The higher the score of a building, the more critical it is for consideration for seismic retrofitting.

7 INTERVENTION STRATEGY

7.1 Overview

There could be multiple interventionstrategies (retrofitting, reduced importance level, demolition, and reconstruction) for improving seismic safety of building stock or a facility in a hospital complex. From a compliance perspective, non-compliant buildings need to be identified. Only then,can a decision on the type of interventionbe made.All the options should be carefully explored before deciding demolition of existing buildings.

While considering retrofitting of a building to an immediate occupancy level, the first thing to consider is whether, if retrofitted, the building would meet the seismic compliance and functional criteria. In case of many older existing buildings, thebuildings may not meet functional requirements and the underlying structure may not be sound enough to meet the desired Importance level. Hospital buildings with a high risk of collapse cannot be used for high Occupancy (such as post-disaster functions). These buildings must be retrofitted (to meet Intended Performance level) orImportance level reduced or demolished.

While evaluating improvement options, many buildings may be found inappropriate for retrofitting for higher Importance levels, because of inherent weaknesses, very low capacity of the base building structure, age of the building, functional issues, and likely high cost of intervention. Damage and environmental deterioration adds a new dimension to complexities (Figure 7).In such a case, the building could be retrofitted to a lower Importance level if a change in occupancy is acceptable. If change in occupancy is not acceptable, the building has to be demolished and rebuilt to meet the intended functional and strength requirements. Figure 8presents a decision-making chart for selection of strategy.

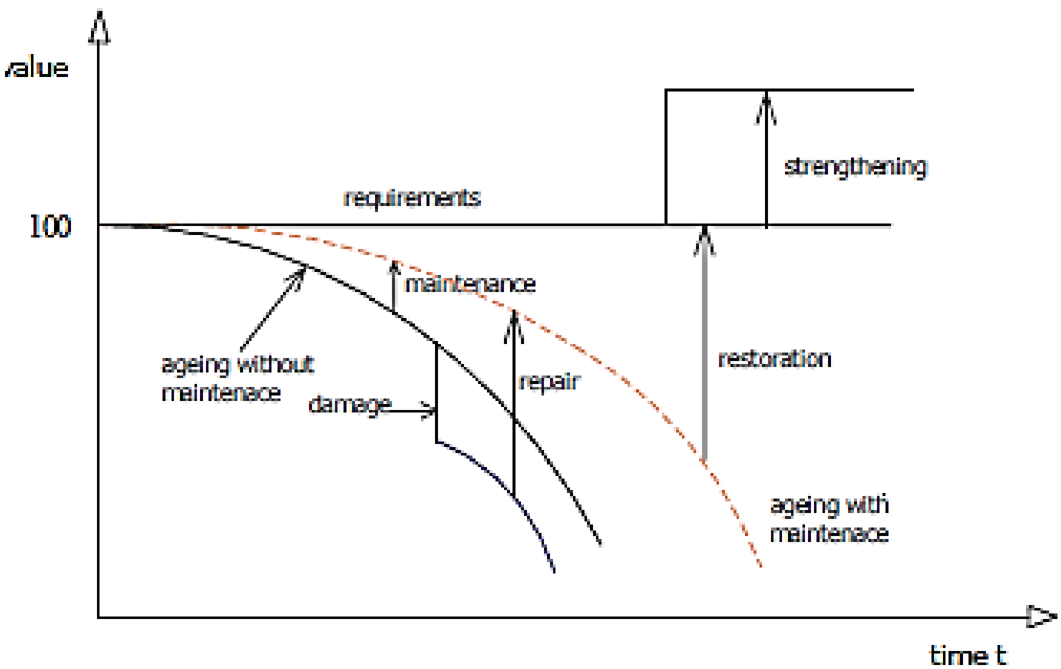


Figure 7. Value alteration of a building (Lungu & Arion 2005)

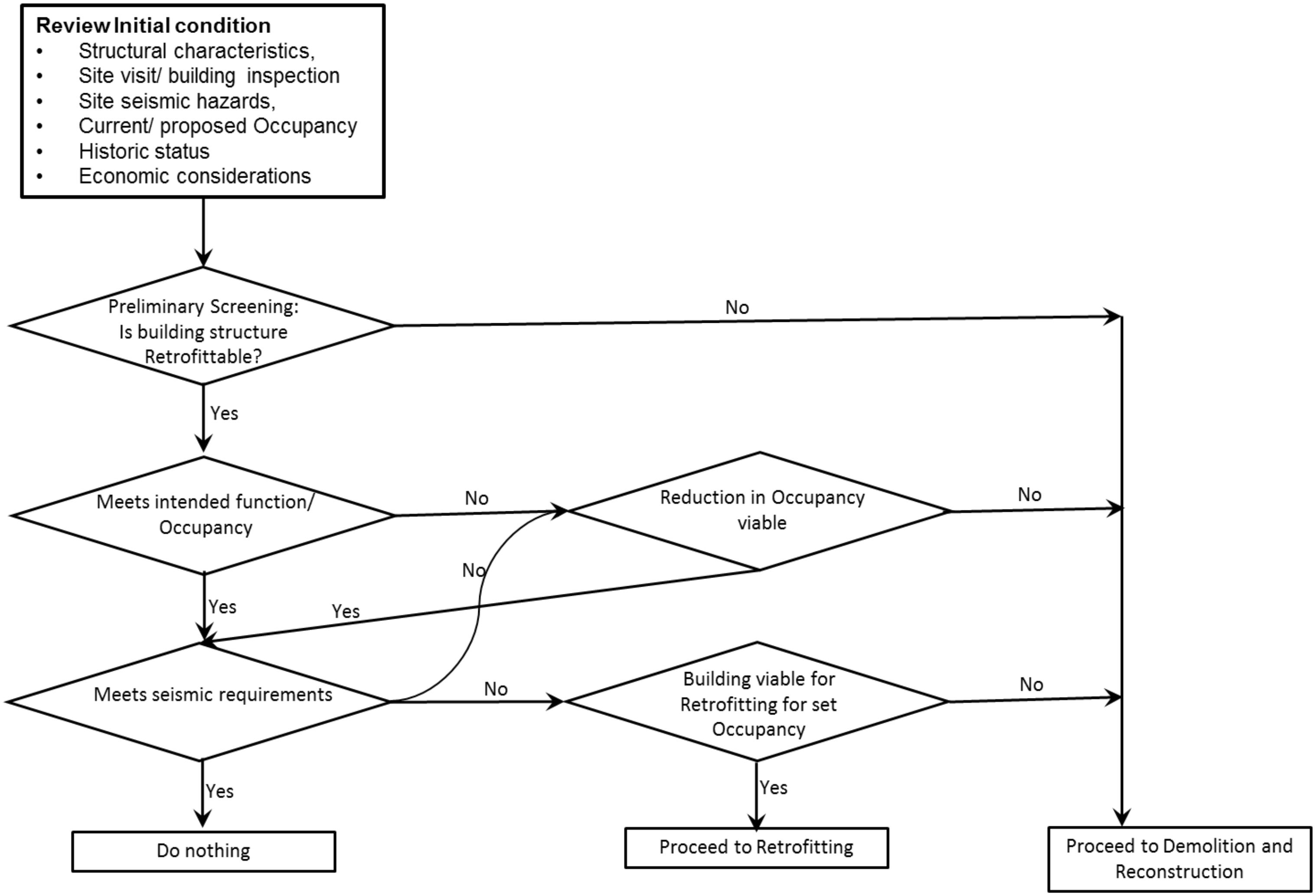


Figure 8. Flow path for review, assessment, and retrofitting of hospital facilities

7.2 Issues to be considered

The following factors should be considered while developing a possible intervention strategy:

- **Seismic hazard at the site:**The higher the hazard, the higher would be the design force, which could make strengthening of low strength masonry (stone or brick in mud mortar) unviable.
- **Condition of the** building (damage, deterioration, maintenance requirements): Severely damaged, significantly deteriorated buildings may not be suitable for intervention or may require significant level of intervention for its seismic improvement.
- **Age of the building:** If structure of a building is sound (not deteriorated or damaged) and it meets intended functional and Occupancy requirements, age cannot be a deciding factor for its demolition and reconstruction.
- **Intended function/ Occupancy:** This is one of the most important criteria when deciding on intervention options for hospital buildings. However, if a building does not meet intended functional/ Occupancy requirements, change in function and reduced Occupancy level should be carefully considered. This may trigger re-planning of the hospital facilities and their interactions.
- **Cost:** Generally, it is considered reasonable to retrofit a building if the retrofitting cost is less than 30% of the replacement cost. However, this cannot be a single criterion for not retrofitting a building. If the building meets intended functional and Occupancy requirements, even higher retrofitting costs could be acceptable, particularly if the building is not old. It should be noted that buildings such as stone masonry buildings in mud mortar with flexible floor/ roof diaphragms are low cost buildings. However, these buildings require higher level of input to bring them to a certain level of occupancy making retrofitting of these buildings unviable. In addition to this, many of these buildings are in deteriorated or damaged state. That will require higher level of input.
- **Building typology and vulnerability:** Seismic resistance of a building structure depends upon the used construction materials, technology and skills, and detailing. Certain building typologies such as rubble stone masonry in mud mortar are highly vulnerable to seismic shaking. The higher the vulnerability of a building, the higher the intervention, i.e. higher the cost would be to bring the building to a suitable level of Occupancy. High vulnerability buildings such as stone in mud mortar buildings may not be suitable for higher level of Occupancy unless very high interventions are made, which could make retrofitting unviable.
- **Performance expectation:**The higher the performance expected, the higher would be the retrofitting cost.
- **Technological capacity available at the site:** While deciding the method of retrofitting, it is important to understand what skills could be available at the site and what materials could be transported.

7.3 Demolition and reconstruction

Demolition and reconstruction should only be considered when all other options are carefully evaluated and exhausted by suitably trained personnel. While evaluating this option, the following needs to be considered: the demolition cost; salvage value; replacement cost; cost of aseismicfeatures in new construction; and seismic retrofitting cost of the representative buildings withdifferent structural systems and construction materials. Any replacement facility has to meet the current requirements.

Table 9provides indicative criteria for demolition of buildings.

Building Type	Damages
Stone masonry in mud mortar and flexible diaphragm	Earthquake Damage Grade 2 or more (understand the building in totality) Buildings with bulging walls, Significant wall separations Buildings with significant water damage, deterioration Walls with high mud content Walls with highly irregular rubble stones, Significant geotechnical issues that could trigger instability of the building,
Brick masonry in cement mortar and rigid diaphragm	Earthquake Damage Grade 3 or more, Buildings with bulging walls, Buildings with significant water damage, deterioration Walls with high mud content Significant geotechnical issues that could trigger instability of the building,
Brick/ Stone masonry in cement mortar and rigid diaphragm	Earthquake Damage Grade 3 or more Buildings with bulging walls, Significant wall separations Buildings with significant water damage, deterioration Significant geotechnical issues that could trigger instability of the building,
RC frame	Earthquake structure damage to Damage Grade 3 or more Buildings with significant environmental deterioration due to water ingress (corroded steel, peeling concrete), Significant geotechnical issues that could trigger instability of the building,

Table 9. Indicative criteria for demolition of a building

7.4 Change ofoccupancy

If the building structure is in good condition, but the building does not meet intended functional and Occupancy requirements, reduced occupancy and change in function shall be considered.

7.5 Repair and retrofit

Most of the hospital buildings in Nepal are unlikely to meet the intended safety requirements expected for intended Occupancy of hospital buildings or other associated buildings (e.g. storage, residences, etc.).In many cases, the principal building structure may meet the coderequirements,however, the secondary structure may be significantly deficient. A point in case is RC frame buildings with masonry infill. In Nepal, the frame is designed for seismic loading, but the interior and exterior walls are not tied to the principal structure. These walls could topple or get damaged, which could impact the of function of the building.

A detailed seismic assessment of the building is a pre-requisiteto determining the intervention for improved seismic performance of a hospital building. Refer to Section 8 for details on seismic assessment and strengthening.

7.6 Holistic approach

A holistic approach towards the whole hospital facility should be developed for evaluation and retrofitting. The following should be considered:

- Understanding the interrelationship between buildings and other facilities

- Understanding interdependency between various facilities of the hospital for their continual function during a disaster
- Understanding building structure vulnerability (primary structure, secondary structure)
- Understanding building non-structural vulnerability
- Single stage rehabilitation or incremental rehabilitation.

8 Seismic Assessment and Retrofit

8.1 Overview

Seismic assessment is defined as a process or methodology for evaluating and quantifying deficiencies in a building. Seismic retrofit is defined as the process of improving the seismic performance of a building by correcting the deficiencies identified in a seismic evaluation.

8.2 Seismic Assessment

Understanding performance of an existing building structure at global or element level (both principal and secondary element), subjected to lateral earthquake forces is a complex subject. However, in simple terms, the earthquake performance (and rating) of a building is generally evaluated based on a hierarchy of risk.

The following data should be collected for seismic assessment of the building and forestablishingits' expected performance:

- Location of the building, name address, GPS coordinates
- Review of all existing architectural, structural andconstruction plans, construction specifications,
- Obtain data from MoH or municipalities regarding the building use, construction date, any modifications or additions, no of users and hours of operation, adjacent buildings, possible use of the building as an emergency shelter, nearest facility that can act as a substitute
- Previously collected data for the building
- Photographs of the building
- Site visit to document the existing conditions and to verify or resolve discrepancy with data collected from other sources
- Non-destructive material testing
- Destructive material testing (design or construction phase only).

The objective of the assessment is to collect sufficient data to establish the as-built condition of the building including:

- General building description (number of stories and dimensions)
- Structural system description including framing, lateral-force-resisting system (LFRS), floor and roof diaphragm construction, structural connections, basement and foundation system
- Hospital building type
- Material properties and site conditions obtained from contract documents
- List of identified seismic deficiencies.

Once this data is collected, it is possible to establish the site hazard, building structural characteristics, and building occupancy (importance) and thus the performance objectives for the buildingas described in per Section 5. Once these are defined, the building can be assessed and deficiencies identified and quantified. Using the selection criteria of Section6, the building retrofit can be prioritized, and using the identified seismic deficiencies, a retrofit programme can be developed.

8.3 Seismic retrofit

The primary goal of retrofitting should be the correction of the main weakness relating to seismic performance of the building and its contents. While developing the strategy for retrofitting, a hierarchical approach should be taken and priorities should be given to addressing structural or non-structural weakness at the top of the hierarchy. At the top of the hierarchy should be the structural and non-structural weaknesses that pose the biggest threat to human safety or function of the building during an earthquake. Unanchored parapets, unrestrained partition walls or equipment fall in high hierarchy categories.

Once the seismic deficiencies are identified and quantified during the assessment process, the next step is to design a seismic retrofit to address those deficiencies and bring the building performance into compliance with the target performance of the building.

Seismic retrofit of an existing building is achieved by implementing retrofit measures that address the deficiencies. One or more of the following strategies are permitted as retrofit measures:

- Improve building configuration to mitigate all building weaknesses
- Improve the connection between various structural elements
- Restrain secondary building components, non-structural elements
- Add new structural elements, where required
- Improve detailing for the transfer of lateral forces from horizontal (floors) to vertical (walls or columns) elements
- Improve ductility of structural elements.

8.4 Seismic retrofitting matrix

An effective seismic retrofitting programme addresses the deficiencies determined during the assessment phase in a cost-effective manner. The retrofit design should minimize occupancy interruptions and maintain the unique architectural features of buildings.

8.4.1 Vertical elements of the LFRS

Table 10 summarizes the upgrade options for deficient vertical elements of the LFRS.

Issue	Deficiency	Seismic retrofit
Deficient configuration	Soft or weak story	• Add strength or stiffness to story
	Torsional irregularity	• Add balancing walls, braced frames, or concrete walls
RC frame building with masonry infill	Inadequate lateral stiffness	• Add new RC walls • Add steel braces
	Inadequate lateral strength	Strategy: Reduce mass • Reduce seismic mass by removing heavy equipment or floor tiles Strategy: Increase strength • Add new concrete walls • Shotcrete existing masonry infill walls

		• Add steel braces • FRP overlay of URM walls Strategy: Increase ductility • Improve ductility of the structural system by improving confinement/ shear capacity, thereby reduce the seismic demand
	Short column effect	• Convert frame system into structural wall system
	Deficient diaphragm	• Improve diaphragm (floor and roof diaphragms are unlikely to be deficient in Nepal)
	Weak beam-column joints	• Jacket or prestress joints
	Weak column- strong beam	• Jacket columns
	Inadequate shear strength	• Fibre composite wrap
	Lack Confinement or short splices	• Fibre composite wrap • Concrete/steel jacket
	Inadequate foundation	• Enlarge shallow foundations • Add micro piles
	Lack of out-of-plan restraint for URM walls	• Provide anchorage for the walls
	Deteriorated or poor masonry	• Replace the deteriorated masonry and repoint the grout
Stone masonry	Deamination/ mechanism failure	Tie multi-wythes together
	Bulging of walls	Remediate bulged part of the wall
	Deteriorated or poor masonry	Replace the deteriorated masonry and repoint the grout
	Weak wall junctions	Provide stitches at wall junctions
	Weak wall	• RCC splint and bandage technique, • RCC jacketing on both faces of the walls with rebars, • jacketing on both faces of the walls with GI wire mesh, • combination of jacketing and splint and bandage with steel or GI wire mesh, • timber splints and bands for RCC-framed structures, • introduction of shear walls • foundation underpinning,
Brick masonry	Bulging of walls	Remediate bulged part of the wall
	Deteriorated or poor masonry	Replace the deteriorated masonry and repoint the grout
	Weak wall junctions	Provide stitches at wall junctions
	Weak wall	• RCC splint and bandage technique, • RCC jacketing on both faces of the walls with rebars, • jacketing on both faces of the walls with GI wire

		mesh, • combination of jacketing and splint and bandage with steel or GI wire mesh, • timber splints and bands for RCC-framed structures, • introduction of shear walls • foundation underpinning,

Table 10. Proposed upgrade matrix for vertical elements of LFRS for Hospital facilities in Nepal

8.4.2 Floors and roofs

Table 11 summarizes the upgrade options for deficient horizontal elements of the LFRS.

Floor/roof	Deficiency	Seismic retrofit
Concrete, wood, metal	Inadequate shear capacity of floor diaphragms	Add FRP overlay (concrete) Add plywood sheathing (wood)
	Inadequate collector	Add steel or concrete beams
	Inadequate connection of floors to vertical elements	Reinforce the connection (shear transfer) of the slab to vertical elements;

Table 11. Proposed upgrade matrix for horizontal elements of LFRSfor Hospital facilities in Nepal

8.4.3 Non-structural components

Table 12 summarizes the upgrade options for deficient anchorage and/or bracing of non-structural components.

Component	Seismic retrofit
Heavy partition walls	Provide wall bracing and anchorage.
	Provide wall bracing and anchorage, and fibre reinforced polymer (FRP) partition walls.
	Remove and replace walls with lighter Sheetrock-type walls.
Ducts	Provide support, bracing, and anchorage to the floors or walls.
piping	Provide support, bracing, and anchorage to the floors or walls.
Shelving	Provide bracing and anchorage to floors and/or walls.
TVs or monitors	Strap item to the mounts and bolt the mounts to the structure.
All	Provide proper anchorage to the structure.
Parapets	Provide bracing.
	Remove parapets.
Generators, air handlers	For large floor mounted equipment, used products with seismic certification and properly anchor the units
Medical equipment	Provide adequate anchorage for floor, wall, and ceiling mounted medical apparatus Provide vibration isolators

Table 12. Proposed upgrade matrix for non-structural components for Hospital facilities in Nepal.

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Appendix A Conceptual seismic retrofit drawings

A.1 STRUCTURAL RETROFITS

Figure A.1 through Figure A.10present examples of seismic retrofit details for bearing wall and concrete frame buildings. The details presented below are indicative only and need to be adopted as required or new details to be developed that suits the local condition, building typologies.

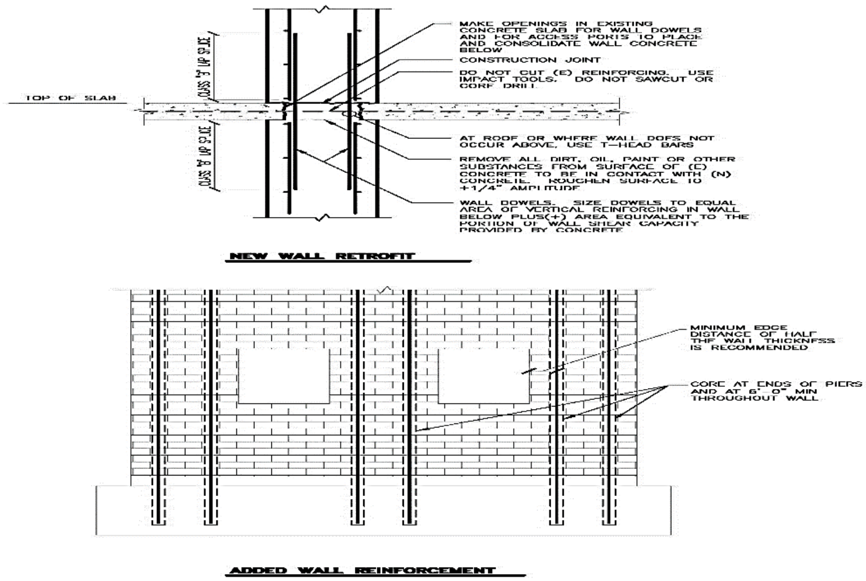

Figure A.1. Add new walls (FEMA 2007)

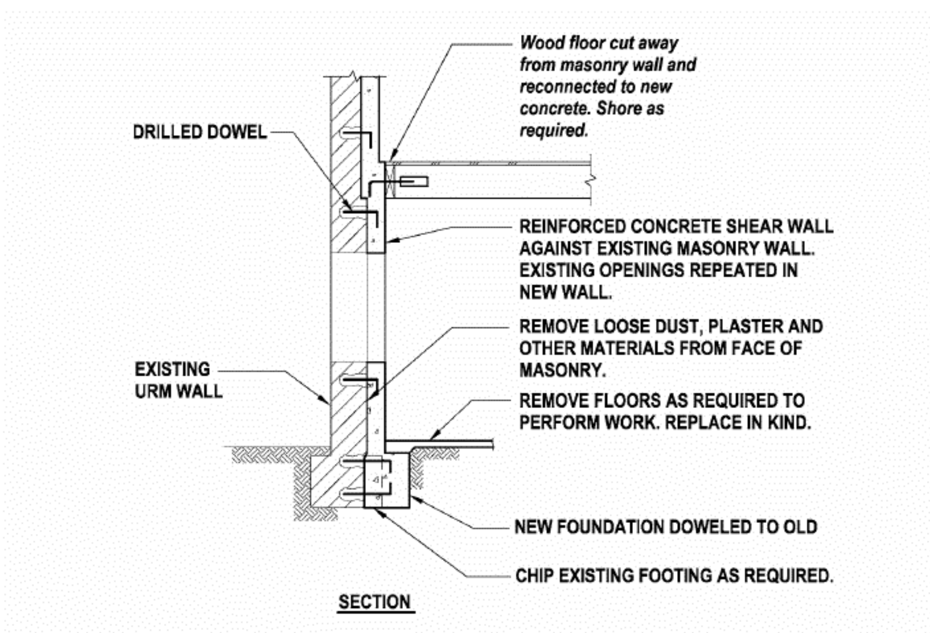

Figure A.2. Shotcrete of existing URM walls (FEMA 2007)

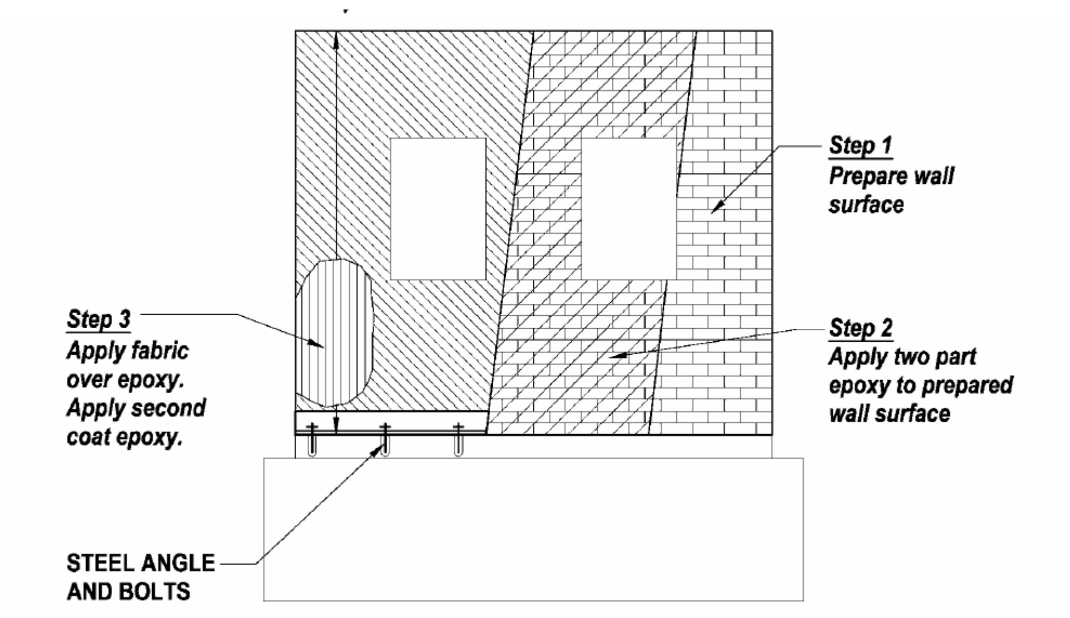

Figure A.3. FRP overlay for URM walls (FEMA 2007)

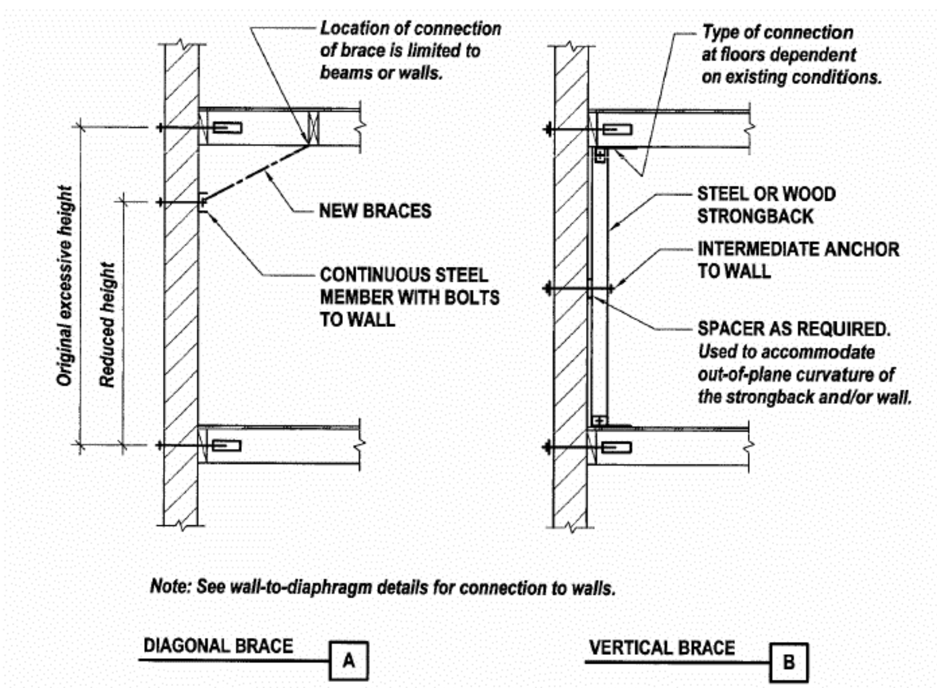

Figure A.4. Out-of-plane wall anchorage (FEMA 2007)

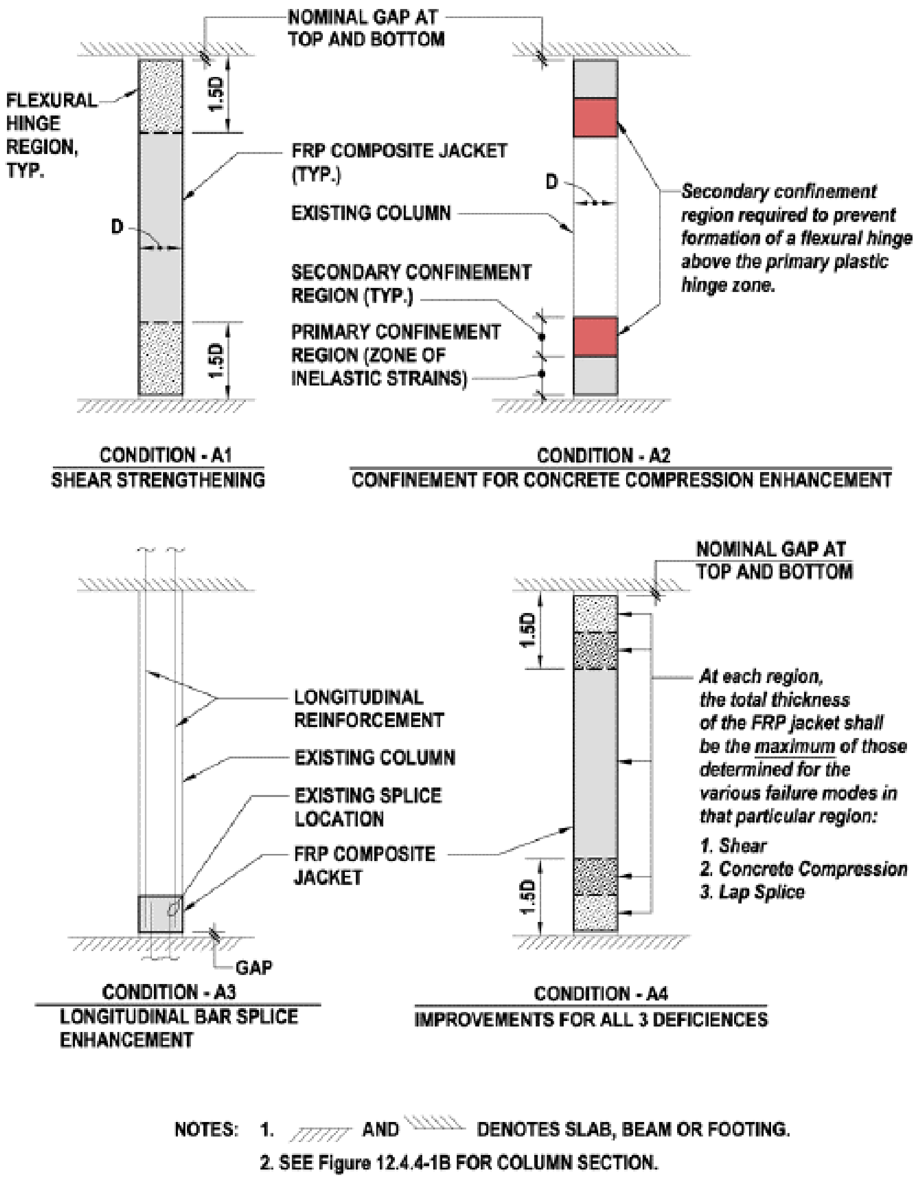

Figure A.5. FRP retrofit of concrete columns (FEMA 2007)

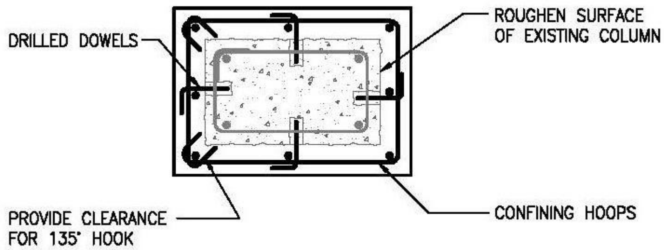

Figure A.6. Concrete jacketing (FEMA 2007)

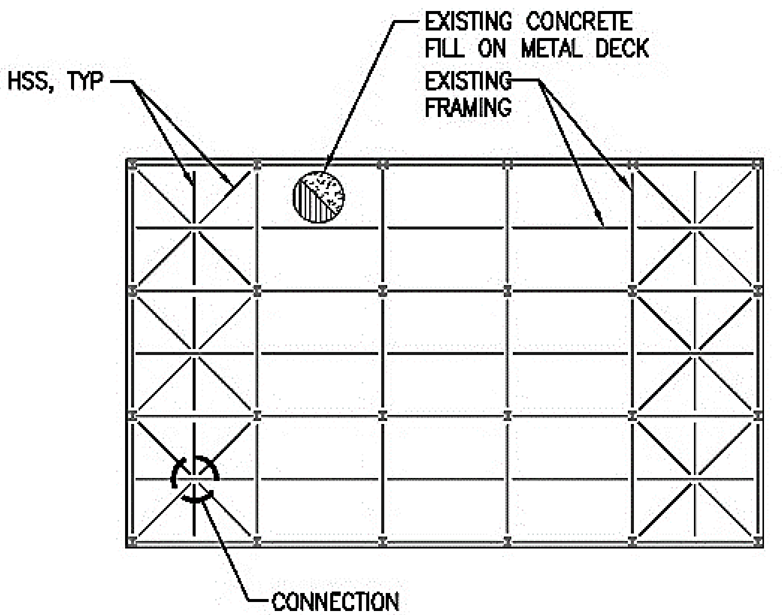

Figure A.7. Diaphragm bracing (FEMA 2007)

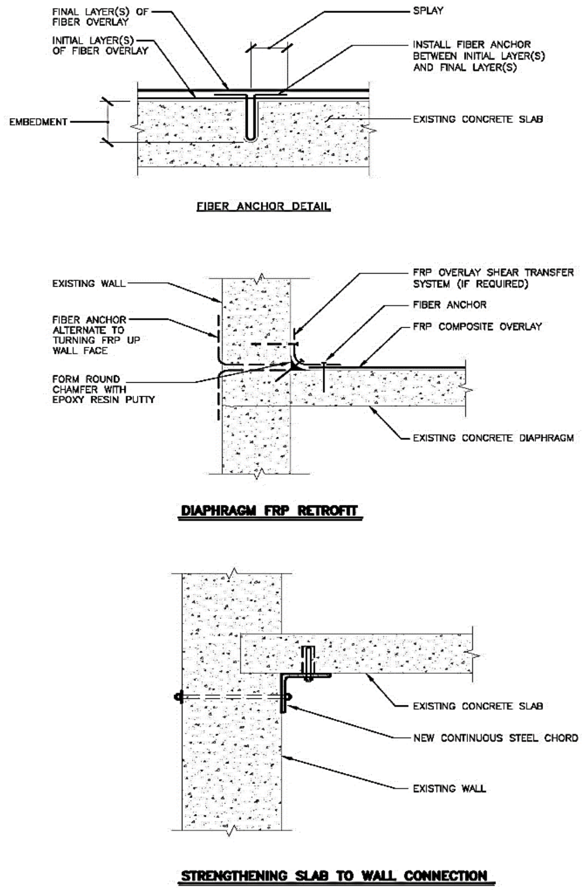

Figure A.8. Diaphragm FRP retrofit (FEMA 2007)

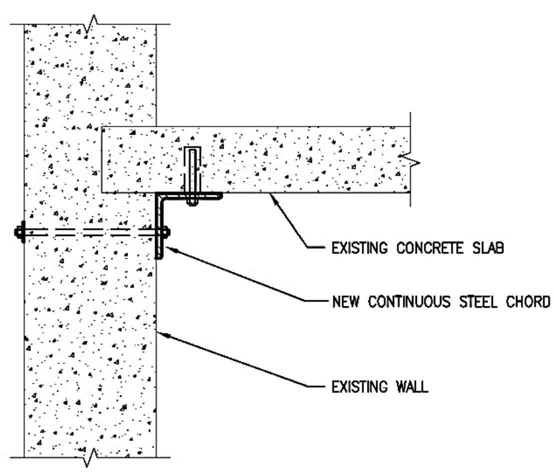

Figure A.9. Strengthening of slab-to-wall connection (FEMA 2007)

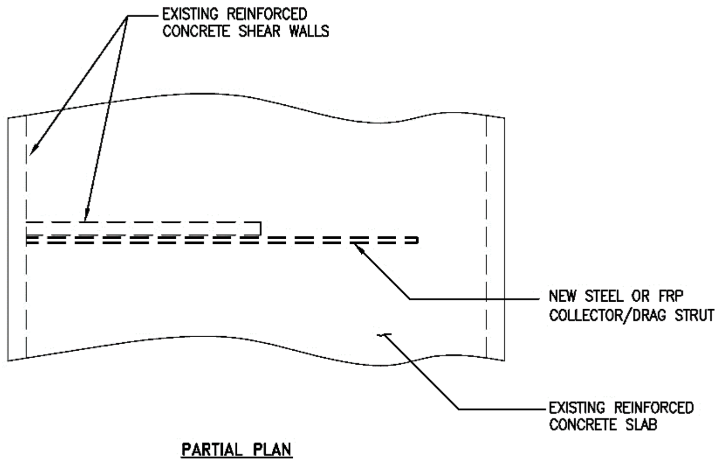

Figure A.10. New collector/drag strut (FEMA 2007)

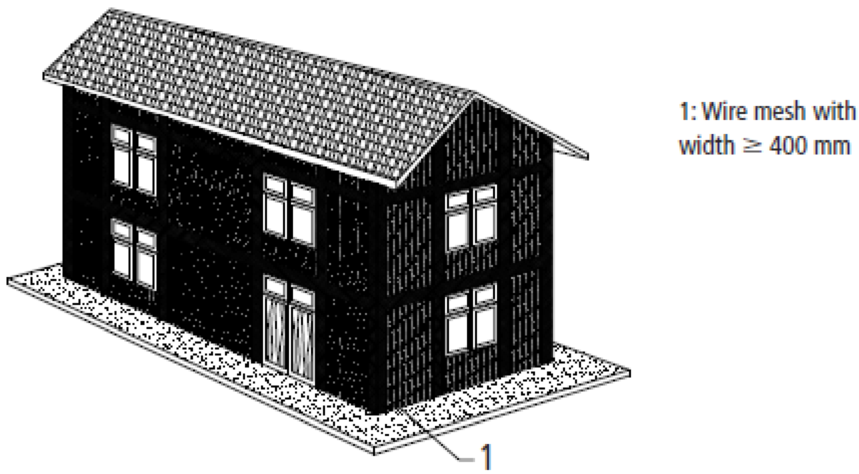

Figure A.11. Splint and bandage (IAEE, 2013)


Figure A.12. Jacketing of a masonry wall (Bothara & Brzev 2011)

Figure A.13. Stitches to multi-wythe stone masonry wall (Bothara & Brzev 2011)

A.2 Nonstructural components

Figure A.14 through Figure A.21 provide details of retrofit options for non-structural components (DGS 2000).

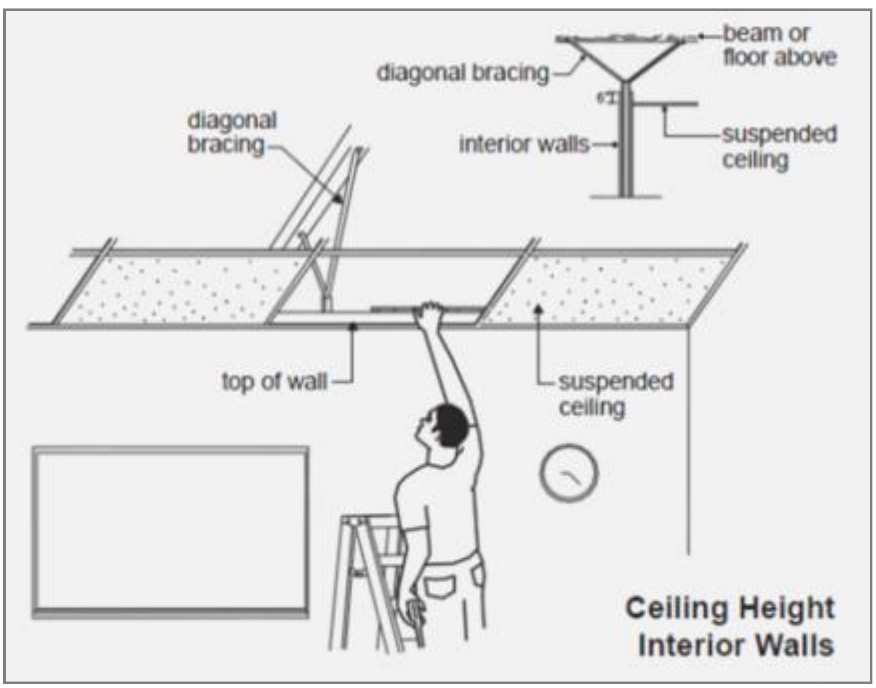

Figure A.14. Bracing of interior walls

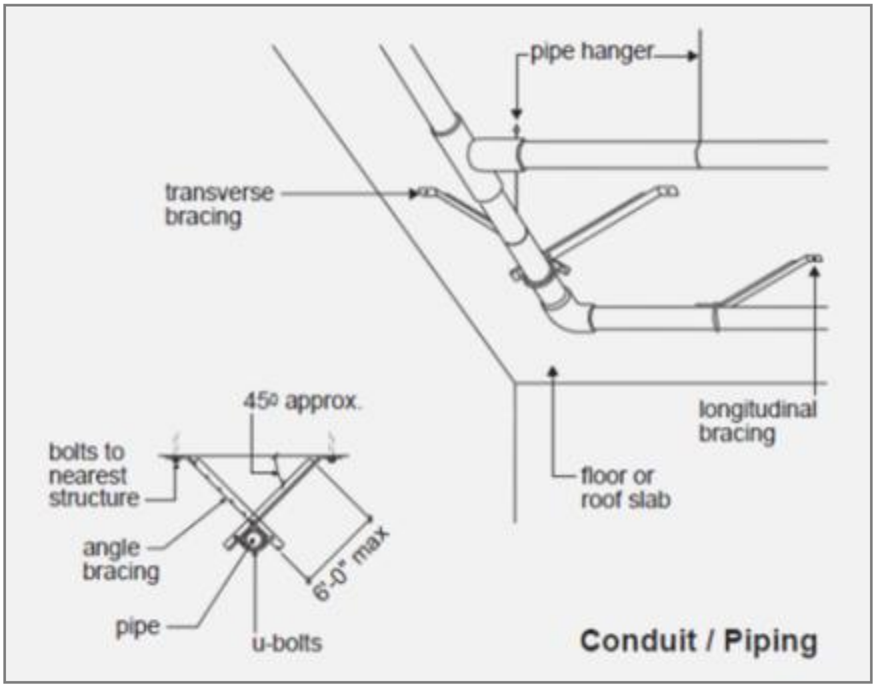

Figure A.15. Bracing and anchorage for piping

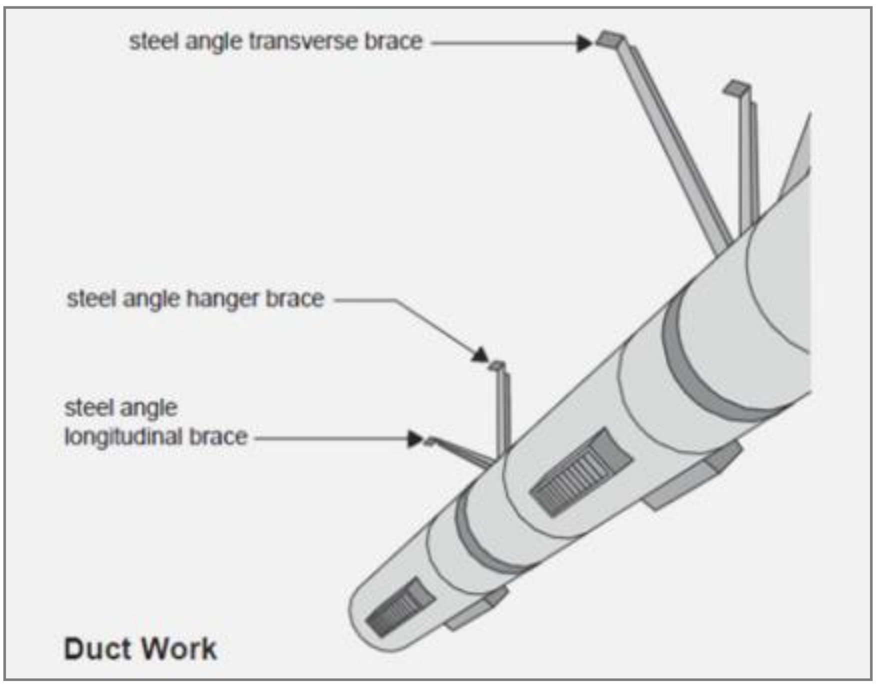

Figure A.16. Bracing and anchorage for ducts

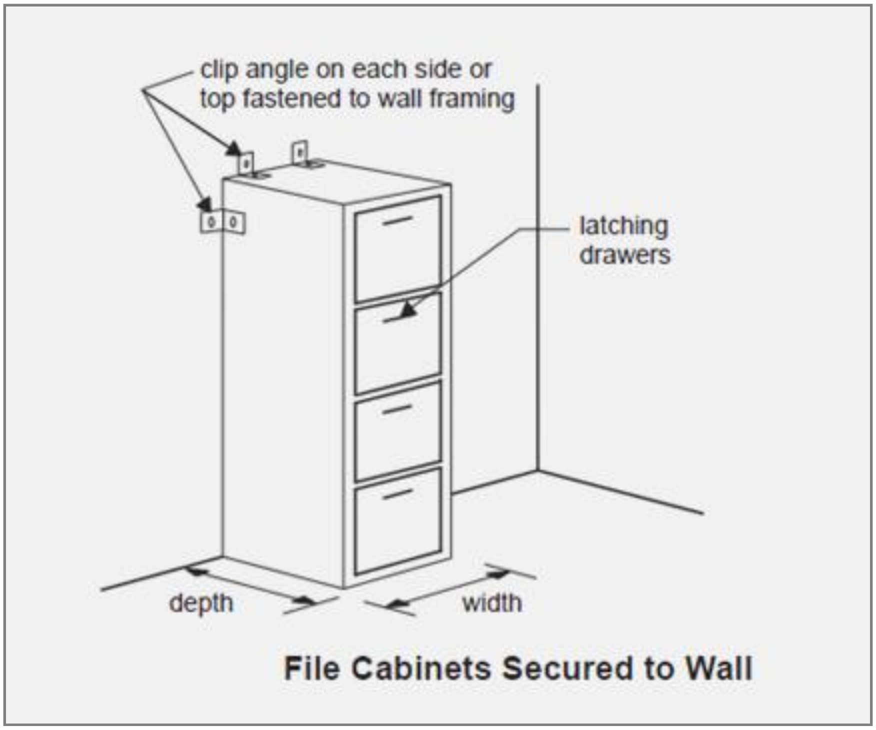

Figure A.17. File cabinet anchorage

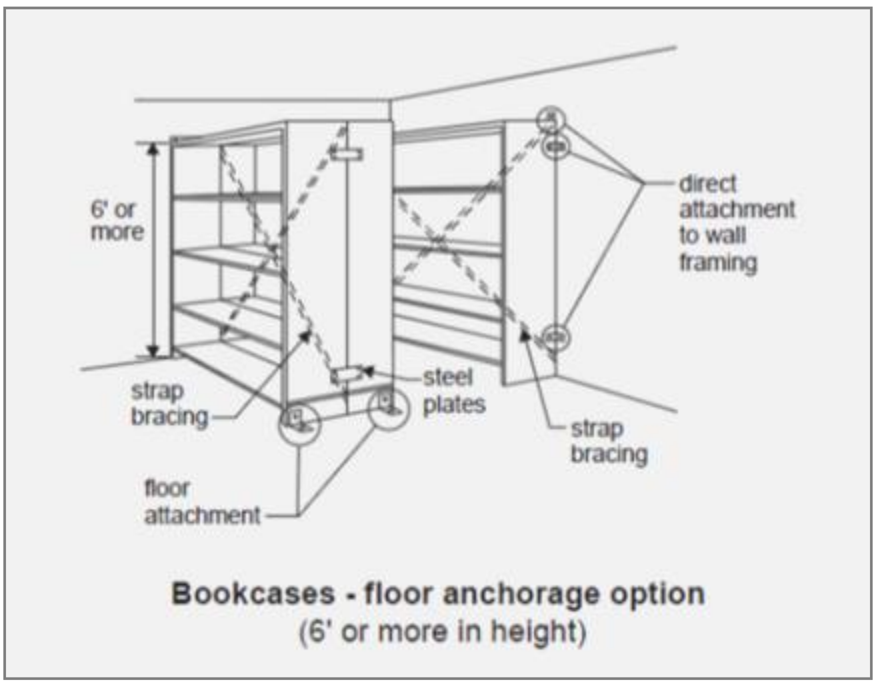

Figure A.18. Anchorage for bookcases 1.8 m or taller

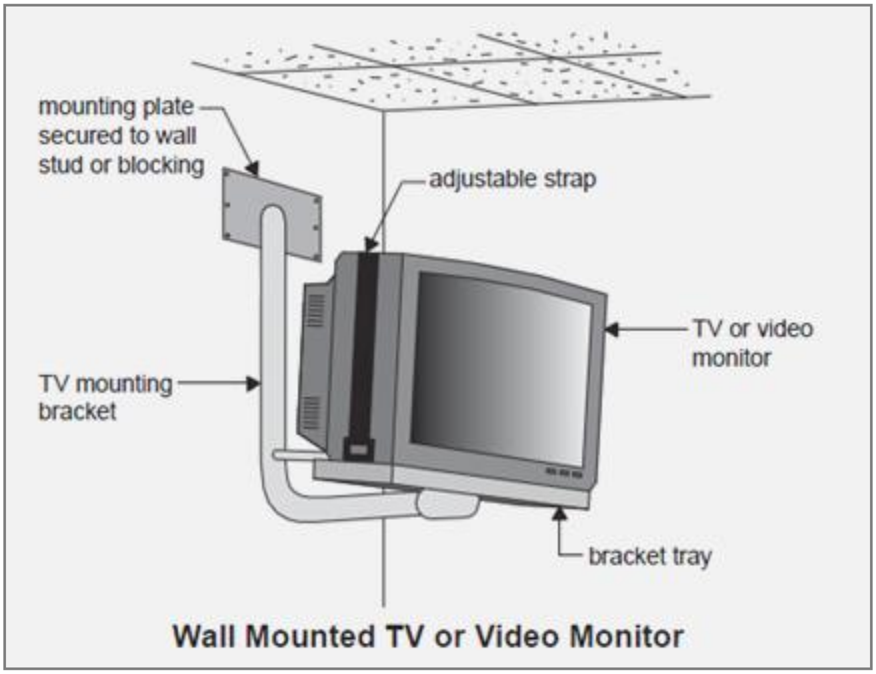

Figure A.19. Attachment of elevated monitor to the structure

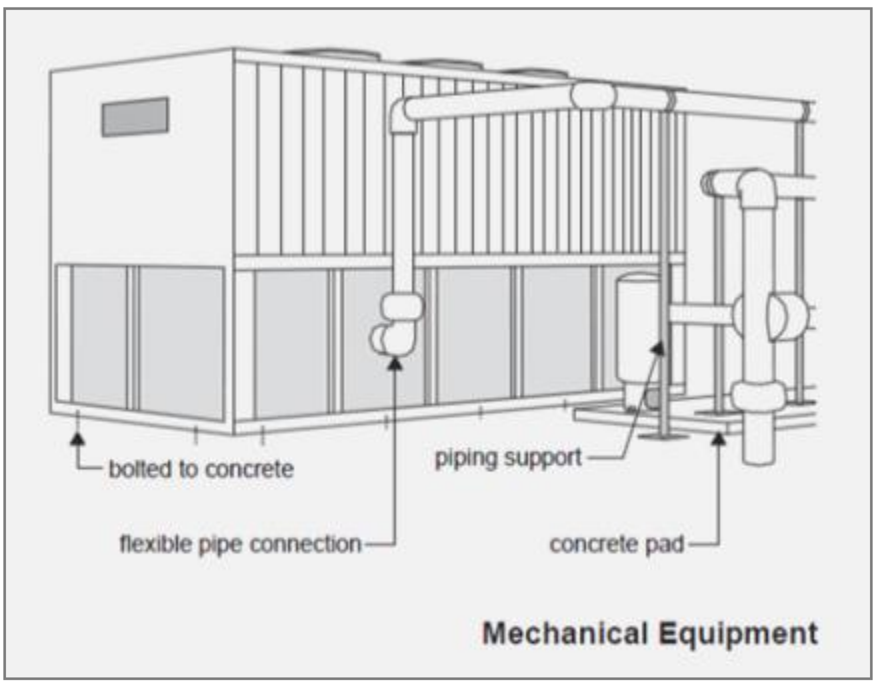

Figure A.20. Anchorage of mechanical equipment

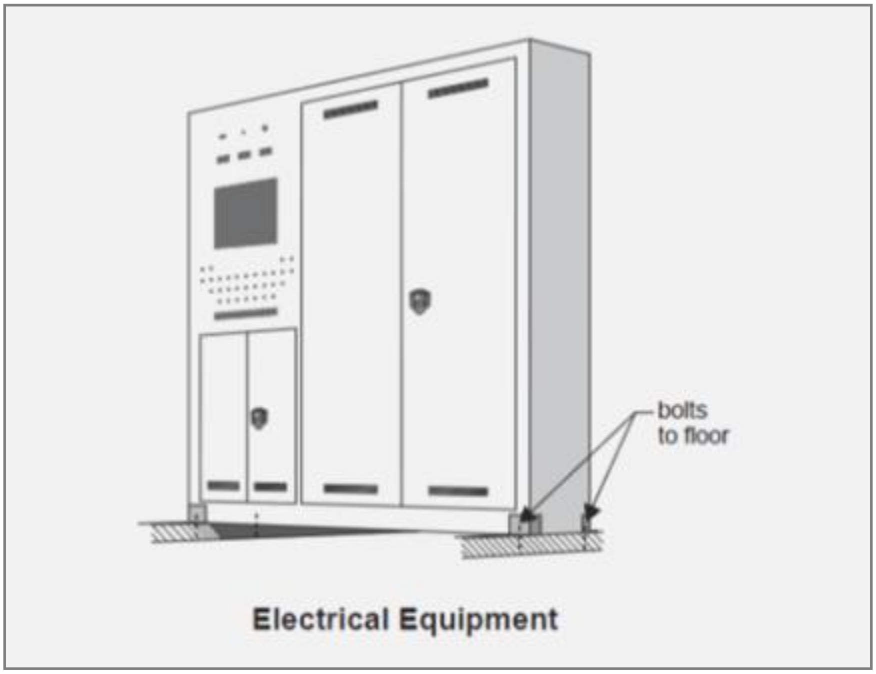

Figure A.21. Anchorage of electrical equipment