SEISMIC VULNERABILITY EVALUATION GUIDELINE FOR PRIVATE AND PUBLIC BUILDINGS

Part II: Post Disaster Damage Assessment

Submitted to:
Government of Nepal
Ministry of Physical Planning and Works
Earthquake Risk Reduction and Recovery Preparedness Programme for Nepal

Submitted by:
National Society for Earthquake Technology-Nepal (NSET)

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Fore Word

(To be written by DUDBC)

Preface

Nepal is situated along southern slope of the Himalayan range, which is susceptible to frequent earthquakes. There is a record of many large earthquakes that have occurred in the past. Kathmandu has suffered damage due to earthquakes several times in the history.

Most losses of lives in the past earthquakes in developing countries have occurred due to collapse of buildings. The most recent Bhuj (2001), Bam (2003), Pakistan (Oct 2005) and China (May 2008) earthquakes can be taken as eye opening events when the buildings of our type suffered different levels of damage.

This guideline is developed with a view to assess the damage state of the buildings in earthquake affected region in more proper and systematic manner. The document provides guidance on post-disaster seismic evaluation procedure of common building types in Nepal and the region. It includes processes of rapid and detail evaluation and discusses various likely damage patterns of the buildings and vulnerability or damage grade related to different damage patterns. The guideline also includes the damage survey form for recording the damage observations and providing recommendation for further action in the form of Safe/Restricted/Unsafe buildings. The result should help house owners and rescue officers to make decision on post disaster response. The most appropriate and timely information can save lives; minimize injury, damage and loss; prevent secondary hazards. Assessment results are very useful for preparedness planning.

Further, technical recommendation for repair, retrofit or demolition of the building can be provided with the use of this document which is necessary as part of the rehabilitation process. For this, damage analysis of different types of building structures have to be classified in the internationally accepted damage categories which are discussed in the document.

This guideline is prepared based on the experience of NSET in assessing the institutional, private and public buildings, hospital and school buildings in earthquake affected areas of Pakistan (Oct 2005), Bam (Dec 2003) and Bhuj (2001). References of the documents such as ATC 20, FEMA 154, FEMA 273, FEMA 274, FEMA 306, FEMA 307, FEMA 308, FEMA 356, ATC 40 etc are taken for the post earthquake seismic evaluation procedures. The contents of the guideline are based on the study of experience of past earthquakes that are widely available.

The document has been reviewed by JICA and other professional structural experts from different organizations. This document has also been presented and discussed in stakeholder’s workshop held in Kathmandu at DUDBC. Feedbacks and comments received during the workshop have been incorporated while revising the document.

The guideline is useful to those who are associated and engaged in the repair, restoration and seismic strengthening of damaged building in quake affected areas. It is believed that the engineers and practitioners from different government, non-government and other organizations will make use of it and the document will be in a continuous process of revision and improvement for future applications.

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Acknowledgements

This guideline has been developed and reviewed by NSET professionals and other national and international team of experts.

Authors are thankful to UNDP and ERRRP-Project (Earthquake Risk Reduction and Recovery Preparedness Project in Nepal for contributing to building the resilience of nations and communities to disaster, to strengthen the institutional and community level capacity to plan and implement earthquake risk reduction strategies and disaster recovery preparedness in Nepal.

Preparation of the document is supported by the Government of Japan through ERRRP-Project for Nepal. So our sincere acknowledgments go to the Government of Japan. We also thank Government of Nepal, Ministry of Physical Planning & Works for providing this task to NEST. Our sincere thanks, in particular, to Mr. Surya Prakash Acharya, Joint Secretary, MoPPW and National Project Director, UNDP/ERRRP Project, Mr. Vijaya P. Singh, UNDP Nepal and Mr. Amrit Man Tuladhar, Project Manager UNDP/ERRRP Project for their constant cooperation during the development of the guideline in all stages of work. Authors are particularly grateful to UNDP, Government of Japan and DUDBC for trusting NSET in preparation of this guideline. Our special thanks to Mr. Manohar Rajbhandari, who has always been a source of inspiration and also for his valuable suggestions and informations.

Authors would like to express their deep appreciation to all those concerned with the preparation and publication of the related documents, reference of which is taken for the preparation of this document, such as ATC 20, FEMA 154, FEMA 273, FEMA 274, FEMA 306, FEMA 307, FEMA 308, FEMA 356, ATC 40 and IS assessment guidelines. NSET would like to acknowledge their contributions to this effort without which the accomplishment of this guideline was difficult.

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1. INTRODUCTION

1.1 Purpose

The purpose of this document is to provide practical criteria and guidance for evaluating earthquake damage to buildings with primary lateral-force-resisting systems consisting of reinforced concrete frame and masonry buildings which are prevalent in Nepal. The procedures in this manual are intended to characterize the observed damage caused by the earthquake in terms of the loss in building performance capability. The intended users of this document are primarily practicing engineers with experience in concrete and masonry design and construction with basic understanding of earthquake resistant design and construction. Information in this document also may be useful to building owners, and government agencies; however these users should consult with a qualified engineer for interpretation or specific application of the document.

1.2 Basis and Scope

The evaluation procedure assumes that when an earthquake causes damage to a building, a competent engineer can assess the effects, at least partially, through visual inspection augmented by investigative tests, structural analysis, and knowledge of the building construction. By determining how the structural damage has changed structural properties, it is feasible to develop potential actions (performance restoration measures) that, if implemented, would restore the damaged building to a condition such that its future earthquake performance would be essentially equivalent to that of the building in its pre-event condition. The costs associated with these conceptual performance restoration measures quantify the loss associated with the earthquake damage.

The theoretical basis of this guideline is based on different documents from FEMA and ATC namely ATC 20, FEMA 154, FEMA 273, FEMA 274, FEMA 306, FEMA 307, FEMA 308, FEMA 356, ATC 40 etc and the experience of damage assessment of the buildings after Kashmir earthquake in Pakistan.

There are four levels of damage assessment:

- Windshield: Overall scope of damage
- Rapid : Assessment sufficient for most buildings
- Detailed: Closer assessment of difficult or complex buildings
- Engineering : Consultant engaged by owner

This guideline covers the rapid and detailed assessment procedures. Process for windshield will be different as it is the overall damage assessment from air i.e. helicopter survey, the last one needs quantitative assessment of individual buildings.

The damage assessment methodology suggested in this guideline is not for grant distribution but different grades of damage identified after detail evaluation can be utilized as a basis for grant dispersion also.

1.3 Guideline Dissemination

The guideline has the potential to improve the situation of earthquake disaster affected area through proper planning if implemented by concerned authorities appropriately. This guideline should reach to engineers and practitioners who are working in the field of construction and disaster and make use of the document effectively and efficiently.

However, distribution of printed guidelines alone has been shown to be ineffective in achieving change in practice. Guidelines are more likely to be effective if they are disseminated by an active education. Hence, training for guideline users should be carried in parallel so that they are in a position to better understand the issue and make best use of the guideline.

Guidelines must obviously be made as widely available as possible in order to facilitate implementation. It is necessary to have wide circulations among engineers and practitioners working in the field of earthquake engineering. It thus requires an integrated effort by the concerned authorities like local government, municipalities, NGO's, INGO's and other related organisations towards dissemination of publication in wider range.

Further dissemination and implementation of a guideline should be monitored and evaluated. The guideline also needs thorough review by experts in the field. This should undergo mandatory updating procedure to transform it into pre-standard and then to building standard.

2. DAMAGE ASSESSMENT PROCESS

2.1 General

This system of overall safety evaluation of earthquake damaged buildings is based on experience of such assessment in Pakistan after Kashmir earthquake. The purpose of rapid evaluation is similar to ATC-20.

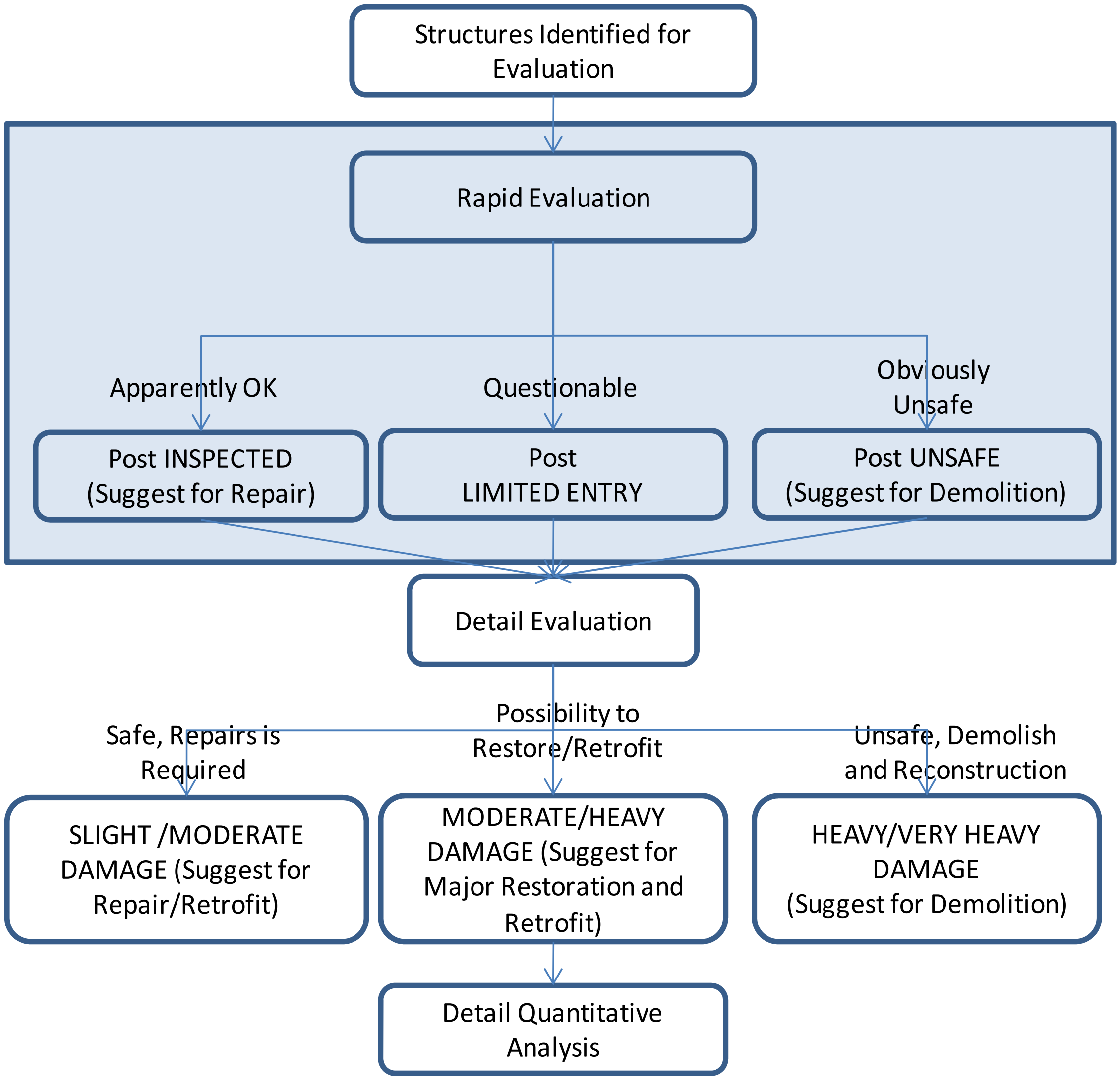


Figure 1: Flowchart showing damage assessment process

The purpose of rapid evaluation is rapid assessment for safety. It is to identify quickly which buildings are obviously unsafe, apparently safe and questionable.

In detailed Evaluation, buildings are inspected more thoroughly, with more investigation into the vertical and lateral load resisting systems. The purpose of detailed evaluations is not only to identify the safe or unsafe but also to identify the buildings that can be restored and retrofitted or need to demolish. Only limited buildings that are difficult to recommend for retrofit or demolition will be recommended for detailed quantitative assessment.

However, after detail retrofit design and cost estimation, if the retrofitting cost is higher, it might be suggested again for reconstruction. General recommendation for feasibility of retrofitting is up to 30% of the reconstruction cost of the same size building. Rapid evaluation methodology is described in **chapter 3** and the detail evaluation in **chapter 4** of this guideline.

2.2 Human Resources

All engineers, architects, sub-engineers can conduct the rapid evaluation once trained on rapid evaluation process and methodology. It is recommended that they are trained during normal time now and conduct refresher course after the earthquake again just before going to the field. Concerned department needs to prepare the roaster of trained professionals and their experience so that a right team is sent for different type of evaluation.

Engineers with structural engineering background and trained on detail evaluation methodology can conduct the detail evaluation for buildings and engineers with lifelines background and trained on detail evaluation of lifelines can conduct the detail evaluation of lifelines.

Engineers/ Architect Sub-engineers (Building Inspectors)	Engineers with Structures Background	Engineers with Lifeline Background
Rapid Evaluation of All Occupancies	Rapid Evaluation of All Occupancies Detail Evaluation of All Occupancies	Detailed Evaluation of Bridges, Roads, Airports, Treatment Plants, Pipelines, Reservoirs, Water Tanks and Dams

3. RAPID EVALUATION

3.1 General

The objective of the Rapid Evaluation is to quickly inspect and evaluate buildings in the damaged area with a minimum manpower available at the time of emergency. The rapid evaluation can be done by civil, structural, geotechnical engineers and architects with experience on building construction and trained on rapid evaluation methodology.

General situation during emergency is given in following bullet points:

- Usually a scarcity of skilled manpower available to conduct building by building inspections
- Designed to utilize the talents and experiences of professionals involved in building construction
- Once all buildings in a given area have been inspected and those that are apparently unsafe have been posted, the remaining structures, the so called gray-area buildings are left for a detailed assessment by a structural engineer

Rapid evaluation is done just after the earthquake to assess the safety of buildings to judge either people can enter the building or not. It can be done by visual inspection.

3.2 Safety Precaution

All possible safety precautions should be exercised as building under study could be in dilapidated condition and could loss its stability in whole or in parts causing casualty. The team must consist at least two personnel, both trained in assessment work. The team personnel must wear safety hats when assessing the buildings. Before entering a house, its condition should be well assessed as the house could be in dangerous state. Wherever the uncertainty exists and team is in doubt, it is better be conservative.

3.3 Steps for Rapid Evaluation

The initial steps in the visual observation of earthquake damage are to identify the location of the wall in the building and to determine the dimensions of the wall (height, length, and thickness). A tape measure is used for quantifying the overall dimensions of the wall. A sketch of the wall elevation should then be prepared. The sketch should include sufficient detail to depict the dimensions of the wall, it should be roughly to scale, and it should be marked with the wall location. Observable damage such as cracks, spalling, and exposed reinforcing bars should be indicated on the sketch. Sketches should be made in sufficient detail to indicate the approximate orientation and width of cracks. Crack width is measured using the crack comparator or tape measure at representative locations along significant cracks. Avoid holes and edge spalls when measuring crack widths. Crack widths typically do not change abruptly over the length of a crack. If the wall is accessible from both sides, the opposite side of the wall should be checked to evaluate whether the cracks extend through the thickness of the wall and to verify that the crack widths are consistent.

Photographs can be used to supplement the sketches. If the cracks are small, they may not show up in the photographs, except in extreme close-up shots. Paint, markers, or chalk can be used to highlight the location of cracks in photographs. However, photographs with highlighted crack should always be presented with a written disclaimer that the cracks have been highlighted and that the size of the cracks cannot be inferred from the photograph.

During a visual inspection, the engineer should carefully examine the wall for the type of damage and possible causes. Indications that the cracks or spalls may be recent or that the damage may have occurred prior to the earthquake should be noted. Visual observation of the nonstructural elements in the building can also be very useful in assessing the overall severity of the earthquake, the inter-story displacements experienced by the building, and the story accelerations. Full-height nonstructural items such as partitions and facades should be inspected for evidence of inter-story movement such as recent scrapes, cracked windows, or crushed wallboard.

Following steps are recommended for conducting rapid evaluation of earthquake damaged building.

I. Study the house from outside, take a walk around the house and do visual inspection

Visual inspection from outside and inside of the building is the only method applicable for rapid evaluation of buildings. Generally, earthquake damage to concrete and masonry walls (common building types in Nepal) is visible on the exposed surface. Observable types of damage include cracks, spalls and delaminations, permanent lateral displacement, and buckling or fracture of reinforcements.

II. Enter the house to do assessment inside if it is safe to do so

Enter the building if entering the house is safe. Inspect the house from inside as done from outside. Identify cracks, spalls and delamination, joints opening, permanent lateral displacement, and buckling or fracture of reinforcements. Come out of the houses as soon as possible.

III. Fill-up the form, note the observations

Rapid evaluation form is given in **Annex III** of this guideline. The key information to be collected are:

1) Information about evaluator
2) Building Description: Owners' name, Address, contact no, total plinth area, type of construction, Type of floor, type of roof, primary occupancy etc.
3) Damage conditions
4) Estimated building damage ratio
5) Safety status (Posting)
6) Further Actions

When filling the form, the evaluators must use:

***General knowledge of construction* -** the evaluator must be able to look at any particular load carrying system and rapidly identify the system, know how it works, and the corresponding load path. For the frame buildings, beam-column system is the primary load carrying system while as for masonry structures, the walls are the main elements of the system.

***Professional experience* -** the evaluator must have practical experience working with the various types of buildings and their load carrying systems. This experience may come from designing and detailing systems, reviewing the designs and details prepared by others, or inspecting the actual construction of the systems.

***Good judgment* -** above all, evaluators must be able to look at a damaged or potentially damaged system and, based on their knowledge and experience, make a judgment on the ability of that system to withstand another event of approximately equal magnitude.

IV. Rapid Evaluation

Six main parameters are evaluated during rapid evaluation process. Safety of the building is judged primarily based on these six parameters. If the building has any of condition 1, 2, 3 or 5 as per the **Table 1**, the building is categorized as unsafe. If the building has condition 4 or 6, it can be termed as unsafe or area unsafe.

Table 1: Criteria for building being unsafe

S.N.	Conditions	Posting
1	Building has collapsed, partially collapsed, or moved off its foundation	Unsafe
2	Building or any story is significantly out of plumb	Unsafe
3	Obvious severe damage to primary structural members, severe cracking of walls, severe cracking of columns, beam-column joints, buckling of reinforcement bars, or other signs of severe distress present	Unsafe
4	Obvious parapet, chimney, or other falling hazard present	Area Unsafe
5	Large fissures in ground, massive ground movement, or slope displacement present	Unsafe
6	Other hazard present (e.g. fallen power line, fallen tree)	Unsafe or Area Unsafe

If these entire six factors give positive result the building is obviously safe. The remaining buildings with damage but do not fall under these six factors are questionable buildings and based on conditions limited entry or restricted use.

As the purpose of the rapid assessment is to identify the buildings' safety rapidly, all the buildings that are done rapid assessment should undergo detail assessment explained in **Section 4** of this guideline.

Photo 1-4 below show different types of damage resulting to unsafe building.

Photo 1: Building Partially Collapsed


Photo 2: Building with a story out of plumb

Photo 3:
Severe Damage to Primary Structural System


Photo 4:
Severe Damage to Primary Structural System

3.4 Posting Safety Status

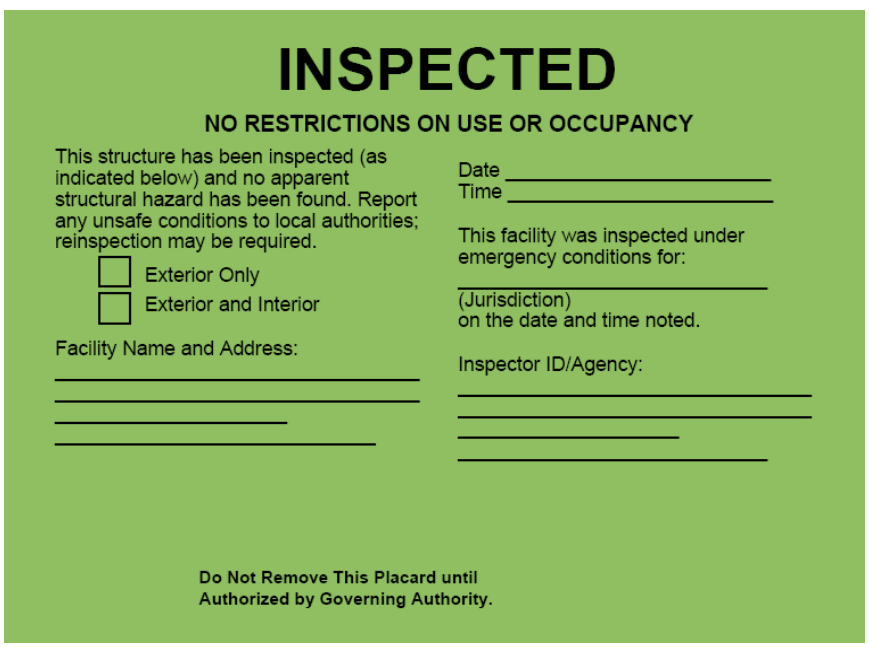
Three kinds of posting similar to ATC-20 are recommended in this guideline also. Posting classifications, colour and description of the posting is given in **Table 2** below.

Table 2: Posting Classifications

Posting Classification	Color	Description
INSPECTED	**Green**	No apparent hazard found, although repairs may be required. Original lateral load capacity not significantly decreased. No restriction on use or occupancy
LIMITED ENTRY/Restricted Use	**Yellow**	Dangerous condition believed to be present. Entry by owner permitted only for emergency purposes and only at own risk. No usage on continuous basis. Entry by public not permitted. Possible major aftershock hazard
UNSAFE	**Red**	Extreme hazard may collapse. Imminent danger of collapse from an aftershock. Unsafe for occupancy or entry, except by authorities.

3.4.1 Inspected

Inspected posting means habitable, minor or no damage - this green placard is used to identify buildings that have been inspected but in which no serious damage has been found. These structures are in a condition that allows them to be lawfully reoccupied; however, repairs may be necessary


INSPECTED

NO RESTRICTIONS ON USE OR OCCUPANCY

This structure has been inspected (as indicated below) and no apparent structural hazard has been found. Report any unsafe conditions to local authorities; reinspection may be required.

☐ Exterior Only

☐ Exterior and Interior

Facility Name and Address:

Date ____________

Time ____________

This facility was inspected under emergency conditions for:

(Jurisdiction)
on the date and time noted.

Inspector ID/Agency:

Do Not Remove This Placard until
Authorized by Governing Authority.

Following are the main criteria for posting this classification:

- Observed damage, if any, does not appear to pose a safety risk
- Vertical or lateral capacity not significantly decreased
- Repairs may be required
- Lawful entry, occupancy and use permitted

3.4.2 Limited Entry or Restricted Use

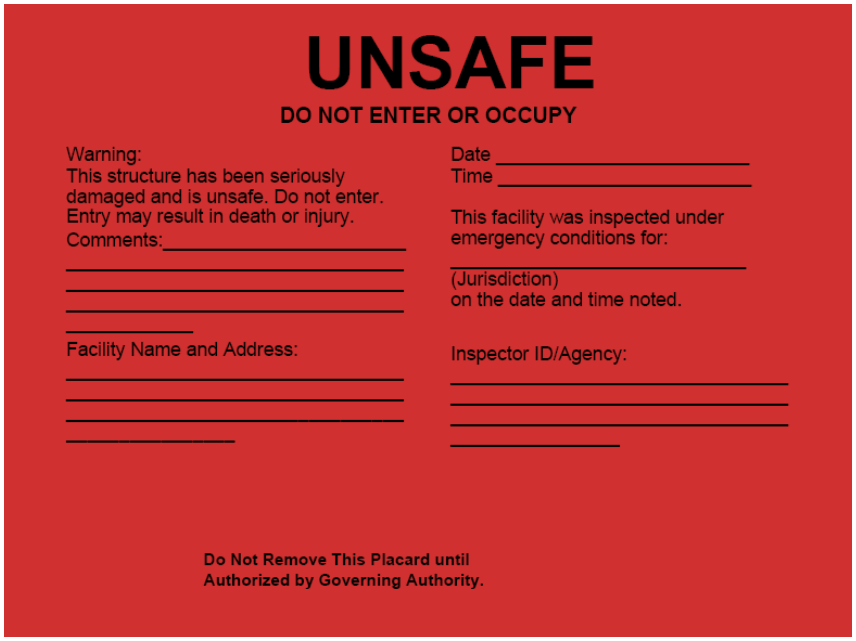
Limited entry or restricted use means damage which represents some degree of threat to occupants. Restricted Use is intended for buildings that have been damaged; yet the damage does not totally preclude occupying the structure. It can mean that parts of a structure could be occupied, or it could be used to denote those buildings that can be entered for a brief period of time only to remove possessions. The use of a Restricted Use placard will minimize the number of buildings which will require additional safety assessments because restrictions can be placed on the use and occupancy of the structure until such a time as the owner can retain an architect or engineer to develop the necessary repair program.

Following are the main criteria for posting this classification:

- Some risk from damage in all or part of building
- Restricted on
  - duration of occupancy
  - areas of occupancy
  - Usage
- Restrictions enforced by owner / manager

3.4.3 Unsafe

UNSAFE posting means not habitable, significant threat to life safety. The red ATC-20 Unsafe placard is used on those structures with the most serious damage. Typically, these are structures that represent a threat to life-safety should they be occupied. It is important to note that this category does not mean the building must be demolished. This placard carries the statement, "THIS IS NOT A DEMOLITION ORDER" to clarify that the building simply is not safe enough to occupy. In the vast majority of cases, structures posted unsafe can be repaired to a safe and usable condition.



Following are the main criteria for posting this classification:

- Falling, collapse, or other hazard
- Does not necessarily indicate that demolition is required
- Owner must mitigate hazards to satisfaction of jurisdiction to gain entry

3.5 Limitations of Rapid Evaluation

The rapid evaluation is carried out just after an earthquake for the purpose of safety evaluation of the buildings so that people can decide to occupy or not enter the building following an earthquake. The result whatever comes from the rapid evaluation MUST NOT BE USED FOR DEMOLITION as many buildings that are assigned as UNSAFE might be possible to restore and retrofit.

4. DETAIL EVALUATION

Detailed assessment is conducted after some time of an earthquake to assess level of damage in detail. Main purpose of this assessment is to assess compensation to household, planning for reconstruction activity or to assess level of intervention required for repair and retrofitting.

4.1 Understanding the Characteristics of Damaging Earthquake

During the evaluation of damage to concrete or masonry wall buildings, information on the characteristics of the damaging earthquake can lead to valuable insight on the performance characteristics of the structure. For example, if the ground motion caused by the earthquake can be estimated quantitatively, the analysis techniques can provide an estimate of the resulting maximum displacement of the structure. This displacement, in conjunction with the theoretical capacity curve, indicates an expected level of component damage. If the observed component damage is similar to that predicted, the validity of the theoretical model is verified in an approximate manner. If the damage differs, informed adjustments can be made to the model.

4.2 Review of Existing Building Data

The data collection process begins with the acquisition of documents describing the pertinent conditions of the building. Review of construction drawings simplifies field work and leads to a more complete understanding of the building. Original architectural and structural construction drawings are central to an effective and efficient evaluation of damage. Potential sources of these and other documents include the current and previous building owners, building departments, and the original architects or engineers. Drawings may also be available from architects or engineers who have performed prior evaluations for the building. In addition to construction drawings, it is helpful to assemble the following documents if possible:

- Site seismicity/geotechnical reports
- Structural calculations
- Construction specifications
- As Built Drawings
- Foundation reports
- Prior building assessments

Review of the existing building information serves several purposes. If reviewed before field investigations, the information facilitates the analytical identification of structural components. This preliminary analysis also helps to guide the field investigation to components that are likely to be damaged. Existing information can also help to distinguish between damage caused by the earthquake and pre-existing damage. Finally, the scope of the field inspection and testing program depends on the accuracy and availability of existing structural information. For example, if structural drawings reliably detail the size and placement of reinforcing, expensive and intrusive tests to verify conditions in critical locations may be unnecessary.

4.3 Assessing the Consequences of the Damaging Earthquake

Methods for inspecting and testing concrete and masonry wall buildings for earthquake damage fall into two general categories, nondestructive and intrusive. Nondestructive techniques do not require any removal of the integral portions of the components. In some cases, however, it may be necessary to remove finishes in order to conduct the procedure. In contrast, intrusive techniques involve extraction of structural materials for the purpose of testing or for access to allow inspection of portions of a component.

4.4 Assessing Pre-existing Conditions

Interpretation of the findings of damage observations requires care and diligence. When evaluating damage to a concrete or masonry wall, an engineer should consider all possible causes in an effort to distinguish between that attributable to the damaging earthquake and that which occurred earlier (pre-existing conditions).

Since the evaluation of earthquake damaged buildings is typically conducted within weeks or months of the event, cracking and spalling caused by earthquakes is normally relatively recent damage. Cracks associated with drying shrinkage or a previous earthquake, on the other hand, would be relatively old. General guidance for assessing the relative age of cracks based on visual observations is as follows.

Recent cracks typically have the following characteristics:

- Small, loose edge spalls
- Light, uniform color of concrete or mortar within crack
- Sharp, uneroded edges
- Little or no evidence of carbonation

Older cracks typically have the following characteristics:

- Paint or soot inside crack
- Water, corrosion, or other stains seeping from crack
- Previous, undisturbed patches over crack
- Rounded, eroded edges
- Deep carbonation

Evaluating the significance of damage requires an understanding of the structural behavior of the wall during the earthquake. The evaluating engineer must consider the implications of the observations with respect to the overall behavior of the building and the results of analytical calculations. The behavior must be correlated with the damage. If the observed damage is not reasonably consistent with the overall seismic behavior of the structure, the crack may have been caused by an action other than the earthquake.

4.5 Survey the Building from Outside

- Begin the survey by walking around the exterior of the building
- Try to determine the structural system
- Examine the structure for vertical discontinuties
- Examine the structure for irregular configuration in plan
- Look for cracking of exterior walls, glass frames etc., which are symptoms of excessive drift
- Examine non-structural elements
- Look for new fractures in the foundation or exposed lower wall of buildings

- Different Inspection and test required to conduct.

4.6 Examine the site for Geotechnical Hazards

- Examine the site for fissures, bulged ground, and vertical movements
- In hillside areas, examine the area for landslide displacement and debris encroaching onto the site
- Since geotechnical hazards can extend in area to include several or more buildings, undamaged buildings in an unstable area may be posted limited entry or unsafe

4.7 Inspect the structural system from inside the building

- Before entering the building, look for falling hazards and consider the danger of collapse
- Enter building
- Check the structural system
- Look in stairwells, basements, mechanical rooms etc. to view the structural system
- Examine the vertical load carrying system
- Examine the lateral load carrying system
- Check the different types of buildings using checklist

4.8 Inspect the Buildings in Critical Locations

Different types of buildings may suffer different types of damage. Masonry buildings have certain types of damage patterns and reinforced concrete buildings have other types. The buildings need to evaluate in detail with those identified damage patterns from past earthquakes. Different types of damage patters for masonry and reinforced concrete buildings are given in this section for the reference.

4.8.1 Earthquake Damage Patterns in Masonry Buildings

4.8.1.1 Corner Separation

Separation of orthogonal walls due to in-plane and out-of-plane stresses at corners is one of the most common damage patterns in masonry buildings. Separations in both sides of a wall result to an unstable condition leading to out-of-plane failure. The failure is due to lack of lateral support at two ends of the wall during out of plane loading.

This type of failure significantly reduces the lateral load carrying system of the building if all the corners are separated. The decision for restoration/retrofitting and demolition depends on extent of such damage. If only limited numbers or portion of the walls is separated, the buildings can be restored and retrofitted. If all/most of the corners are separated it is difficult to restore the original capacity by restoration and retrofitting.

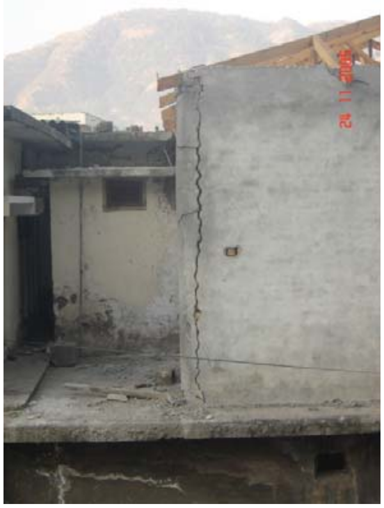


Photo 5: Heavy corner separation

Photo 6: Moderate corner separation

4.8.1.2 Diagonal Cracking

Diagonal cracking of piers either starting from corners of openings or in solid walls is another common type of damage to unreinforced masonry walls. The major reasons of the failure are either bed joint sliding or diagonal tension.

Bed joint sliding: In this type of behavior, sliding occurs on bed joints. In this type of damage, sliding on a horizontal plane, and a stair-stepped diagonal crack where the head joints open and close to allow for movement on the bed joint. Pure bed joint sliding is a ductile mode with significant hysteretic energy absorption capability. If sliding continues without leading to a more brittle mode such as toe crushing, then gradual degradation of the cracking region occurs until instability is reached.

Diagonal Tension: Typical diagonal tension cracking—resulting from strong mortar, weak units, and high compressive stress—can be identified by diagonal cracks (“X” cracks) that propagate through the units. In many cases, the cracking is sudden, brittle, and vertical load capacity drops quickly. The cracks may then extend to the toe and the triangles above and below the crack separate.

Significance of diagonal cracking for these two types of cases is given in Table 3 and Table 4 respectively (Ref: FEMA 306, Chapter 7).

Table 3: Level and description of damage to masonry wall pier in diagonal cracking on bed joint sliding mode

LEVEL OF DAMAGE	DESCRIPION OF DAMAGE	TYPICAL PERFORMANCE RESTORATION MEASURES
Insignificant-Slight	1. Hairline cracks/spalled mortar in head and bed joints either on a horizontal plane or in a stair stepped fashion has been initiated, but no offset along the crack has occurred and the crack plane or stair-stepping is not continuous across the pier. 2. No cracks in masonry units.	Not necessary for restoration of structural performance. (Measures may be necessary for restoration of nonstructural characteristics.)
Moderate	1. Horizontal cracks/spalled mortar at bed joints indicating that in-plane offset along the crack has occurred and/or opening of the head joints up to approximately 1/4”, creating a stair-stepped crack pattern. 2. 5% of courses or fewer have cracks in masonry units.	• Replacement or enhancement is required for full restoration of seismic performance. • For partial restoration of performance: ▪ Repoint spalled mortar and open head joints.
Heavy	1. Horizontal cracks/spalled mortar on bed joints indicating that in-plane offset along the crack has occurred and/or opening of the head joints up to approximately 1/2”, creating a stair-stepped crack pattern. 2. 5% of courses or fewer have cracks in masonry units.	▪ Replacement or enhancement is required for full restoration of seismic performance. ▪ For partial restoration of performance: o Repoint spalled mortar and open head joints. o Inject cracks and open head joints.
Extreme	Vertical load-carrying ability is threatened. • Stair-stepped movement is so significant that upper bricks have slid off their supporting brick. • Cracks have propagated into a significant number of courses of units. • Residual set is so significant that portions of masonry at the edges of the pier have begun or are about to fall.	Replacement or enhancement required.

Table 4: Level and description of damage to masonry wall pier in diagonal cracking on Diagonal Tension mode

LEVEL OF DAMAGE	DESCRIPION OF DAMAGE	TYPICAL PERFORMANCE RESTORATION MEASURES
Insignificant-Slight	Hairline diagonal cracks in masonry units in fewer than 5% of courses.	Not necessary for restoration of structural performance. (Measures may be necessary for Restoration of nonstructural characteristics.)
Moderate	1. Diagonal cracks in pier, many of which go through masonry units, with crack widths below 1/4”. 2. Diagonal cracks reach or nearly reach corners. 3. No crushing/spalling of pier corners.	• Repoint spalled mortar. • Inject cracks.
Heavy	1. Diagonal cracks in pier, many of which go through masonry units, with crack widths over 1/4”. Damage may also include: • Some minor crushing/spalling of pier corners and/or • Minor movement along or across crack plane.	Replacement or enhancement is required for full restoration of seismic performance. For partial restoration of performance: • Replace/drypack damaged units. • Repoint spalled mortar. • Inject cracks.
Extreme	Vertical load-carrying ability is threatened • Significant movement or rotation along crack plane. • Residual set is so significant that portions of masonry at the edges of the pier have begun or are about to fall.	Replacement or enhancement is required

Photo7: Diagonal cracking of masonry piers starting from corner of openings

Photo 8: Diagonal cracking of solid wall

Photo 9: Diagonal cracking of solid wall (Bed joint sliding mode)

4.8.1.3 Out of Plane Failure flexural failure

Out-of-plane failures are common in URM buildings. Usually they occur due to the lack of adequate wall ties, bands or cross walls. When ties are adequate, the wall may fail due to out-of- plane bending between floor levels. In case of long walls, without cross walls, the failure mode is out of plane bending horizontally. One mode of is rigid-body rocking motion occurring on three cracks: one at the top of the wall, one at the bottom, and one at mid-height. As rocking increases, the mortar and masonry units at the crack locations can be degraded, and residual offsets can occur at the crack planes. The ultimate limit state is that the walls rock too far and overturn. Important variables are the vertical stress on the wall and the height-to-thickness ratio of the wall. Thus, walls at the top of buildings and slender walls are more likely to suffer damage.

Table 5 compares different level of damages for out-of-plane flexural mode of failure (Ref: FEMA 306, Chapter 7). Photos 10 to 11 show the out of plane failure of masonry walls.

Table 5: Out-of-plane flexural failure of masonry wall

LEVEL OF DAMAGE	DESCRIPION OF DAMAGE	TYPICAL PERFORMANCE RESTORATION MEASURES
Insignificant-Slight	1. Hairline cracks at floor/roof lines and mid-height of stories. 2. No out-of-plane offset or spalling of mortar along cracks.	Not necessary for restoration of structural performance. (Measures may be necessary for restoration of nonstructural characteristics.)
Moderate	1. Cracks at floor/roof lines and midheight of stories may have mortar spalls up to full depth of joint and possibly: • Out-of-plane offsets along cracks of up to 1/8".	Repoint spalled mortar:
Heavy	1. Cracks at floor/roof lines and mid-height of stories may have mortar spalls up to full depth of joint. 2. Spalling and rounding at edges of units along crack plane. 3. Out-of-plane offsets along cracks of up to 1/2".	Replacement or enhancement is required for full restoration of seismic performance. For partial restoration of out-of-plane performance: • Replace/dry pack damaged units • Re-point spalled mortar
Extreme	1. Vertical-load-carrying ability is threatened: • Significant out-of-plane or in-plane movement at top and bottom of piers "walking"). • Significant crushing/spalling of bricks at crack locations.	Replacement or enhancement required.

 Photo 10: Out of plane failure of stone wall	 Photo11: Out of plane failure of block wall

4.8.1.4 In-plane flexural failure

There are two types of failure mode for in-plane flexural failure. One with “Flexural Cracking/Toe Crushing/Bed Joint Sliding” and another with “Flexural Cracking/Toe Crushing” (Ref: FEMA 306)

Flexural Cracking/Toe Crushing/Bed Joint Sliding: This type of moderately ductile behavior has occurred in relatively short walls with L/h_{eff} ratio of about 1.7, in which bed joint sliding and toe crushing strength capacities are similar. Damage occurs in the following sequence. First, flexural cracking occurs at the heel of the wall. Then diagonally-oriented cracks appear at the toe of the wall, typically accompanied by spalling and crushing of the units. In some cases, toe crushing is immediately followed by a steep inclined crack propagating upward from the toe. Next, sliding occurs along a horizontal bed joint near the base of the wall, accompanied in some cases by stair stepped bed joint sliding at upper portions of the wall. With repeated cycles of loading, diagonal cracks increase. Finally, crushing of the toes or excessive sliding, leads to failure.

Flexural Cracking/Toe Crushing: This type of behavior typically occurs in stockier walls with $L/heff > 1.25$. Based on laboratory testing, four steps can usually be identified. First, flexural cracking happens at the base of the wall, but it does not propagate all the way across the wall. This can also cause a series of horizontal cracks to form above the heel. Second, sliding occurs on bed joints in the central portion of the pier. Third, diagonal cracks form at the toe of the wall. Finally, large cracks form at the upper corners of the wall. Failure occurs when the triangular portion of wall above the crack rotates off the crack or the toe crushes so significantly that vertical load is compromised. Note that, for simplicity, the figures below only show a single crack, but under cyclic loading, multiple cracks stepping in each direction are possible.

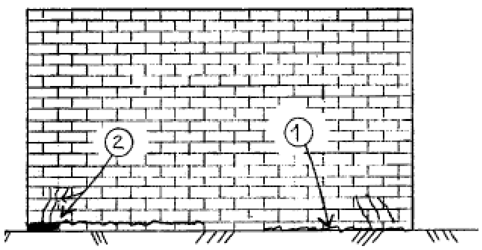
Significance of in-plane flexural cracking for these two types of cases is given in Table 6 and Table 7 respectively.

Table 6: In-plane flexural failure of masonry wall (Flexural Cracking/Toe Crushing/Bed Joint Sliding Case)

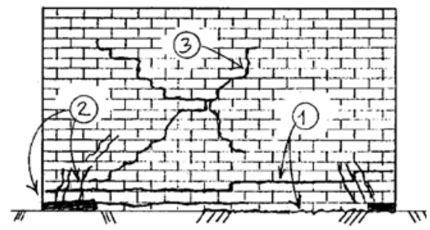
LEVEL OF DAMAGE	DESCRIPION OF DAMAGE	TYPICAL PERFORMANCE RESTORATION MEASURES
Insignificant-Slight	1. Horizontal hairline cracks in bed joints at the heel of the wall. 2. Possibly diagonally-oriented cracks and minor spalling at the toe of the wall.	Not necessary for restoration of structural performance. (Measures may be necessary for restoration of nonstructural characteristics.)
Moderate	1. Horizontal cracks/spalled mortar at bed joints at or near the base of the wall indicating that inplane offset along the crack has occurred up to approximately 1/4”. 2. Possibly diagonally-oriented cracks and spalling at the toe of the wall. Cracks extend upward several courses. 3. Possibly diagonally-oriented cracks at upper portions of the wall which may be in the units.	• Replace/drypack damaged units. • Repoint spalled mortar and open head joints. • Inject cracks and open head joints. • Install pins and drilled dowels in toe regions.
Heavy	1. Horizontal bed joint cracks near the base of the wall similar to Moderate, except width is up to approximately 1/2”. 2. Possibly extensive diagonally-oriented cracks and spalling at the toe of the wall. Cracks extend upward several courses. 3. Possibly diagonally-oriented cracks up to 1/2” at upper portions of the wall.	• Replace/drypack damaged units. • Repoint spalled mortar and open head joints. • Inject cracks and open head joints. • Install pins and drilled dowels in toe regions.
Extreme	Vertical load-carrying ability is threatened • Stair-stepped movement is so significant that upper bricks have slid off their supporting brick. • Toes have begun to disintegrate. • Residual set is so significant that portions of masonry at the edges of the pier have begun or are about to fall.	Replacement or enhancement required.

Table 7: In-plane flexural failure of masonry wall (Flexural Cracking/Toe Crushing/)

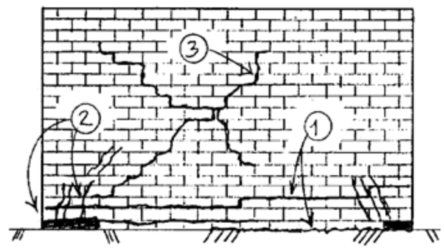
LEVEL OF DAMAGE	DESCRIPION OF DAMAGE	TYPICAL PERFORMANCE RESTORATION MEASURES
Insignificant-Moderate	1. Horizontal hairline cracks in bed joints at the heel of the wall. 2. Horizontal cracking on 1-3 cracks in the central portion of the wall. No offset along the crack has occurred and the crack plane is not continuous across the pier. 3. No cracks in masonry units.	Not necessary for restoration of structural performance. (Measures may be necessary for restoration of nonstructural characteristics.)
Heavy	1. Horizontal hairline cracks in bed joints at the heel of the wall. 2. Horizontal cracking on 1-3 cracks in the central portion of the wall. Some offset along the crack may have occurred. 3. Diagonal cracking at the toe of the wall, likely to be through the units, and some of units may be spalled.	Replacement or enhancement is required for full restoration of seismic performance. For partial restoration of performance: • Repoint spalled mortar. • Inject cracks
Extreme	1. Horizontal hairline cracks in bed joints at the heel of the wall. 2. Horizontal cracking on 1 or more cracks in the central portion of the wall. Offset along the crack will have occurred. 3. Diagonal cracking at the toe of the wall, likely to be through the units, and some of units may be spalled. 4. Large cracks have formed at upper portions of the wall. In walls with aspect ratios of *L*/*heff* >1.5, these cracks will be diagonally oriented; for more slender piers, cracks will be more vertical and will go through units.	Replacement or enhancement is required for full restoration of seismic performance. For partial restoration of performance: • Replace/drypack damaged units. • Repoint spalled mortar. • Inject cracks. • Install pins and drilled dowels in toe regions.



Insignificant to Slight Damage

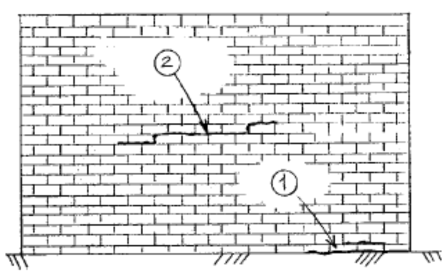


Moderate Damage

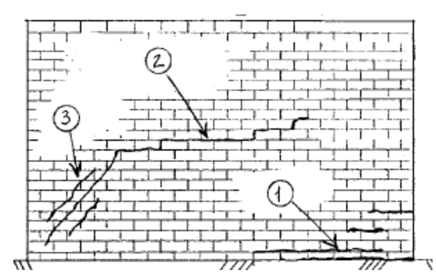


Heavy Damage

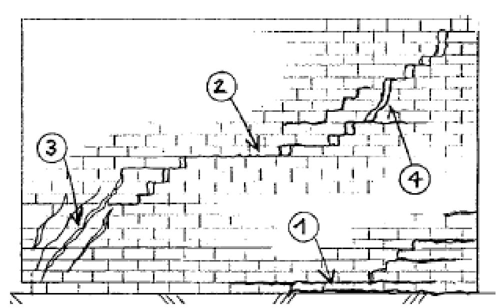
Figure 2: Illustrations on in-plane flexural failure of masonry wall (Flexural Cracking/Toe Crushing/Bed Joint Sliding Case)



Insignificant to Moderate Damage



Heavy Damage



Extreme Damage

Fig 3: Illustrations on in-plane flexural failure of masonry wall (Flexural Cracking/Toe Crushing)

4.8.1.5 Delamination of Walls

Delamination of two wyths of masonry walls is another type of damage. This type of damage can be tested by sounding test described in section 4.9.1. At the last stage of this type of damage one wyth of the wall get collapsed. Phot 11 and 12 show the delamination of walls during earthquakes.

Photo 11: Delamination of outer stone masonry wall

Photo 12: Delamination of outer and inner stone masonry walls

4.8.2 Earthquake Damage Patterns in Reinforced Concrete Frame Buildings

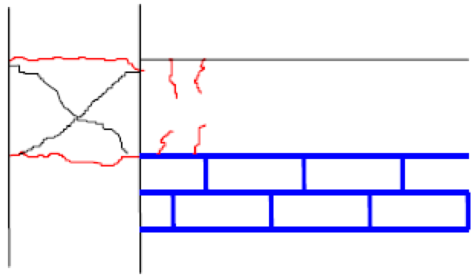
4.8.2.1 Beam-Column Joint Failure

This type of failure is caused by weak connections of the framing elements. Distress is caused by over-strength of the members framing into the connection, leading to very high principal tension stresses. Table 8 gives different level of connection damage.

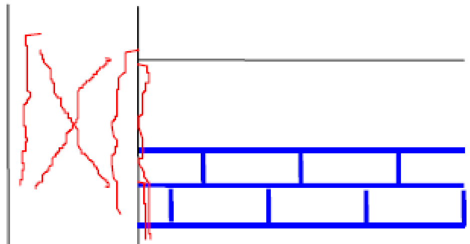
Table 8: Beam-column joint damage

LEVEL OF DAMAGE	DESCRIPION OF DAMAGE	TYPICAL PERFORMANCE RESTORATION MEASURES
Insignificant-Slight	Slight X hairline cracks in joint	Inject Cracks
Moderate	X-cracks in joint become more extensive and widen to about 1/8”.	Inject Cracks
Heavy	• Extensive X-cracks in joint widen to about 1/4”. • Exterior joints show cover concrete spalling off from back of joint. Some side cover may also spall off.	• Remove spalled and loose concrete. Remove and replace buckled or fractured reinforcing. • Provide additional ties over the length of the replaced bars. Patch concrete. Inject cracks.
Extreme	Significant loss of load carrying capacity • Ties broken • Concrete came out • Bars Buckled	Restore/replacement

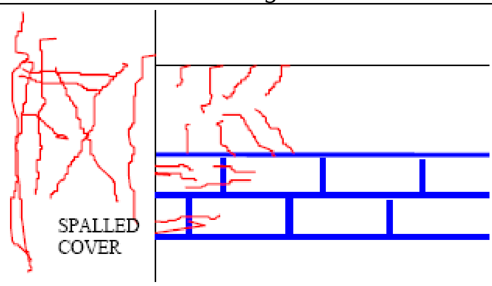
Illustrations and photographs of Beam-Column Joint damage are given below. Illustrations are from FEMA 306.



Typical appearance of Insignificant-light Damage



Typical appearance of Moderate Damage



Typical appearance of Heavy Damage

Photo 13: Extreme Damage of Beam-Column Joint

4.8.2.2 Lap-splice Damage

Lack of sufficient lap length, in hinge zones, leads to eventual slippage of splice bars. The cover spalls off due to high compression stresses, exposing the core concrete and damaged lap splice zone. Table 9 gives different level of connection damage.

Table 9: Lap Splice Damage

LEVEL OF DAMAGE	DESCRIPION OF DAMAGE	TYPICAL PERFORMANCE RESTORATION MEASURES
Insignificant-Slight	Flexural cracks at lap level. Slight hairline vertical cracks.	Inject cracks in frame.
Moderate	Tensile flexural cracks at floor slab level with some evidence of toe crushing over the bottom 1/2”. Longitudinal splitting cracks loosen the cover concrete.	Inject cracks in frame.
Heavy	Significant spalling of the cover concrete over the length of the lap splice, exposing the core and reinforcing steel	Remove spalled and loose concrete. Provide additional ties over the length of the exposed bars. Patch concrete. Apply composite overlay to damaged region of column.
Extreme	Significant loss of load carrying capacity • Cover spalled • Core concrete cracked • Ties Broken • Reinforced bars slipped	Restore/replacement

Illustrations and photographs of lap-splice damage are given below. Illustrations are from FEMA 306.

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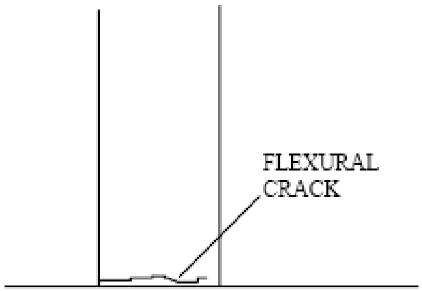
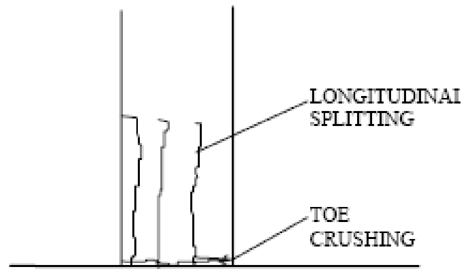


Typical appearance of Insignificant-light Damage
</td>
<td>


Typical appearance of Moderate Damage
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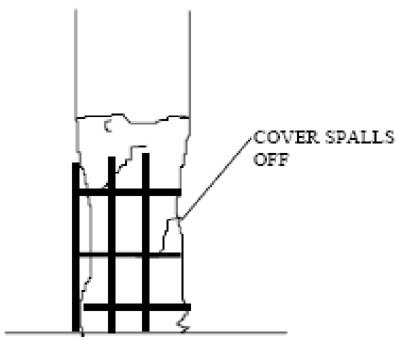


Typical appearance of Heavy Damage
</td>
<td>


Photo 14: Extreme Damage of Lap splice in column
</td>
</tr>
</table>

4.8.2.3 Short Column Damage

Short columns tend to attract seismic forces because of high stiffness relative to other columns in a story. Short column behavior may also occur in buildings with clerestory windows, or in buildings with partial height masonry infill panels.

If not adequately detailed, the columns may suffer a non-ductile shear failure which may result in partial collapse of the structure. A short column that can develop the shear capacity to develop the flexural strength over the clear height will have some ductility to prevent sudden non-ductile failure of the vertical support system.

Photos 15, 16 and 17 show the short column damage of the columns.

Photo 15: Slight-moderate damage

Photo 16: Heavy Damage

Photo 17: Extreme Damage

4.8.2.4 Soft-story damage

This condition commonly occurs in buildings in urban areas where ground floor is usually open for parking or shops for commercial purposes. Soft stories usually are revealed by an abrupt change in inter-story drift. Although a comparison of the stiffness in adjacent stories is the direct approach, a simple first step might be to plot and compare the inter-story drifts.

The photos 18 show the soft story damage of the columns.

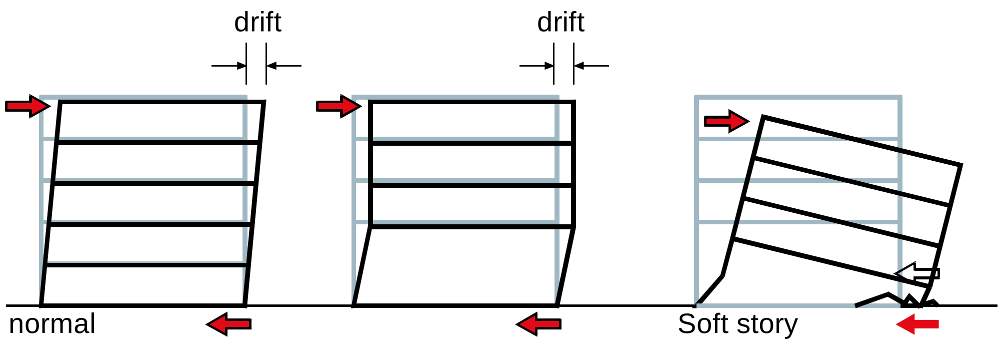


Figure 4: Soft-story failure mechanism

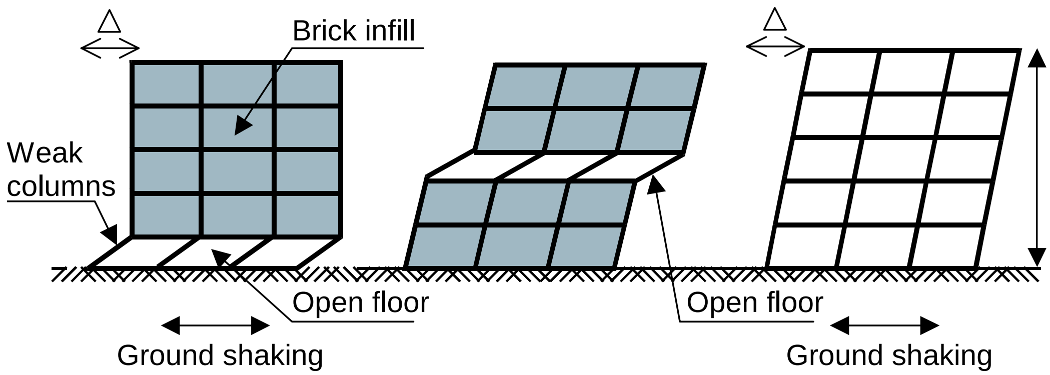


Figure 5: Soft-story failure in a building with masonry infill

Photo 18: Earthquake damage due to soft story

4.8.2.5 Shear/flexure cracks in column and beam members

Column and beam members of reinforced concrete buildings sustain two basic types of failure, namely:

a) Flexure/Bending Failure: As the column/beam deform under increased loading, it can fail in two possible ways. If relatively more steel is present on the tension face, concrete crushes in compression; this is a brittle failure and is therefore undesirable. If less steel is present on the tension face, the steel yields first and redistribution occurs in the beam and eventually the concrete crushes in compression; this is a ductile failure.

b) Shear Failure: A column/beam may also fail due to shearing action. A shear crack is inclined at 45^0 to the horizontal. Closed loops stirrups and ties are provided to avoid such shearing action. Shear damage occurs when the area of these stirrups is insufficient. Shear failure is brittle, and therefore, has larger impact if this type of damage observed.

Photo 19: Shear cracks in beam near to support and at mid span

Photo 20: Shear crack in beam near to support

Photo 21: Shear crack in column

Photo 22: Buckling of column bars

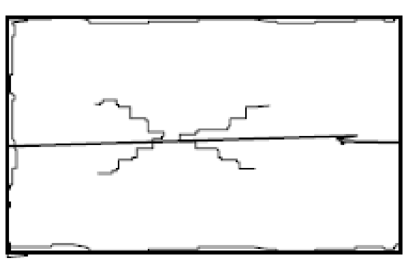
4.8.2.6 Damage to Infill-Wall

Masonry infill panel in between concrete frames get damaged in in-plane and out-of plane. The out-of-plane failure pattern is discussed here.

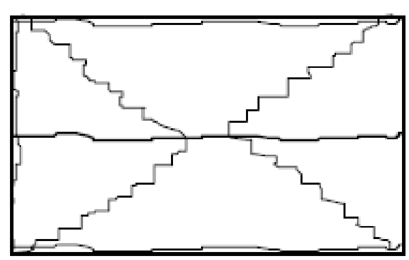
Table 10 gives different level of infill wall damage (Ref: FEMA 306).

Table 10: Infill panel damage

LEVEL OF DAMAGE	DESCRIPION OF DAMAGE	TYPICAL PERFORMANCE RESTORATION MEASURES
Insignificant-Slight	Flexural cracking in the mortar beds around the perimeter, with hairline cracking in mortar bed at mid-height of panel.	Re-point spalled mortar.
Moderate	Crushing and loss of mortar along top, mid-height, bottom and side mortar beds. Possibly some in-plane damage, as evidenced by hair-line X-cracks in the central panel area.	Apply shotcrete, ferrocement, or composite overlay to the infill.
Heavy	Severe corner-to-corner cracking with some out-of plane dislodgment of masonry. Top, bottom and mid height mortar bed is completely crushed and/or missing. There is some out-of-plane dislodgment of masonry. Concurrent in-plane damage should also be expected, as evidenced by extensive X-cracking	Remove and replace infill.
Extreme	The infill panel has failed in out of plane	Rebuilt infill wall



Moderate damage to Infill panel



Heavy damage to infill panel

Figure 6: Illustration of infill panel damage.

Photo 23: Moderate-Heavy Damage to Infill wall

Photo 24: Extreme Damage to Infill wall

4.9 Conduct Test

4.9.1 Sounding Test

Description

A rebound hammer provides a method for assessing the in-situ compressive strength of concrete. In this test, a calibrated hammer impact is applied to the surface of the concrete. The amount of rebound of the hammer is measured and correlated with the manufacturer's data to estimate the strength of the concrete. The method has also been used to evaluate the strength of masonry.

Equipment

A calibrated rebound hammer is a single piece of equipment that is hand operated

Execution

The person operating the equipment places the impact plunger of the hammer against the concrete and then presses the hammer until the hammer releases. The operator then records the value on the scale of the hammer. Typically three or more tests are conducted at a location. If the values from the tests are consistent, record the average value. If the values vary significantly, additional readings should be taken until a consistent pattern of results is obtained.

Since the test is relatively rapid, a number of test locations can be chosen for each wall. The values from the tests are converted into compressive strength using tables prepared by the manufacturer of the rebound hammer.

	
Photo Courtesy: NSET	Photo Courtesy: NSET
Photo 25: Use of Rebound hammer	Photo 26: Rebound hammer

Personal Qualification

A technician with minimal training can operate the rebound hammer. An engineer experienced with trebound hammer data should be available to supervise to verify that any anomalous values can be explained.

Reporting Requirements

The personnel conducting the tests should provide sketches of the wall, indicating the location of the tests and the findings. The sketch should include the following information:

- Mark the location of the test marked on either a floor plan or wall elevation.
- Record the number of tests conducted at a given location.
- Report either the average of actual readings or the average values converted into compressive strength along with the method used to convert the values into compressive strength.
- Report the type of rebound hammer used along with the date of last calibration.
- Record the date of the test.
- List the responsible engineer overseeing the test and the name of the company conducting the test.

Limitations

The rebound hammer does not give a precise value of compressive strength, but rather an estimate of strength that can be used for comparison. Frequent calibration of the unit is required (ACI, 1994). Although manufacturers' tables can be used to estimate the concrete strength, better estimates can be obtained by removing core samples at selected locations where the rebound testing has been performed. The core samples are then subjected to compression tests. The rebound values from other areas can be compared with the rebound balues that correspond to the measured core compressive strength.

The results of the rebound hammer tests are sensitive to the quality of the concrete on the outer several inches of the wall. More reproducible results can be obtained from formed surfaces rather than from finished surfaces. Surface moisture and roughness can also affect the readings. The impact from the rebound hammer can produce a slight dimple in the surface of the wall. Do not take more than one reading at the same spot, since the first impact can affect the surface, and thus affect the results of a subsequent test.

When using the rebound hammer on masonry, the hammer should be placed at the center of the masonry unit. The values of the tests on masonry reflect the strength of the masonry unit and the mortar. This method is only useful in assessing the strength of the outer wythe of a multi-wythe wall.Rebound Hammer Test

4.9.2 Rebar Detection Test

Description

Covermeter is the general term for a rebar detector used to determine the location and size of reinforcing steel in a concrete or masonry wall. The basic principle of most rebar detectors is the interaction between the reinforcing bar and a low frequency magnetic field. If used properly, many types of rebar detectors can also identify the amount of cover for the bar and/or the size of the bar. Rebar detection is useful for verifying the construction of the wall, if drawings are available, and in preparing as-built data if no previous construction information is available.

Equipment

Several types and brands of rebar detectors are commercially available. The two general classes are those based on the principle of magnetic reluctance and those based on the principle of eddy. The various models can have a variety of features including analog or digital readout, audible signal, onehanded operation, and readings for reinforcing bars and prestressing tendons. Some models can store the data on floppy disks to be imported into computer programs for plotting results.

Conducting Test

The unit is held away from metallic objects and calibrated to zero reading. After calibration, the unit is placed against the surface of the wall. The orientation of the probe should be in the direction of the rebar that is being detected. The probe is slid slowly along the wall, perpendicular to the orientation of the probe, until an audible or visual spike in the readout is encountered.

The probe is passed back and forth over the region of the spike to find the location of the maximum reading, which should correspond to the location of the rebar. This location is then marked on the wall. The procedure is repeated for the perpendicular direction of reinforcing.

If size of the bar is known, the covermeter readout can be used to determine the depth of the reinforcing bar. If the depth of the bar is known, the readout can be used to determine the size of the bar. If neither quantity is known, most rebar detectors can be used to determine both the size and the depth using a spacer technique.

The process involves recording the peak reading at a bar and then introducing a spacer of known thickness between the probe and the surface of the wall. A second reading is then taken. The two readings are compared to estimate the bar size and depth. Intrusive testing can be used to help interpret the data from the detector readings. Selective removal of portions of the wall can be performed to expose the reinforcing bars. The rebar detector can be used adjacent to the area of removal to verify the accuracy of the readings.

Photo Courtesy: NSET

Photo 27: Use of rebar detector for verification of reinforcement details

Photo Courtesy: NSET

Photo 28: Ferroscan detector

Personnel Qualifications

The personnel operating the equipment should be trained and experienced with the use of the particular model of covermeter being used and should understand the limitations of the unit.

Reporting Requirements

The personnel conducting the tests should provide a sketch of the wall indicating the location of the testing and the findings. The sketch should include the following information:

- Mark the locations of the test on either a floor plan or wall elevation.
- Report the results of the test, including bar size and spacing and whether the size was verified.
- List the type of rebar detector used.
- Report the date of the test.
- List the responsible engineer overseeing the test and the name of the company conducting the test.

Limitations

Pulse-velocity measurements require access to both sides of the wall. The wall surfaces need to be relatively smooth. Rough areas can be ground smooth to improve the acoustic coupling. Couplant must be used to fill the air space between the transducer and the surface of the wall. If air voids exist between the transducer and the surface, the travel time of the pulse will increase, causing incorrect readings.

Some couplant materials can stain the wall surface. Non-staining gels are available, but should be checked in an inconspicuous area to verify that it will not disturb the appearance.

Embedded reinforcing bars, oriented in the direction of travel of the pulse, can affect the results, since the ultrasonic pulses travel through steel at a faster rate than will significantly affect the results. The moisture content of the concrete also has a slight effect (up to about 2 percent) on the pulse velocity.

Pulse-velocity measurements can detect the presence of voids or discontinuities within a wall; however, these measurements cannot determine the depth of the voids.

4.9.3 In-Situ Testing In-Place Shear

<u>Description</u>

The shear strength of unreinforced masonry construction depends largely on the strength of the mortar used in the wall. An in-place shear test is the preferred method for determining the strength of existing mortar. The results of these tests are used to determine the shear strength of the wall.

<u>Equipment</u>

- Chisels and grinders are needed to remove the bricks and mortar adjacent to the test area.
- A hydraulic ram, calibrated and capable of displaying the applied load.
- A dial gauge, calibrated to 0.001 inch.

<u>Execution</u>

Prepare the test location by removing the brick, including the mortar, on one side of the brick to be tested. The head joint on the opposite side of the brick to be tested is also removed. Care must be exercised so that the mortar joint above or below the brick to be tested is not damaged.

The hydraulic ram is inserted in the space where the brick was removed. A steel loading block is placed between the ram and the brick to be tested so that the ram will distribute its load over the end face of the brick. The dial gauge can also be inserted in the space.

The brick is then loaded with the ram until the first indication of cracking or movement of the brick. The ram force and associated deflection on the dial gage are recorded to develop a force-deflection plot on which the first cracking or movement should be indicated. A dial gauge can be used to calculate a rough estimate of shear stiffness.

Inspect the collar joint and estimate the percentage of the collar joint that was effective in resisting the force from the ram. The brick that was removed should then be replaced and the joints repointed.

Photo Courtesy: NSET

Photo Courtesy: NSET

Photo 29-30: Test set up for In-situ Shear test

Personnel Qualifications

The technician conducting this test should have previous experience with the technique and should be familiar with the operation of the equipment. Having a second technician at the site is useful for recording the data and watching for the first indication of cracking or movement. The structural engineer or designee should choose test locations that provide a representative sampling of conditions.

Reporting Results

The personnel conducting the tests should provide a written report of the findings to the evaluating engineer. The results for the in-place shear tests should contain, at a minimum, the following information for each test location:

- Describe test location or give the identification number provided by the engineer.
- Specify the length and width of the brick that was tested, and its cross-sectional area.
- Give the maximum mortar strength value measured during the test, in terms of force and stress.
- Estimate the effective area of the bond between the brick and the grout at the collar joint.
- Record the deflection of the brick at the point of peak applied force.
- Record the date of the test.
- List the responsible engineer overseeing the test and the name of the company conducting the test.

Limitations

This test procedure is only capable of measuring the shear strength of the mortar in the outer wythe of a multi-wythe wall. The engineer should verify that the exterior wythe being tested is a part of the structural wall, by checking for the presence of header courses. This test should not be conducted on veneer wythes.

Test values from exterior wythes may produce lower values when compared with tests conducted on inner wythes. The difference can be due to weathering of the mortar on the exterior wythes. The exterior brick may also have a reduced depth of mortar for aesthetic purposes.

The test results can only be qualitatively adjusted to account for the presence of mortar in the collar joints. If mortar is present in the collar joint, the engineer or technician conducting the test is not able to discern how much of that mortar actually resisted the force from the ram.

The personnel conducting the tests must carefully watch the brick during the test to accurately determine the ram force at which first cracking or movement occurs. First cracking or movement indicates the maximum force, and thus the maximum shear strength. If this peak is missed, the values obtained will be based only on the sliding friction contribution of the mortar, which will be less than the bond strength contribution.

4.10 Detail Evaluation

Detail evaluation form is given in **Annex IV** of this guideline. Form should be filled in reference with section 4.1 to 4.9 mentioned above. The detail evaluation should also recommend different grade of damage. The damage grade goes from damage grade 1 to damage grade 5. Different level of damage grades with photographs for masonry and reinforced concrete buildings are given in section 4.11 of this guideline.

4.11 Identification of Damage Levels

4.11.1.1 Earthquake damage grades of Masonry buildings with flexible floor and roof

<u>Damage Grade 1</u>

<table>
<tr><td colspan="2">
</td></tr>
<tr><td>Thin cracks in plaster, falling of plaster bits in limited parts, fall of loose stone from upper part of building in rare cases</td><td>Building need not be vacated, only architectural repairs needed, Seismic strengthening advised</td></tr>
</table>

<u>Damage Grade 2</u>

<table>
<tr><td>
</td><td></td></tr>
<tr><td>Thin cracks in many walls, falling of plaster in last bits over large area, damage to non-structural parts like chimney, projecting cornices; The load carrying capacity s not reduced appreciably.</td><td>Architecture repairs needed, Seismic strengthening advised.</td></tr>
</table>

Damage Grade 3

Large and extensive cracks in most walls, roof tiles detach, tilting or falling of chimneys, failure of individual non-structural elements such as partition/ gable walls. Load carrying capacity of structure is partially reduced.	Cracks in wall need grouting, architectural repairs required, Seismic strengthening advised

Damage Grade 4

Gaps occur in walls, walls collapse, partial structural failure of floor/ roof, Building takes a dangers state.	Vacate the building, demolish and construct or extensive restoration and strengthening

Damage Grade 5

	
Total or near total collapse	Clear the site and reconstruction

4.11.1.2 Earthquake damage grades of Masonry buildings with rigid floor and roof

<u>Damage Grade 1</u>

Thin cracks in plaster, falling of plaster bits in limited parts, fall of loose stone from upper part of building in rare cases	Building need not be vacated, only architectural repairs needed, Seismic strengthening advised

<u>Damage Grade 2</u>

	
Thin cracks in many walls, falling of plaster in last bits over large area, damage to non-structural parts like chimney, projecting cornices; The load carrying capacity s not reduced appreciably.	Architecture repairs needed, Seismic strengthening advised.

Damage Grade 3

Large and extensive cracks in most walls, roof tiles detach, tilting or falling of chimneys, failure of individual non-structural elements such as partition/ gable walls. Load carrying capacity of structure is partially reduced.	Cracks in wall need grouting, architectural repairs required, Seismic strengthening advised

Damage Grade 4

	
Gaps occur in walls, walls collapse, partial structural failure of floor/ roof, Building takes a dangers state.	Vacate the building, demolish and construct or extensive restoration and strengthening

Damage Grade 5

Total or near total collapse	Clear the site and reconstruction

4.11.1.3 Earthquake damage grades of Reinforced Concrete Buildings

<u>Damage Grade 1</u>

	
Fine cracks in plaster over frame members or in walls at the base, Fine cracks in partitions and infill	Building need not be vacated, only architectural repairs needed, Seismic strengthening advised.

<u>Damage Grade 2</u>

	
Cracks in columns and beams of frame and in structural walls, Cracks in partition and infill walls, fall of brittle plaster and cladding, falling mortar from joints of wall panel	Architecture repairs needed, Seismic strengthening advised.

Damage Grade 3

	
Cracks in column and beam at the base, spalling of concrete covers, buckling of steel bars, Large cracks in partitions and infill walls, failure of individual infill panels	Cracks in wall need grouting, architectural repairs required, Seismic strengthening advised

Damage Grade 4

	
Large cracks in structural elements with compression failure of concrete and fracture of rebars, bond failure of beam bars, tilting of columns, collapse of few columns or single upper floor	Vacate the building, demolish and construct or extensive restoration and strengthening

Damage Grade 5

	
Collapse of ground floor or parts of the building	Clear the site and reconstruction

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ANNEXES

Annex I: Examples of Rapid Evaluation


Yellow


Red


Green


Red

Annex II: Examples of Detailed Evaluated Buildings

Annex III: Rapid Evaluation Form

Rapid Evaluation Safety Assessment Form

Inspection

Inspector ID: ________ Inspection date and time: ________ ☐ AM ☐ PM

Organization: ________ Areas inspected: ☐ Exterior only ☐ Exterior and interior

Building Description

Building Name: ________

Building contact/phone: ________

Approx. "Footprint area" (sq. ft): ________

Address:

District: ________

Municipality/VDC : ________

Ward No: ____ Tole: ________

Type of Construction

☐ Adobe ☐ Stone in mud ☐ Stone in cement ☐ Brick in cement ☐ Wood frame

☐ Bamboo ☐ Brick in mud ☐ Brick in cement ☐ R.C frame ☐ Others: ________

Type of Floor

☐ Flexible ☐ Rigid

Type of Roof

☐ Flexible ☐ Rigid

Primary Occupancy:

☐ Residential ☐ Hospital ☐ Government office ☐ Police station

☐ Educational ☐ Industry ☐ Office Institute ☐ Mix

☐ Commercial ☐ Club ☐ Hotel/Restaurant ☐ Others: ________

Evaluation

Observed Conditions:

	Minor/None	Moderate	Severe
➢Collapsed, partially collapsed, or moved off its foundation	☐	☐	☐
➢Building or any story is out of plumb	☐	☐	☐
➢Damage to primary structural members, cracking of walls, or other signs of distress present	☐	☐	☐
➢Parapet, chimney, or other falling hazard	☐	☐	☐
➢Large fissures in ground, massive ground movement, or slope displacement present	☐	☐	☐
➢Other hazard (Specify) e.g tree, power line etc:	☐	☐	☐

____

Comments: ________

____

Estimated Building Damage (excluding contents)

☐ None

☐ 0-1%

☐ 1-10%

☐ 10-30%

☐ 30-60%

☐ 60-100%

☐ 100%

Posting Choose a posting based on the evaluation and team judgment. Severe conditions endangering the overall building are grounds for an Unsafe posting. Localized Severe and overall Moderate conditions may allow a Restricted Use posting. Post INSPECTED placed at main entrance. Post RESTRICTED USE and UNSAFE placards at all entrances.

☐ **INSPECTED** (Green placard) ☐ **RESTRICTED USE** (Yellow placard) ☐ **UNSAFE** (Red placard)

Record any use and entry restrictions exactly as written on placard: ________

____

Further Actions Check the boxes below only if further actions are needed.

☐ Barricades needed in the following areas:

☐ Detailed evaluation recommended: ☐ Structural ☐ Geotechnical ☐ Other ________

Comments: ________

____

Annex IV: Detail Evaluation Form

Detailed Evaluation Safety Assessment Form

Inspection

Inspector ID: ____________________ Inspection date and time: ________________ ☐ AM ☐ PM

Organization: ____________________ Areas inspected: ☐ Exterior only ☐ Exterior and interior

Building Description

Building Name: ______________________________

Building contact/phone: ______________________________

Approx. "Footprint area" (sq. ft): ____________________

Address:

District: ______________________________

Municipality/VDC : ______________________________

Ward No: ________ Tole: ____________________

Type of Construction

☐ Adobe ☐ Stone in mud ☐ Stone in cement ☐ Brick in cement ☐ Wood frame

☐ Bamboo ☐ Brick in mud ☐ Brick in cement ☐ R.C frame ☐ Others: __________

Type of Floor

☐ Flexible ☐ Rigid

Type of Roof

☐ Flexible ☐ Rigid

Primary Occupancy:

☐ Residential ☐ Hospital ☐ Government office ☐ Police station

☐ Educational ☐ Industry ☐ Office Institute ☐ Mix

☐ Commercial ☐ Club ☐ Hotel/Restaurant ☐ Others: __________

Sketch (Optional)

Provide a sketch of the building or damage portions, Indicate damage points.

Estimated Building Damage

If requested by the jurisdiction, estimate building damage (repair cost ÷ replacement cost, excluding contents).

☐ None

☐ 0-1%

☐ 1-10%

☐ 10-30%

☐ 30-60%

☐ 60-100%

☐ 100%

Detailed Evaluation Safety Assessment Form **Page 2**

Evaluation Investigate the building for the condition below and check the appropriate column.

	Damage Levels									Comments
	Extreme			Moderate-Heavy			Insignificant-Light			
	>2/3	1/3-2/3	<1/3	>2/3	1/3-2/3	<1/3	>2/3	1/3-2/3	<1/3	
Overall hazards:										
➢Collapse or partial collapse										
➢Building or storey leaning										
➢Others										
Structural hazards:										
➢Foundation										
➢Roofs, floors (vertical loads)										
For Masonry Buildings:										
➢Corner separation										
➢Diagonal cracking										
➢Out of plane failure										
➢In-plane flexural failure										
➢Delamination										
For Reinforced Concrete Buildings:										
➢Joint										
➢Lap splice										
➢Columns										
➢Beams										
➢Infill										
Nonstructural hazards:										
➢Parapets										
➢Cladding, glazing										
➢Ceilings, light fixtures										
➢Interior walls, partitions										
➢Life lines (electric, water, etc)										
➢Other ____________										
Geotechnical hazards:										
➢Slope failure, debris										
➢Ground movement										
➢Other										

General Comments: ____________________

Recommendations:

Damage Grade

☐ **Grade 1** ☐ **Grade 2** ☐ **Grade 3** ☐ **Grade 4** ☐ **Grade 5**

Retrofit / Demolition

☐ **Repair** ☐ **Retrofit** ☐ **Demolish**

Further Actions Check the boxes below only if further actions are needed.

☐ Barricades needed in the following areas:

☐ Detailed evaluation recommended: ☐ Structural ☐ Geotechnical ☐ Other ____________

Comments: ____________________