

# Seismic Vulnerability Assessment of Existing Buildings: It's Importance

Th. Kiranbala Devi, Nganthoi Naorem

**Abstract:** *Earthquake induced damage has been increased over the few years. Gujarat (2001), Sumatra (2004), Pakistan (2005) and Haiti (2010) are the examples of devastating damage due to earthquake. Collapse of non – engineered and engineered buildings and structures is the chief contributor to the loss of lives and injuries to people. Vulnerability Atlas of India states that there are about 11 million seismically vulnerable houses in Seismic Zone- V , while the corresponding figure for Seismic Zone – IV is 50 million. In all, there are about 80 million building units in India, which are vulnerable, and pose unprecedented risk, if earthquake strikes. However, severe damage was observed in a relatively small percentage of existing buildings even after damaging earthquakes in the World. Identifying such vulnerable buildings to future earthquake is important. To identify such buildings, three levels of seismic vulnerability assessment methods starting from simple to sophisticated procedure, (a) Rapid Visual Screening (RVS) , (b) Simplified Vulnerability Assessment (SVA) and (c) Detailed Vulnerability Assessment (DVA) can be carried out according to the problems detected in the building.*

**Keywords:** Collapse, damage, seismic zone, structures, vulnerable

## I. INTRODUCTION

Most building codes in the world explicitly or implicitly accept structural damage to occur in a building during strong earthquakes as long as the hazard to life is prevented. Indeed many earthquakes caused such damage in the past. Seismic design codes were improved after such earthquake disasters, but old constructions were left unprotected by the new technology. Most of the loss of lives and casualties in earthquake are caused due to the collapse of structures and buildings . Therefore, rapid growth of cities with unabated construction of buildings and structures in the recent past co- related with high degree of population density is really a big challenge in high seismic zone , i.e. Zone –IV and V (IS : 1893 - 2002). Since standard codes of building constructions are improved and upgraded , vulnerability assessment of buildings both new and old are becoming necessitated . In fact, assessment of seismic vulnerability status of existing buildings and strengthening of it for seismic resistance is very important and it should be in co-operated in the planning of seismic hazard mitigation.

Recognising the importance of improving seismic resistance of existing buildings, after the 1995 Hyogo – Ken Nanbu earthquake, Japanese Diet (Congress) even enforced a law on December 25, 1995, requiring numbers of un- identified people and owner of buildings must make effort to perform vulnerability assessment of the structures and must make efforts to strengthen the structures, if needed.

## II. VULNERABILITY ASSESSMENT

Assessment of an existing structure for safety is much more difficult task than evaluation of a design on paper. The basic objective of the exercise is to assess the hazard safety of existing buildings and to demonstrate and encourage owners for retrofitting methods of unsafe buildings, particularly those where safety of large number of people is involved. Seismic evaluations of the buildings systematically performed in three levels 1. Rapid Visual Screening, 2. Simplified Vulnerability Assessment and 3. Detailed Vulnerability Assessment

**I. Rapid Visual Screening (RVS) :** This requiring only visual evaluation and limited additional information. The important feature of this procedure is that it permits vulnerability assessment based on walk – around of the building by a trained evaluator. This is recommended for all buildings.

**II. Simplified Vulnerability Assessment (SVA):** This method is more complex than RVS procedure. The procedure requires limited engineering analysis based on information from visual observations and structural drawings or on site measurements and hence more accurate. For this method, a qualified experienced structural engineer is required. This procedure is recommended for all buildings with high concentration of people.

**III. Detailed Vulnerability Assessment (DVA) :** The procedure requires detailed computer analysis, similar to or more complex than that required for design of a new building. The detailed vulnerability assessment procedure is highly specialised and recommended for all important and life line buildings. Detailed seismic vulnerability evaluation is a technically complex and expensive procedure and can only be performed on a limited number of buildings. Therefore, it is very important to use simpler method (RVS) that can help readily evaluate the vulnerability profile of different types of buildings, so that the more complex evaluation procedures can be limited to the most critical buildings.

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### III. DAMAGE STATISTIC FROM MAJOR EARTHQUAKES

After major earthquakes in Japan as well as in the world, the Architectural Institute of Japan (AIJ) investigated and

assessed damage level of other buildings. In the assessment, a heavily damaged area was first identified, and the damage level of all buildings in the area was assessed by structural engineers and researchers.

**Table. 1. Damage Statistics of Buildings From Major Earthquakes:**

Earthquake, year	Magnitude	Operational Damage	Heavy Damage	Collapse	Total
Mexico City, 1985	8.1	4,251 (93.8%)	194 (4.3%)	87 (1.9%)	4,532
Lazaro Cardenas, Mexico, 1985	8.0	137 (83.5%)	25 (15.2%)	2 (1.2%)	164
Baguio City, Philippines, 1990	7.7	138 (76.2%)	34 (18.8%)	9 (5.0%)	181
Erzincan City, Turkey, 1992	6.8	328 (77.4%)	68 (16.8%)	28 (6.6%)	424
Kobe (pre-1981 construction), 1995	6.9	1,186 (79.4%)	149 (10.0%)	158 (10.6%)	1,493
Kobe (post -1982 construction), 1995	6.9	1,733 (94.0%)	73 (4.0%)	38 (2.1%)	1,844

The damage statistics show that 75 to 95 percent of buildings in severely damaged areas remained operational after the strong earthquakes in Mexico City, Erzincan City, and Kobe City. Wide difference in percentage of damaged buildings in Kobe in respect of pre and post 1981

constructions indicate the essential of performing seismic vulnerability assessment of buildings periodically as these buildings had shown different seismic resistance, as built using new construction materials and adopting different building construction codes (changed codes).

**Table. 2. Seismic Vulnerability Classification for Different Structural Types:**

All buildings can be divided in to the following primary categories: (1) masonry buildings, (2) RCC buildings, (3) steel buildings, and (4) timber buildings. These can be further divided into various sub-categories. Based on their

seismic resistance the following vulnerability classification has been proposed based on the European Macroseismic Scale (EMS-98) and modified during development of World Housing Encyclopaedia.

Material	Type of Load-Bearing Structure	Sub-Types	Vulnerability Class					
			A	B	C	D	E	F
Masonry	Stone Masonry Walls	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	O					
		Massive stone masonry (in lime/cement mortar)	-	-	O	-		
		Mud walls	O					
	Earthen/Mud/Adobe/Rammed Earthen Walls	Mud walls with horizontal wood elements	-	O	-			
		Adobe block walls	O	-				
		Rammed earth/Pise construction	O	-				
		Unreinforced brick masonry in mud mortar	-	O	-			
	Burnt clay brick/block masonry walls	Unreinforced brick masonry in mud mortar with vertical posts	-	O	-	-		
		Unreinforced brick masonry in lime mortar	-	O	-	-		
		Unreinforced brick masonry in cement mortar with reinforced concrete floor/roof slabs		-	O	-		
		Unreinforced brick masonry in cement mortar with lintel bands (various floor/roof systems)		-	O	-		
		Confined brick/block masonry with concrete posts/tie columns and beams			-	O	-	
	Concrete block masonry	Unreinforced, in lime/cement mortar (various floor/roof systems)		-	O	-		
		Reinforced, in cement mortar (various floor/roof systems)			-	O	-	
Structural concrete	Moment resisting frame	Designed for gravity load only (predating seismic codes i.e. no seismic features)	-	-	O	-		
		Designed with seismic features (various ages)			-	-	O	-
		Frame with unreinforced masonry infill walls		-	O	-	-	
		Flat slab structure		-	O	-	-	
		Precast frame structure		-	O	-		
		Frame with concrete shear walls (dual system)			-	-	O	-
	Shear wall structure	Walls cast in-situ				-	O	-
		Precast wall panel structure		-	O	-		
		With brick masonry partitions			-	O		-

Wooden structures	Moment-resisting frame	With cast in-situ concrete walls			-	-	O	-
		With lightweight partitions					O	-
	Braced frame	With various floor/roof systems					O	-
	Light metal frame	Single storey LM frame structure			-	-	O	-
	Load-bearing timber frame	Thatch roof	-	-	O	-		
		Post and beam frame			-	O	-	
		Walls with bamboo/reed mesh and post (Wattle and Daub)		-	O	-		
		Frame with (stone/brick) masonry infill	-	-	O	-		
		Frame with plywood/gypsum board sheathing		-	O	-		
		Frame with stud walls				-	O	-

O Most likely vulnerability class

- Most likely lower range

- Most likely upper range

**Table 3. Classification of Damage to Buildings:**

The damage classifications based on the European Macroseismic Scale (EMS-98) define building damage to be in Grade 1 to Grade 5. The damage classifications help in

evaluation of earthquake intensity following an earthquake. They are used in RVS to predict potential damage of a building during code-level earthquake.

Classification of damage to masonry buildings	Classification of damage to reinforced concrete buildings
<b>Grade 1: Negligible to slight damage (No structural damage, slight non-structural damage)</b> Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.	<b>Grade 1: Negligible to slight damage (No structural damage, slight non-structural damage)</b> Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and in fills.
<b>Grade 2: Moderated damage (Slight structural damage, moderate non-structural damage)</b> Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys and munitys.	<b>Grade 2: Moderated damage (Slight structural damage, moderate non-structural damage)</b> 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.
<b>Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)</b> Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls etc.).	<b>Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)</b> Cracks in columns and beam-column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced bars. Large cracks in partition and infill walls, failure of individual infill panels.
<b>Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)</b> Serious failure of walls (gaps in walls); partial structural failure of roofs and floors.	<b>Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)</b> Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforcing bars; tilting of columns. Collapse of a few columns or of a single upper floor.

<b>Grade5:Destruction(very heavy structural damage)</b> Total or near total collapse of the building.	<b>Grade5:Destruction(very heavy structural damage)</b> Collapse of ground floor parts (e.g.wings) of the building.
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**Table. 4. Expected Damage Level as Function of RVS score:**

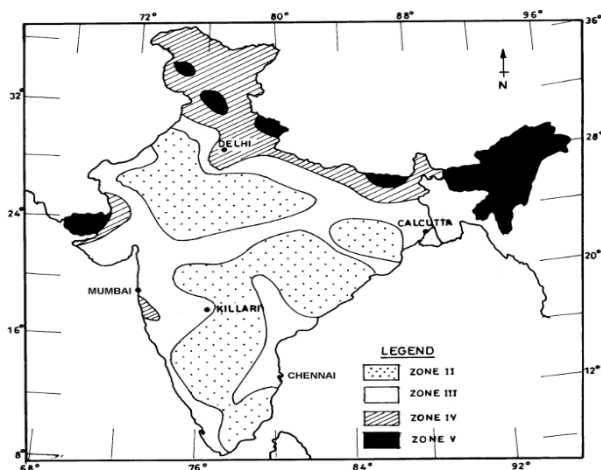
The probable damage can be estimated based on the RVS score and is given below. However, it should be realised that the actual damage will depend on a number of factors that are not included in the RVS procedure. As a result, this table should only be used as indicative to determine the

necessity of carrying out simplified vulnerability assessment of the buildings. These results can also be used to determine the necessity of retrofitting buildings where more comprehensive vulnerability assessment may not be feasible.

RVSScore	Damage Potential
$S < 0.3$	High probability of Grade 5 damage; Very high probability of Grade 4 damage
$0.3 < S < 0.7$	High probability of Grade 4 damage; Very high probability of Grade 3 damage
$0.7 < S < 2.0$	High probability of Grade 3 damage; Very high probability of Grade 2 damage
$2.0 < S < 3.0$	High probability of Grade 2 damage; Very high probability of Grade 1 damage
$S > 3.0$	Probability of Grade 1 damage

#### IV. SEISMICITY IN INDIA

India has been divided in to four seismic zones, (Fig. 1), (IS: 1893-2002).Details of different seismic zones are given in table 5.



**Fig. 1. Seismic zoning map of India (IS: 1893-2002, part 1)**

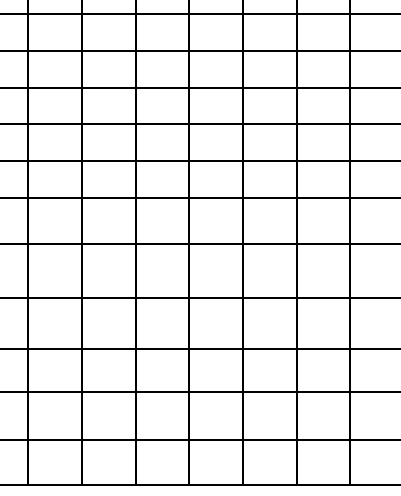
**Table 5. Seismic hazards related to seismic zones:**

Zone- II	Low seismic hazard (maximum damage during earthquake may be up to MSK intensity VI)
Zone - III	Moderate seismic hazard (maximum damage during earthquake may upto MSK intensity VII)
Zone - IV	High seismic hazard (maximum damage during earthquake may be up to MSK intensity VIII)
Zone - V	Very high seismic hazard ( maximum damage during earthquake may be of MSK intensity IX or greater )

## Rapid Visual Screening of Buildings for Potential Seismic Vulnerability

**FEMA – 154/ATC – 21 Based Data Collection Form**

**(Seismic Zones II)**

<div style="display: flex; justify-content: space-between;"> <div> <b>Form 10/11/12 - IF Based Data Collection Form</b>            (See the Notes 1)         </div> <div>           Address: _____            _____ Pin _____            Other Identifiers _____            GPS Coordinates (if available) _____            No. Stories _____ Year Built _____            Surveyor _____ Date _____            Total Floor Area (sq.ft./ sq. m) _____            Building Name _____            Use _____            Current Visual Condition : Excellent <input type="checkbox"/> / Good <input type="checkbox"/> / Damaged <input type="checkbox"/> / Distressed <input type="checkbox"/>            Building on Stilts / Open Ground Floor : Yes <input type="checkbox"/> / No <input type="checkbox"/>            Construction Drawing Available : Yes <input type="checkbox"/> / No <input type="checkbox"/> </div> </div>										
<div>  </div>										
<b>Plan and Elevation Scale:</b>										
<b>OCCUPANCY</b>				<b>SOIL TYPE (IS 1893:2002)</b>			<b>FALLING HAZARDS</b>			
Assembly Govt. Office Commercial Historic Residential Emer.Service Industrial School		Max. No. of persons 0 – 10      11 – 100 101 – 1000   1000+		Type I   Type II   Type III Hard Soil   Medium Soil   Soft Soil			<input type="checkbox"/> Chimneys <input type="checkbox"/> Parapets <input type="checkbox"/> Catching <input type="checkbox"/> Other			
<b>BASIC SCORE, MODIFIERS, AND FINAL SCORE, S</b>										
Building Type URM4		Wood S1	S2 (FRAME)	C1 (LM)	C2 (MRF)	C3 (SW)	URM1 (INF)	URM2 (BAND+RD)	URM3 (BAND+FD)	
Basic Score 3.6		6.0	4.6	4.6	4.4	4.8	4.4	4.6	4.8	4.6
Mid.Rise (4 to7 stories) 0.6		N/A	+0.2	N/A	+0.4	- 0.2	- 0.4	- 0.2	- 0.4	- 0.6
High Rise (>7 stories) N/A		N/A	+1.0	N/A	+1.0	+0.8	0.0	- 0.4	N/A	N/A
Vertical Irregularity -1.5		-3.0	- 2.0	N/A	- 1.5	-2.0	-2.0	-1.5	-2.0	-1.5
Plan Irregularity - 0.8      - 0.8      - 0.8		- 0.8	- 0.8	- 0.8				- 0.8	- 0.8	- 0.8
Code Detailing N/A		N/A	+0.4	N/A	+0.6	+0.4	N/A	N/A	N/A	N/A
Soil Type II - 0.4		- 0.4	- 0.8	- 0.4	- 0.6	- 0.4	- 0.4	- 0.2	- 0.4	- 0.4
Soil Type III - 0.8		- 0.8	- 1.4	- 1.0	- 1.4	- 0.8	- 0.8	- 0.8	- 0.8	- 0.8
Liquefiable Soil 1.4		- 2.0	- 2.0	- 2.0	- 2.0	- 2.0	- 2.0	- 1.6	- 1.4	- 1.4





Basic Score 2.4	4.4	3.6	3.8	3.0	3.6	3.2	3.4	3.6	3.0
Mid Rise (4 to7 stories) - 0.4	N/A	+0.4	N/A	+0.2	+0.4	+0.2	+0.4	+0.4	- 0.4
High Rise (>7 stories) N/A	N/A	+0.8	N/A	+0.5	+0.8	+0.4	N/A	N/A	N/A
Vertical Irregularity -1.5	-3.0	- 2.0	N/A	- 2.0	-2.0	-2.0	-2.0	-2.0	-1.5
Plan Irregularity - 0.5 - 0.5 - 0.5	- 0.5	- 0.5	- 0.5				- 0.5	- 0.5	- 0.5
Code Detailing N/A	N/A	+1.4	N/A	+1.2	+1.6	+1.2	+ 2.0	+ 2.0	N/A
Soil Type II - 0.4	- 0.2	- 0.6	- 0.6	- 0.6	- 0.8	- 0.6	- 0.8	- 0.8	- 0.4
Soil Type III - 0.8	- 0.6	- 1.2	- 1.0	- 1.0	- 1.2	- 1.0	-1.2	- 1.2	- 0.8
Liquifiable Soil - 1.6	- 1.2	- 1.6	- 1.6	- 1.6	- 1.6	- 1.6	- 1.6	-1.6	- 1.6

### FINAL SCORE, S

#### Result Interpretation (Likely building performance )

$S < 0.3$	High probability of Grade 5 damage, Very high probability of Grade 4 damage
$0.3 < S < 0.7$	High probability of Grade 4 damage, Very high probability of Grade 3 damage
$0.7 < S < 2.0$	High probability of Grade 3 damage, Very high probability of Grade 2 damage
$2.0 < S < 3.0$	High probability of Grade 2 damage, Very high probability of Grade 1 damage
$S > 3.0$	Probability of Grade 1 damage

Further  
Evaluation  
Recommended

YES NO

\* = Estimated, subjective, or unreliable data FRAME = Steel Frame SW = Sheer Wall URM3 =Unreinforced burnt brick  
DNK = Do Not Know INF= Burnt Brick Masonry Infill Wall LM = Light Metal or stone masonry (cem mortar)  
MRF = Moment – Resisting Frame BAND = Seismic Band RD = Rigid Diaphragm  
FD = Flexible Diaphragm URM4 = Unreinforced masonry (lime mortar)

### Rapid Visual Screening of Buildings for Potential Seismic Vulnerability

#### FEMA – 154/ATC – 21 Based Data Collection Form

(Seismic Zones IV & V)

<table border="1"> <tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> </table>																																																																																																					Address: _____ _____ Pin _____ Other Identifiers _____ GPS Coordinates (if available) _____ No. Stories _____ Year Built _____ Surveyor _____ Date _____ Total Floor Area (sq.ft./ sq. m) _____ Building Name _____ Use _____ Current Visual Condition : Excellen <input type="checkbox"/> / Good <input type="checkbox"/> / Damaged <input type="checkbox"/> / Distressed <input type="checkbox"/> Building on Stilts / Open Ground Floor : Yes <input type="checkbox"/> / No <input type="checkbox"/> Construction Drawing Available : Yes <input type="checkbox"/> / No <input type="checkbox"/>
<p style="text-align: center;"><b>PHOTOGRAPH</b> <b>(OR SPECIFY PHOTOGRAPH NUMBERS)</b></p>																																																																																																					

Plan and Elevation Scale:

OCCUPANCY			SOIL TYPE (IS 1893:2002)					FALLING HAZARDS		
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<b>BASIC SCORE, MODIFIERS, AND FINAL SCORE, S</b>										
Building Type URM4	Wood	S1	S2	C1	C2	C3	URM1	URM2	URM3	
	(FRAME)	(LM)	(MRF)	(SW)	(INF)	(BAND+RD)	(BAND+FD)			
Basic Score	3.8	2.8	3.2	2.5	2.8	2.6	2.8	2.8	1.8	
1.4										
Mid.Rise (4 to7 stories)	N/A	+0.2	N/A	+0.4	+0.4	+0.2	+0.4	+0.4	- 0.2	-
0.4										
High Rise (>7 stories)	N/A	+0.6	N/A	+0.6	+0.8	+0.3	N/A	N/A	N/A	
N/A										
Vertical Irregularity	-2.0	- 1.0	N/A	- 1.5	-1.0	-1.0	-1.0	-1.0	-1.0	
-1.0										
Plan Irregularity	- 0.5	- 0.5	- 0.5				- 0.5	- 0.5	- 0.5	- 0.5
- 0.5 - 0.5 - 0.5										
Code Detailing	N/A	+0.4	N/A	+0.2	+1.4	+0.2	N/A	N/A	N/A	
N/A										
Soil Type II	- 0.4	- 0.4	- 0.4	- 0.4	- 0.4	- 0.4	- 0.4	- 0.4	- 0.4	
- 0.4										
Soil Type III	- 0.8	- 0.6	- 0.6	- 0.6	- 0.6	- 0.4	- 0.6	- 0.6	- 0.6	
- 0.6										
Liquifiable Soil	- 0.8	- 1.2	- 1.0	- 1.2	- 0.8	- 0.8	- 0.6	- 0.6	- 0.8	
- 0.8										
<b>FINAL SCORE, S</b>										
<b>Result Interpretation</b> ( <i>Likely building performance</i> )								Further Evaluation Recommended		
S < 0.3 High probability of Grade 5 damage, Very high probability of Grade 4 damage										
0.3 < S < 0.7 High probability of Grade 4 damage, Very high probability of Grade 3 damage										
0.7 < S < 2.0 High probability of Grade 3 damage, Very high probability of Grade 2 damage										
2.0 < S < 3.0 High probability of Grade 2 damage, Very high probability of Grade 1 damage										
S > 3.0 Probability of Grade 1 damage										

\* = Estimated, subjective, or unreliable data    FRAME = Steel Frame    SW = Sheer Wall    URM3 =Unreinforced burnt brick  
 DNK = Do Not Know    INF= Burnt Brick Masonry Infill Wall    LM = Light Metal or stone masonry (cem mortar)  
 MRF = Moment – Resisting Frame    BAND = Seismic Band    RD = Rigid Diaphragm  
 FD = Flexible Diaphragm    URM4 = Unreinforced masonry (lime mortar)

## V. CONCLUSION

With the development of new technology and employing of new construction materials many buildings though constructed by adopting standard seismic resistance building construction codes are considered no longer sufficient for seismic resistance of structure and expose to hazard in future earthquakes, mainly the old buildings remained unprotected. However small is the destruction and collapse of buildings in percentage, loss of lives and injuries are caused due to poor earthquake resistance of buildings. To identify these small numbers of seismically vulnerable buildings, assessment of the buildings and structures periodically and in systematic manner is very important. For the safety and mitigation of disastrous effects of earthquake hazard, performing seismic vulnerability assessment of all buildings in high seismic zone regions at least by RVS

method and strengthening of the structures, if needed is highly recommended.

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