

Lecture 17: Concept of risk and vulnerability studies; Different methods; Different level of risk assessment.**Topics**

- Introduction
- Seismic Vulnerability
- Vulnerability assessment of dwelling buildings, Damage probability matrices and Vulnerability functions
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- Applicability in India
- Building Types Considered in RVS Procedure
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- Detailed Vulnerability Assessment (DVA)
- Seismic Risk Assessment

Keywords: *Seismic Vulnerability, Methods, Rapid Visual Screening, Risk Assessment*

Topic 1**Introduction**

- For seismic microzonation and hazard delineation the different themes, considering both geomorphological and seismological are integrated to generate seismic microzonation maps. The final microzonation maps can be represented in three forms,
 1. Hazard map,
 2. Vulnerability map, and
 3. Risk map.
- Because earthquake loss not only depends on the hazard caused by earthquakes, but also on exposure (social wealth) and its vulnerability. Usually hazard map gives the hazard index (HI) based on hazard calculation and site conditions.
- Vulnerability map gives us the expected degree of losses within a defined area resulting from the occurrence of earthquakes and often expressed on a scale from 0 (no damage) to 1 (full damage). However, this definition neglects the decisive factor of "time" for the repair of the damage.

- A key question that must be addressed in hazard reduction: “how much loss might a city or region suffer from future earthquakes?” Earthquake loss depends not only on the hazard caused by earthquakes, but also on exposure and its vulnerability.
- Vulnerability study includes all the exposure such as man-made facilities that may be impacted in an earthquake. It includes all residential, commercial, and industrial buildings, schools, hospitals, roads and railroads, bridges, pipelines, power plants, communication systems, and so on.
- In a training program for disaster management, vulnerability was described as “the propensity of things to be damaged by a hazard,” and more exactly, “the degree of loss to a given element at risk (or set of elements) resulting from a given hazard at a given severity level”.
- In contrast to the concept of risk, here the probability of the occurrence of a hazard is not considered. Thus, vulnerability is to be understood as separate from risk. “Risk, as defined here, means the sum of all losses that can be expected from the occurrence of a particular natural phenomenon”.
- This includes the occurrence probability of a natural event and encompasses the expected number of dead and injured, damages to material goods and the interruption of economic activities. Risk map will be combination of hazard classes and vulnerability classes an output risk classes.

Topic 2

Seismic Vulnerability

- The seismic vulnerability of a structure can be described as its susceptibility to damage by ground shaking of a given intensity. The aim of a vulnerability assessment is to obtain the probability of a given level of damage to a given building type due to a scenario earthquake.
- The various methods for vulnerability assessment that have been proposed in the past for use in loss estimation can be divided into two main categories: empirical or analytical, both of which can be used in hybrid methods.
- A vulnerability assessment needs to be made for a particular characterisation of the ground motion, which will represent the seismic demand of the earthquake on the building.
- The selected parameter should be able to correlate the ground motion with the damage to the buildings. Traditionally, macroseismic intensity and peak ground acceleration (PGA) have been used, whilst more recent proposals have linked the seismic vulnerability of the buildings to response spectra obtained from the ground motions.

- Each vulnerability assessment method models the damage on a discrete damage scale; frequently used examples include the Medvedev-Sponheuer-Karnik scale called as MSK scale (Medvedev and Sponheuer, 1969), the Modified Mercalli scale (Wood and Neumann, 1931) and the EMS98 scale (Grünthal, 1998) (Figure 17.1).

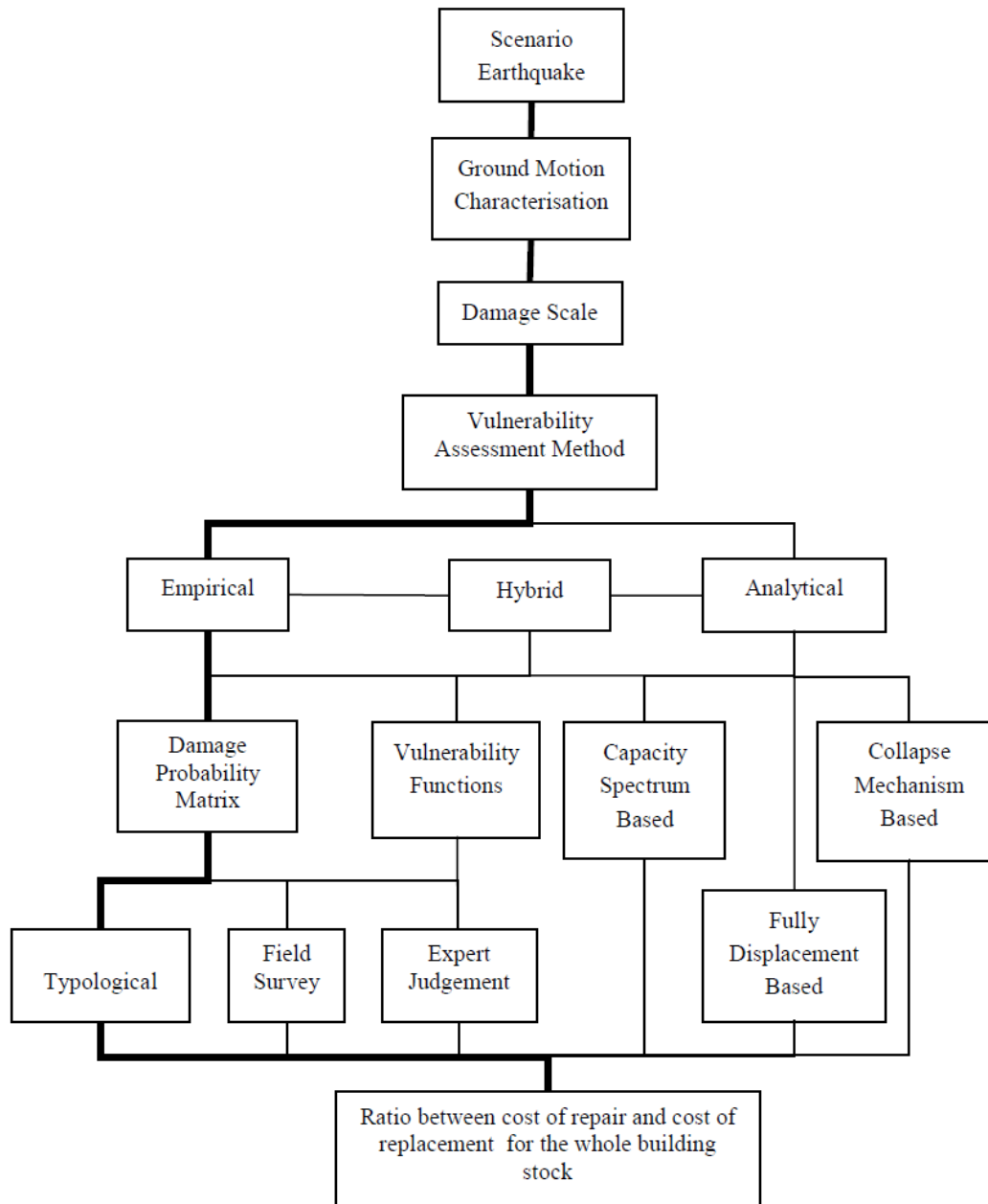


Fig 17.1: The components of seismic risk assessment and choices for the vulnerability assessment procedure; the bold path shows a traditional assessment method

- In empirical vulnerability procedures, the damage scale is used in reconnaissance efforts to produce post-earthquake damage statistics, whilst in analytical procedures this is related to limit-state mechanical properties of the buildings, such as interstorey drift capacity.
- The evolution of vulnerability assessment procedures for both individual buildings and building classes is described in the following sections, wherein the most important references, applications and developments pertaining to each methodology are reported.
- A larger emphasis has been placed on the vulnerability assessment of the built environment at an urban scale for use in risk and loss assessment methodologies.
- There are two approaches commonly followed in vulnerability estimation:
 1. Deterministic - Through dynamic analysis of single structures and building types, the earthquake shaking performance can be computed. A typical example to this side is HAZUS (Risk estimation software developed by the Federal Emergency Management Agency, FEMA).
 2. Empirical - Based on post earthquake surveys data on damage for various building classes are collated and related to estimated or measured ground motion.
- The major part of losses due to earthquakes has its origin in the deficient seismic behaviour of structures. In spite of the advances of research in earthquake engineering in general and particularly on seismic design codes, catastrophic losses have occurred recently in many countries in the world, including countries in which earthquake engineering studies are priority tasks.
- It is clear that new developments in earthquake resistant design can only be applied to new projects, which represent a small part of the existing structures in a seismic area. Therefore, the only possibility of reducing earthquake losses is improvement of the seismic behaviour of existing structures.

Topic 3

Vulnerability assessment of dwelling buildings, Damage probability matrices and Vulnerability functions

- Dolce et al., (1994) classified methodologies for the evaluation of structural vulnerability in four groups:
 1. Direct, which assesses in a simple way the damage caused in a structure by a given earthquake;

2. Indirect, which determines first a vulnerability index of the structure and then assesses the relationship between damage and seismic intensity;
 3. Conventional, which is essentially a heuristic method, introducing a vulnerability index independent of the damage prediction;
 4. Hybrid, which combines elements of the previous methods with expert judgments.
- The selection of one of these methods depends on the objectives of the study, the type of the results required and on the available information. On the other hand, fragility functions, damage probability matrices and vulnerability functions obtained from observed structural damages during past earthquakes in a seismic area were the preferred tools in seismic risk studies performed in the past (Kappos et al., 1995; Benedetti and Petrini, 1984; Barbat et al., 1996).
 - The damage probability matrices and vulnerability functions are defined in the following way:
 1. Damage Probability Matrices (DPM) express in a discrete form the conditional probability $P[D = j|i]$ to obtain a damage level j , due to an earthquake of severity i (Whitman 1974); and
 2. Vulnerability Functions are relations expressing the vulnerability in a continuous form, as functions of certain parameters that describe the size of the earthquake (Benedetti and Petrini 1984).
 - The vulnerability assessment is performed in terms of qualitative parameters: buildings are classified in vulnerability classes, and a DPM is assigned to each class or, alternatively, scores are attributed to the buildings considering their typological, structural, geometric and constructive characteristics; a simple model is then defined as a function of the evaluated scores relating the seismic input to the expected damage (Benedetti and Petrini, 1984; FEMA, 1998).
 - A complete observed damage data base would be desirable for applying such approaches; however, this is only possible in certain high seismicity areas where postearthquake survey studies have been properly performed. Where the information is limited, damage matrices and vulnerability functions can be established using the available data and local expert opinion (Anagnos et al., 1995).
 - Finally, in countries without any available damage data base, the information obtained in other similar areas is applied in a direct (Chavez and García-Rubio, 1995) or modified form, using expert judgment (Bustamante et al., 1995).
 - Some authors have used hybrid methodologies to assess the vulnerability of buildings (Chavez and García-Rubio, 1995), developing fragility curves and

damage probability matrices in order to estimate the feasibility of seismic rehabilitation of existing reinforced concrete (RC) buildings.

- India's national vulnerability assessment methodology, as a component of earthquake disaster risk management framework should include the following procedures:
 1. Rapid visual screening (RVS) procedure requiring only visual evaluation and limited additional information (Level 1 procedure). This procedure is recommended for all buildings.
 2. Simplified vulnerability assessment (SVA) procedure requiring limited engineering analysis based on information from visual observations and structural drawings or on-site measurements (Level 2 procedure). This procedure is recommended for all buildings with high concentration of people.
 3. Detailed vulnerability assessment (DVA) procedure requiring detailed computer analysis, similar to or more complex than that required for design of a new building (Level 3 procedure). This procedure is recommended for all important and lifeline buildings.
- The building profile for different construction types that is developed on the basis of application of the first procedure (rapid visual screening) will be useful to short-list the buildings to which simplified vulnerability assessment procedure should be applied.
- The simplified vulnerability assessment procedure will provide more reliable assessment of the seismic vulnerability of the building, and will form the basis for determining need for more complex vulnerability assessment.

Topic 4

Rapid Visual Screening (RVS)

- The rapid visual screening will be useful for all buildings except critical structures where detailed vulnerability assessment is always required. A simpler and more approximate procedure for vulnerability assessment (Level 0 procedure) can also be developed; however, this is not recommended due to the non-technical and highly empirical nature of Level 0 assessment procedure, which will make progressive transition to higher level procedures untenable.
- The use of Level 0 procedure in a national earthquake disaster risk management framework for urban areas may also communicate incorrect message regarding the complexity of the problem and make later migration to technically rigorous procedures difficult.

- A procedure for rapid visual screening (RVS) was first proposed in the US in 1988, which was further modified in 2002 to incorporate latest technological advancements and lessons from earthquake disasters in the 1990s.
- This RVS procedure, even though originally developed for typical constructions in the US have been widely used in many other countries after suitable modifications. The most important feature of this procedure is that it permits vulnerability assessment based on walk-around of the building by a trained evaluator.
- The evaluation procedure and system is compatible with GIS-based city database, and also permits use of the collected building information for a variety of other planning and mitigation purposes.

Topic 5

RVS Procedure, Objectives and Scope

- The rapid visual screening method is designed to be implemented without performing any structural calculations. The procedure utilises a scoring system that requires the evaluator to
 1. Identify the primary structural lateral load-resisting system, and
 2. Identify building attributes that modify the seismic performance expected for this lateral load-resisting system. The inspection, data collection and decision-making process typically occurs at the building site, and is expected to take around 30 minutes for each building.
- The screening is based on numerical seismic hazard and vulnerability score. The scores are based on the expected ground shaking levels in the region as well as the seismic design and construction practices for the city or region.
- The scores use probability concepts and are consistent with the advanced assessment methods. The RVS procedure can be integrated with GIS-based city planning database and can also be used with advanced risk analysis software.
- The methodology also permits easy and rapid reassessment of risk of buildings already surveyed based on availability of new knowledge that may become available in future due to scientific or technological advancements.
- The RVS methodology can be implemented in both rural and urban areas. However, the variation in construction practice is more easily quantifiable for urban areas and the reliability of the RVS results for rural areas may be very low.
- It is therefore preferable that the RVS methodology be used for non-standard (or non-government) constructions in rural areas only with adequate caution. The RVS

methodology is also not intended for structures other than buildings. For important structures such as bridges and lifeline facilities, the use of detailed evaluation methods is recommended.

- Even in urban areas, some very weak forms of non-engineered buildings are well-known for their low seismic vulnerability and do not require RVS to estimate their vulnerability. These building types are also not included in the RVS procedure.

Topic 6

Applicability in India

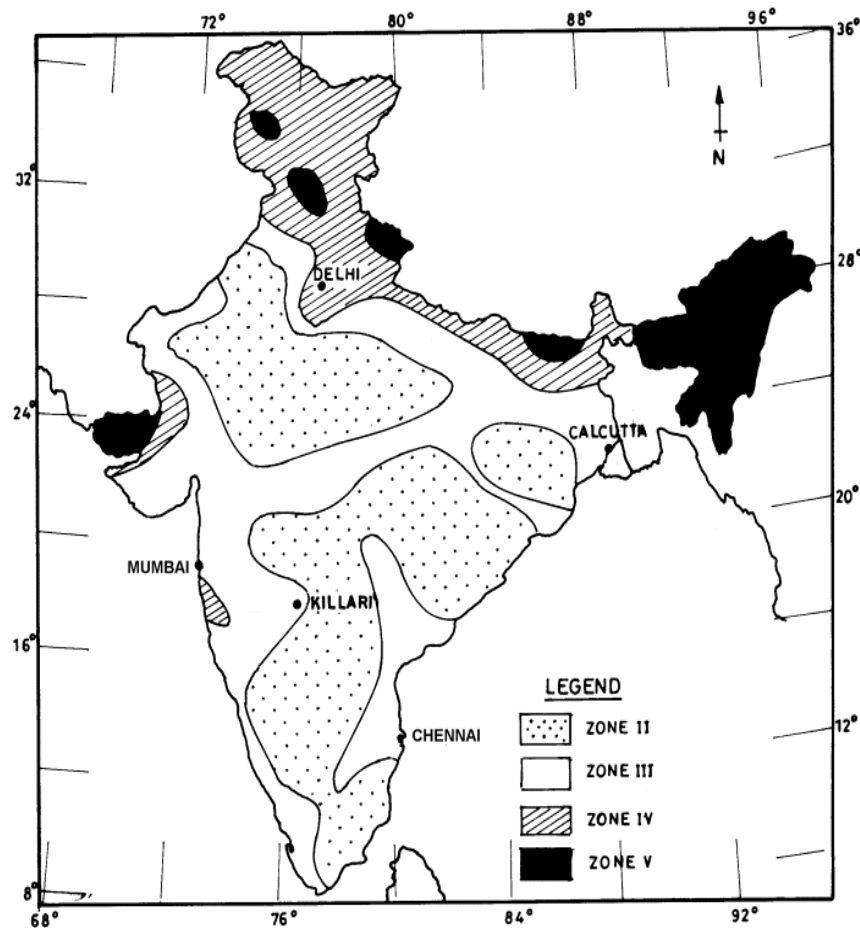


Fig 17.2: Seismic zoning map of India (IS 1893-2002 (Part 1)).

- As per IS 1893:2002 (Part 1), India has been divided into 4 seismic zones (Figure 7.2). The details of different seismic zones are given Table 17.1:

Table 17.1: Seismic zones of India

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

- When a particular damage intensity occurs, different building types experience different levels of damage depending on their inherent characteristics.
- For carrying out the rapid visual screening, only three hazard zones have been defined, corresponding to low seismic risk (Zone II), moderate seismic risk (Zone III) and high seismic risk (Zones IV and V).
- More precise categorisation of hazard zones between Zone IV and Zone V does not enable better assessment of structural vulnerability using RVS procedure due to the influence of a large number of other factors on the building performance when the ground shaking is very intense.

Topic 7

Building Types Considered in RVS Procedure

- A wide variety of construction types and building materials are used in urban areas of India. These include local materials such as mud and straw, semi-engineered materials such as burnt brick and stone masonry and engineered materials such as concrete and steel.
- The seismic vulnerability of the different building types depends on the choice of building materials. The building vulnerability is generally highest with the use of local materials without engineering inputs and lowest with the use of engineered materials.
- The basic vulnerability class of a building type is based on the average expected seismic performance for that building type. All buildings have been divided into six vulnerability class, denoted as Class A to Class F based on the European Macroseismic Scale (EMS-98) recommendations.
- The buildings in Class A have the highest seismic vulnerability while the buildings in Class F have lowest seismic vulnerability. A building of a given type, however, may have its vulnerability different from the basic class defined for that type

depending on the condition of the building, presence of earthquake resistance features, architectural features etc.

- It is therefore possible to assign a vulnerability range for each building type to encompass the expected vulnerability considering the different factors affecting its likely performance.
- The vulnerability ranges and the basic vulnerability class of different building types are given in Table below. The basic class is denoted by 0 in below Table, while the brackets specify the likely range of vulnerability of the buildings.
- All buildings can be divided into 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 (Table 17.2).

Table 17.2: Vulnerability of different building types

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)	0							
		Massive stone masonry (in lime/cement mortar)	-	-	0	-				
	Earthen/Mud/Adobe/Rammed Earthen Walls	Mud walls	0							
		Mud walls with horizontal wood elements	-	0	-					
		Adobe block walls	0	-						
		Rammed earth/Pise construction	0	-						
	Burnt clay brick/block masonry walls	Unreinforced brick masonry in mud mortar	-	0	-					
		Unreinforced brick masonry in mud mortar with vertical posts	-	0	-	-				
		Unreinforced brick masonry in lime mortar	-	0	-	-				
		Unreinforced brick masonry in		-	0	-				

		cement mortar with reinforced concrete floor/roof slabs						
		Unreinforced brick masonry in cement mortar with lintel bands (various floor/roof systems)	-	0	-			
		Confined brick/block masonry with concrete posts/tie columns and beams			-	0	-	
	Concrete block masonry	Unreinforced, in lime/cement mortar (various floor/roof systems)	-	0	-			
		Reinforced, in cement mortar (various floor/roof systems)			-	0	-	
Structural concrete	Moment resisting frame	Designed for gravity loads only (predating seismic codes i.e. no seismic features)	-	-	0	-		
		Designed with seismic features (various ages)			-	-	0	-
		Frame with unreinforced masonry infill walls	-	0	-	-		
		Flat slab structure	-	0	-	-		
		Precast frame structure	-	0	-			
		Frame with concrete shear walls (dual system)			-	-	0	-
	Shear wall structure	Walls cast in-situ				-	0	-
		Precast wall panel structure	-	0	-			
Steel	Moment-resisting frame	With brick masonry partitions			-	0	-	-
		With cast in-situ concrete walls			-	-	0	-
		With lightweight partitions				-	0	-
	Braced frame	With various floor/roof systems				-	0	-
	Light metal frame	Single storey LM frame structure			-	-	0	-
Wooden structures	Load-bearing timber frame	Thatch roof	-	-	0	-		
		Post and beam frame			-	0	-	
		Walls with bamboo/reed mesh and post (Wattle and Daub)	-	0	-			
		Frame with (stone/brick) masonry infill	-	-	0	-		
		Frame with plywood/gypsum board sheathing	-	0	-			
		Frame with stud walls				-	0	-

0 Most likely vulnerability class

| - Most likely lower range

- | Most likely upper range

- The RVS procedure has considered 10 different building types, based on the building materials and construction types that are most commonly found in urban areas. These included both engineered constructions (designed and constructed by following the specifications) and non-engineered constructions (designed or constructed without following the specifications).
- Some masonry building types constructed using local materials are prevalent in urban areas but are not included in this methodology since their seismic vulnerability is known to be very high (vulnerability class A and B) and do not require visual screening to provide any additional information regarding their expected structural performance. These include all constructions using random rubble masonry in mud mortar, earthen walls, adobe and tin sheet constructions.
- The likely damage to structures have been categorised in different grades depending on their impact on the seismic strength of the building. The different damage levels that have been recommended by European Macroseismic Scale (EMS-98) are described in Table 17.3 below.

Table 17.3: Classification of damage to buildings (European Macroeismic Scale)

Classification of damage to masonry buildings	Classification of damage to reinforced concrete buildings
<p>Grade 1: Negligible to slight damage (No structural damage, slight non-structural damage) 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.</p>	<p>Grade 1: Negligible to slight damage (No structural damage, slight non-structural damage) Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.</p>
<p>Grade 2: Moderate damage (Slight structural damage, moderate non-structural damage) Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys and mumpys.</p>	<p>Grade 2: Moderate damage (Slight structural damage, moderate non-structural damage) Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.</p>
<p>Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage) 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.).</p>	<p>Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage) Cracks in columns and beam-column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced bars. Large cracks in partition and infill walls,</p>

	failure of individual infill panels.
Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage) Serious failure of walls (gaps in walls); partial structural failure of roofs and floors.	Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage) Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforcing bars; tilting of columns. Collapse of a few columns or of a single upper floor.
Grade 5: Destruction (very heavy structural damage) Total or near total collapse of the building.	Grade 5: Destruction (very heavy structural damage) Collapse of ground floor parts (e.g. wings) of the building.

- 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.
- Table 17.4 below provides guidance regarding likely performance of the building in the event of design-level earthquake. This information can be used to decide the necessity of further evaluation of the building using higher level procedures. It can also be used to identify need for retrofitting, and to recommend simple retrofitting techniques for ordinary buildings where more detailed evaluation is not feasible. Generally, the score $S < 0.7$ indicates high vulnerability requiring further evaluation and retrofitting of the building.

Table 17.4: Performance of buildings during design level earthquakes

RVS Score	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

- 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.

Topic 8

Uses of RVS Results

- The results from rapid visual screening can be used for a variety of applications that are an integral part of the earthquake disaster risk management programme of a city or a region. The main uses of this procedure are:
 1. To identify if a particular building requires further evaluation for assessment of its seismic vulnerability.
 2. To rank a city's or community's (or organisation's) seismic rehabilitation needs.
 3. To design seismic risk management program for a city or a community.
 4. To plan post-earthquake building safety evaluation efforts.
 5. To develop building-specific seismic vulnerability information for purposes such as regional rating, prioritisation for redevelopment etc.
 6. To identify simplified retrofitting requirements for a particular building (to collapse prevention level) where further evaluations are not feasible.
 7. To increase awareness among city residents regarding seismic vulnerability of buildings.

Topic 9

The simplified vulnerability assessment (SVA)

- The simplified vulnerability assessment (SVA) procedure is more complex (and therefore more accurate) than the RVS procedure. This method utilises engineering information such as size and strength of lateral load resisting members and more explicit information on the design ground motion.
- This data is used to carry out a highly simplified analysis of the structure to estimate the building drift. Since good correlation exists between building drift and damage, the analysis results can be used to estimate the potential seismic hazard of the building.
- Unlike the RVS procedure, the simplified vulnerability assessment requires the use of a computer; however, the required inputs can be collected in paper form for later entry into the software system. Such procedure has been developed for RCC buildings by IIT Bombay and the SVA procedure can be adopted on a large scale.

- The results of the simplified vulnerability assessment procedure can be used to determine the potential status of the selected buildings, and to further short-list the buildings requiring detailed vulnerability assessment.

Topic 10

Detailed Vulnerability Assessment (DVA)

- The detailed vulnerability assessment (DVA) of a building requires carrying out comprehensive engineering analysis considering the nature of potential ground motions and the non-linear behaviour of the structural members.
- The detailed vulnerability assessment procedure is highly specialised and very few engineers in our country are currently capable of performing this task. The procedure also requires extensive as-built information regarding a building, which may not be readily available in the Indian context.
- Since very reliable information is essential for some critical facilities, the detailed vulnerability assessment procedure is most suitable for these structures. The DVA procedure should also be integrated in the national policy for seismic vulnerability assessment so that suitable tools and human resources can be developed as per national requirement.
- While developing the earthquake disaster risk management framework, the current status of technical knowledge in India also needs to be considered. Our country currently does not have the required technical skills and trained manpower to implement any vulnerability assessment programme on a large scale.
- While broad consensus on the procedures for Level 1, Level 2 and Level 3 assessment exists among the experts, these procedures should also be benchmarked with experiences from our past earthquake.
- There is an urgent need to continue implementation of vulnerability assessment procedures in parallel with the other tasks of fine-tuning the technical aspects of these procedures based on benchmarking with past earthquake field data.

Topic 11

Seismic Risk Assessment

- Seismic risk assessment and loss estimation is an essential first step to seismic hazard reduction for a large structural inventory. Knowing the seismic risk and potential losses allows for proper budgetary planning, raising public awareness, assessment and allocation of the necessary manpower for mitigation and disaster management operations, educating the public and professionals on preparedness and mitigation, and prioritization of retrofit applications (EERI, 1997).

- Components of seismic risk assessment and loss estimation are
 1. Hazard analysis;
 2. Local site effects (microzonation);
 3. Exposure information (structural inventory);
 4. Vulnerability analysis;
 5. Estimation of risk and loss (Coburn, et al., 1994; CSSC, 1999; Chandler and Nelson, 2001; Bendimerad, 2001).
- The standard definition of risk is the probability or likelihood of damage and consequent loss to a given element at risk, over a specified period of time. It is important to note the distinction between risk and vulnerability.
- Risk combines the expected losses from all levels of hazard severity, also taking their occurrence probability into account, while vulnerability of an element is usually expressed for a given hazard severity level (Coburn et al. 1994).
- Loss is defined as the human and financial consequences of damage, including injuries or deaths, the costs of repair, or loss of revenue. The distinction between risk and loss is often very loose and, based on their definition, these terms are sometimes used interchangeably.
- Since the standard definition of risk is a probability or likelihood of loss, between zero and one, it may be more appropriate to express risk as

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability}$$

while loss depends on the value of the exposure at risk, given by

$$\text{Loss} = \text{Hazard} \times \text{Vulnerability} \times \text{Exposure}$$

- Thus, while seismic hazard is purely a product of natural processes, seismic risk and loss are dependent on the vulnerability and societal exposure in terms of the built environment, human population, and value of operations.

End of Lecture 17 Concept of risk and vulnerability studies; Different methods; Different level of risk assessment