EARTHQUAKE VULNERABILITY CONCEPTS: AN OVERVIEW

Goal

To present a holistic overview of the earthquake vulnerability as a concept

Learning outcomes

After completing this session you will be able to

- Comprehend the categorization of earthquake vulnerability into physical, social and economic components and discuss them in detail
- Understand options available for vulnerability reductions

Learning objectives

As you work through this session you will learn to

- ✓ Distinguish between structural and non structural vulnerabilities of physical structures
- ✓ Give characteristics of earthquake resistant communities
- ✓ List causative factors of vulnerability in the built environment
- ✓ List vulnerable elements in the built environment
- ✓ Outline vulnerability at household, community and national levels
- ✓ List options available for vulnerability reduction

Keywords/phrases

Earthquake vulnerability
Physical
Structural
Non structural
Social
Economic
Built environment
Vulnerability reduction

1. Earthquake Vulnerability

Within minutes of shaking, the earthquake reveals the vulnerabilities of buildings, households, communities, and of a country. The consequences expose flaws in governance, planning, siting of physical structure, design, construction, and use of the built environment in country with seismic hazard. It reveals the influence of prevailing culture and way of life, on the capacity of the community to be preparedness for an earthquake hazard. The scale of physical damage and social disruption inflicted upon a community or a nation by an earthquake event is the measure of how vulnerable the community or the nation is.

Vulnerability is a set of prevailing or consequential conditions, which adversely affect an individual, a household or a community's ability to mitigate, prepare for or respond to the earthquake hazard.

Vulnerability can also be defined as the degree of loss to a given element at risk, or set of such elements, resulting from an earthquake of a given magnitude or intensity, which is usually expressed on a scale from 0 (no damage) to 10 (total loss).

Earthquake vulnerability is thus a function of the potential losses from earthquakes (death and injury to people, damage and other physical structures) and the level of preparedness (the extent to which a society has been able to translate mitigation measures into practice). It reflects the unattended weakness in the built environment of a community and the constraints in the society that affects ability (or inability) to absorb losses after an earthquake and to recover from the damage. Vulnerability condition precedes the earthquake event and contributes to its severity, impedes emergency response, and usually continues long after the earthquake has struck.

Distinguishing characteristics of a community that is earthquake-resistant

- The extent of investments in public policies to protect people, property, and community resources through the adoption and implementation of mitigation, preparedness, emergency response, and recovery and reconstruction measures and regulations, and
- The attitudinal extent of policymakers and stakeholders who seek to add a value of at least one dollar for every dollar invested in mitigation.

Antonyms of the phrase "**earthquake vulnerability**" are "**earthquake-resistance**" in case of the built environment, and "**earthquake resilience**" in case of social vulnerabilities.

2. Vulnerability Categories

A range of factors, including, determines vulnerability

- The population density
- Level and nature of physical assets
- Economic activities located in the earthquake risk zones.

Human action and hazard risks continually interact to alter vulnerability, both at the household and macroeconomic level.

Anderson and Woodrow (1989) grouped vulnerabilities into three categories:

- **Physical/material vulnerability**: inherent weakness of the built environment and lack of access to resources, especially of poor section of the population
- **Social/organizational vulnerability**: inherent weakness in the coping mechanism, lack of resiliency, lack of commitment
- **Attitudinal/motivational vulnerability**: fatalism, ignorance, and low level of awareness

3. What Makes a Communities' Built Environment Vulnerable to Earthquakes?

3.1 Vulnerable elements in the physical environment

The likelihood of an earthquake disaster increases when the community's built environment (i.e., buildings and lifeline systems--or community infrastructure) is comprised of the following vulnerable elements (Hays et al., 1998):

- Older residential and commercial buildings and infrastructure constructed of unreinforced masonry (i.e., URM's) or any other construction materials having inadequate resistance to lateral forces of ground shaking, or if they were built to seismic codes and standards that are now considered by engineers to be outdated and inadequate
- Older non-engineered residential and commercial buildings that have no lateral resistance and are vulnerable to fire following an earthquake.
- New buildings and infrastructure that have not been sited, designed, and constructed with adequate enforcement of modern, state-of-the-art building regulations, lifeline standards, and land use ordinances.
- Buildings and lifeline systems sited in close proximity to an active fault system, or on poor soils that either enhance ground shaking or fail through permanent displacements (e.g., liquefaction and landslides), or in low-lying or coastal areas subject to either seiches or tsunami flood waves.
- Modern buildings of poor design and construction (examples are buildings that were damaged seriously even in low intensity of shaking in Ahmedabad and Bhuj in the January 2001 earthquake).
- Schools and other buildings that have been built to low construction standards.
- Communication and control centers that are concentrated in one area.
- Hospital facilities that is insufficient for large number of casualties and injuries.
- Bridges, overhead crossings and viaducts that have not been built to withstand lateral forces of earthquakes and are likely to collapse or be rendered unusable by ground shaking.
- Electrical, gas, and water supply lines that are likely to be knocked out of service by ground failure (i.e., liquefaction, lateral spreads, and landslides).

3.2 Factors contributing to earthquake vulnerability of built environment in developing countries

Large settlements already in seismic areas

There are large human settlements located in earthquake/prone areas. Many of these settlements have a significant proportion of old buildings that are of poor quality either because of aging and lack of maintenance, or because of the deterioration of the material quality.

> The member city project under the RADIUS compared the vulnerability of over 60 cities in the developing countries. Bilham et al. (2001) indicated that over 50 million people in the urban settlements at the foot of the Himalayan Range are vulnerable to earthquake.

Unfortunately, most of the people subject to such high level of vulnerability are unaware of the earthquake treat they face.

Prevalence of non-engineered constructions

It is estimated for most of the cities of in the developing countries, that non-engineered construction account for more than half, and in some case more than even 90%, as in Kathmandu. The volume of such non-engineered buildings is, unfortunately growing, especially in the periphery of cities.
On the other hand, about 75% of fatalities attributed to earthquakes this century were caused by the collapse of buildings that were not adequately designed for earthquake resistance, were built with inadequate materials, or were poorly constructed (Coburn, 1992).

Erosion of the traditional wisdom in building construction is also responsible for the increased vulnerability of traditional building types.

- Extensive use of timber bands running over the walls
- Use of wooden pins to provide integrity between structural members of the building for restricting relative displacement,
- Very strict selection of quality materials,
- Adequate thickness of the walls
- High level of craftsmanship

are regarded as the positive elements that have been found to be incorporated in the ages-old historical monuments and buildings that have survived many earthquakes in the cities of Kathmandu Valley.

Prevalence of the use of poor building typologies

The type of housing construction is a major risk factor for injuries due to earthquakes. Statistics for 1950-1990 shows that the greatest proportion of victims dies in the collapse of masonry buildings (e.g., adobe, rubble stone, rammed earth, or unreinforced fire-brick and concrete block masonry buildings) (Coburn, 1992). Such buildings are known to have collapsed even at low intensities of ground shaking. Generally these buildings have heavy roofs and walls. During collapse, they kill many of the people inside.

Concrete-frame houses are generally safer i.e. they are less likely to collapse, if constructed properly with adequate engineering. Non-engineered concrete-frame buildings are vulnerable and, when they collapse, they are considerably more lethal and kill higher percentage of people than masonry structures.

Inadequate control in building construction

While the building code is mandatory in China and Japan, and they have developed the required institutional capacity and the municipal levels, in many countries, the **seismic building code** is yet a recommended practice, and the municipal organizations do not have the institutional capacity for the strict implementation of the seismic code for building construction.

In recent years, national building codes were drafted in countries (example Nepal, Bangladesh, and Indonesia) that did not have them. However, in many countries, including such large seismic country as India with a glorious tradition of earthquake engineering in world-class academic centers, the earthquake code is not mandatory and millions of buildings are constructed annually without any seismic resistance.

The collapse of about 85 modern multi-story buildings in Ahmedabad is attributed to one of the following causes:

- Poor design and construction practice. Seismic design provisions were not mandatory in the building permit process. Lateral seismic load was not considered in the design
- Presence of soft storeys for commercial and parking purposes
- Lack of proper seismic detailing (inadequate spacing and improper bending of transverse reinforcement steel in the columns, inadequate splice and embedment length for the longitudinal bars in the columns,
- Pounding effect due to the lack of appropriate space between buildings,
- Poor quality of materials and poor quality control, and
- Addition of load without any consideration of the design (e.g., huge water tanks and in a case, even a swimming pool was added to the roof-top when the buildings were already in use.).

4. Social and Economic Vulnerability

4.1 Who are vulnerable?

Household level

Earthquakes affect the full range of social classes – from royalties to the homeless. Apparently, earthquake treats everyone equally. However, some are more equal than others! Actually, the poor and socially disadvantaged groups of the society are the most vulnerable to, and affected by, earthquakes and other natural hazards, reflecting their social, cultural, economic and political environment.

Usually, communities in seismic countries are subject to a multitude of natural hazards and environmental problems. The natural hazards themselves are the source of transient hardship and distress, and a factor contributing to persistent poverty. Disasters exacerbate poverty by inflicting physical damage, loss of income-generating opportunities, and the resulting indebtedness.

Thus at the household level, **poverty** is the single most important factor determining vulnerability to natural hazards including earthquake. The poor are the vulnerable. The vulnerability is reflective of

- The location of housing (*poor and marginal lands*)
- Poor quality building (*non-engineered, using poor quality materials*)
- Primary types of occupation, level of access to capital (*low*)
- Degree (*low*) of concentration of assets (Benson, 2001).

Community level

Vulnerability of the individual households, naturally, contributes to the communities' overall vulnerability to earthquakes. However, existing social and cultural structures within the community determines, to a great extent, the resilience of the community to the disaster. The socio-cultural networks – extended family, neighbors, community organizations (e.g., community and religious trusts), and the interdependence within communities, provide the strength during disasters. Destruction of such network, for example by relocation during the reconstruction phase of an earthquake, causes the community to be more vulnerable.

Such community networks, the interdependence and also the traditional values are also disturbed during urbanization and economic advancement. It is seen that the traditional coping mechanism no longer is capable to continue the in-built resiliency to disasters. Individual and collective preparedness towards earthquake is necessary. Earthquakes are a difficult societal problem because they have low annual probability of occurrence, but a high probability of causing adverse societal consequences. Continued preparedness, making it a culture of community life makes communities resilient towards earthquake. Lack of it makes communities vulnerable.

National Level

A nation, or its government, in a seismic country is vulnerable to earthquakes and disaster risks unless it actively realizes the inevitability of earthquakes and the treat they represent to the nation, and invests in mitigation, the most cost-effective long-term strategy for loss reduction. Nation's declared policies to protect people, property, and community resources, provide the legal mandate for implementing mitigation, preparedness, emergency response, and recovery and reconstruction and regulation. Countries without such policies, or those not implementing such policies (if they exist), in line with their developmental policies are vulnerable to disasters including earthquake disasters.

Lack of effective communication and dialogue between government and the people makes a country vulnerable. Strict and centralized governance with top-down approach makes nations vulnerable at every phases of a disaster.

To manage its earthquake risk effectively, a community must have the capability to adopt, adjust, and change its public policy on the basis of scientific, technical, political, and legal consensus that is evolving with time as the community, lives with and learns from earthquakes, both in its country and in other countries having similar hazard and built environments.

The following are the vulnerabilities that were revealed by earthquake to surprise people

- Discovering after the earthquake disaster that the active fault system was located directly beneath the affected community or very close to the community.
- Experiencing unanticipated damage and loss of function to essential buildings (e.g., hospitals, schools, government buildings) and lifelines (e.g., elevated highway systems, ports), especially when the scientific and technical consensus before the earthquake is that these structures are earthquake resistant.
- Discovering that portions of the community are susceptible to fire following the earthquake.
- Experiencing thousands, to tens of thousands, of deaths and injuries, and thousands, to hundreds of thousands, of persons left without homes and jobs.
- Sustaining unexpected loss of community revenue, economic loss, and insured payments in the billions of dollars.
- Discovering that the country lacks the capability for speedy emergency response and effective recovery and reconstruction.
- Discovering after the earthquake disaster that the causes of the surprises were within the power of the country's policymakers and stakeholders (earth scientists, engineers, planners, insurers, businesses, and others) to correct before the disaster occurred.

5. Options for Vulnerability Reduction

In order for a community's risk management measures and regulations to be effective, the community must integrate risk assessment with risk management, choosing specific measures or regulations having a benefit/cost of at least one to eliminate or reduce perceived vulnerabilities in the built environment.

Every community at risk from earthquakes has many proven and cost-effective options available to it to reduce its perceived unacceptable risk. Each option carries a cost and an expected benefit. Because risk is not static-changing over time as the level of understanding of earthquakes and their consequences increases risk management requires a long-term investment of resources to realize the greatest benefit/ cost. The primary and secondary options are listed hereafter.

Option	Benefit/ cost range	Benefit
Earthquake scenarios	l-10	Facilitates planning for the expected and the unexpected
Building codes	1-1,000	Prevents collapse of buildings; protects life, reduces injuries
Standards and guidelines	1-1,000	Protects community infrastructure
Siting criteria for land use	1-10	Avoids surface fault rupture, soil failure, and soil-structure resonance
Relocation and rerouting	1-10	Reduces likelihood for damage to important facilities
Demolition	1-1,000	Eliminates collapse hazards and potential for loss of life
Retrofit, strengthening upgrading, and repair	1-100	Prevents collapse, eliminates vulnerabilities, and reduces damage
Performance-based design	1-100	Prevents loss of function and use
Base isolation	1-100	Ensures continued functioning of essential and critical structures
Soil remediation	1-100	Prevents liquefaction, landslides, and lateral spreading
Protective works	l-10	Prevents release of hazardous materials
Change in use	l-10	Reduces likelihood of loss of function
Change in building density	1-l 0	Lowers the risk to people
Insurance	1-1,000,000	Spreads the risk and enhances recovery; hope for fostering mitigation in the future
Public-private partnerships	1-10	Spreads the responsibility
Training	1-10	Expands the capability of professionals
Non-structural mitigation	1-100,000	Protects equipment and contents; ensures use

Source: Hays et al., 1998.

The options and benefits of vulnerability reduction mentioned above are based on experiences in developed countries. A refinement of approaches is necessary for selecting and implementing these options in developing countries. Acceptability of the options by the local communities depending upon the acceptable level of risks and the community's capacity to understand and implement technical measures should be considered and the options should be selected on a consensus basis. Grafting high-tech solutions may not prove sustainable in many developing countries.

References

1. Bothara, J. K., Parajuli, Y. K., Arya A. S., and Sharpe, R. D., Seismic Safety In Owner-Built Buildings, *Proceedings 12 WCEE, Auckland, New Zealand, 2000*

2. Rashidov, T., Mirjalilov, A., and Kuzmina, E., Assessment Of Vulnerability And Risk Of Lifeline Systems Within The Framework Of The Radius Project For Tashkent, *Proceedings 12 WCEE, Auckland, New Zealand, 2000*

3. Coburn, A, Spence, R. J. S., and Pomonis, A. (1992), Factors determining human casualty levels in earthquakes: mortality prediction in building collapse, in *proceedings of the First International Forum on Earthquake-Related Casualties, Madrid, July 1992,* USGS.

4. Coburn, A and Spence, R. J. S., (1992), *Earthquake Protection,* Chichester, John Wiley and Sons Ltd., 1992:2-1, 74-80, 277-285.

5. Bilham, R., Gaur, V. K., and Molnar, P. (2001), Himalayan Seismic Hazard, *Science, vol. 293, 24 August, 2001.*

6. Hays, W., Mohammadioun, B., and Mohammadioun, J., (eds.), 1998, Seismic Zonation: A Framework for Linking Earthquake Risk Assessment and Earthquake Risk Management (Monograph), Quest Editions Presses Academiques