CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

An earthquake is defined as any abrupt ground shaking caused by seismic energy travelling through the Earth's rocks [1]. Seismic waves are produced when energy stored in the Earth's crust is unexpectedly released, usually when masses of rock straining against each other crack and "slide." The most typical locations for earthquakes are geologic faults, which are small zones where rock masses shift in respect to one another. The principal fault lines that run along the boundaries of the enormous tectonic plates that make up the Earth's crust are the world's primary fault lines

1.2 BASIC TERMINOLOGY OF EARTHQUAKE

1.2.1 Focus

The source of an earthquake is located deep under the surface. The place inside the crust where the energy is released is known as the focus.

1.2.2 Epicenter

The location on the Earth's surface just above an earthquake's focal or hypocentre.

1.2.3 Fault plane

A fault is a weak spot within a tectonic plate where pressure from underneath can break through, generating earthquake shaking.

1.2.4 Magnitude

The term magnitude is used to describe the earthquake size [2]. There could be other methods for calculating an earth's magnitude, including the richer scale. Scientists use the moment magnitude scale to calculate an earthquake's magnitude based on physical parameters like the area of slip along the fault plane.

1.2.5 Modified Mercalli scale

An earthquake can also be measured using the modified Mercalli scale. The rating is based on how the quake affects the people in the area, as well as the amount of damage it causes. The numbers on the scale are roman numbers.

1.2.6 Seismology

The study of earthquakes is known as seismology. Seismologists are experts who investigate earthquakes.

1.2.7 Aftershocks

Smaller earthquakes that occur following a large earthquake in the same area are known as aftershocks. They're caused by the area's adjustment to fault movement, and some are the result of continued movement within the same fault zone.

1.2.8 Foreshock

A foreshock is a smaller earthquake that occurs in the same area as a larger earthquake that occurs later.

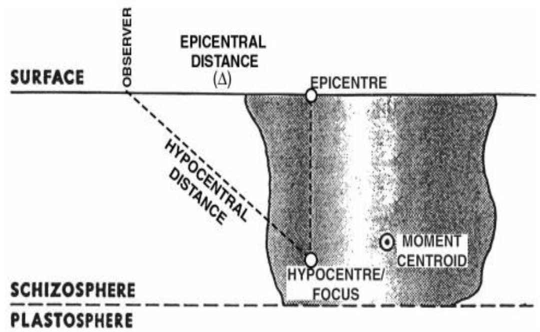


Figure 1.1 Terminology of earthquake [3]

1.3 OVERVIEW OF INDIA SEISMIC ZONES

The Bureau of Indian Standards divided the country into four seismic regions based on past seismic activity: Zone II, Zone III, Zone IV, and Zone V. Zone-V is the most seismically active of the four zones, whereas Zone-II is the least. Figure 1.2 depicts the Seismic Zone of India.

Table 1.1 Seismic Zone in India Based on Intensity on M.M. Scale

Seismic Zone	Intensity on M.M Scale
Zone-II (Low-Intensity Zone)	6 (or less)
Zone-III (Moderate Intensity Zone)	7
Zone-IV (Severe Intensity Zone)	8
Zone-V (Very Severe Intensity Zone)	9 (and above)

Figure 1.2 Seismic zone of India [4]

1.4 MAJOR EARTHQUAKE IN HISTORY

Table 1 shows seismic events with more than 1000 fatalities and injuries that happened in different parts of the world between 1900 and 2015 [5][6]

Table 1.2 Seismic events in the world and the effected of human life

Year	Day & Month	Location	Death	Magnitude
1902	19-Apr	Guatemala	2,000	7.5
	16-Dec	Turkestan	4,500	6.4

1903	19-Apr	Turkey	1,700	
	28-Apr	Turkey	2,200	6.3
1905	04-Apr	India, Kangra	19,000	8.6
	08-Sep	Italy, Calabria	2,500	7.9
1906	31-Jan	Colombia	1,000	8.9
	16-Mar	Taiwan, Kagi	1,300	7.1
	18-Apr	San Francisco, CA	2,000	8.3
	17-Aug	Chile, Santiago	20,000	8.6
1907	14-Jan	Jamaica, Kingston	1,600	6.5
	21-Oct	Central Asia	12,000	8.1
1908	28-Dec	Italy, Messina	70,000	7.5
1909	23-Jan	Iran	5,500	7.3
1912	09-Aug	Turkey, Marmara Sea	1,950	7.8
1915	13-Jan	Italy, Avezzano	29,980	7.5
1917	21-Jan	Indonesia, Bali	15,000	

	30-Jul	China	1,800	6.5
1918	13-Feb	China, Canton	10,000	7.3
1920	16-Dec	China, Gansu	200,000	8.6
1923	24-Mar	China	5,000	7.3
	25-May	Iran	2,200	5.7
	01-Sep	Japan, Kanto	143,000	8.3
1925	16-Mar	China, Yunnan	5,000	7.1
1927	07-Mar	Japan, Tango	3,020	7.9
	22-May	China, nr Xining	200,000	8.3
1929	01-May	Iran	3,300	7.4
1930	06-May	Iran	2,500	7.2
	23-Jul	Italy	1,430	6.5
1931	31-Mar	Nicaragua	2,400	5.6
1932	25-Dec	China, Gansu	70,000	7.6
1933	02-Mar	Japan, Sanriku	2,990	8.9
	25-Aug	China	10,000	7.4

1934	15-Jan	India, Bihar-Nepal	10,700	8.4
1935	20-Apr	Formosa	3,280	7.1
	30-May	Pakistan, Quetta	30,000	7.5
	16-Jul	Taiwan	2,700	6.5
1939	25-Jan	Chile, Chillan	28,000	8.3
	26-Dec	Turkey, Erzincan	30,000	8
1940	10-Nov	Romania	1,000	7.3
1942	26-Nov	Turkey	4,000	7.6
	20-Dec	Turkey, Erbaa	3,000	7.3
1943	10-Sep	Japan, Tottori	1,190	7.4
	26-Nov	Turkey	4,000	7.6
1944	15-Jan	Argentina, San Juan	5,000	7.8
	01-Feb	Turkey	2,800	7.4
	07-Dec	Japan, Tonankai	1,000	8.3
	12-Jan	Japan, Mikawa	1,900	7.1

1945	27-Nov	Iran	4,000	8.2
1946	31-May	Turkey	1,300	6
	10-Nov	Peru, Ancash	1,400	7.3
	20-Dec	Japan, Tonankai	1,330	8.4
1948	28-Jun	Japan, Fukui	5,390	7.3
	05-Oct	Turkmenistan	110,000	7.3
1949	05-Aug	Ecuador, Ambato	6,000	6.8
1950	15-Aug	India, Assam; Tibet	1,530	8.7
1954	09-Sep	Algeria, Orleansvl	1,250	6.8
1957	27-Jun	USSR (Russia)	1,200	
	02-Jul	Iran	1,200	7.4
	13-Dec	Iran	1,130	7.3
1960	29-Feb	Morocco, Agadir	10,000	5.9
	22-May	Chile	4,000	9.5

1962	01-Sep	Iran, Qazvin	12,230	7.3
1963	26-Jul	Yugoslavia, Skopje	1,100	6
1966	19-Aug	Turkey, Varto	2,520	7.1
1968	31-Aug	Iran	12,000	7.3
1969	25-Jul	Eastern China	3,000	5.9
1970	04-Jan	Yunnan, China	10,000	7.5
	28-Mar	Turkey, Gediz	1,100	7.3
	31-May	Peru	66,000	7.8
1972	10-Apr	Iran, southern	5,054	7.1
	23-Dec	Nicaragua	5,000	6.2
1974	10-May	China	20,000	6.8
	28-Dec	Pakistan	5,300	6.2
1975	04-Feb	China	10,000	7.4
	06-Sep	Turkey	2,300	6.7
	04-Feb	Guatemala	23,000	7.5
	06-May	Italy, northeastern	1,000	6.5

1976	25-Jun	New Guinea	422	7.1
	27-Jul	China, Tangshan	255,000	8
	16-Aug	Philippines	8,000	7.9
	24-Nov	Iran-USSR border	5,000	7.3
1977	04-Mar	Romania	1,500	7.2
1978	16-Sep	Iran, Tabas	15,000	7.8
1980	10-Oct	Algeria, El Asnam	3,500	7.7
	23-Nov	Italy, southern	3,000	7.2
1981	11-Jun	Iran, southern	3,000	6.9
	28-Jul	Iran, southern	1,500	7.3
1982	13-Dec	W. Arabian Peninsula	2,800	6
1983	30-Oct	Turkey	1,342	6.9
1985	19-Sep	Mexico, Michoacan	9,500	8.1

1986	10-Oct	El Salvador	1,000	5.5
1987	06-Mar	Colombia-Ecuador	1,000	7
1988	20-Aug	Nepal-India border	1,450	6.6
	07-Dec	Armenia, Spitak	25,000	7
1990	20-Jun	Iran, western	40,000	7.7
	16-Jul	Philippines, Luzon	1,621	7.8
1991	19-Oct	India, northern	2,000	7
1992	12-Dec	Indonesia, Flores	2,500	7.5
1993	29-Sep	India, southern	9,748	6.3
1995	16-Jan	Japan, Kobe	6,000	6.9
	27-May	Sakhalin Island	1,989	7.5
1997	10-May	Iran, northern	1,560	7.5
	04-Feb	Afghanistan	2,323	6.1
	30-May	Afghanistan	4,000	6.9

1998	17-Jul	Papua New Guinea	2,183	7.1
1999	25-Jan	Colombia	1,185	6.3
	17-Aug	Turkey	17,118	7.4
	20-Sep	Taiwan	2,297	7.6
2001	26-Jan	India, Bhuj	19,988	7.7
2002	25-Mar	Afghanistan	1,000	6.1
2003	26-Dec	Iran, Bam	31,884	6.7
2005	8-Oct	Pakistan	75,000	7.6
2006	26-May	Indonesia's Yogyakarta region	5,700	6.4
2008	12-May	China, Sichuan	87,500	8.0
2009	30-Sep	Sumatra, Indonesia	1,117	7.5
2010	12-Jan	Haiti	3,00,000	7.0
	14-Aprai	China	3,000	6.9
2011	11-Mar	Japan	20,896	9.0

2015	25-Aprail	Nepal	9,000	7.8

1.5 COMPONENTS OF STRUCTURES

In a building, inertia forces are generated anywhere there is mass when the ground trembles. These inertia forces move through the structure of the building from various mass points to the foundations and eventually to the soil or ground below through structural components that are both horizontally and vertically orientated [7] (Figure 1.3); these chains are called Load Paths. Structural Elements (SEs) are building elements that aid in transferring inertia forces to the ground along this load path. For example, in a moment frame building, the slabs, beams, columns, and footings are the structural elements that transmit all earthquake-induced inertia forces down to the building's foundation. When many interconnected SEs travel between mass points in the building and soil points beneath the foundations, buildings have many load routes.

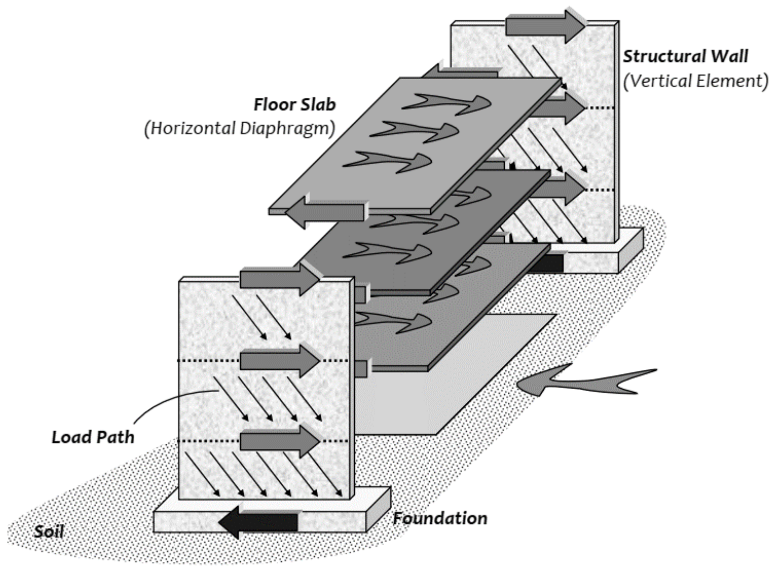


Figure 1.3 SEs create load path in each direction [7]

Even though SEs in buildings carry earthquake-induced inertia forces generated in the building down to foundations, there are many items in buildings, such as contents of buildings**,** appendages to buildings, and services & utilities, which are supported by SEs, whose inertia forces are also carried down to foundations by SE**s.** These are called Non-Structural Elements (NSEs). Appendages, non-structural components, building attachments, architectural, mechanical, and electrical elements, secondary systems, secondary structural elements, and secondary structures are used in various texts to describe NSEs. As the mass of the NSEs increases, the connection between NSE and the SE becomes stiffer and more substantial. The seismic action of the NSEs begins to affect the SEs with which it is connected; hence, the entire building is affected. The classification of building components is presented in figure 1.4, respectively.

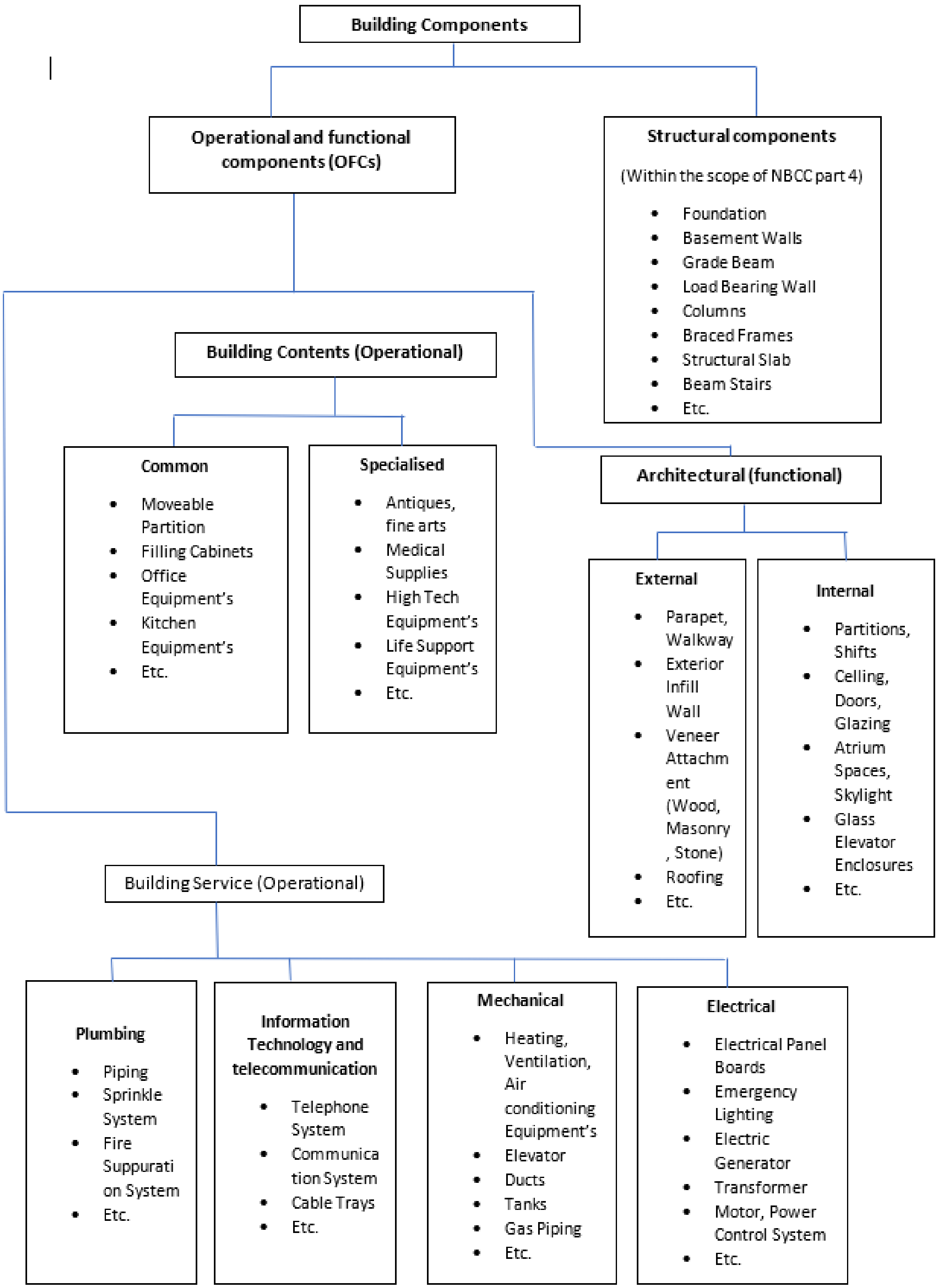


Figure 1.4 Operational and structural components of a building [8]

1.6 PHYSICAL CHARACTERISTICS OF NSES

The physical characteristics of NSEs include [9]

(1) Accelerations imposed on NSEs are greater than those set on buildings, owing to the amplification of ground motion along the building's height;

(2) NSEs lack the ductility to disperse the energy acquired during violent shaking. NSEs' elasticity is primarily determined by their internal design and the design of their connections with SEs;

(3) NSEs have low damping;

(4) NSEs can undergo resonance when their natural frequencies are close to the fundamental and other dominant frequencies of the building;

(5) NSEs are generally connected to the SEs at multiple points; and

(6) NSE responses to earthquake shaking differ from those of SEs.

1.7 CLASSIFICATION OF NON-STRUCTURAL ELEMENTS (NSEs)

NSEs can be listed under three groups based on their use and function, namely

1.7.1 Building Contents

Items needed to make spaces functional, such as (i) furniture and minor items, storage shelves, (ii) facilities and equipment, such as refrigerators, washing machines, gas cylinders, TVs, multi-level material stacks, false ceilings, generators and motors, and (iii) door and window panels and frames, large-panel glass panes with frames (as windows or infill walling material), and other partitions within the buildings.

1.7.2 Appendages to buildings

Items projecting out of the buildings or attached to their exterior surfaces, either horizontally or vertically, such as chimneys projecting out from buildings, glass or stone cladding used as façades, parapets, small water tanks rested on top of buildings, sunshades, advertisement hoardings affixed to the vertical face of the building or anchored on top of the building, and small communication antennas mounted atop buildings. Thus, some of these are architectural elements, while the rest are functional.

1.7.3 Services and utilities:

Plumbing lines (e.g., water supply mains, gas pipelines, sewage pipelines, and rainwater drain pipes), electricity cables, and telecommunication wires from the outside to the inside of the building and within the building, air-conditioning ducts, elevators, and fire hydrant systems are all items required for facilitating essential activities in the buildings (including water pipes through the buildings).

Different types of NSCs linked with the primary structures are shown in Figure 1.5.

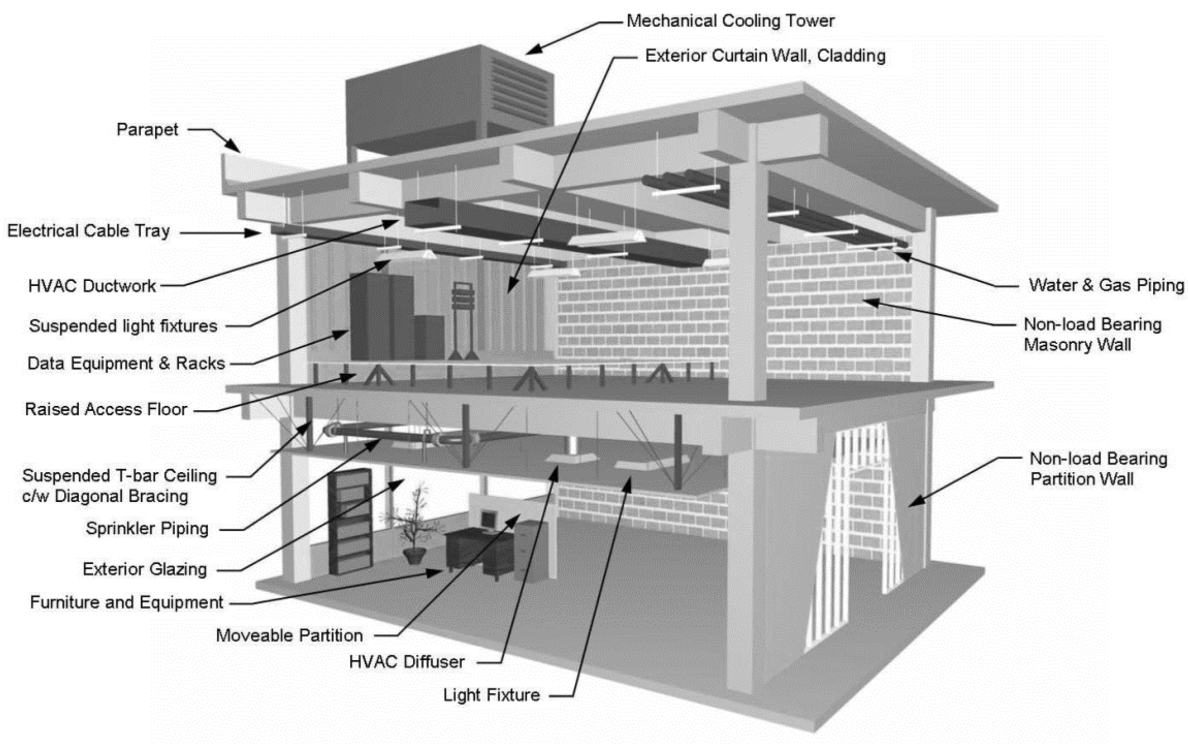


Figure 1.5 Example of the NSCs [10]

Non-structural elements could be categorised for seismic hazard evaluation purposes based on the engineering demand factor to which they are sensitive. Non-structural elements are classified into two parts: "acceleration-sensitive" and "displacement-sensitive" (Figure 1.6). Inertia forces coming from horizontal and/or vertical accelerations at different levels in the supporting structure produce overturning or excessive sliding/displacement of acceleration-sensitive non-structural elements, causing overturning or excessive sliding/displacement of the elements. Suspended building utility systems, such as pipe systems, cable trays, and anchored or free-standing building utility systems or contents, are examples of acceleration-sensitive non-structural elements. Inter-storey displacements or drifts in the supporting structure are the most common causes of damage to displacement-sensitive non-structural elements, resulting in severe distortions in the elements. Architectural components such as windows, partitions, and other strongly linked items to the underlying structure are examples of displacement-sensitive non-structural elements.

(a) (b)

Figure 1.6 Classification of non-structural elements: a) Acceleration Sensitive, b) Displacement-Sensitive [11]

1.8 PERFORMANCE OF NON-STRUCTURAL ELEMENTS DURING PAST EARTHQUAKES

SEs and NSEs are both vulnerable to earthquake shaking. The life of residents of such buildings are jeopardised due to the lack of SE safety; naturally, NSEs are lost in such structures. As a result, the endeavour to ensure earthquake safety for NSEs is based on the assumption that SEs are safe at the projected amount of seismic shaking. Only after the building's structural safety and earthquake resistance have been established can efforts be undertaken to ensure the NSEs' safety and performance. Damage to NSEs in typical structures results in (1) collateral damage to people and other objects/facilities and (2) loss of functionality of the nonstructural elements. In addition to the above two factors, the NSEs' functionality is endangered in crucial and lifeline structures. For example, in a hospital, secondary disasters can occur if oxygen cylinders tumble or their pipelines to operation theatres and wards are disrupted.

Furthermore, suppose the X-ray machine topples during the earthquake. In that case, damage-sensitive components inside are rendered useless after the quake, jeopardising its vital function of providing the majority of required services following the earthquake, not to mention the direct and indirect human and financial losses incurred as a result. As a result, earthquake damage or loss of NSEs can result in (a) injury or death, (b) loss of NSE function, and (c) direct and indirect financial losses.

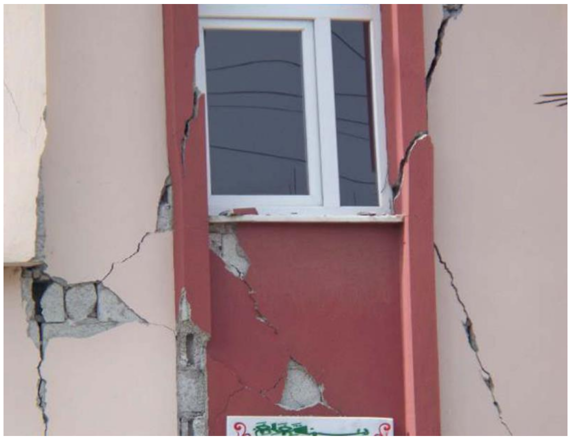
1.9 SOME DAMAGE TYPES

Massive NSEs will slip and topple if not attached to the vertical or horizontal SEs. For example, if a wet battery bank is simply placed on some supports that are not meant to withstand seismic forces, the batteries can tumble, leading to loss of performance and possibly acid spillage (Figure 1.7). When the infill walls of a masonary building are not correctly secured, it is severely damaged during the seismic activity. Figure 1.8 depicts the behaviour of the infill wall following the seismic event. The 6.5-magnitude Bam earthquake, which struck the city of Bam, the town of Baravat, and several surrounding villages in Kerman province on December 26, 2003, destroyed over 70% of the buildings in the stricken area and caused extensive non-structural damage to the structurally intact buildings. According to the Ban Earthquake Report of 2003, NSCs are harmed during seismic activity.

Figure 1.9 shows how distinct seismic action affected most of the NSCs connected to the main components.

Figure 1.7 Poor earthquake performance of NSEs 1971 San Fernando Earthquake [12]

(a) (b)



(c)

(d)

Figure 1.8 Failure mechanism of infill wall due to (a and b) detachment; (c) tension strut; and (d) crushing of wall caused by the Van earthquake [13-14]

NSCs	Earthquake Damages
Suspended Ceiling	 Lander, 1992 (Bam Earthquake Report 2003) 

Northridge 1994 (Bam Earthquake Report 2003)

L'aquilia 2009 (Apalermo et al 2010)

Bam 2003 (Bam Earthquake Report 2003)

Door and Windows

Bam 2003 (Bam Earthquake Report 2003)

Hiati 2009 (Apalermo et al 2010)

Hector Mine 1999 (Historical UBC 2005)

Building Veneer

Bam 2003 (Bam Earthquake Report 2003)

L'aquilia 2009 (Apalermo et al 2010)

Building Contents

Northridge 1994 (Historical UBC 2005)

Bam 2003 (Bam Earthquake Report 2003)

Bam 2003 (Bam Earthquake Report 2003)

Exit Way

San Fernando 1971 (Historical UBC 2005)

Bam 2003 (Bam Earthquake Report 2003)

Figure 1.9 Seismic Consideration of NSCs [15-16]

1.10 MAJOR CONCERNS

Over the previous four decades in India, the cost of NSEs has risen as a percentage of the project's total construction cost. Table 1.2 shows the particular qualities of buildings constructed at various times over the last four decades. Figure 1.10 depicts the overall evolution of costs. With high expectations of functional performance of buildings and higher maintenance costs, the cost of NSEs soared from a paltry 5% in the 1970s to a dominating 70% in the 2000s. Since, changes in building performance are projected to be minimal, NSE costs are expected to saturate during the next decade.

Furthermore, many NSEs (used in modern buildings) have not been tested to show that they can withstand substantial earthquake motion. Over the previous three decades, the average economic loss due to earthquake-related NSE failure in the United States has been estimated to be roughly US$2-0-4.5 billion per year [17-18]. Figure 1.11 summarises studies conducted in the aftermath of the 1994 Northridge earthquake in the United States and the 1995 Hyogo-ken Nanbu earthquake in Japan in terms of the cost-share of various building items in the United States and Japan [18-20]. Table 1.3 shows the economic losses incurred due to NSE failure during various earthquakes.

Table 1.3 Evolution of NSEs used in building over the last four decades in INDIA

Era	Dominant Building Type	NSE Highlights
1960-1970s	Masonry buildings	Plastering with cement mortar, battened electrical wire, and ceramic plumbing lines

1970-1980s	RC buildings	Cement wall cladding, high-tech coatings, rooftop water tanks, and hidden electrical wiring
1980-1990s	Multi-storey RC buildings	Plaster of Paris and wall putties on walls, elevators, window air conditioners, PVC and metallic plumbing lines
1990-2000s	High-rise RC buildings	False Ceilings, Façades (e.g., glass, stone), Finishes Services (e.g., Split and central ACs, advanced electrical power control devices, advanced plumbing features, fire fighting, multiple elevators, multiple water tanks on rooftops, data and communication cables, advanced bathroom fixtures), expensive furniture and contents of buildings

Table 1.4 Economic losses due to failure of NSEs [17]

S No.	**Earthquake**	**Losses due to failure of Nonstructural elements**
1	Loma Prieta 1989	$ 50 million reported at some facilities
2	Northridge 1994	Economic loss associated with Northridge earthquake is as high as $5.2 billion, which is five-sixth of the total direct economic loss to non residential buildings

3	Nisqually 2001	Estimated $2 billion loss was associated with damage to nonstructural components and business interruption
4	Niigata Ken 2004	Economic loss, both direct and indirect, sustained at Sanyo Electrical Company was in the tune of $ 690 million

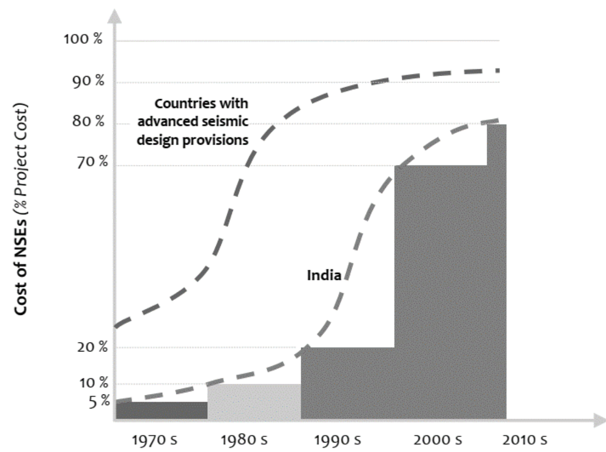


Figure 1.10 Evolution trends in costs of NSEs used in buildings over the last four decades: in India and in countries with advanced seismic provisions for design of buildings and NSEs

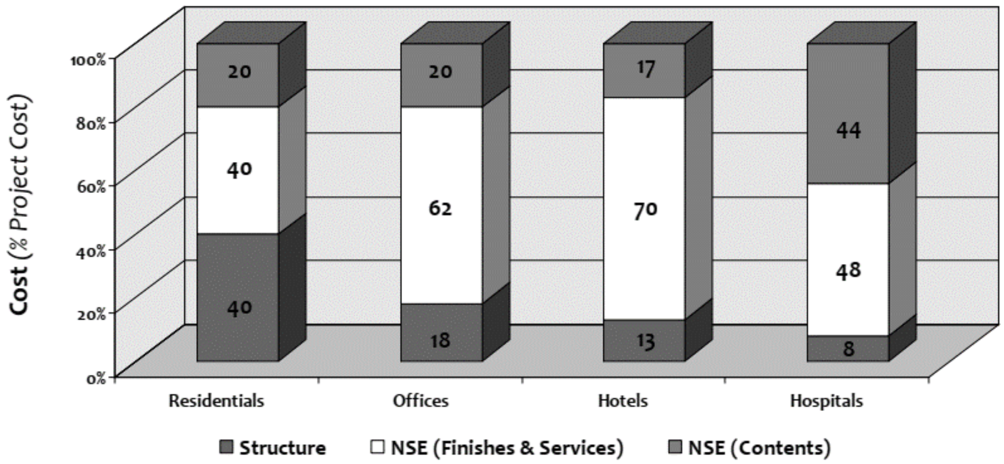


Figure 1.11 Cost share of structure and NSEs in building projects implemented in USA and Japan: Major cost share is of NSEs [21]

1.11 METHODS FOR THE ANALYSIS OF THE STRUCTURES

The choice of linear elastic or nonlinear modelling of the element force-deformation behaviour and whether or not geometric nonlinearities are taken into account largely dictates the analytic approach to be taken. Dynamic rather than static analysis approaches can be used because of the dynamic character of earthquake loads and the modelling of structural mass distribution. In general, there are three methods for the dynamic analysis of the structures, 1) Linear time history method, 2) response spectrum method, and 3) nonlinear time history method.

1.11.1 Linear time history method

Although simple elastic linear approaches may appear ancient by today's research standards, they are the current standard-of-practice for seismic design for most cases. Despite several attempts to develop nonlinear static or dynamic design methodologies [22], the great majority of practical earthquake engineering work is still done at the elastic level, using either

a) Equivalent linear static, in which a fixed lateral load pattern is applied to an elastic structural model; b) linear time history analysis; and c) modal response spectrum analysis, where the modal responses are combined to estimate the peak MDOF response [23]. The elastic seismic loads (i.e., design spectral acceleration values) are always divided by the appropriate reduction R (or behaviour q) factor, which is supposed to indicate the ductility and overall strength of a yielding system. Although there has been little current research on elastic methods, recent advances in the nonlinear analysis have served to shed some light on the concept of employing elastic results to capture nonlinear behaviour.

For a dynamic system, the equilibrium equations are as follows:

$$\boldsymbol{M}\ddot{u}(t) + \boldsymbol{C}\dot{u}(t) + \boldsymbol{K}u\ (t) = \boldsymbol{R}\ (t) \tag{1.1}$$

M, **C**, and **K** are the mass, damping, and stiffness matrices, respectively**;** **R**(t) is the external load vector, and $u(t), \dot{u}(t)\ and\ \ddot{u}(t)$are the finite element assemblage's displacement, velocity, and acceleration vectors, respectively. Engineering judgement usually determines whether to conduct a static or dynamic analysis (i.e., include or exclude velocity and acceleration-dependent forces from the study). Eq. (1) describes a system of second-order linear differential equations, and the solution of this system can be determined using standard differential equations solution processes.

1.11.2 Non-linear time history method

The most precise and realistic analysis technique available is nonlinear dynamic analysis. It's also known as "nonlinear time history analysis," "nonlinear response history analysis," and "nonlinear dynamic technique," according to ASCE 41-06 [24]. (NDP). Earthquake loading is modelled as a natural or synthetic seismic activity on a structural model that includes inelastic (nonlinear) force-deformation connections and, at most, a first-order estimate of geometric nonlinearities (P-Delta effects). Seismic activity movement throughout the structure gives comprehensive reaction histories for any given variable (e.g. displacements, stress resultants), resulting in a wealth of data. While modelling options can lead to varying levels of complexity, different ground motion records will result in quite different demands. This record-to-record volatility dominates the implementation of dynamic approaches. Because a single-time history analysis is of little practical use, a properly selected group of many ground motion records is required to obtain credible response estimations.

Furthermore, to explore structural behaviour at various response or damage regimes, single or multiple levels of seismic hazard, typically equivalent to one or more levels of the IM, may be required (e.g. elastic, post-yield or near-collapse). As a result, narrow-range and broad-range assessments can divide nonlinear dynamic analysis processes into two categories. Only a restricted, single-point estimate of structural response is necessary for most practical design/assessment circumstances. This is in line with current seismic codes, which only specify a design hazard spectrum (usually with a 10% chance of exceeding the threshold in 50 years) and necessitate ensuring that a structure will not incur major or life-threatening damage at such a degree of intensity. As a result, seismic codes (for example, ASCE 7-10 2010 [25]; EN1998 2005 [23]) require that ground motion data meet or surpass the design spectrum in the temporal range of interest. When using 3 to 6 records, the overall greatest of the recorded peak responses is used as the structural demand; however, when using seven or more records, the average of the peak responses might be used.

1.11.2.1 Incremental Dynamic Analysis

In order to account for the uncertainties inherent in any seismic hazard while analysing the performance of a structure under seismic activities, a wide range of seismic recordings and more

than one hazard levels should be examined in the framework of seismic response of structures. Non-linear dynamic studies based on a single or multiple hazard level approach is the most reliable and computationally costly methodology for performance-based assessment. The two most appropriate methods for executing this work are multiple-stripe dynamic analysis and incremental dynamic analysis in structural fragility analysis and life-cycle cost analysis [26]. The abbreviation IDA is used for both methods to be consistent with current technical literature. The main goal of an IDA study is to construct a curve based on the intensity level's relationship to the structural systems maximum seismic reaction. An intensity measure (IM) and an engineering demand parameter (EDP) are used to define the intensity level and seismic reaction.

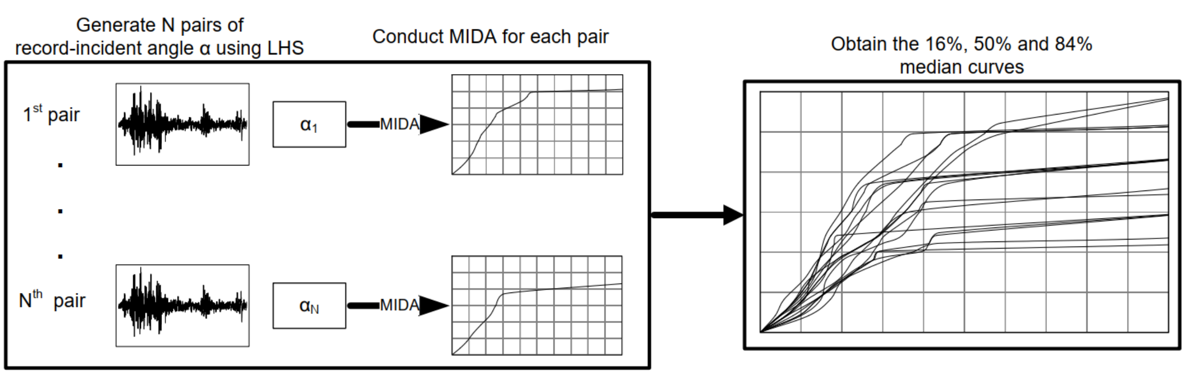


Figure 1.12 The MIDA procedure

One of the most crucial tasks in IDA is deciding on an IM and EDP. The importance of choosing an efficient IM is emphasised by Giovenale et al. [27]. The IM should be a monotonically scalable ground motion intensity measure, such as the peak ground acceleration (PGA), peak ground velocity (PGV), and the ξ =5% damped spectral acceleration at the structure first-mode period (SA(T1,5%)), among others. On the other hand, the damage can be measured using any of the EDPs whose values can be linked to specific structural damage states. In the past, a variety of response-based EDPs have been studied and critically assessed for their application in seismic damage assessment. EDPs are divided into four types by Ghobarah et al. [28] based on maximum deformation, cumulative damage, and combinations of maximum deformation and cumulative damage. A number of natural records, each characterized by its longitudinal and transverse components, are applied to the system to compensate for the randomness of the seismic action, according to Lagaros [29] multicomponent incremental dynamic analysis (MIDA), which is an extension of IDA. The MIDA framework differs from the original one-component version of the IDA in that for every record, several MIDA representative curves can be produced depending on the incident angle chosen. In contrast, in most circumstances, the one-component version of the IDA only produces one IDA representative curve. Figure 1.12 shows a diagram of the MIDA method.

1.12 FEM BASED SOFTWARE

The necessity to address challenging engineering elasticity and structural analysis issues gave rise to FEA theories and techniques [30]. The governing equations are approximated piecewise in a finite element model of a problem. The main principle of the FEM is that by substituting an assembly of discrete components for a solution region, it is possible to represent or approximate that region (discretization) analytically. Software like Etabs, Ansys, Abaqus, etc., uses the FEM method to tackle complex issues. Applications like Ansys or Abucos are good for element analysis, while Etabs is better than other frame analysis software. Etabs can solve the nonlinear static and dynamic analysis of the structures. The Wilson FNA (Fast Nonlinear Analysis) Method, a new numerical integration approach, is used in Etabs for nonlinear time history analysis [31]. This approach analyses structures with predefined, confined nonlinearity using an extremely effective iterative vector superposition process.

1.13 SUMMARY

This chapter deals with the essential component of structures. The structure is basically constructed by two components called primary components and secondary components. For building estimation, NSCs performed a significant role. During seismic activity, if NSCs are not adequately linked with the main components, it causes severe effects on the buildings and human life. Sometimes the cost of the NSCs is higher than 65% of the total cost of the structures. In India, design provisions for preventing the damages of NSCs during seismic action are low compared to other countries. Two methods are used for the structure analysis: the linear time history method and non-linear time history method. The incremental dynamic approach is a part of the nonlinear time history method, in which the ground motion data is incremental increases for the analysis of the structures, respectively.