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Evaluation of Seismic Behavior of Non-structural elements in Building

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MASTER OF TECHNOLOGY

in

Structural Engineering

by

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CANDIDATE DECLARATION

I, **Anchal Kaw**, M.Tech (Structural Engineering) student, having **Roll no: 2K23/STE/03**, hereby certify that the work which is being presented in the dissertation entitled "**Evaluation of Seismic Behavior of Non-structural elements in Building**" in the partial fulfilment of the requirements of the award of the Degree **Master of Technology in Structural Engineering**, submitted in the **Department of Civil Engineering, Delhi Technological University** is an authentic record of my work carried out under the supervision of Prof. Shilpa Pal, Department of Civil Engineering, Delhi Technological University, Delhi. The matter present in this dissertation has not been submitted by me for the award of any other degree of this or any other institute.

Place: Delhi | ANCHAL KAW

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CERTIFICATE

I hereby certify that the project Dissertation entitled "**Evaluation of Seismic Behavior of Non-structural elements in Building"** which is submitted by Anchal Kaw, Roll No. 2K23/STE/03, to Department of Civil Engineering, Delhi Technological University in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of project work carried out by her under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi
Date: May 31, 2025

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ABSTRACT

Non-Structural elements (NSEs) are the components of building that do not participate in the load transfer mechanism. Past studies have revealed that the effect of seismic forces on NSEs is ignored and was considered only on the structural components. However, NSEs have a significant impact on buildings performance during events like earthquake. Certain NSEs such as multiple pipes, cable tray, firefighting system, HVAC duct system, etc. affect the behavior of building during a seismic event. In some places where earthquakes occur frequently, these NSEs cause severe damage to the building as they are not included in seismic design because they are considered non-structural. This study compares the lateral forces acting on NSEs obtained from Eurocode8 and IS 16700 showing that the lateral forces acting on NSEs increase with building height. Results reveal that IS16700 is underestimating the lateral forces acting on NSEs whereas lateral forces from Eurocode 8 are approximately twice as high as those from IS16700, thus adopting a more conservative approach. This comparison highlights the need for incorporating the effect of lateral forces on NSEs in Indian codes in a detailed manner to increase its focus on non-structural elements so that it aligns with best practices for improving the seismic safety.

Critical structures such as hospitals should remain fully functional post seismic disaster therefore the seismic performance of NSEs is important in a building. These NSEs must be properly designed, anchored and installed in healthcare facilities to prevent damage to NSEs. Through an analytical study, this research underlines the importance of time period of structure and utility systems on the overall seismic design of NSEs, with a focus on healthcare units like hospital buildings. This study evaluates the seismic behavior of two NSEs – cable tray and multiple pipes supported on two different utility system (conventional and modular) within G+3 hospital building located in seismic zone V in India. Results reveal that modular support systems significantly reduced the lateral displacements by approximately 80 % to 90 % as compared to conventional systems. Moreover, the time period of cable tray is 0.14 seconds for the conventional support system whereas the time period of modular system is 0.017 seconds indicating higher stiffness and reduced risk of resonance.

This time period has an inverse relationship with stiffness of the NSEs as a result of this more flexible elements experience amplified displacements and forces as compared to stiffer elements when subjected to seismic loading. International codes such as Eurocode 8 takes into consideration the dynamic behavior of NSEs by including effect of their time period of both utilities and building in lateral force calculation. However, Indian codes such as IS 16700 and IS 1893 lack provisions for considering the dynamic characteristics of NSEs such as the effect of time period in lateral force calculation. This study also reveals the critical role of utility support system selection in improving the performance of NSEs during earthquake and safeguarding the continuity of essential services in lifeline structures such as hospitals.

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ANCHAL KAW

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LIST OF SYMBOLS AND ABBREVIATIONS

NSEs	Non-Structural Elements
SEs	Structural elements
UBC	Uniform Building Code
IBC	International Building Code
NZS	New Zealand Code
NDMA	National Disaster Management Authority
EC 8	Eurocode 8
DL	Dead load
LL	Live load
EL	Earthquake load
Fa	Horizontal seismic force acting on non-structural element
Ta	Time period of non-structural element
T_1	Time period of building
Aa	Seismic amplification factor
S	Soil factor
Z	Zone factor
I	Importance factor
Rp	Component response modification factor
Wp	Weight of non-structural element
Sa	Seismic coefficient
qa	Behavior factor
ƴa	Importance factor
FOS	Factor of safety

CHAPTER 1

INTRODUCTION

1.1 GENERAL

A building is composed of two main components: -Structural elements (SEs) and Non-structural elements (NSEs). Structural elements such as beam, column, slab, foundation participate in transferring gravity as well as seismic forces from superstructure to foundation through a well-defined load path. Non-structural elements include mechanical, electrical and architectural component of the building that are responsible for the effective functioning of the building. When these components fail, it may impact the building's occupant's well-being and can cause enormous economic and financial losses.

Architectural components include cladding, door and window panes, glasses, parapets, partition walls and infill walls. Mechanical components include boilers and furnaces, chimneys, conveyors, HVAC systems, Piping systems and pressure vessels. Electrical components include distribution systems such as cable trays, bus ducts, conduits, transformers, motors, communication systems and lighting fixtures. Although these elements constitute up to 85-90% of the total building cost, past studies reveal that the seismic behavior of these NSEs has not received adequate attention and the Indian seismic codes doesn't provide adequate guidelines for the seismic design of these components. The good seismic performance and behavior of the non-structural components for critical and lifeline structures such as hospitals, emergency centers and fire stations are extremely important during the earthquake shaking.

During 2001 Bhuj earthquake in India, numerous water tanks and sign boards located on top of building collapsed and caused heavy damage to the building. The loss of human lives and structure were so extensive that no focused-on destruction instigated by NSEs. Despite of all these factors that were observed during these earthquakes, design of non-structural elements (NSEs) was often overlooked as compared to that of structural elements.

The major focus of structural design engineers was to prevent the failure of structure as they serve as the main lateral load resisting system unlike NSEs which are not permanently attached to the structure and do not participate in the load transfer mechanism.

1.2 NON-STRUCTURAL ELEMENTS

NSEs are the components of buildings that do not participate in load transfer mechanism rather they are important for effective functioning of the building. NSEs are connected to structure by structural elements. The seismic forces acting on a building due to base excitation of the ground during earthquake has an adverse effect on both structural as well as non-structural components. Figure 1.1 shows various types of NSEs in a building.

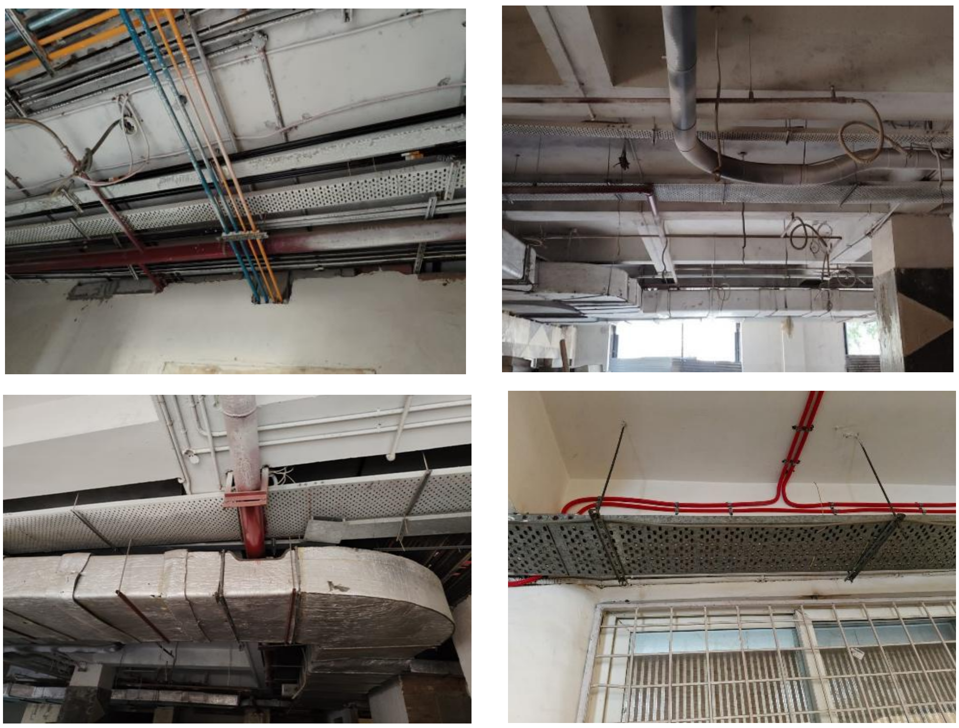

Figure 1.1 Non-structural elements in a building

NSEs can be categorized into the following three groups on the basis of their use and function: -

1) Content of building: - It includes furniture, equipment, false ceiling, door and window frames and panels, infill wall materials, elevators and escalators.
2) Appendages to building: - It includes horizontal and vertical elements projecting out of building such as chimneys, stone cladding, facades, overhead water tanks etc.
3) Services and utilities: - It includes services that are essential for proper functioning of building such as electricity cables, water supply pipes, HVAC duct system, firefighting system, oxygen pipes, drainage pipes etc.

The categorization of NSEs can be also done into two types depending on their behavior during earthquake shaking namely: -

1) Acceleration sensitive NSEs- It includes heavy and relatively stiffer items that can topple or fall during an earthquake if they are not properly anchored therefore affecting the building functionality.
2) Deformation-sensitive NSEs- It includes light and flexible items that are subjected to pull and shear during earthquake and these can pull off from supports if they are not anchored properly with structural elements and they undergo relative displacements at ends.

1.3 IMPORTANCE OF NON-STRUCTURAL ELEMENTS

NSEs are those elements which do not contribute to primary load bearing mechanism of the building. Failure of NSEs during earthquake can result in financial losses, hinder the escape route of building by blocking them, interfere with the occupant safety by falling on them, cause loss of lives and it can render building nonfunctional. The cost of NSEs will vary for different type of buildings. For Critical and lifeline structures such as hospital buildings, emergency centers etc. these constitute up to 90% of total building cost. In case of hospital buildings failure of NSEs can hinder the working of healthcare facilities. Hospital building has maximum number of non-structural elements hence these must be properly anchored and secured so that building remains functional post-earthquake.

A hospital building is considered to be safe when all the routes for medical facilities are open and easily accessible and the hospital building suffers least damage or no damage with no loss of lives after disasters like earthquake occur. The hospital building should remain fully functional and operational for the patients after such hazardous events. In case of commercial buildings NSEs constitute up to 80-85% of total building cost. Commercial buildings such as hotels, malls, offices etc. are highly overcrowded. Failure of NSEs in these buildings can cause loss of lives and it can also result in stampede due to limited staircase in such buildings.
Some common type of failures of non-structural components due to earthquake are given in Table 1.1. [1]

Table 1.1 Various types of failures in NSEs [1]

Item	**Type of failure**
Pumps and boilers	Failure of anchored supports
Tanks	Failure of supports
Parapets	Failure by toppling
Storage racks	Toppling or content falling
False ceilings	Failure of panels by falling
Windows	Detaching of frames, glass breaking
Suspended light fittings	Failure caused by excessive sway
Masonry infill walls	In plane or out of plane failure

Recent studies [2] reveal that cost of NSEs are quite higher than that of SEs present in the building. The comparison of cost of NSEs for different building is shown below in Figure 1.2. [1]

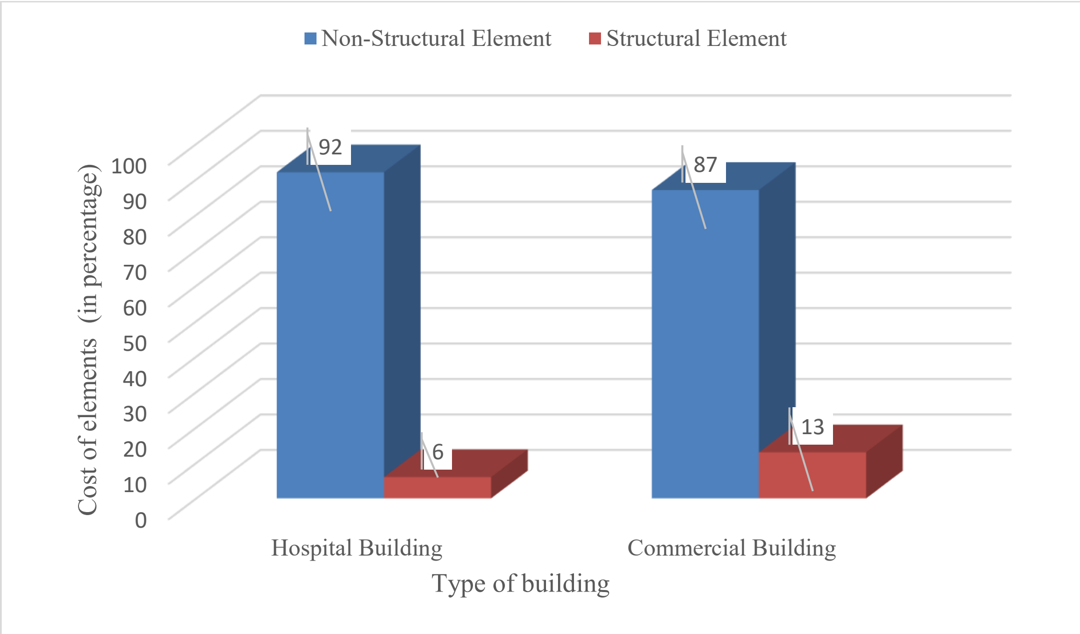

Figure 1.2 Comparison of Cost of NSEs for Hospital and Commercial Building [1]

1.4 CURRENT DESIGN GAPS IN INDIAN AND INTERNATIONAL CODES

IS 1893:2016 (Part 1)[3] provides various provisions for the seismic design of non-structural elements. It explains how various equipment and different type of electrical, mechanical and plumbing system in a building are subjected to earthquake shaking at locations where they are supported and connected to structural elements. It provides guidelines for both type of cantilever projections such as vertical projection (example: tower, chimney, tanks etc.) and horizontal projection (example: brackets, cornice etc.). The recommendations for seismic design of NSEs provided in IS 1893:2016 are completely inadequate and unclear.

IS 16700:2023 [4] provides guidelines for the seismic design of both acceleration-sensitive as well as displacement- sensitive NSEs laid down by various statutory and non- statutory bodies and the respective owner of the particular building.

Different type of displacement- sensitive NSEs are attached to the building at various levels and the non-structural elements are connected to structural elements by supports and they allow relative displacement at its ends when they are subjected to lateral loading due to seismic base excitation. The formula for calculation of lateral forces acting on different type of acceleration-sensitive NSEs due to seismic base excitation is defined in IS 16700. This formula however doesn't consider the effect of time period of both structural components as well as non-structural components. Time period of NSEs as well as SEs have a major effect on the performance of the building. If the time period of NSEs resonates with the time period of the building a phenomenon known as resonance takes place which ultimately leading to the collapse of the building. Thus, Indian standard codes need upgradation as the provisions provided by them underestimate the seismic demand which causes failure of NSEs and affects the behavior of building making it dysfunctional.

The NDMA (National Disaster Management Authority) also provides data about safety of hospital buildings during critical events like earthquake. These guidelines are important for critical and lifeline structures like hospitals to function properly post-earthquake and are not applicable to other buildings such as commercial buildings, residential buildings etc. The NDMA guidelines are essential to protect the collapse of critical structures. The expected performance of a hospital and commercial building during earthquake shaking has been compared below in Table 1.2.

Eurocode 8 [5]provides guidelines for the seismic design of NSEs. It clearly specifies that NSEs as well as their attachment, supports and anchorages must be seismically resistant. It considers the effect of time period of both NSEs and SEs while calculating lateral forces acting on NSEs in a building during a seismic event. It provides more realistic approach to calculate the lateral forces acting on NSEs rather than Indian seismic codes which underestimate the seismic demand.

Table 1.2 Expected Performance of building during earthquake [1]

	Intensity of earthquake	Commercial building	Hospital building	Expected performance level (Commercial building)	Expected performance level (Hospital building)
	Mild	No damage	No damage		
Structural elements (SEs)	Moderate	Minor damage	No damage	Life safety (LS)	(Immediate Occupancy) (IO)
	Severe	No collapse	Minor damage		
	Mild	No damage	No damage		
Nonstructural elements (NSEs)	Moderate	Slight damage	Functional	Immediate Occupancy (IO)	Fully operational (FO)
	Severe	-------------	No Permanent damage		

1.5 SCOPE OF THE WORK

The present study investigates the effect of lateral forces acting on non-structural elements in building under seismic loading. Firstly, the effect of lateral forces acting on NSEs in hospital and commercial building is analyzed using international codes such as Eurocode 8 and Indian seismic codes such as IS 16700. Secondly, it also involves the assessment of dynamic behavior of two non-structural elements namely, cable tray and multiple pipes placed at each floor of G+3 Hospital building located in Seismic Zone V in India. The main aim of this study is to understand the dynamic behavior of NSEs and their effect on overall structural response. Furthermore, this study also analyzes the effect of lateral forces acting on different support system (both conventional and modular support system) on which these NSEs such as cable tray and multiple pipes are supported.

1.6 OBJECTIVE OF THE STUDY

To evaluate the effect of lateral forces acting on non-structural elements in buildings and their dynamic behavior when supported by different support system, the following objectives are formulated: -

1) To study the impact of Non-Structural Elements on Structure during Seismic loading.
2) A Comparative Study of the Effect of Non-Structural Elements on Structures Using Eurocode 8 and IS 16700.
3) To analyze the dynamic behavior of Non-structural elements under seismic loading by evaluating their time period based on lateral displacements.
4) To compare the seismic performance of NSEs supported by conventional support system versus modular support system.
5) To highlight the absence of adequate provisions in Indian seismic codes for the seismic design of non-structural elements and their utility systems and its comparison with international codes such as Eurocode.

1.7 OUTLINE OF THE THESIS

The current thesis is for MTech dissertation and it is basically divided into five chapters. The brief outline of each chapter is given below: -

Chapter 1 gives a brief information about the non-structural elements explaining their types, behavior, failures and importance during the seismic events. It also highlights the current gaps in Indian and International codes related to NSE design. The scope and objective of this study are also clearly defined in this chapter.

Chapter 2 gives a review about the previous research work in this area and studies related to seismic behavior of non-structural elements. It basically summarizes the findings from various research papers and helps to establish a research gap and explains the need for the current study.

Chapter 3 outlines about the approach adopted for this research work. It includes the selection of building, identification of various NSEs, and the design methods used.

It also describes the analytical procedures, software used for this study and code-based comparisons of lateral forces acting on NSEs.

Chapter 4 discusses about results and discussions that are obtained based on the selective methodology. Graphs, tables and comparisons are used to support the findings.

Chapter 5 provides the key outcomes of the study for this dissertation and the proposed future work scope.

At the end of this dissertation references, certificate and publications are provided.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Earthquakes can cause severe damage to both life and property, especially in the regions which are highly prone to seismic activities. Past studies reveal that earlier structural engineers primarily focused on seismic design of structural elements such as beam, column, slab, foundation to ensure the safety of structure and to prevent its failure during events like earthquake. However, in the recent times performance and behavior of non-structural elements that are not the part of main load resisting system are gaining much attention as they affect the building functionality and safety during a seismic event. The performance of these elements plays a crucial role in critical structures such as hospitals where failure of such components can affect the building functionality. The failure of cable tray and multiple pipe system can cause power outages thereby affecting the life support systems, various emergency equipment, disrupt essential services like water supply, oxygen supply which can risk the life of patient.

Despite their importance, non-structural elements are ignored during the seismic design of buildings. Damages to non-structural elements can result in economic losses, building dysfunctionality, loss of lives. This led to more detailed research into seismic design guidelines of NSEs and their interaction with structure during earthquake. The research in this area varies from experimental investigations to complex analytical work for examining the behavior of NSEs.

International codes such as Eurocode 8[5], FEMA guidelines [1], uniform building code (UBC), international building code (IBC), New Zealand code (NZS) provide various guidelines for seismic design of NSEs. Most of these codes recommend that NSEs should be designed using higher seismic coefficients values as compared to the building. These codes also recommend that floor response spectrum should be used for important and critical NSEs. However, our Indian standard such as IS 1893 [3] and IS 16700 [4] lack such provisions and doesn't provide adequate guidelines for seismic design of NSEs.

2.2 LITERATURE REVIEW

O'Reilly et al. (2020) proposed a method for quantifying and classifying of seismic risk of both acceleration sensitive and deformation sensitive non-structural elements. Even though NSEs do not participate in load transfer mechanism but they are subjected to lateral forces during a seismic event. In hospital, office, school and hotel buildings they constitute up to 92%, 82%, 60%, 87% of the total building cost. Both these points indicate that NSEs are very crucial in buildings when thinking about the damage and financial losses after an earthquake. However, we still do not have proper guidelines on how much risk these NSEs face during earthquakes. This paper presents a technique to classify the risk levels of NSEs based on factors like building shaking, response of NSEs and other uncertainties to make it accurate and modern. This method is simple and compares how risky different NSEs are in terms of safety and money.[6]

Carofilis et al. (2021) compared how much acceleration NSEs might experience using both existing seismic codal provisions for buildings and advanced calculation methods. Recent studies indicate that strong to medium earthquakes affect the building performance. Many international codes estimate the shaking (acceleration) experienced by NSEs, but these estimates are not accurate leading to underestimation of seismic design. The authors conducted this test on three storied and nine storied steel frame buildings and used FEMA guidelines to simulate an earthquake of similar magnitude for both these buildings. The comparative study showed that the various building codes underestimate the values of actual acceleration demand acting on acceleration sensitive NSEs whereas the state-of-the-art methodology provides better results for actual acceleration demand on NSEs without performing Nonlinear time history analysis. [7]

Braga et al. (2011) assessed various types of failure patterns in the partition and infill walls (NSEs) of several Moment Resisting Framed Reinforced Concrete buildings in Italy. This damage included small cracks to complete collapse of walls affecting the overall structural integrity of the buildings. This damage caused serious problems such as injuries, deaths, unstable buildings etc. This research was conducted to identify most common type of non-structural damage and their main causes. The most common type of damage that was observed in the structural systems are in-plane and out-of-plane wall failures. [8]

This paper also suggested improvements in building design codes to prevent the collapse and failure of NSEs during seismic events.

Mondal et al. (2005) carried out comparative study of various international codes and studied their design guidelines for the seismic design of NSEs. This study revealed that most of these codes recommend the values of seismic coefficients for NSEs should be kept generally higher than the supporting building. These codes also considered natural frequency of the building and NSEs for the lateral force estimation on NSEs for accurate estimation of seismic demand. However, Indian seismic codes such as IS 1893 and IS 16700 doesn't provide adequate provisions for seismic design of non-structural elements. This paper suggested various improvements in Indian standard such as provisions for seismic relative displacements should be included for deformation sensitive NSEs, a parameter considering flexibility should be considered, floor response spectrum should be considered for dangerous and important NSEs. [9]

Rota et al. (2023) used a methodology which included installation of cost-effective accelerometers for monitoring the NSEs behavior during a seismic event. These devices measure the intensity of building shaking (acceleration) during an earthquake. They compared this shaking with certain limits called as acceleration thresholds. If the intensity of shaking exceeds this threshold value, it could be life threatening for people residing in that particular building. These threshold limits were based on how different NSEs react during an earthquake, using special charts called as fragility curves. To validate this method the acceleration obtained by these devices were compared with the allowable limits given in the Italian building code. This method also involves the use of real time probabilistic assessment to prevent NSEs damage. [10]

Devin et al. (2019) analyzed various experimental and numerical models to predict behavior of NSEs during an earthquake. These models help in better understanding of these elements. In order to perform this analysis properly, proper understanding of the properties of NSEs is very important. Behavior of NSEs should be modelled accurately and simulations should be created in such a way that they match real life tests. Present day building design software lacks enough data to fully include these elements. Even though some research work has been done in this area to improve this, but we need more research to create adequate guidelines. NSEs should be included in seismic design along with structural elements for efficient seismic design of buildings. [11]

Berto et al. (2020) did a detailed study to check the safety of valuable non-structural elements such as free-standing equipment during the earthquakes. The analysis was carried out by developing computer models of reinforced concrete buildings. In this analysis two types of earthquake data were used, one causing extreme damage and one causing smaller damage to check how the different floors of buildings behave during earthquake shaking. They studied how the acceleration and floor movement were affected by ground shaking at different story height in buildings. They suggested a new method called as stability chart to check the safety of valuable free standing NSEs during earthquakes.[12]

Dhakal et al. (2016) conducted research on non-structural elements and building contents at university and observed that in the year 2010-2011 several earthquakes occurred in Canterbury, New Zealand which caused damage to NSEs and contents of building which ultimately resulted in huge loss of lives, financial losses and disruptions in buildings operations. As a result of this more allocation of resources was done for the research which aimed at improving the seismic resistance of secondary structural system. The researchers at Canterbury University in New Zealand aimed to improve the seismic performance of NSEs such as partitions, infill walls etc. to prevent damage. [13]

Pesaralanka et al. (2023) assessed the behavior of multi-storey RC frame building with stiffness irregularity (soft story) during earthquakes. They found that position of soft story in buildings can affect the performance of structure during events like earthquake. Soft story at the bottom of building causes instability to a greater extent because of the weak vertical stiffness. Presence of Soft story at mid-level of buildings causes amplification in acceleration for non-structural parts. Moreover, when the results of this study were compared with building code formulas these formulas gave wrong results because these formulas were based on simple linear approach. This study revealed that the building codes either overestimate or underestimate how much non-structural parts of the building will shake. [14]

Lam et al. (2002) developed a new method to check the behavior of NSEs in building during earthquake **s**haking**.** The economic losses due to failure of NSEs such as pipes, equipment, ceilings etc. have increased and is relatively more than the structural damage. As a result of this, a simple three-step procedure was used and seismic demand was represented in terms of displacement, velocity and acceleration to predict behavior of elements during seismic events. This new method is applicable in the areas where earthquakes are not very strong or frequent. [15]

Challagulla et al. (2020) created a computer model to study how these sliding non-structural elements impact the main building during an earthquake. This study used a numerical model called as Coulomb's friction model that includes friction to study this movement. Two types of earthquake zones (seismic zone III and V) were considered for this research. A new term called as displacement ratio measured how much these building moves because of sliding of the NSEs. Various factors such as time period, friction coefficients, mass affected the values of displacement response. Thus, the main aim of this study was that the sliding effects must be considered in the seismic design of building.[16]

Bianchi et al. (2020) tested a two-storey building made from prefabricated timber and concrete. They used both light and heavy partition walls and placed the building on platform for shake table testing to induce real earthquake like conditions. This study revealed how much these walls shook and the floors move during earthquake. NSEs such as infill walls, partitions, electrical and mechanical systems sustain heavy damage during a seismic event whereas the main structure remains undamaged in a low-damage building system. The repair cost of NSEs is very high therefore this study was done to understand the behavior of NSEs during seismic base excitation and recommend improvements in seismic design of NSEs. [17]

Pinkawa et al. (2014) assessed different methods to calculate the lateral forces acting on NSEs.A comparative study of these methods was done and the results reveal that the codal design provisions underestimated the seismic demand leading to failure of NSEs.Various other methods such as Time history method provided better results but they involve complex mathematical calculations. The main aim of this study was to provide recommendations to current seismic codes to upgrade and improve the codal provisions for NSEs as they are inadequate.[18]

Hadianfard et al. (2022) analyzed how four concrete buildings vibrate at different stages of construction. The buildings were analyzed for the following construction stages: after the construction of frame, after adding interior and exterior walls, after adding floors and roof. They used special equipment to measure the vibrations and two different methods to analyze the data. The results reveal that addition of these elements made building stiffer and stronger against the earthquake shaking. NSEs can increase or decrease the vulnerability of building to earthquakes depending on the stage of construction and type of building.[19]

Challagulla et al. (2023) showed that seismic behavior of NSEs is affected by the behavior of the structure to which it is attached. It also tells that the seismic behavior of NSEs attached to floors is affected by structural regularity and the soil conditions of a reinforced concrete frame building. The seismic load on the non-structural components was measured by floor response spectrum. The results reveal that structure with mass irregularity are subjected to higher lateral forces, displacements and the floor spectral acceleration of the building increase with the flexibility of the soil. The artificial neural networks were used to develop the prediction models for dynamic amplification factors and the results were validated by using dynamic time history analysis.[14]

2.3 RESEARCH GAP

There has been limited research focused on the impact of non-structural elements on structures during earthquake loading. The majority of research focuses mostly on structural factors, ignoring the important role that non-structural elements might play during seismic activity. It is essential to investigate how non-structural components affect structures during earthquakes because there is an absence of significant research in this field. Improved building designs can result from a deeper understanding, increasing overall safety and resilience during seismic activity.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

This chapter outlines the approach adopted to determine the effect of lateral forces acting on non-structural elements and its impact on structure or building during a seismic event. This section is designed to address the absence of adequate design guidelines for NSEs in Indian standards comparative to the international codes such as Eurocode 8 and to analyze their behavior under lateral earthquake loading. In order to fulfill the objectives of this research work, a two-phase approach was applied.

The first phase basically involved the determination of lateral forces acting on NSEs in both hospital and commercial building using Eurocode 8 and Indian standard IS 16700. The formula for calculation of lateral load on non-structural elements is quite different for Eurocode 8 and IS 16700 during seismic events. In this research work, comparison of these codes for the design of NSEs is done to identify which code provides the best practices and adopts a more conservative approach resulting in better seismic safety of non-structural elements.

The second phase involves the assessment of dynamic behavior of two non-structural elements such namely, cable tray and multiple pipes in healthcare facilities such as hospital building. This analysis involved the use of STAAD Pro. software for the design of the G+3 hospital building. This software was also used for designing different support system (conventional and modular) for various types of NSEs present on each floor of hospital building. The main aim of this study is to understand the dynamic behavior of NSEs and the effect of lateral forces acting on different support system (both conventional and modular support system) on which these NSEs such as cable tray and multiple pipes are supported. This analysis is done to identify the importance of dynamic characteristics and design optimization of NSEs for improved seismic performance of NSEs. The stepwise procedure followed in this research work is explained in Figure 3.1 and 3.2.

3.2 METHODOLOGY FLOW CHART

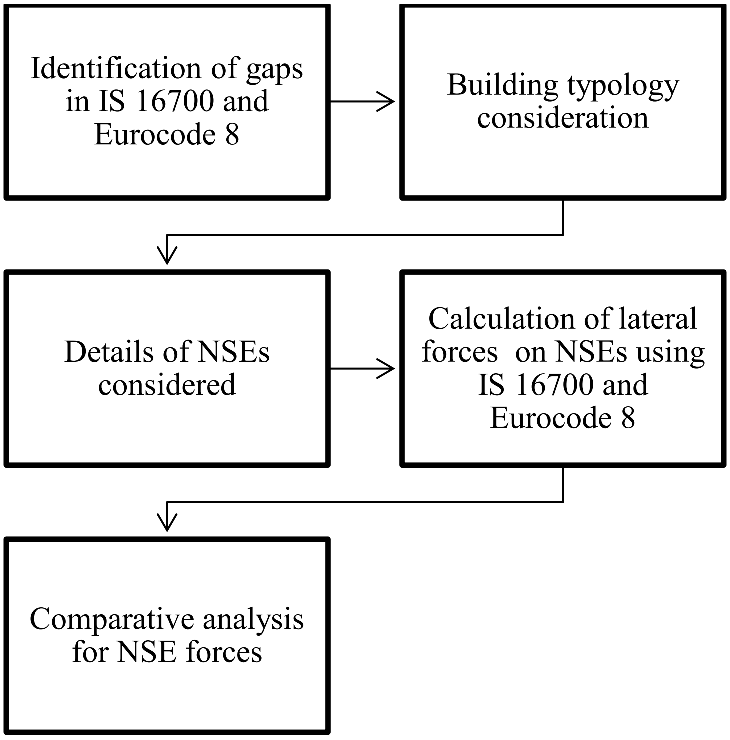

Figure 3.1 Flow chart of Phase I Methodology: Assessment of lateral forces acting on NSEs and their impact on performance of building during a seismic event.

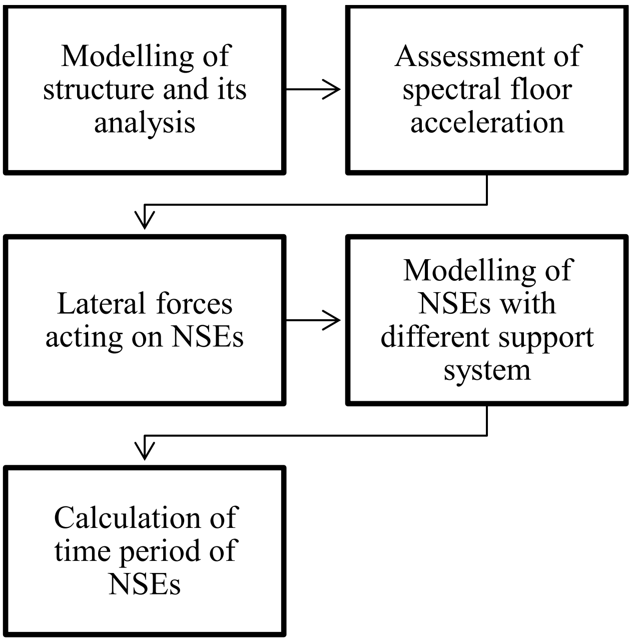

Figure 3.2 Flow chart of Phase II Methodology: Assessment of dynamic behavior of NSEs in healthcare facilities.

3.3 CALCULATION OF LATERAL FORCES ACTING ON NSEs

The phase I methodology involves the calculation of lateral forces acting on NSEs in commercial and hospital building using Eurocode 8 and IS 16700. The following methodology was adopted: -

3.3.1 Identification of gaps in IS 16700 and Eurocode 8

The design lateral force acting on acceleration-sensitive NSEs as per IS 16700:2023 is calculated from the formula given below: -

$$Fp = \frac{Z\left(1+\frac{x}{h}\right) ap\ Ip\ Wp}{Rp}$$

Where Z = Seismic zone factor

I = Importance factor

Rp = component response modification factor

Wp = weight of NSE

ap = component amplification factor

x = height of NSEs above the level of application of seismic action

h = overall height ofbuilding

The lateral force acting on NSE for the seismic design of these elements as per Eurocode 8 is calculated from the formula given below: -

$$Fa = \frac{Sa\ Wa\ ɣa}{qa}$$

Where

$$Sa = \alpha\ S\left[\frac{3\left(1+\frac{z}{H}\right)}{(1+(1-\frac{Ta}{T1})^2}\right] - 0.5$$

Sa = Seismic coefficient

ɣa = Importance factor

Wa = weight of NSE

z = height of NSEs above the building base

h = overall height ofbuilding

qa = behavior factor

Ta = time period of NSEs

T_1 = time period of building

S = soil factor

The differences in the formulas of Eurocode 8 and IS 16700 for lateral force calculation of NSEs are summarized in Table 3.1.

Table 3.1 Detailed comparison between Eurocode 8 and IS 16700

FACTOR	IS 16700	EUROCODE 8	Explanation of Gap
Time period of NSE (Ta)	Not considered	Considered	Eurocode 8 uses the time period of NSE to calculate lateral forces on NSE. IS16700 does not consider Ta at all.
Time period of building (T_1)	Not considered	Considered	Eurocode 8 considers the interaction between building motion and NSE through T1. IS 16700 does not consider T1 in NSE design
Seismic amplification factor (Aa)	Not considered	Considered	Eurocode 8 includes amplification of acceleration due to increase in building height.IS 16700 does not consider such amplification factor
Soil factor (S)	Not considered	Considered	Eurocode8 considers the effect of soil type and IS 16700 fails to do so.
Dynamic interaction	Not considered	Considered	Eurocode 8 considers the interaction between structure and NSE. IS 16700
Formula complexity	Simple	Complex	Eurocode 8 uses more detailed approach for design of NSE.is16700 uses generalized approach for design of NSE.

3.3.2 Building Typology Consideration

A G+3 Hospital and commercial building located in Seismic zone V in India is selected and analyzed. The overall height of both buildings is 12 m and the height of each floor is taken as 3 m. The length of the hospital building is 33.07 m and length of commercial building is 25 m. To understand the impact of lateral forces acting on NSEs during an earthquake, six non-structural elements are selected on each floor of hospital building (multiple pipes, firefighting system, HVAC duct system, cable tray, pneumatic pipes, oxygen pipes). In case of commercial building four non-structural elements are considered on each floor (multiple pipes, firefighting system, HVAC duct system, cable tray.

3.3.3 Details of NSEs

The weight per unit length of various types of NSEs used in commercial and hospital building are given in Table 3.2.

Table 3.2 Weight per unit length of NSEs (source-public domain)

Non-structural elements (NSEs)	**Weight per unit length**
Multiple pipes 1. Pipe size (200 NB) 2. Pipe size (100 NB)	 0.673 kN /m 0.194 kN/m
Firefighting system Pipe size (150 NB)	 0.388 kN/m
Cable tray (450mm)	0.550 kN/m
HVAC Duct system	0.588 kN/m
Oxygen pipe	0.0052 kN/m
Pneumatic pipe	0.021 kN/m

3.3.4 Calculation of lateral forces acting on NSEs using Eurocode 8 and IS 16700 in Hospital building

A G+3 Hospital Building having plan dimensions (33*33) m. To understand the impact of Non-structural element during an earthquake, we have analyzed six non-structural elements on each floor of the hospital building. The design lateral forces acting on these elements has been calculated below: -

Non-Structural Element I (Multiple Pipe) Ground Floor: -

Length of building = 33.07 m

Pipe size = 200 NB

Weight of pipe (water filled) = 0.673 kN/m

Length of pipe = 33.07 m

Total pipe weight = 22.256 kN

No. of support = 17

Spacing of support = 1.94 m

Unfactored load on each support per pipe = 22.256 / 17 = 1.309 kN

FOS = 1.5

Factored load on each support per pipe = 1.964 kN

Wp = 1.964 kN

Using IS 16700 Formula: -

$$Fp = \frac{Z\left(1 + \frac{x}{h}\right) ap\ Ip\ Wp}{Rp}$$

The various factors for multiple pipes are discussed below: -

Z	ap	rp	Ip	Wp
0.36	1	2.5	2	1.964

The lateral forces acting on multiple pipe size 200 NB present on each floor of hospital building is given in Table 3.3.

Table 3.3 Lateral forces acting on multiple pipes using IS 16700

Height of building	Force on one support	Total force
Ground floor x = 3m	Fp = 0.707 kN	Fp = 12.019 kN
First floor x= 6m	Fp = 0.848 kN	Fp = 14.416 kN
Second floor x = 9m	Fp = 0.989 kN	Fp = 16.813 kN
Third floor x= 12m	Fp = 1.131 kN	Fp = 19.227 kN

Using Eurocode 8 formula

$$Fa = \frac{Sa\ Wa\ ýa}{qa}$$

$$Sa = \alpha\ S \left[\frac{3\left(1 + \frac{z}{H}\right)}{(1 + (1 - \frac{Ta}{T1})^2} \right] - 0.5$$

α = ag /g = agR × ýa = 0.4 g × 1 / g = 0.4

S = 1 (Type A soil)

Aa = 3 Table C.2 (EN 1992-4 - 2018)

Sa = 0.4 × 1 × [1 + 3/ 12] ×3 – 0.5] ≥ 0.4

Sa (G.F) = 1.3 ≥ 0.4, Sa_1 =1.6, Sa_2= 1.9, Sa_3 = 2.2

Fa = 1.3×1.964×1/2 = 1.276 kN

Table 3. 4 Lateral forces acting on multiple pipes using Eurocode 8

Height of building	Force on one support	Total force
Ground floor x = 3m	Fa = 1.277 kN	Fa= 21.709 kN
First floor x= 6m	Fa = 1.571 kN	Fa = 26.707 kN
Second floor x = 9m	Fa = 1.866 kN	Fa = 31.722 kN
Third floor x= 12m	Fa = 2.161 kN	Fa = 36.737 kN

Similarly, lateral forces are calculated for all the other six non-structural elements considered in hospital building using Eurocode 8 and IS 16700.

COMMERCIAL BUILDING

In order to calculate lateral forces on NSEs in G+3 commercial building having plan dimensions 25*25 m following four NSEs were considered: - Multiple pipes, Cable tray, HVAC duct system, Firefighting system.

Non-Structural Element I (Multiple Pipe): -

Length of building = 25 m

Pipe size = 200 NB

Weight of pipe (water filled) = 0.673 kN/m

Length of pipe = 25 m

Total pipe weight = 16.825 kN

No. of support = 13

Spacing of support = 1.92 m

Unfactored load on each support per pipe = 16.825/13= 1.294 kN

FOS = 1.5

Factored load on each support per pipe = 1.294 kN

Wp = 1.941 kN

Using IS 16700 Formula

$$Fp = \frac{Z\left(1+\frac{x}{h}\right) ap\ Ip\ Wp}{Rp}$$

Z	ap	rp	Ip	Wp
0.36	1	2.5	2	1.941

The lateral forces on multiple pipes in commercial building using IS16700 are given in Table 3.5.

Table 3.5 The lateral forces on multiple pipes using IS 16700

Height of building	Force on one support	Total force
Ground floor x = 3m	Fp = 0.699 kN	Fp = 9.087 kN
First floor x = 6m	Fp = 0.839 kN	Fp = 10.907 kN
Second floor x = 9m	Fp = 0.978 kN	Fp = 12.714 kN
Third floor x = 12m	Fp = 1.118 kN	Fp = 14.534 kN

Using Eurocode 8 Formula

$$Fa = \frac{Sa\ Wa\ \gamma a}{qa}$$

The lateral forces on multiple pipes in commercial building using Eurocode 8 are given in Table 3.6.

Table 3.6 The lateral forces on multiple pipes in commercial building

Height of building	Force on one support	Total force
Ground floor x = 3m	Fa = 1.262 kN	Fa= 16.406 kN
First floor x= 6m	Fa = 1.553 kN	Fa = 20.189 kN
Second floor x = 9m	Fa = 1.844 kN	Fa = 23.97 kN
Third floor x= 12m	Fa = 2.135 kN	Fa = 27.756 kN

Similarly, lateral forces are calculated for all the other four non-structural elements considered in commercial building using Eurocode 8 and IS 16700.

3.3.5 Comparative Analysis of Lateral Forces Acting on NSEs

Comparative analysis of lateral forces calculated from Eurocode 8 and IS16700 on each floor of hospital and commercial building is given in Table 3.7 and 3.8.

Table 3.7 Total forces due to all the non-structural elements in Hospital building

Height of building	IS 16700	EUROCODE 8
Ground floor x = 3m	Fp = 47.37 kN	Fa = 84.288 kN
First floor x= 6m	Fp = 56.849 kN	Fa = 103.70 kN
Second floor x = 9m	Fp = 66.322 kN	Fa = 123.169 kN
Third floor x= 12m	Fp = 75.819 kN	Fa = 142.616 kN

Total Lateral Force as per (IS 16700) = 246.36 kN

Total Lateral Force as per (Eurocode 8) = 453.773 kN

Table 3.8 Total forces due to all the non-structural elements in Commercial building

Height of building	IS 16700	EUROCODE 8
Ground floor x = 3m	Fp = 35.475 kN	Fa = 63.062 kN
First floor x= 6m	Fp = 42.582 kN	Fa = 77.603 kN
Second floor x = 9m	Fp = 49.656 kN	Fa = 92.159 kN
Third floor x= 12m	Fp = 56.76 kN	Fa = 106.653 kN

Total Lateral Force as per (IS 16700) = 184.473 kN

Total Lateral Force as per (Eurocode 8) = 339.477 kN

Total lateral forces acting on NSEs using Eurocode 8 in a hospital and commercial building are approximately double to that obtained from IS 16700.This shows that Indian standard codes underestimate seismic design on NSEs resulting in failure of these elements during earthquake.

3.4 ASSESSMENT OF DYNAMIC BEHAVIOR OF NSEs IN HEALTHCARE FACILITIES

The phase II methodology involves the assessment of seismic behavior of two non-structural elements namely, cable tray and multiple pipes placed at each floor of G+3 Hospital building located in Seismic zone V in India. The main aim of this study is to understand the dynamic behavior of NSEs and the effect of lateral forces acting on different support system (both conventional and modular support system) on which these NSEs such as cable tray and multiple pipes are supported. The following methodology was adopted.

3.4.1 Modelling of structure and its analysis

A G+3 Hospital building is modelled using STAAD Pro. software. It primarily involved the definition of the layout of the complete structure. A moment resisting reinforced concrete frame is modelled having plan dimensions 33m *33m. The overall height of building is 14 meters, the storey height of each floor is 3 meters and the depth of the foundation is taken as 2 meters. The geometric modelling involves creation of nodes, beams which are basically modelled as horizontal members, columns which are modelled as vertical members and the slabs. Material property is assigned for both concrete and steel. Grade M25 is selected for concrete and Fe 415 is selected for steel members. Section properties for beam (300mm*500mm), column (400mm*400mm) and slab (150mm) are assigned in the properties section to the respective members. All the base nodes are assigned fixed supports. Under the loading section Dead load (DL), Live load (LL), Seismic load (EL) and the load combinations are defined. Seismic loads are defined under seismic definitions section as per IS1893 (Part I):2016 [3] considering seismic zone factor as 0.36, importance factor 1.5 as hospital building is a critical structure, response reduction factor (RF) as 5, the time period of the structure is 0.219 seconds in both x and z direction and a hard type of soil with damping ratio 5 %.

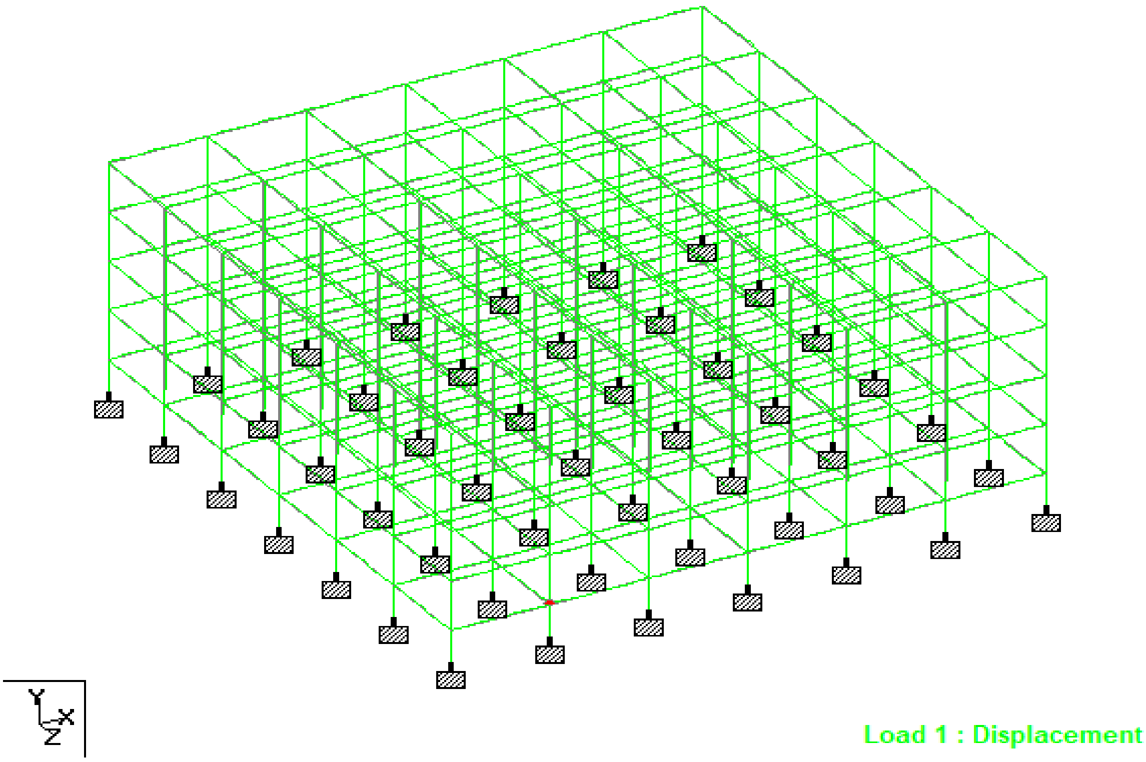

Figure 3. 3 G+3 Hospital Building

Load Combination Used: -

(DL+LL)

(DL+EL)

(DL+LL+EL)

1.5(DL+LL)

1.5(DL+EL)

1.2(DL+LL+EL).

Under the analysis section, select perform analysis and carry out the analysis of the structure. After the analysis is done the results are obtained for the column displacement at each floor in x direction. The maximum value lateral displacement in x direction is taken out from the following (DL+EL) and (DL+LL+EL) load combination for each floor and these displacements are then used for the calculation of spectral floor acceleration or seismic coefficient (Sa) for each floor of the hospital building.

3.4.2 Assessment of Spectral Floor Acceleration

The lateral displacement values obtained from the analysis of G+3 Hospital building is used for the calculation of floor acceleration at each floor by using the time period of the structure and the lateral displacement at each floor level. The time period of the structure is calculated by using the relevant formula from IS 1893 (Part 1):2016

$$Ta = \frac{0.09 * h}{\sqrt{d}}$$

The floor spectral acceleration (Sa) is calculated using the relation:

$$a = \omega^2 * x$$

where x = lateral displacement at each floor level

Ta = time period of the structure

a = floor acceleration

This floor acceleration is equivalent to the seismic coefficient (Sa) and it used for the calculation of lateral forces acting on Non-structural elements on each floor of hospital building.

3.4.3 Lateral Forces Acting on NSEs

Using the values of floor acceleration or seismic coefficient (Sa) for each floor, the lateral force for each floor is calculated for Non-structural elements by using the formula from Eurocode 8:

$$\boldsymbol{Fa} = \frac{\boldsymbol{Sa} * \boldsymbol{Wa} * \boldsymbol{\gamma a}}{\boldsymbol{qa}}$$

Where Fa = horizontal seismic force

Wa = weight of non-structural element

Sa = seismic coefficient

ɣa = Importance factor value ranges from 1 to 1.5

qa = Behaviour factor

The value of behavior factor for different types of non-structural elements is given in Table 3.9.

Table 3.9 Value of behavior factor for different Non-structural elements

Type of Non-structural elements	Behavior factor qa
Cantilever parapets, signs and billboards	1.0
Hazardous material storage and fluid piping	1.0
Storage racks	2.0
Conveyors, electrical equipment	2.0
Elevators, anchorage elements for false ceilings	2.0
Non-hazardous fluid piping	2.0
High pressure and fire suppression piping	2.0
Anchorage elements for book stacks	2.0
Chimneys, masts and tanks (acting along more than one half of their total height)	1.0
Chimneys, masts and tanks (acting along less than one half of their total height)	2.0

These lateral forces are then applied to both the conventional and the braced support system of non-structural elements such as multiple pipes and cable tray at different floor levels in a hospital building.

3.4.4 Modelling of Non-Structural Elements with Different Support Systems

The effect of lateral forces induced during earthquake shaking is considered on two types of NSEs (Cable tray and multiple pipes) present in a G+3 hospital building. The support system for both these NSEs is modelled using STAAD pro software. Conventional and modular support system are modelled in this software and both these support systems support these non-structural elements. Modelling of conventional support system is done by taking three ISMC 75 steel channel sections for cable tray and six for multiple pipes arranged properly to form a supporting frame for these two NSEs. Steel grade Fe250 is selected and all the ends of channel sections are modelled as simply supported.

The load cases considered under loading section include self-weight of the utility system, weight of NSE applied as uniformly distributed load along the width of frame based on weight per unit width of cable trays and multiple pipes, lateral forces acting on these frames in x direction induced due to seismic forces. The model was analyzed under the combined effect of all these loads and the lateral displacement of the utility system for conventional system is observed for all the floors. Similarly, modular support system for cable tray is modelled using five and multiple pipes using eight ISMC 75 steel channel sections. Steel grade Fe 250 is selected under the properties section and the ends of the channel sections are assumed to be simply supported. The load cases are taken similar to the conventional support system and the analysis on the modular frame is carried out. The lateral displacements acting on this frame supporting these two NSEs is computed for all the floors using this software to check the seismic behavior of these NSEs during a seismic event.

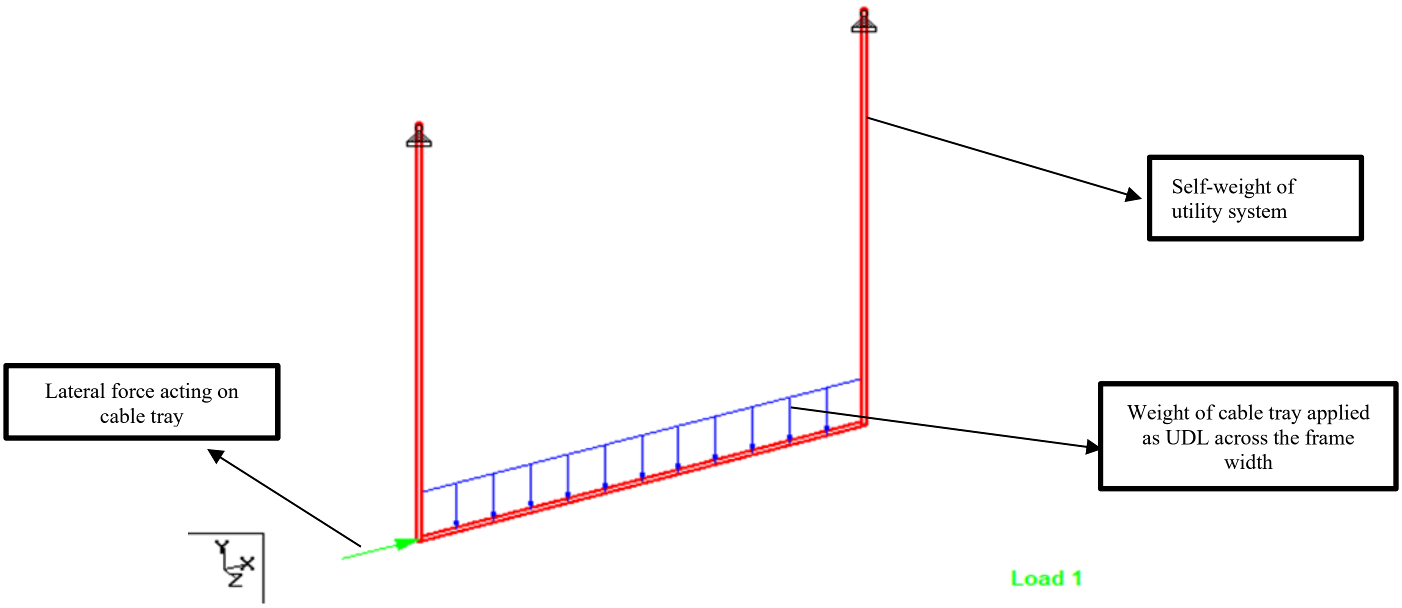

Figure 3.4 Forces acting on conventional support system (cable tray)

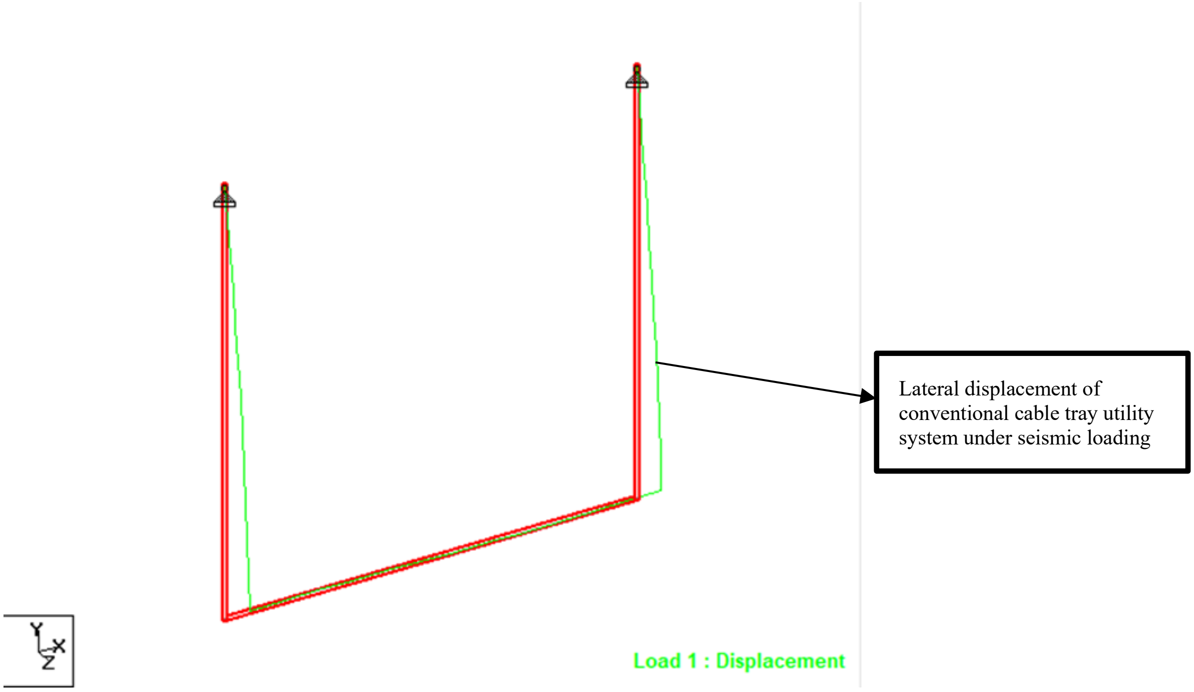

Figure 3.5 Displacement of conventional support system (Cable tray)

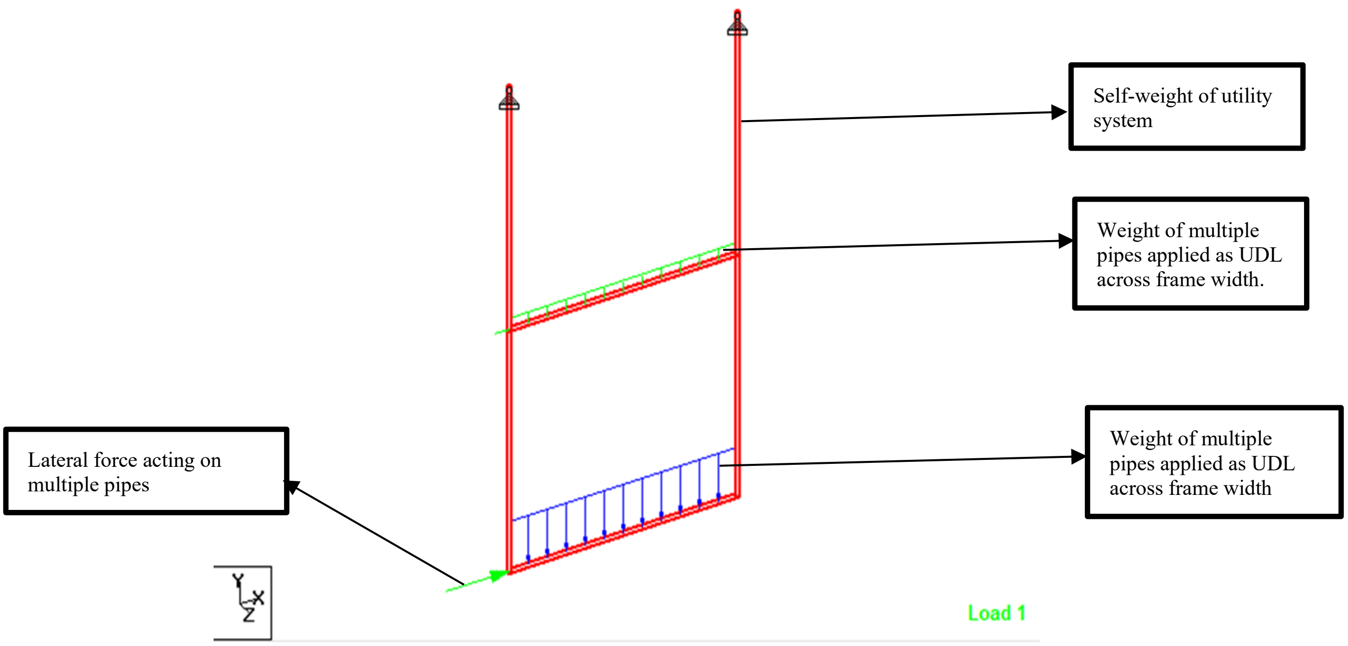

Figure 3.6 Forces acting on conventional support system (Multiple pipe)

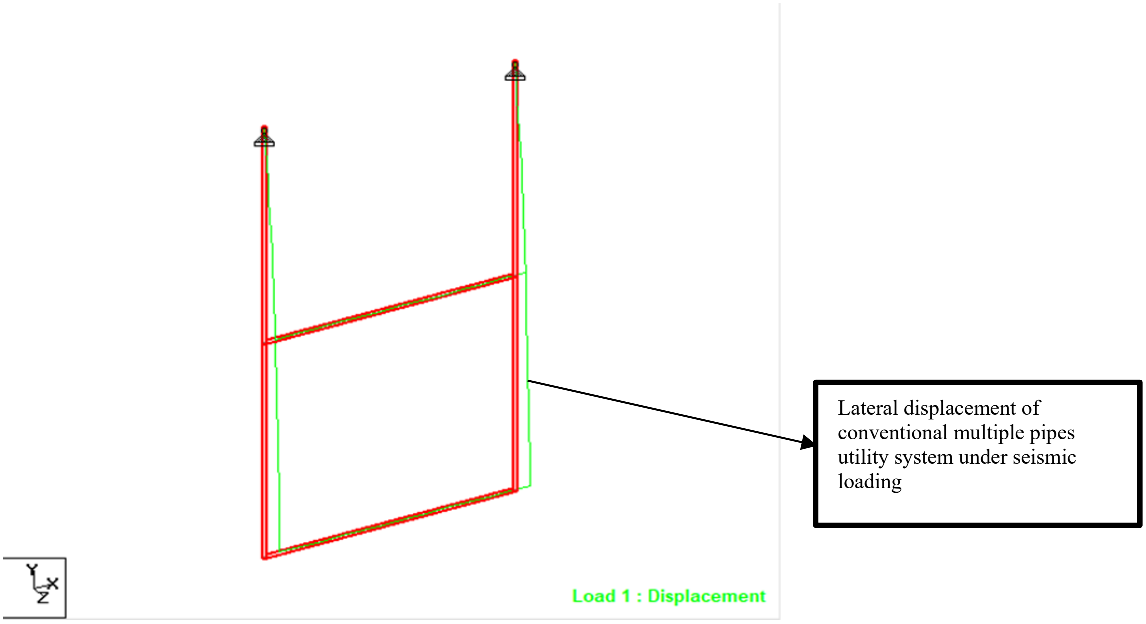

Figure 3.7 Displacement of conventional support system (Multiple pipe)

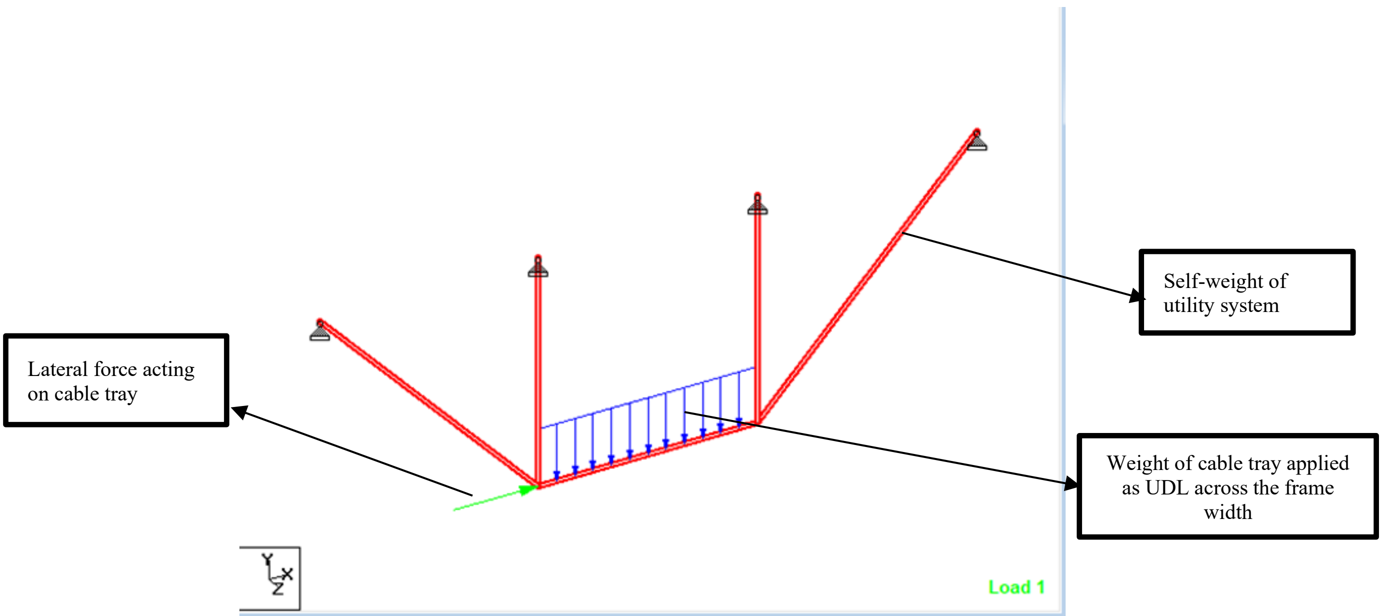

Figure 3.8 Forces acting on modular support system (Cable tray)

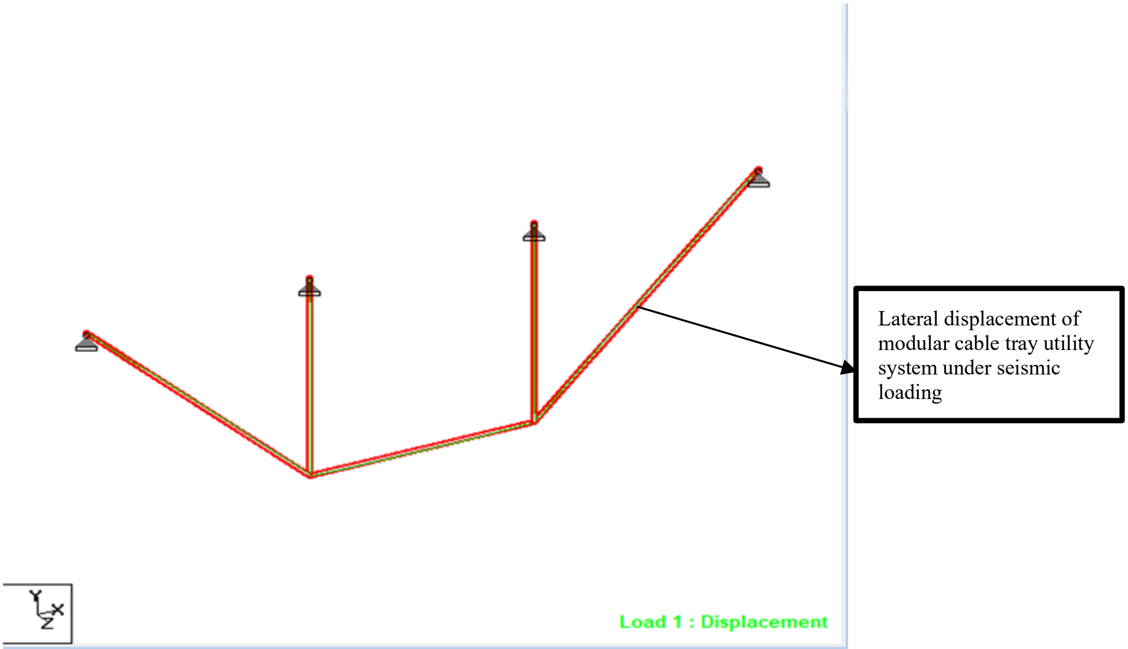

Figure 3.9 Displacement of modular support system (Cable tray)

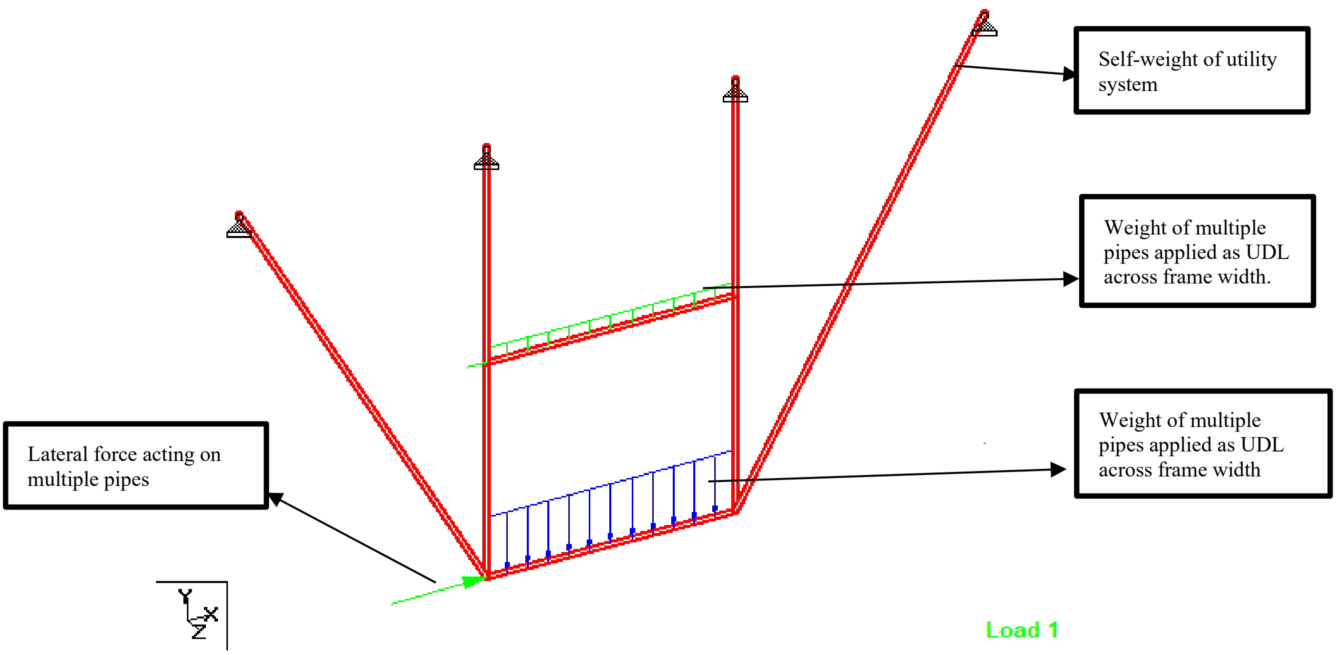

Figure 3.10 Forces acting on modular support system (Multiple pipe)

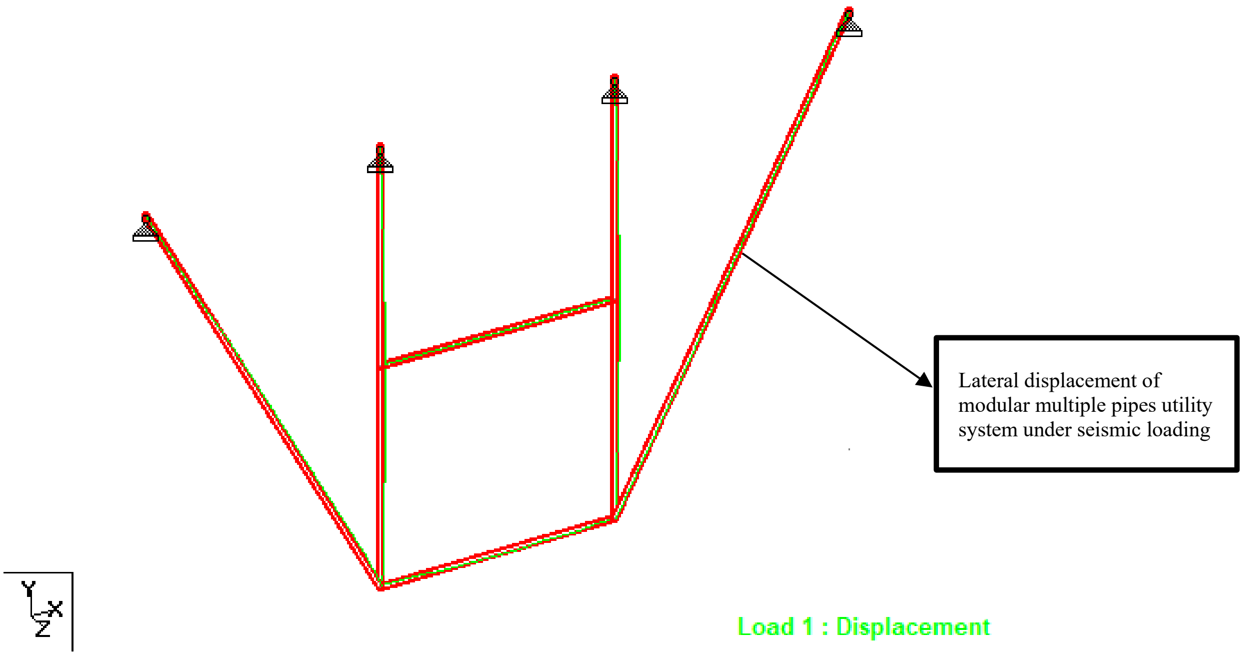

Figure 3.11 Displacement of Modular support system (Multiple pipe)

3.4.5 Calculation of Time Period of NSEs

The time period of both cable tray and multiple pipes is calculated using the relevant formula from Indian seismic codes. The value of spectral acceleration for each floor level of hospital building has already been determined and the lateral displacement of the NSEs has been calculated by applying the lateral forces on NSEs.Thus, the time period for both type of utility system (conventional and modular support system) is determined for both the NSEs on each floor.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 GENERAL

This chapter presents the results that are obtained from assessment of seismic behavior of non-structural elements in a building. These findings have been obtained from the analytical approach described in the previous chapter. The behavior of various types of NSEs such as multiple pipes, cable tray, firefighting system, pneumatic pipes, HVAC duct system, oxygen pipe has been analyzed in terms of lateral forces acting on them during a seismic event. The results reveal how these non-structural elements and with different support system (modular and conventional), respond to earthquake loading. This research work also reveals how these NSEs interact with the overall structure during an earthquake and affect the overall behavior of structural system.

A Comparative study with the help of different type of codes such as international codes (Eurocode 8) and Indian standard (IS 16700) are also discussed to identify gaps in current design method in Indian seismic codes and recommend improvements in the current seismic codes. Graphs, tables and figures have been used to demonstrate the results more clearly.

The result in this chapter have been organized in a systematic manner, beginning with the comparison of Eurocode 8 and IS 16700 codal provisions for the design of both acceleration sensitive and deformation sensitive NSEs. The next step involved the comparison of lateral forces on various NSEs in commercial and hospital buildings and the final step involved the determination of time period of NSEs and lateral displacements acting on them on each floor of hospital building for the assessment of dynamic behavior of cable tray and multiple pipes.

4.2 SUMMARY OF CODAL DIFFERENCES (EUROCODE 8 AND IS 16700)

Indian seismic codes underestimate the seismic demand acting on NSE as compared to Eurocode 8 which adopts a more conservative approach. The various factors that lead to underestimation of Indian seismic codes are as follows:

(1) Indian codes don't consider the effect of soil conditions whereas European code considers a factor called as soil factor for seismic design of NSEs.This factor is responsible for the amplification of ground motion. During earthquake, soft soils cause amplification of ground motion leading to higher seismic forces as compared to that of rocky soils. The European code considers this amplification effect ensuring that the buildings that are constructed on soft soil are designed for increased seismic load.

(2) The provisions provided in IS16700:2023 are mainly intended for high rise buildings and it does not clearly define the provisions for various other type of buildings indicating the limited scope of Indian codes.

(3) IS16700 considers simple force transfer mechanism between NSEs and SEs however Eurocode 8 considers dynamic interaction between them. This leads to more conservative approach by Eurocode 8 in force estimation.

(4) The behavior of a building is greatly influenced by the time period of both NSEs and SEs. If the time period of NSEs matches or is close to the time period of the building a phenomenon known as resonance occurs which amplifies the effect of ground motion leading to increased sway or sometimes collapse of the building. Time period of both non-structural elements and structural elements is not considered for estimation of forces in NSEs in Indian codes. It provides a simplified formula for estimation of lateral forces without considering the frequency effects. As a result of this lateral forces calculated by Indian codes do not estimate the forces accurately. Eurocode 8 results in more accurate estimation of forces by considering frequency effects.

The comparison of IS 16700:2023 and Eurocode 8 codes is presented in Table 4.1.

Table 4.1 Various parameters of Eurocode 8 and IS 16700

Factor	IS 16700	EUROCODE 8
Type of soil	Type 1 rock or hard soil	Type A (Rock)
Seismic zone	Zone V (Z = 0.36)	PGA = 0.4 g
Importance factor	Ip = 2	Ɣa = 1
Behavior or Response modification factor	Rp = 2.5	qa = 2
Amplification factor	ap = 1	Aa = 3
Soil factor	--	S = 1

These differences directly affect the lateral force estimation on NSEs in both hospital and commercial building and emphasize the need for updated provisions in Indian standard as the Indian seismic codes underestimate the values of lateral forces. Due to such underestimation of lateral forces acting on NSEs, they often fail during earthquakes as they have not been designed properly for seismic loads. This results in damage to utility systems, falling components such as collapse of false ceilings, damage to infill partition walls and disruption of the building functionality.

4.3 COMPARATIVE ANALYSIS OF LATERAL FORCES ACTING ON NSEs IN BUILDINGS USING EUROCODE 8 AND IS 16700

The lateral forces acting on these elements on each floor of hospital and commercial buildings are evaluated using IS 16700:2023 and Eurocode 8. Results reveal that hospital building having a greater number of NSEs are subjected to larger lateral forces as compared to the commercial buildings. Also, these forces acting on these NSEs increase with increase in the storey height of the building as shown in Figure 4.1 and 4.2. The lateral forces calculated from IS 16700:2023 are significantly lower as compared to that of Eurocode 8. The forces obtained from Eurocode 8 are approximately twice as high as those obtained from Indian code. This clearly shows that the Indian codes underestimate the seismic demand on non-structural elements.

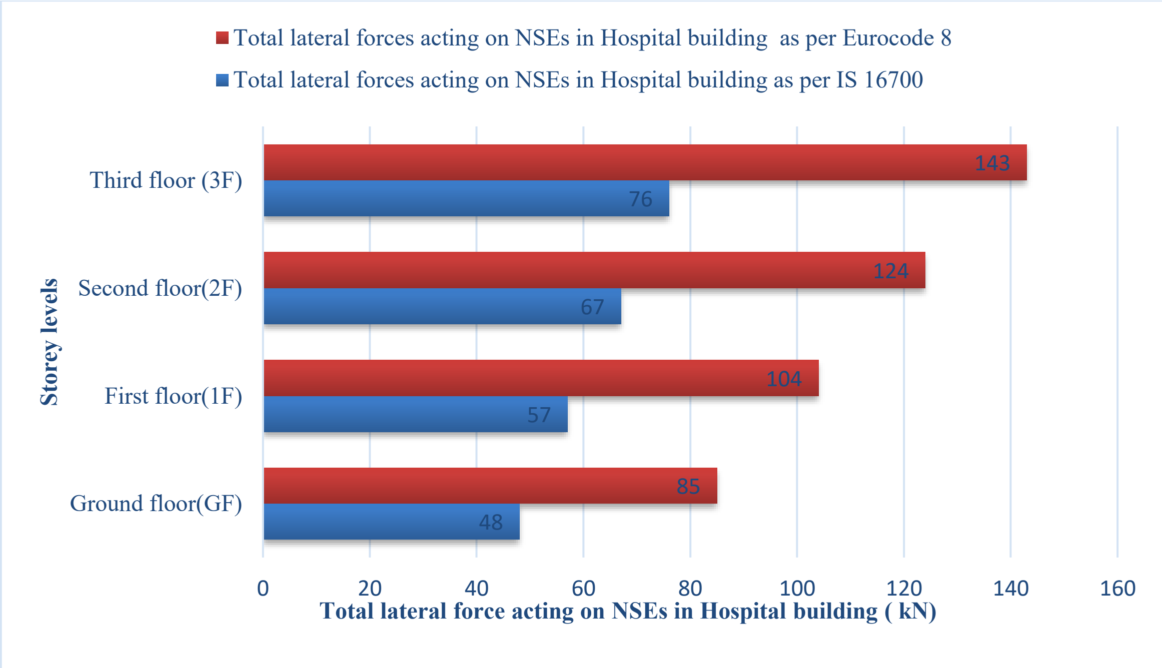

Figure 4.1 Lateral forces calculation in Hospital building

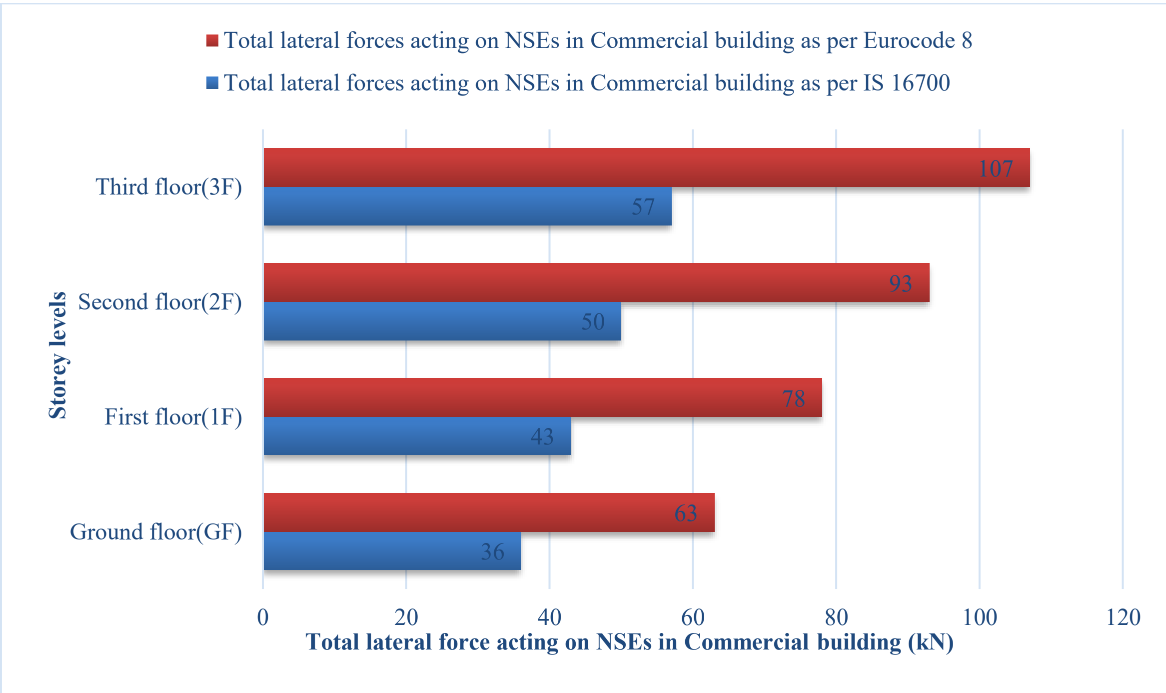

Figure 4.2 Lateral forces calculation in Commercial building

4.4 COMPARISON OF LATERAL DISPLACEMENT AND TIME PERIOD OBSERVATIONS OF NSEs IN DIFFERENT UTILITY SUPPORT SYSTEM

This section outlines the lateral displacement and time period values for cable tray and multiple pipes having two type of support system namely conventional and modular system.

4.4.1 Lateral displacement values of cable tray and multiple pipes in modular and conventional utility support system

Non-structural elements with conventional support system show high lateral displacements and NSEs with modular or braced support system show minimal displacements as the modular system restrains the lateral displacement. Figure 4.3 and Figure 4.4 clearly shows the comparison between the lateral displacement values of modular and conventional support system.

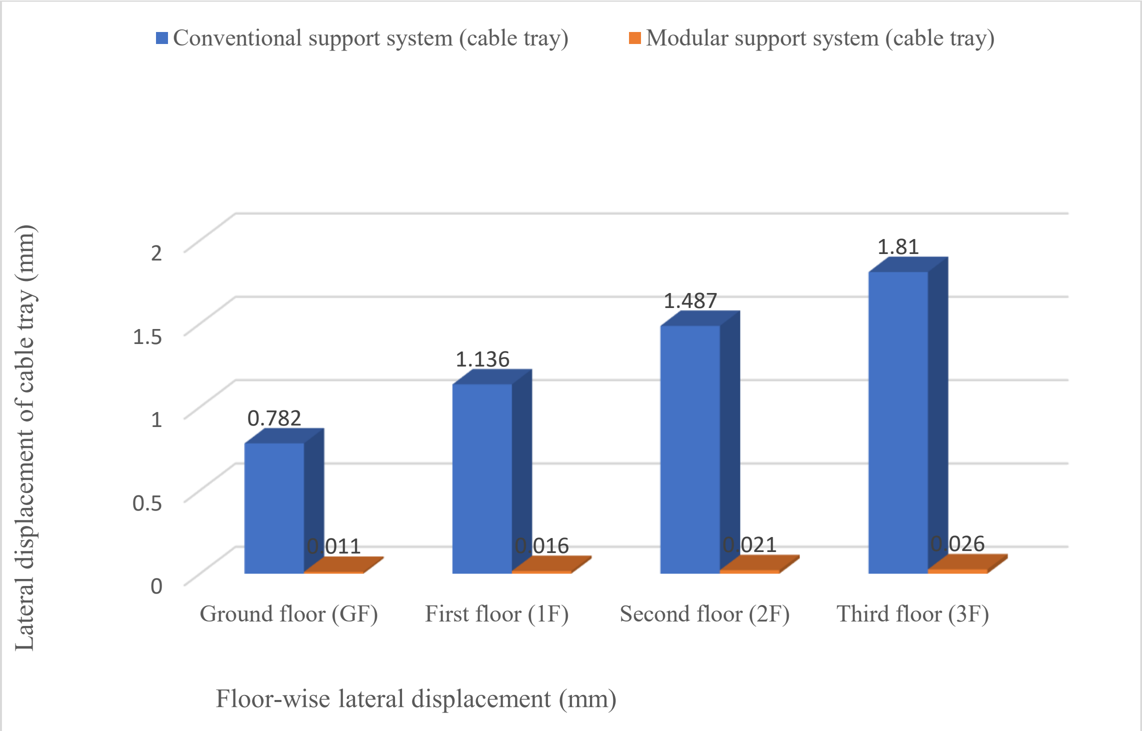

Figure 4.3 Lateral displacement of Cable tray: Modular vs Conventional

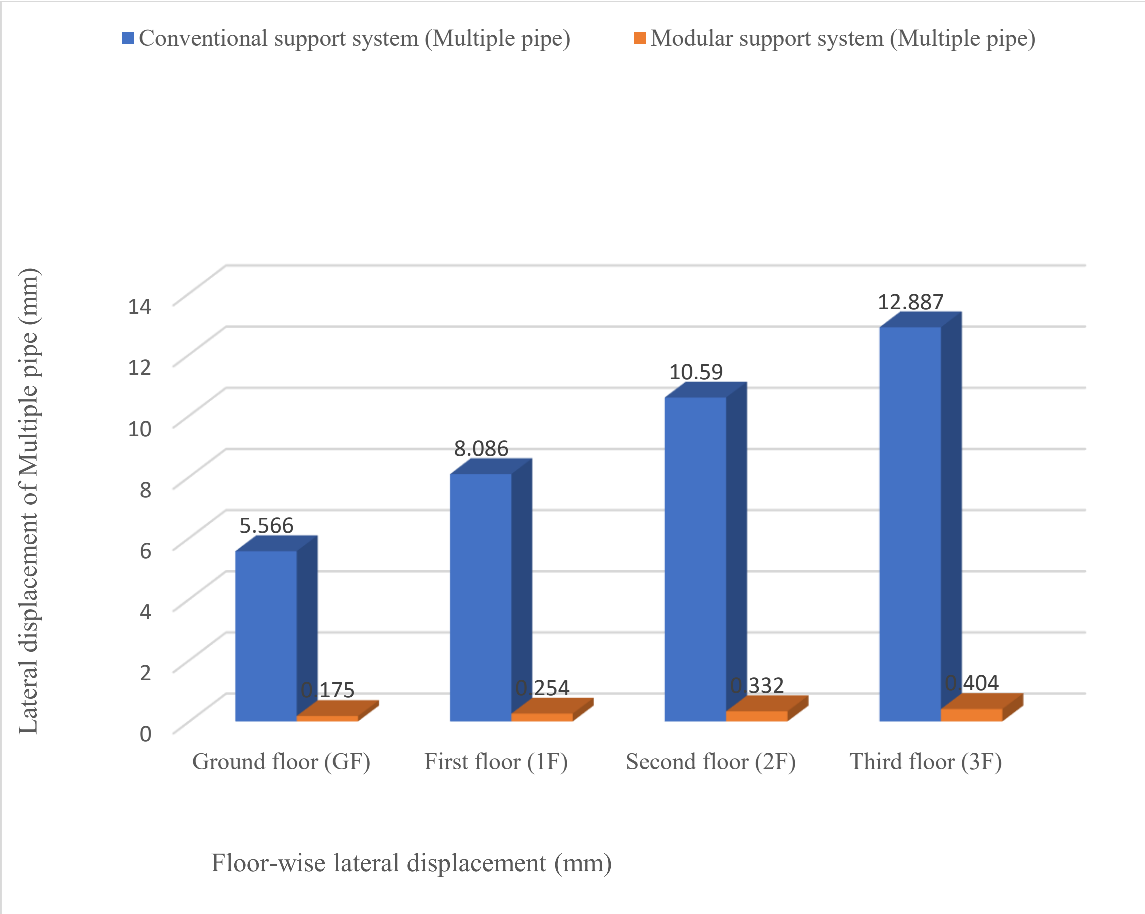

Figure 4.4 Lateral displacement of cable tray: Modular vs Conventional

4.4.2 Time period calculation of cable tray and multiple pipes for conventional and modular support system

The time period of non-structural element on each floor of G+3 hospital building is computed using lateral displacement experienced by NSEs on various floors of the building and the value of spectral floor acceleration. The time period of cable tray and multiple pipes for conventional support system and modular or braced support system has been discussed in Table 4.2,4.3,4.4 and 4.5.

Table 4.2 Time period of cable tray for conventional support system

Height of the building	Nodal displacement NSE (in metre)	Floor spectral acceleration (Sa)	Time period NSE (in sec)
Ground floor	0.000782	1.496	0.143653909
First floor	0.001136	2.173	0.143661095
Second floor	0.0014487	2.846	0.14175933
Third floor	0.00181	3.463	0.143645793

Table 4.3 Time period of multiple pipes for conventional support system

Height of the building	Nodal displacement NSE (in metre)	Floor spectral acceleration (Sa)	Time period NSE (in sec)
Ground floor	0.005566	1.496	0.383253097
First floor	0.008086	2.173	0.383280632
Second floor	0.01059	2.846	0.383274919
Third floor	0.012887	3.463	0.383291808

Table 4.4 Time period of cable tray for modular support system

Height of the building	Nodal displacement NSE (in metre)	Floor spectral acceleration (Sa)	Time period NSE (in sec)
Ground floor	0.000011	1.496	0.017037678
First floor	0.000016	2.173	0.017049435
Second floor	0.000021	2.846	0.017067585
Third floor	0.000026	3.463	0.017216319

Table 4.5 Time period of multiple pipes for modular support system

Height of the building	**Nodal displacement NSE (in metre)**	**Floor spectral acceleration (Sa)**	**Time period NSE (in sec)**
Ground floor	0.000175	1.496	0.067956827
First floor	0.000254	2.173	0.067930821
Second floor	0.000332	2.846	0.067862751
Third floor	0.000404	3.463	0.067864758

The results reveal that: -

1) Non-structural elements with conventional support system are more flexible and they are subjected to amplified displacements generally greater than 1mm, higher time period ranging from (0.14 to 0.38) seconds and lower stiffness compared to braced system.
2) Non-structural elements with modular or braced support system experience minimum lateral displacements generally less than 1mm, lower time period ranging from (0.017 to 0.07) seconds and higher stiffness as compared to conventional system.

4.5 VALIDATION OF TIME PERIOD USING SPRING ANALOGY

To validate the time period of NSEs obtained from the software model, a spring mass system is considered. Following assumptions are taken to solve this spring analogy by Holzer's method.

1) The system is idealized using linear springs.
2) Springs k_1 and k_3 are considered in parallel and both these springs are connected in series with spring k_2.
3) The equivalent stiffness (keq) is calculated using the formulas for springs in parallel and spring in series.
4) This method is solved using Holzer's approach.

Calculation of Time period of conventional cable tray

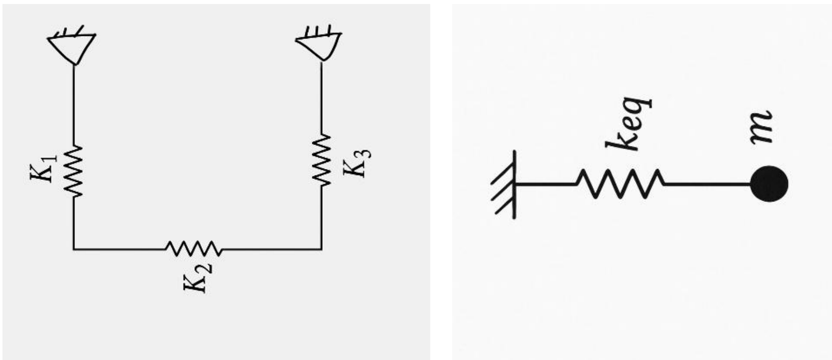

Figure 4. 5 Spring mass system for conventional cable tray utility system

Weight of cable tray = 0.550 kN/m

Spacing of cable tray = 2.36 m

Total weight of cable tray per support = 0.550*2.36 = 1.298 kN

Total factored weight of cable tray per support = 1.298 *1.5 = 1.947 kN

Mass of cable tray (m_1) = weight of cable tray (W) / acceleration due to gravity (g)

m_1 = W/g = 1.947*1000 / 9.81 = 198.675 kg

m_1 = 198.675 kg

Area of steel channel section (A)= 5870.956 mm^2

h = 1905 mm

Volume of channel section = A* h = 0.01118417118 m^3

Density of steel = 7850 kg/m^3

Mass of steel section m_2 = volume * density

m_2 = 7850* 0.01118417118 = 87.795 kg

m_2 = 87.795 kg

Since, there are three steel sections therefore total mass of these three-steel section is calculated below: -

m_2 = 3*87.795 = 263.387 kg

Total mass = 263.387 + 198.675 = 462.062 kg

Modulus of elasticity of steel (E) = 2*10^5 N/mm^2

Moment of inertia (I) = 653483.3382 mm^4

$E_1 = E_2 = E_3$ = 2* 10^5 N/ mm^2

$I_1 = I_2 = I_3$ = 653483.3382 mm^4

$K_1 = 3\, E_1 I_1 / L_1^3$ = 3 *2* 10^5 *653483.3382 / $(678)^3$ = 1258.04 N/mm

$K_2 = 3\, E_2 I_2 / L_2^3$ = 3 *2* 10^5 *653483.3382 / $(650)^3$ = 1427.729 N/mm

$K_3 = 3\, E_3 I_3 / L_3^3$ = 3 *2* 10^5 *653483.3382 / $(678)^3$ = 1258.04 N/mm

Since k1 and k3 are connected in parallel

$kp = k_1 + k_3$

kp = 2516.08 N/mm

Now this kp is in series with k_2

$1/ ks = 1/ kp + 1/ k_2$

ks = 910.866 N/mm

$ks = k_T$

$T = 2\Pi\sqrt{(m/k)}$

T = 0.14 sec

Time period of cable tray = 0.14 sec

This time period obtained using the spring analogy matches the value obtained from software analysis, thereby validating the results.

Similarly, time period for all the other elements is calculated and validated by using this approach.

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE

5.1 GENERAL

This chapter presents the conclusions obtained from the assessment of seismic behavior of non-structural elements in both commercial and hospital buildings. This work highlights the importance of NSEs such as cable tray, multiple pipes, firefighting system, HVAC duct system, pneumatic pipes, oxygen pipes etc. in buildings which are often ignored during the seismic design of buildings. This analysis revealed that these elements contribute to additional lateral displacements and forces during seismic events influencing the seismic performance of building.

The general findings show that ignoring the impact of these non-structural elements lead to underestimation of seismic demands and ultimately it can cause failure of these components during earthquakes. These findings are particularly important for critical and lifeline structures such as hospitals, emergency centers where the functionality of these components is essential for post-disaster operations. Therefore, the inclusion of design considerations for non-structural elements is a step taken towards the seismic safety of buildings.

5.2 CONCLUSION

This study focuses on evaluating the lateral forces acting on NSEs using the international code Eurocode 8 and the Indian standard IS 16700 and on analyzing the dynamic behavior of NSEs supported by different utility system. Based on this analysis, following conclusions are drawn: -

1) Seismic forces acting on NSEs increases with increase in the storey height of the building.
2) Lateral forces obtained using Eurocode 8 are approximately twice as high as those obtained from IS 16700.
3) The comparative analysis revealed that Eurocode 8 adopts a more conservative approach resulting in better seismic safety of NSEs.

This comparison also indicates that IS 16700 doesn’t provide conservative estimates for calculation of lateral forces on NSEs especially for critical and lifeline structures. This suggests that there is need to revise the Indian seismic codes to incorporate more detailed NSEs design consideration to improve their seismic safety.

4) Modular support system drastically increases the seismic resilience by reducing the lateral displacement of NSEs by approximately 90 % but no provision has been provided in Indian seismic codes for design of support system for NSEs.
5) Non-structural elements with conventional support system are more flexible and they are subjected to amplified displacements generally greater than 1mm, higher time period ranging from (0.14 to 0.38) seconds and lower stiffness compared to braced system.
6) Non-structural elements with modular or braced support system experience minimum lateral displacements generally less than 1mm, lower time period ranging from (0.017 to 0.07) seconds and higher stiffness as compared to conventional system. This analysis also authenticated the theoretical relationship between time period and stiffness as they are inversely related.
7) Time period of NSEs and spectral acceleration (Sa) are directly proportional to each other and inversely proportional to stiffness and this relationship is not defined in Indian seismic codes.
8) Dynamic characteristics such as time period of NSEs and structure also play a vital role as they impact the behavior of NSEs under seismic loading but the current Indian standards for earthquake resistance design of structures such as IS 1893 and IS 16700 provides inadequate design provisions for non-structural elements and doesn’t provide guidelines for dynamic behavior of NSEs. This study highlights the need for Indian codes to incorporate parameters like time period of NSEs and structure in lateral force calculation on NSEs and the design optimization of NSEs for improved seismic performance of NSEs.

5.3 FUTURE SCOPE

This study highlights the need to update the current guidelines for the seismic design of non-structural elements. The current research work basically focused on analytical comparisons using Eurocode 8 and IS 16700 but the future research work can be extended in the following ways: -

1) The validation of analytical results can be done by conducting shake table tests and other experimental setups to understand the real behavior of NSEs under dynamic loading.
2) The results obtained from this analytical procedure are used to propose detailed design recommendations to IS codes for improvement in seismic safety of non-structural elements in critical and lifeline structures.
3) Future studies can focus on inclusion of natural frequency of building, effect of soil (soil factor), frequency of NSEs and the interaction between structure and NSEs in seismic design codes for accurate determination of seismic demand during an earthquake.
4) This study can be extended to various other building types such as irregular buildings, high rise buildings, buildings with soft story and a wider variety of NSEs to generalize the findings.
5) By making use of advance tools such as advanced finite element method for detailed modelling of non-structural elements and this will help in predicting the accurate behavior of NSEs under seismic loading.

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[1] Kaw, A., Pal, S., and Mitra, S. (2025), "Influence of building dynamics and utility systems on seismic performance of Non-structural elements" 16th International Conference on Recent Engineering & Technology held on 16th & 17 th May 2025 at East West College of Engineering, Bangalore, India.

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[2] Kaw, A., Pal, S., and Mitra, S. (2025), "Evaluation of seismic behavior of non-structural elements in building" 1st International conference on Structural integrity and interaction of materials in civil engineering structures- (SIIMCES 2025) to be held from 21- 23 May 2025


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