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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Earthquakes are among the most destructive natural hazards affecting human life, infrastructure, and the economy. In earthquake-prone regions, buildings are generally designed to resist seismic forces and prevent collapse during major ground motion. Traditionally, seismic design practices mainly focused on structural components such as beams, columns, slabs, and foundations. However, observations from past earthquakes have shown that even when the main structural system remains safe, extensive damage often occurs in non-structural elements (NSEs), leading to severe economic loss, interruption of essential services, and safety hazards.[12]

Modern buildings contain a large number of utility and architectural systems including cable trays, pipelines, HVAC ducts, suspended ceilings, electrical equipment, communication systems, façade panels, and mechanical installations. These components play an important role in maintaining functionality and operational continuity of buildings. During earthquakes, non-structural elements are subjected to significant inertial forces and floor acceleration amplification caused by structural vibration. Improper anchorage, inadequate support systems, and poor seismic detailing may result in failure of these components.

Recent earthquakes such as the Bhuj Earthquake (2001), Nepal Earthquake (2015), Christchurch Earthquake (2011), and Turkey-Syria Earthquake (2023) highlighted the vulnerability of non-structural systems. Damage to utility systems caused disruption of hospitals, industries, transportation facilities, and communication networks even when structural collapse did not occur. In many buildings, failure of suspended utilities and mechanical systems created additional hazards such as fire, leakage, falling objects, and service interruption.[5]

The importance of non-structural seismic safety has increased significantly in recent years due to rapid urbanization, increasing use of sophisticated building services, and growth of industrial infrastructure. Essential facilities such as hospitals, data centers, airports, power plants, and commercial buildings require continuous functionality even after seismic events. Therefore, proper seismic design of non-structural elements has become an important aspect of earthquake engineering.[3]

Recognizing the importance of NSEs, the latest revision of Draft IS 1893 (Part 1):2025 introduced a dedicated chapter titled "Architectural Elements and Utilities," which specifically addresses seismic safety requirements for non-structural components. This represents a significant advancement in Indian seismic design practice. However, experimental validation and practical implementation of these provisions are still limited. [10]

The present study focuses on the seismic behaviour of cable tray systems installed in a three-storey RC frame subjected to shake table excitation. The study evaluates acceleration amplification, anchorage response, and seismic performance of rigid and flexible support systems under varying excitation frequencies. The findings of the study aim to contribute toward improved understanding and seismic design of utility support systems in buildings**.**

1.2 NON-STRUCTURAL ELEMENTS

Non-Structural Elements (NSEs) are components of a building that are not part of the primary load-resisting structural system but are necessary for architectural, mechanical, electrical, and functional purposes. These elements do not directly contribute to the overall structural stability of the building; however, they are essential for occupancy, operational continuity, and safety.[11]

NSEs are generally classified into three categories:

1. Architectural Components:

These include: False ceilings, Partition walls, Glass façades, Cladding panels, Doors and windows, Decorative elements.

2. Mechanical and Electrical Utilities:

These include: Cable trays, HVAC ducts, Suspended pipelines, Electrical conduits, Fire sprinkler systems, Mechanical equipment.

3. Contents and Equipment:

These include: Storage racks, Computers, Medical equipment, Industrial machinery, Communication systems.

AEUs shall be classified based earthquake behaviour into three types, namely:

a) Acceleration-sensitive AEUs (A-AEUs): stiff and massive AEUs, which slide and/or topple at the level of their base, during earthquake shaking;

b) Deformation-sensitive AEUs (D-AEUs): flexible and long AEUs, which move or swing by large amounts in translation and/or rotation, shaking; and during earthquake

c) Acceleration-cum-deformation-sensitive AEUs (AD-AEUs): massive and long AEUs, which sustain both effects mentioned in (a) and (b) above.[10]

During earthquakes, NSEs experience dynamic forces due to floor motion and acceleration amplification. Since many utility systems are suspended or connected through anchorage systems, they are highly sensitive to vibration and resonance effects. Failure of these systems can occur due to: Inadequate anchorage, Poor support detailing, Excessive displacement, Connection failure, Resonance amplification. [1]

Among various NSEs, cable tray systems are particularly vulnerable because they are lightweight, suspended, and distributed throughout buildings. Damage to these systems can interrupt critical services and increase post-earthquake recovery time. [3]

Figure 1.1 Non-Structural Components in a building

1.3 IMPORTANCE OF NON-STRUCTURAL ELEMENTS

The importance of non-structural elements in earthquake engineering has increased significantly because NSE damage often accounts for a major portion of total earthquake-related losses. Studies from past earthquakes indicate that non-structural damage may contribute more economic loss than structural damage in modern buildings.[5]

In hospitals and emergency facilities, damage to utility systems such as cable trays, pipelines, and electrical systems can disrupt life-saving operations. Similarly, in industries and commercial buildings, failure of utility systems can stop production activities and communication services.

Cable tray systems are particularly important because they support electrical power and communication cables throughout buildings. Failure of cable tray supports during earthquakes may result in: Power failure, Communication interruption, Fire hazards, Falling debris, Damage to connected systems.

Another important aspect is floor acceleration amplification. During seismic excitation, upper floors generally experience larger acceleration than the base due to dynamic amplification. As a result, utility systems installed at higher floors are subjected to larger seismic demand. Improper support systems may lead to excessive displacement and anchorage failure. [1]

Non-structural elements are also important from a resilience and sustainability perspective. Modern performance-based seismic design aims not only to prevent collapse but also to ensure operational continuity after earthquakes. Therefore, seismic protection of utility systems has become essential for resilient infrastructure development. [3]

The introduction of dedicated NSE provisions in Draft IS 1893 (Part 1):2025 highlights the growing recognition of utility system safety in Indian seismic design practice. Proper seismic detailing of utility systems can significantly reduce earthquake losses and improve post-earthquake functionality of buildings.

Table 1.1 Different Types of failures in NSEs [14]

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

Figure 1.2 Failure of office partitions, ceilings, light fixtures, heavy soffit and HVAC.

Table 1.2 Expected Performance of building during earthquake [14]

	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		

1.4 Current Design Gaps in Indian and International Codes for Non-Structural Elements (NSEs)

The introduction of the “Architectural Elements and Utilities” chapter in Draft IS 1893 (Part 1):2025 represents an important step toward addressing non-structural seismic safety in India. However, several gaps still remain in both Indian and international practices.

One major limitation is the lack of experimental validation of codal force provisions for utility systems such as cable trays and suspended pipelines.

Indian codes currently provide limited guidance regarding: Flexible utility supports, Anchorage detailing, Dynamic response modification, Resonance control, Seismic restraint systems.

International codes such as ASCE 7 guidelines provide comparatively detailed provisions for non-structural systems. However, even these standards still face challenges related to: Complex utility interaction, Experimental validation, Multi-support systems, Performance-based design approaches. [11]

Furthermore, limited experimental research has been conducted in India on Shake table testing of utility systems, Comparison of rigid and flexible supports, Dynamic anchorage force demand, Utility resonance behaviour. [8]

These research gaps highlight the need for further experimental and analytical investigations to improve seismic design methodology for non-structural utility systems.

Table 1.3: Comparison Indian vs International Codes for NSEs

PARAMETER	**Draft IS 1893 (Part 1): 2025**	**ASCE 7-22**
Main Approach	Simplified force-based method	Detailed force-based method
Non-Structural Coverage	Basic provisions for A-AEUs and MEP systems	Extensive provisions for all non-structural components
Seismic Force Formula	Simpler equation with height factor	Advanced equation with amplification and reduction factors
Height Amplification	Increases with floor height	Stronger amplification using $(1+2.5z/h)$
Important Factors	Importance factor I	a_p, R_p, and Ip factors
Anchorage Design	Basic anchorage requirements	Detailed anchorage and bracing design
Equipment Qualification	Limited provisions	Detailed seismic qualification and testing
Complexity	Easier for design practice	More complex but more accurate
Research Use	Developing stage in India	Widely used in international research

1.5 SCOPE OF THE WORK

The present study focuses on the experimental investigation of seismic behaviour of non-structural cable tray systems installed in a three-storey reinforced concrete (RC) frame subjected to shake table excitation. The work evaluates the seismic response of rigidly supported and flexibly supported cable tray systems under excitation frequencies ranging from 0.5 Hz to 12 Hz. Measurement of floor acceleration, cable tray acceleration, amplification factors, resonance behaviour, anchorage response, and displacement characteristics using accelerometer data obtained from the base, floor slabs, and cable tray locations. Comparative evaluation of rigid and flexible support systems is also carried out to study their influence on seismic force transfer and dynamic amplification. The experimentally obtained results are compared with codal provisions of Draft IS 1893 (Part 1):2025 and ASCE 7 to evaluate the applicability and conservativeness of seismic force estimation procedures for non-structural utility systems. The study is limited to scaled laboratory shake table testing of cable tray systems installed in RC frame structures and aims to provide practical seismic design recommendations for utility support and anchorage systems.

1.6 OBJECTIVE OF THE STUDY

The primary objective of the present study is to experimentally evaluate the seismic response of cable tray systems installed in a three-storey reinforced concrete frame subjected to dynamic earthquake excitation using shake table testing. The study specifically investigates the influence of rigid and flexible support systems on the seismic performance of non-structural utility components.

The detailed objectives of the study are as follows:

1. To experimentally determine the acceleration response of the RC frame and cable tray systems under varying excitation frequencies.
2. To compare the seismic response of rigidly supported and flexibly supported cable tray systems.
3. To determine peak floor acceleration (PFA), cable tray amplification factors, and support performance indices using experimental data.
4. To compare experimentally obtained seismic force demands with codal provisions of Draft IS 1893 part 1:2025 and ASCE 7.
5. To contribute toward experimental validation of newly introduced non-structural provisions in Draft IS 1893 (Part 1):2025.

1.7 OUTLINE OF THE THESIS

The present thesis is organized into five chapters related to the seismic behaviour of cable tray systems installed in RC frames.

Chapter 1 presents the background and importance of non-structural elements in seismic engineering. It discusses the vulnerability of utility systems during earthquakes and highlights the significance of the newly introduced provisions related to architectural elements and utilities in Draft IS 1893 (Part 1):2025. The chapter also presents the scope, objectives, and overall organization of the thesis.

Chapter 2 reviews previous research related to the seismic performance of non-structural elements, cable tray systems, anchorage behaviour, floor acceleration amplification, and utility support systems. International standards such as ASCE 7 also reviewed.

Chapter 3 describes the experimental setup used in the study. Details of the three-storey RC frame model, shake table arrangement, cable tray support systems, accelerometer placement, and testing procedure are presented. The methodology for obtaining acceleration response and calculating amplification factors is also explained.

Chapter 4 presents the experimental acceleration results obtained from shake table testing. Floor acceleration amplification, cable tray response, resonance effects, support performance indices, and comparison between rigid and flexible support systems are discussed in detail. Comparative analysis between experimental forces and codal predictions is also presented.

Chapter 5 summarizes the important findings obtained from the experimental study. Conclusions regarding seismic behaviour of cable tray systems, codal applicability, and effectiveness of support systems are presented. Recommendations for future research and codal improvements are also discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

In addition to structural members, earthquakes also inflict significant damage to non-structural elements (NSEs) of buildings. NSEs include cable trays, pipelines, HVAC systems, ceilings, and electrical utilities. These things might not be part of the main system that resists loads, but they are very important for buildings to function and be safe. Damage to such systems during earthquakes may cause service interruption, economic loss and safety hazards.

The seismic behaviour of NSEs has attracted more attention in recent years. Past earthquakes have demonstrated that utility systems are highly vulnerable to floor acceleration amplification, resonance effects and poor anchorage conditions. Seismic response of non-structural components has been studied by several researchers using experimental, analytical and numerical approaches.

The latest version of Draft IS 1893 (Part 1):2025 is the first version to have provisions on Architectural Elements and Utilities, which shows the growing importance of seismic safety of NSEs in Indian design practice. However, experimental studies on cable tray systems and their support behaviour under seismic excitation are limited.

Therefore, this chapter provides a comprehensive review of the previous research on non-structural elements, floor acceleration amplification, support systems and seismic behaviour of the cable tray systems to identify the existing research gaps and to establish the need for the present study.

2.2 LITERATURE REVIEW

Medina et al. (2013) prepared an analytical framework to quantify peak horizontal acceleration demands acting on acceleration-sensitive NSCs, which are critical for seismic design. It emphasizes components with low natural periods mounted on flexural-type structural systems and evaluates their response under a suite of forty earthquake records representative of stiff soil conditions. Three structural configurations—low-rise, mid-rise, and high-rise buildings—are examined under varying seismic intensity levels to capture a wide range of response behaviour. A key contribution of the study is the formulation of a component acceleration factor, defined as the combined effect of component amplification and in-structure amplification, enabling simplified yet realistic design calculations. The results are critically compared with provisions of ASCE 7 – Minimum Design Loads for Building and Other Structures, and the study advocates reconsideration of existing design limits, particularly suggesting the elimination of upper bounds on lateral seismic forces for non-structural components.[1]

Ding et al. (2024) studied a comprehensive investigation into both the elastic and inelastic seismic behaviour of non-structural components (NSCs) installed in multi-storey steel moment-resisting frame structures. The components are modeled as single degree of freedom (SDOF) systems with varying natural periods and strength reduction factors, and are attached at different floor levels of the primary structure. A total of 38 structural models, representing three-, five-, and seven-storey steel frames designed in accordance with Eurocode 8, are analyzed using nonlinear time history methods. The study utilizes an extensive dataset of 100 ground motion records, including both near-field and far-field earthquakes, scaled to represent different intensity levels corresponding to elastic and inelastic structural responses. Based on the results, predictive relationships are developed for estimating displacement demands and spectral accelerations of NSCs, while also critically evaluating existing code provisions and recommending improvements that account for inelastic behaviour. [2]

Filiatrault et al. (2021) highlights importance of integrating non-structural elements into performance-based seismic design frameworks to ensure overall building functionality and safety. It proposes the use of a direct displacement-based design approach tailored for non-structural components that are prone to damage due to excessive deformation rather than force demands. He elaborates on the core principles of this methodology and discusses the modifications required to adapt it for such components. As an illustrative example, the design of a suspended piping restraint system is carried out using this approach, and its performance is assessed through nonlinear dynamic analyses, demonstrating the suitability of the method for realistic seismic design applications. [3]

Dhanani et al. (2013) prepared a numerical approach adopted to analyze the seismic behaviour of NSEs in a three-storey asymmetric building using time-history analysis. The response of these elements, in terms of displacement and acceleration, is evaluated at different floor levels. The findings reveal that the displacement of NSEs is comparatively lower at the center of the first floor, emphasizing the importance of location and structural irregularity in determining their seismic response. [4]

Baird et al. (2014) An extensive field survey conducted after the 2011 Christchurch Earthquake involving over 200 multi-storey buildings highlighted the recurring vulnerability of vertical non-structural components (VNSCs) during seismic events. Components such as façade systems, cladding panels, external infill walls, and internal partitions were observed to suffer significant damage, even in buildings designed according to modern codes. This research examines the issues identified during post-earthquake damage assessments from the Canterbury earthquake sequence and evaluates the seismic demands on these components using nonlinear time-history analyses. The study compares analytically predicted damage levels, derived from code-based guidelines and experimental data, with actual field observations, thereby identifying critical gaps and suggesting the need for improved displacement-based design considerations for VNSCs. [5]

D'Angela at al. (2025) addresses the seismic performance of rocking-dominated non-structural components, which represent a diverse category of elements that can undergo significant motion during earthquakes due to lack of proper anchorage or inherent geometric instability. Examples include museum exhibits, medical equipment, and laboratory instruments that are highly sensitive to seismic disturbances. The study presents an extensive review of past and current research, including theoretical frameworks, computational modeling techniques, and experimental findings related to rocking behavior. It also evaluates current seismic design practices and proposes protective strategies to mitigate damage. Importantly, the paper identifies critical gaps in existing knowledge and outlines future research needs to improve the design and safety of rocking non-structural elements in seismic regions. [6]

Shahane et al. (2021) illustrates the behaviour of a displacement-sensitive non-structural component, specifically a signboard, through a detailed numerical example. Using STAAD software, key structural response parameters such as base shear, displacement, time period, mass participation, and nodal and beam displacements are evaluated to assess the influence of the non-structural element on overall building response. [7]

Bonati et al. (2025) describes the development of an advanced experimental “testing set” intended for evaluating the seismic resistance of building envelope systems and their individual components. The system includes a specialized testing machine and an accompanying protocol that has been formulated by integrating insights from past experimental studies and recent seismic code developments. The testing procedure is specifically tailored to assess the behaviour of non-structural elements such as façade cladding and precast concrete panel connections under seismic loading conditions. Through experimental investigations, particularly on precast panel connections, the study proposes a systematic criterion for assessing and improving their seismic design, thereby contributing to enhanced safety and performance of building envelope systems. [8]

Walters et al. (2012) examines a recently developed installation strategy for rooftop photovoltaic (PV) arrays that eliminates the need for mechanical anchorage, instead utilizing a friction-based “isolated” support system. This technique is especially advantageous for flat-roofed commercial and institutional buildings, as it simplifies installation and reduces both time and cost while protecting the roof membrane from potential damage. However, the absence of anchorage introduces concerns related to seismic-induced sliding and wind uplift, making it necessary to evaluate its performance carefully. The approach is conceptually similar to seismic isolation, where friction plays a key role in controlling movement. To address these issues, the study presents important seismic design considerations and proposes an analytical method to predict sliding displacements and determine the required gaps to accommodate movement, thereby enhancing the safety and reliability of such PV systems. [9]

2.3 RESEARCH GAP

From the literature review, it is observed that most previous studies on seismic behaviour of non-structural elements (NSEs) are based on international codes such as ASCE 7 and FEMA guidelines, while very limited research is available on the newly introduced provisions of Draft IS 1893 (Part 1):2025 for Architectural Elements and Utilities. Experimental investigations on cable tray systems installed in RC frames under seismic excitation are also limited in Indian research practice.

Previous studies mainly focused on structural safety, whereas the seismic response of utility systems such as cable trays, pipelines, and support systems has not been extensively studied experimentally. Limited research is available on: Floor acceleration amplification, Resonance behaviour, Anchorage force demand, Comparison of rigid and flexible support systems, Validation of codal seismic force provisions using shake table testing.

Additionally, there is a lack of experimental comparison between actual seismic force demand and codal predictions provided in Draft IS 1893(Part 1):2025 for non-structural utility systems.

Therefore, the present study aims to address these gaps through experimental shake table investigation of cable tray systems installed in a three-storey RC frame by evaluating acceleration amplification, support performance, and seismic force demand under varying excitation frequencies.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

This chapter describes the methodology adopted for the experimental study on the seismic behaviour of cable tray systems installed in a three-story reinforced concrete (RC) frame, subjected to shake table excitation. The methodology is mainly aimed at evaluating the dynamic response of non-structural utility systems to varying excitation frequencies and investigating the influence of support flexibility on seismic performance.

A scaled three-storey RC frame model with cable tray utility systems installed at different floors was used for the investigation. In order to compare the seismic response characteristics of two different support configurations i.e. rigid supports and flexible supports were considered. Based on the shake table tests, the sinusoidal excitations with a frequency range of 0.5 Hz to 12 Hz were imposed to simulate the earthquake-induced vibrations.

Accelerometers were placed at the base, first, second, third floors and cable tray locations for measuring the acceleration response during testing. The experimental results were used to determine the peak floor acceleration (PFA), amplification factors, cable tray amplification and support performance indices. The study also investigated resonance behaviour and floor-wise amplification of accelerations in utility systems.

The experimental setup, instrumentation details, testing procedure, data acquisition system and calculation methodology adopted for the seismic response evaluation of non-structural utility systems have been discussed in detail in this chapter.

3.2 PROBLEM STATEMENT

The previous versions of IS 1893 had very little in terms of seismic design provisions for non-structural elements in India. The addition of the chapter “Architectural Elements and Utilities” to Draft IS 1893 (Part 1):2025 is a significant step towards enhancing the seismic safety of utility systems. However, as these provisions are newly introduced, there is limited experimental validation on seismic response of cable tray system,

Floor acceleration amplification effects, Behaviour of rigid and flexible utility supports, Anchorage force demand, Resonance induced amplification, Applicability of codal force assumptions.

Also, there is very little experimental study in Indian research practice to evaluate the seismic response of cable tray systems installed inside RC frames by shake table testing.

Therefore, the present study aims to experimentally investigate the seismic response of cable tray systems installed in a three-storey RC frame subjected to different excitation frequencies. The study aims to compare the rigid and flexible support system, to evaluate the acceleration amplification at different floor levels and to evaluate the suitability of Draft IS 1893 part 1:2025 provisions for seismic design of non-structural utility systems.

3.3 METHODOLOGY FLOW CHART

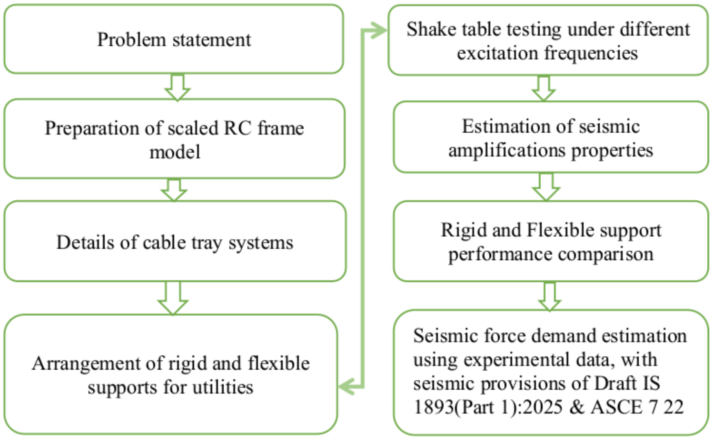


Figure 3.2 Methodology flow chart adopted for assessment of lateral forces on NSEs

3.4 EXPERIMENTAL SETUP

3.4.1 Preparation of scaled RC frame model

3 storey RC frame is modelled with,

Frame specifications: Storey Height 1.2 m

Bay width: 0.15m

Material: Aluminium section frame

Slab: 120mm

Figure 3.3 Three storey frame model

A 3 storey RC frame on earthquake lab is selected and analysed. The overall height of frame is 1.2m and height of each floor is taken as 0.4m. the length, width and thickness of RC frame slab is 0.3m ,0.15m, 0.012m.

3.4.2 Details of cable tray systems as NSEs

Fabrication of Cable tray as NSE model is done using a 1mm steel sheet of dimension width 10mm, length 260mm where, Drill side perforation holes of 2mm dia. @ 8mm spacing is done along the width and 245mm along the length of sheet.

3.4.3 Arrangement of rigid and flexible supports for utilities

Support System: Simulate real suspended system

1.) Flexible support: using thin steel wire(1mm) as hanger rods

2.) Rigid support: using screw 1mm diameter connected with bolts as hanger rods

a) Cable tray attached at 1st floor slab b) Cable tray attached at 2nd floor slab

c) Cable tray attached at 3rd floor slab

Figure 3.3 Installation of cable tray at each floor as flexible and rigid supported

3.4.4 Shake table testing under different excitation frequencies

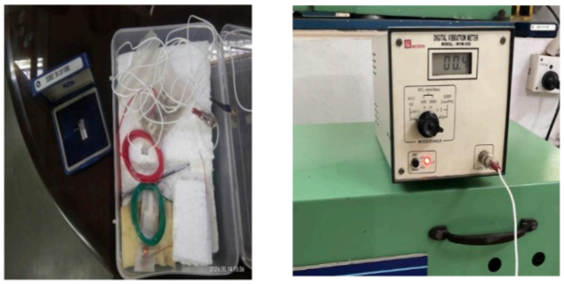
Using Horizontal Motions: Artificial sine sweep (0.5Hz to 12 Hz) with applying the frequency at interval of 0.5 Hz

Accelerometers installed at the,

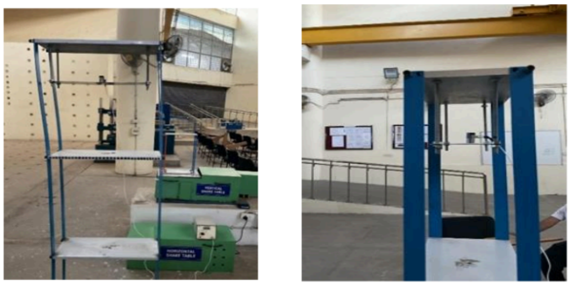
1. Base of shake table,

2. Centre of each floor slab

3. Centre of each cable tray



a)Accelerometer **b) Digital vibration meter**



c) Accelerometer attached at centre of the cable tray

Figure 3.4 Shake table testing under different excitation frequencies

Measurement:

1. Floor acceleration

2. NSE acceleration

3. Amplification factor

3.5 ESTIMATION OF SEISMIC AMPLIFICATIONS PROPERTIES

The frequency and acceleration responses obtained experimentally from the shake table test of the three-storey RC frame model were used to estimate the seismic amplification properties of the cable tray system. The measured values of acceleration at the base, floor levels and cable tray locations were studied for the excitation frequencies between 0.5 Hz and 12 Hz.

The following parameters were calculated from the frequency–acceleration results: Peak Floor Acceleration (PFA), Floor Amplification Factor, Cable Tray Amplification

The analysis was done to find out: floor-wise seismic amplification, the resonance behaviour, the acceleration transfer and the performance of the rigid and flexible cable tray supports, under the seismic excitation.

Table 3.1 Acceleration value at different frequency

Frequency (Hz)	**Acceleration values(g)**									
	B	**F1**	**F2**	**F3**	**FL1**	**RI1**	**FL2**	**RI2**	**FL3**	**RI3**
0.5	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
1	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
1.5	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.2	-0.2	-0.3	-0.2	-0.3
2.5	-0.3	-0.3	-0.3	-0.3	-0.3	-0.2	-0.2	-0.3	-0.2	-0.2
3	-0.3	-0.3	-0.3	-0.2	-0.3	-0.1	0	-0.2	-0.1	-0.2
3.5	-0.3	-0.2	-0.3	-0.2	-0.2	0	-0.2	-0.2	0.1	-0.2
4	-0.3	-0.2	-0.2	-0.2	-0.2	0	-0.2	-0.2	0.2	-0.1
4.5	-0.3	-0.2	-0.2	-0.2	-0.2	0	-0.1	-0.2	0.4	-0.1
5	-0.3	-0.1	-0.2	-0.1	-0.1	0.1	-0.1	-0.1	0.6	0
5.5	-0.3	-0.1	-0.1	0	-0.1	0.1	0	0	0.7	0
6	-0.2	0	-0.1	0	-0.1	0.1	0.1	0	0.8	0.1
6.5	-0.2	0	0	0.1	0.8	0.4	1	0.4	0.8	0.2
7	-0.1	0.1	0	0.5	1.5	0.4	2.3	1.5	1.1	0.5

7.5	-0.1	0.1	0.1	0.2	0.7	0.2	1.1	1.4	2.1	0.3
8	0	0.3	0.1	0.2	1	0.5	0	0.3	0.5	0.2
8.5	0	0.5	0.2	0.3	1.8	0.7	0.1	1.5	0.3	0.3
9	0	0.4	0.3	0.4	2	1.3	0.2	1.4	0.3	0.4
9.5	0	0.6	0.4	0.6	0.3	1.1	0	0.2	0.2	0.5
10	0.1	0.8	0.5	0.7	0.1	1	0	0.2	0.4	0.6
10.5	0.2	0.5	0.5	0.7	0	0.2	0.1	0.3	0.2	1.5
11	0.3	0.4	0.7	1.5	0.1	0.1	0.2	0.4	0.2	1.9
11.5	0.1	0.7	0.9	1	0.5	0.3	1	1.4	1	0.8
12	0.2	0.8	1.2	1.3	1.7	0.6	2.3	1.3	3	0.9

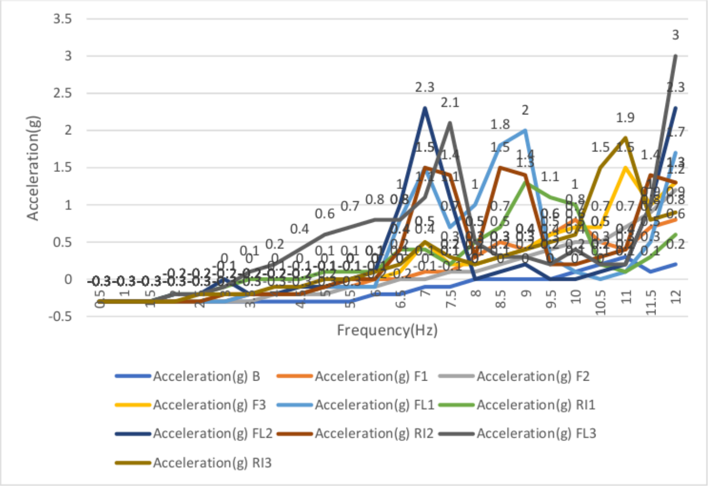


Figure 3.5 Acceleration values at different frequency

Here, Resonance behaviour was observed near: 6.5-8.5 Hz, Maximum floor acceleration occurred at the 3rd floor = 1.5 g, while Maximum cable tray acceleration occurred at flexible supported 3rd floor = 3 g.

3.5.1 Peak Floor Acceleration (PFA)

Peak Floor Acceleration (PFA) represents the maximum acceleration response experienced at a particular floor during seismic excitation.[1,11]

Table 3.2 Value of Peak floor acceleration value at different floors

Floor	PFA(g)
Base	0.3
1st Floor	0.8
2nd Floor	1.2
3rd Floor	1.5

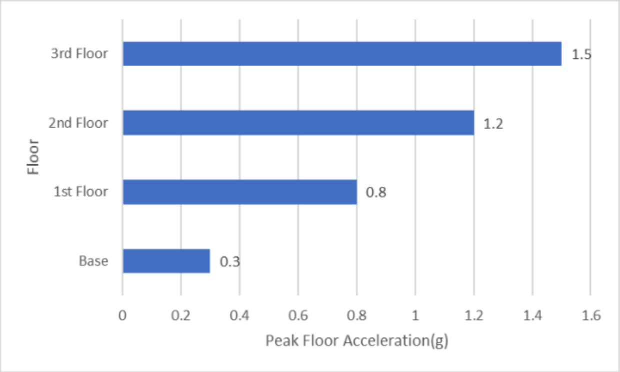


Figure 3.6 Peak floor acceleration value at different floors

Maximum floor acceleration occurred at the: 3rd Floor = 1.5g. Resonance causes sharp acceleration amplification which causes higher modes amplify upper floor response. This indicates significant amplification in the RC frame.

3.5.2 Floor Acceleration Amplification

Amplification Factor measures increase in acceleration from base to floor level.

Amplification Factor, AF= (af_{loor}/a_{base}) [11]

If, AF>1

Then, structural dynamic amplification exists and floor motion exceeds base excitation

This is common in flexible frames, resonance conditions, higher mode excitation

Table 3.3 Value of Amplification factor at different floors

Floor	Amplification Factor
1st Floor	2.66
2nd Floor	4.00
3rd Floor	5.00

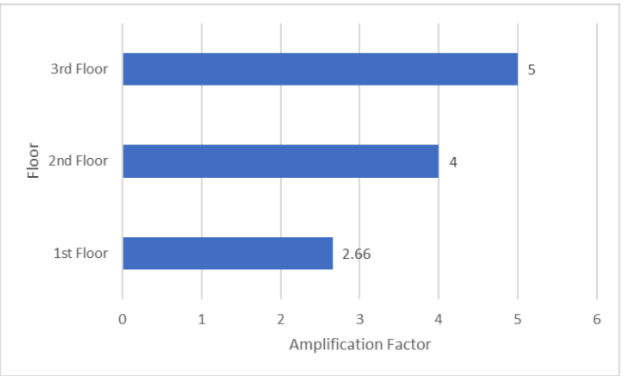


Figure 3.7 Amplification factor at different floors

3.5.3 Cable Tray Amplification

Measures dynamic amplification of tray relative to supporting floor.[11]

If, $AF_{tray} > 1$

Then**,** tray vibration exceeds floor vibration, resonance or flexibility exists. This parameter is highly important because, utilities may fail even when structure remains safe and anchorage forces increase drastically.

Table 3.4 Value of Amplification at Cable tray at each floor with different supports

Tray Support	Amplification
Flexible – 1st Floor	2.5
Rigid – 1st Floor	1.375
Flexible – 2nd Floor	1.91
Rigid – 2nd Floor	1.25
Flexible – 3rd Floor	2
Rigid – 3rd Floor	1.266

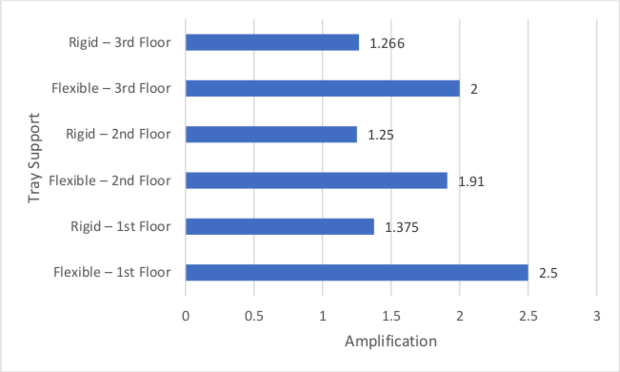


Figure 3.8 Amplification of Cable tray at each floor with different supports

Flexible supports showed: Lower force transfer, Higher displacement flexibility

Rigid supports showed: Higher anchorage demand, Greater force concentration

Flexible cable trays at upper floors experienced: Higher acceleration amplification, Greater dynamic sensitivity.

This supports ASCE recommendations for flexible seismic restraint systems.

3.6 RIGID AND FLEXIBLE SUPPORT PERFORMANCE COMPARISON

Research objective to compare Rigid bolted support vs Flexible hanger support to measure Acceleration amplification, Dynamic response, Seismic force transfer.

Using experimental data:

For example, for 3rd Floor

Table 3.5 Peak Acceleration value at different support system

Support Type	Peak Acceleration
Flexible	3.0g
Rigid	1.9 g

Now, Calculating Amplification Factor: Using, AF = (a_{tray}/a_{floor})

For flexible support: $AF_{flexible} = (3.0/1.5)$

$AF_{flexible} = 2$

For rigid support: $AF_{rigid} = (1.4/1.5)$

$AF_{rigid} = 0.93$

Similarly, AF for support system at other floors

Table 3.6 Value of Amplification factor for different support system at each floor

Floor	Peak Acceleration (g)	Flexible AF	Rigid AF
1st Floor	0.8	2.5	1.375
2nd Floor	1.2	1.91	1.25
3rd Floor	1.5	2	1.26

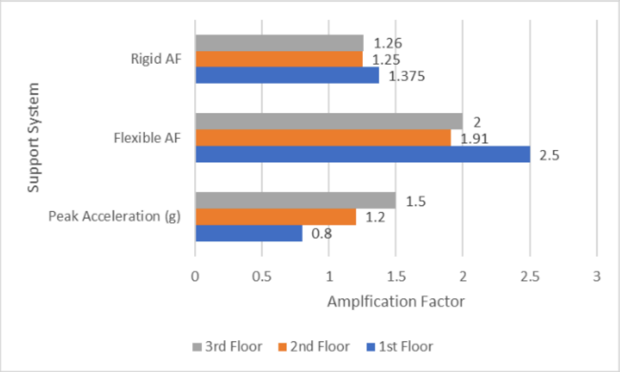


Figure 3.9 Amplification factor for different support system at each floor

The shake table study showed that support flexibility significantly affects the seismic response of suspended cable tray systems. Flexible supports transferred lower seismic forces to anchorage connections because they absorbed part of the vibration energy and behaved like semi-isolation systems. However, they produced higher acceleration amplification, larger vibration response, and greater displacement, especially at upper floors.

In contrast, rigid supports reduced tray displacement and provided better positional stability, but they directly transferred inertial forces to the bolts and anchors, resulting in higher force concentration and greater anchorage demand.

The results indicate that flexible systems are effective for reducing anchorage forces under high-frequency vibration, while rigid systems are more suitable for controlling displacement.

Resonance effects became more significant above 6.5 Hz, where amplification increased rapidly.

Overall, the study highlights the need to balance flexibility and rigidity for safe and efficient seismic design of non-structural components. Flexible supports should be preferred for cable trays installed above the second floor to reduce seismic force transfer while Rigid anchorage systems require stronger bolting and base plate design near resonance frequencies. Cable tray systems located at higher elevations must consider amplification effects in seismic design and anchorage detailing.

3.7 SEISMIC FORCE DEMAND ESTIMATION USING EXPERIMENTAL DATA, WITH SEISMIC PROVISIONS OF Draft IS 1893 (Part 1): 2025 & ASCE 7 22

"Anchor Failure vs Code Assumptions"

Objective is to compare seismic anchorage force predicted by Draft IS 1893 (Part 1): 2025 & ASCE 7 vs Actual dynamic force observed from shake table acceleration data.

Goal: Determine whether Draft IS 1893 (Part 1): 2025 is Conservative, Accurate, Unsafe.

3.7.1 Experimental Force Calculation

Using Experimental Acceleration from Data available

Calculating Experimental Seismic Force

Used: Cable tray mass = 0.2kg and $g = 9.81 m/s^2$

For 3rd Floor Experimental Force

$a = 1.5g$

$F_{exp} = 0.2 \times (1.5 \times 9.81)$

$F_{exp} = 3N$

Similarly, Calculating experimental seismic force for other floors we get,

Table 3.7 Experimental Seismic Force calculated at each floor

Floor	Experimental Peak Acceleration (g)	Experimental Force(N)
Base	0.3	0.58
1st Floor	0.8	1.56
2nd Floor	1.2	2.35
3rd Floor	1.5	3

3.7.2 Calculating Draft IS 1893(Part 1):2025 Seismic Force

IS 1893 AEU provisions use design lateral force F_{AEU} for the design of such anchorages connecting A-AEYs to the SEs of the building shall be taken as:

$$F_{AEU} = \left[Z\left(1 + \frac{x}{H}\right) I_{AEU} \left(\frac{a_{AEU}}{R_{AEU}}\right)\right] W_{AEU} \geq 0.04 W_{AEU} \tag{3.7.1}$$

Source: Draft IS 1893 (Part 1): 2025[10]

Where,

Z = earthquake zone factor as per Draft IS 1893(Part 1):2025

x = height of the point of attachment of A-AEU above top of the foundation of the structure

I_{AEU} = importance factor of the A-AEU

H = overall height of the structure above top of the foundation

W_{AEU} = weight of the A-AEU

a_{AEU} = acceleration amplification factor of the A-AEU

R_{AEU} = elastic force reduction factor of the A-AEU

For Cable tray,

Calculating:

For 3rd floor,

Z = Seismic in Zone-IV (DELHI) = 0.35 (as per Draft IS 1893 (Part 1): 2025)

$x = 1.2$m

$I_{\mathrm{AEU}} = 2.5$ (as per Draft IS 1893 (Part 1): 2025)

$a_{\mathrm{AEU}} = 2.5$ (as per Draft IS 1893 (Part 1): 2025)

$R_{\mathrm{AEU}} = 5$

Seismic Coefficient, Cp = $[Z(1+\frac{x}{H})I_{\mathrm{AEU}}(a_{\mathrm{AEU}}/R_{\mathrm{AEU}})\}]$

Cp = 0.875

Tray weight: Wp = 0.2 × 9.81 =1.962N = 2N

Then:

$F_{IS} = 0.875 \times 2$, $F_{IS} = 1.75N$

$F_{IS} = 1.75N \geq 0.04W_{AEU} \geq 0.04 \times 2 = 0.08N$

Similarly calculating for other floors,

Table 3.6 Calculating Seismic force based on Draft IS 1893 (Part 1):2025

Floor	Seismic Coefficient	IS1893 Force(N)
Base	0.437	0.875
1st Floor	0.581	1.16
2nd Floor	0.726	1.45
3rd Floor	0.875	1.75

3.7.3 Calculating ASCE 7 Seismic Force

As per ASCE 7 the horizontal seismic design force shall be calculated as

$$Fp = 0.4S_{DS}I_pW_p\left[\frac{H_f}{R_\mu}\right]\left[\frac{C_{AR}}{R_{po}}\right] \qquad (3.7.2)$$

Source: ASCE 7-22[11]

The Force limits are $F_{p,max} = 1.6S_{DS}I_pW_p$ & $F_{p,min} = 0.3S_{DS}I_pW_p$

Where: F_p = Horizontal seismic design force on component

S_{DS} = Design spectral acceleration at short period

I_p = Component importance factor

W_p = Operating weight of component

H_f = Height amplification factor

R_μ = Structural ductility reduction factor

C_{AR} = Component resonance amplification

R_{po} = Component overstrength factor

Calculating:

Cable tray mass = 2 kg

Tray weight:

$W\text{p} = 0.2 \times 9.81 = 1.962\text{N} = 2\text{N}$

S_{DS}=1.0 (as per ASCE 7-22)

I_p=1.5 (as per ASCE 7-22)

R_{po}=1.5 (as per ASCE 7-22)

R_μ= 1.3 (as per ASCE 7-22)

C_{AR}= 1 (as per ASCE 7-22)

H_f=1+2.5(z/h) (as per ASCE 7-22)

For Tray at 3rd floor:

H_f= 1+ 2.5(1.2/1.2) = 3.5

Now,

F_p=0.4×1×1.5×2×(3.5/1.3)×(1/1.5) = 2..15N

Similarly, calculating seismic forces for other floors,

Table 3.7 Calculating Seismic force based on ASCE 7

Floor	Height Amplification Factor (H_f)	FEMA/ASCE 7 Force
Base	1	0.61
1st Floor	1.83	1.12
2nd Floor	2.6	1.60
3rd Floor	3.5	2.15

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 GENERAL

This chapter presents the experimental results of shake table study of three-storey reinforced concrete (RC) frame connected with cable tray systems under seismic excitation. This study investigates the seismic response of non-structural cable tray systems with flexible and rigid support conditions as per the newly introduced Architectural Elements and Utilities (AEUs) provisions of Draft IS 1893(Part 1):2025.

The experiment consisted of a scaled three-story RC frame on a shake table. Two different support configurations, namely rigid anchorage and flexible hanger support systems, were used to install cable tray models at each floor level.

Accelerometers were placed at the base, floor slabs and at the centre of cable trays to measure acceleration response under different excitation frequencies from 0.5 Hz to 12 Hz.

The measured acceleration responses were utilized to assess the following seismic performance parameters: Peak Floor Acceleration (PFA) Amplification Factor (AF) and Cable Tray Amplification.

The obtained results were also compared with seismic design assumptions given in IS 1893:2025 and ASCE 7 provisions for non-structural components.

4.2 EXPERIMENTAL RESPONSE OF RC FRAME

It was observed that the acceleration response of the RC frame increases significantly with the increase in the excitation frequency. The structure response was relatively stable at low frequency, but with the increase of excitation frequency to the dynamic characteristics of the frame, acceleration response amplification was obvious.

The maximum acceleration response was observed at the upper floor levels due to the floor acceleration amplification effects. The experimental results indicated that the seismic demand on non-structural cable tray systems increased dramatically with elevation.

In the experimental investigation the maximum acceleration amplification = 1.5g was observed on the third floor. Such behaviour indicates substantial dynamic interaction of RC frame with attached utility systems.

4.3 FREQUENCY VERSUS FLOOR ACCELERATION RESPONSE

The floor acceleration response in relation to the excitation frequency indicated that the acceleration amplification increased rapidly beyond the excitation frequency of 6 Hz. A rapid increase in vibration response was observed near the resonance region.

The maximum dynamic response of the cable tray systems was observed in the frequency range of 6.5 Hz to 8.5 Hz. This behaviour was a proof of the existence of resonance effects on the structural and non-structural system.

The trend of floor acceleration response was observed as generally: $(a_{floor}) > (a_{base})$, indicating the high seismic amplification at upper story levels.

4.4 AMPLIFICATION FACTOR OF RC FRAME

The results clearly indicate that floor acceleration amplification plays a critical role in the seismic behaviour of non-structural components. The amplification factor values obtained experimentally were considerably higher than simplified assumptions generally adopted in conventional design approaches.

The upper floor levels experienced increased inertial demand, which directly influenced the seismic force transferred to cable tray supports and anchorage systems.

4.5 BEHAVIOR OF FLEXIBLE AND RIGID CABLE TRAY SUPPORTS

The seismic response of cable trays was studied for flexible hanger supports and rigid anchorage systems. The flexible support system allowed a greater movement and vibration of the cable tray during the seismic excitation. The rigid support system controlled the displacement but transferred larger inertial forces to the anchorage connections results indicated that flexible supports improved motion response but decreased concentrated force transfer to bolts and anchorage systems. In contrast, the rigid supports resulted in less tray displacement, but with higher concentration of the anchorage force Such behaviour underscored the importance of selecting appropriate support systems for seismic restraint of utility components in buildings.

4.6 SUMMARY OF CODAL DIFFERENCES (ASCE 7 & DRAFT IS1893:2025)

This is a big step forward in Indian seismic design practice. IS 1893:2025 has introduced new requirements for architectural features and utilities. However, the detailing and analytical procedures are still less exhaustive compared to international standards like ASCE 7. ASCE 7 includes detailed procedures for calculation of seismic force on non-structural components considering amplification effects, component response modification factors, importance factors, and floor acceleration amplification. It also contains general recommendations for anchorage systems, flexible utility connections, suspended systems, and design considerations for individual components. [11]

Contrarily, Draft IS 1893(Part 1):2025 generally gives generalized provisions for architectural elements and utilities without detailed amplification formulations for different support systems and dynamic interaction effects. The Indian code primarily deals with estimation of equivalent static forces and basic anchorage requirements. [10]

The experimental observations of the present study show that the utility response is strongly affected by the amplification of the floor acceleration and the resonance behaviour, especially at the top floors. The effects are explained in more detail in ASCE 7 in comparison to Draft IS 1893(Part 1):2025.

Table 4.1 Main Difference between codes

Parameter	Draft IS 1893(Part 1):2025	ASCE 7
Floor amplification	Limited	Detailed
Dynamic amplification	Basic	Included
Resonance effect	Not detailed	Considered
Flexibility effect	Limited	Included
Anchorage detailing	Moderate	Extensive

Further refinement of the provisions for amplification and dynamic response may be required in the future revision of Draft IS 1893(Part 1):2025.

4.7 COMPARATIVE ANALYSIS OF LATERAL FORCES ACTING ON NSEs IN FRMAE USING EXPERIMENTAL FORCE, Draft IS 1893(Part 1):2025 & ASCE 7

The experimentally measured seismic force was compared with code-predicted forces using Draft IS 1893(Part 1):2025, and ASCE 7 provisions. The cable tray weight was considered as 0.2 kg. The predicted forces obtained were shown in Table 4.2

Table 4.2 Experimental, Draft IS 1893(Part 1):2025 & ASCE 7 lateral seismic forces acting on NSEs

Floor	Experimental Force	IS1893 2025 Force	ASCE 7 Force
Base	0.58	0.875	0.61
1st Floor	1.56	1.16	1.12
2nd Floor	2.35	1.45	1.60
3rd Floor	3	1.75	2.15

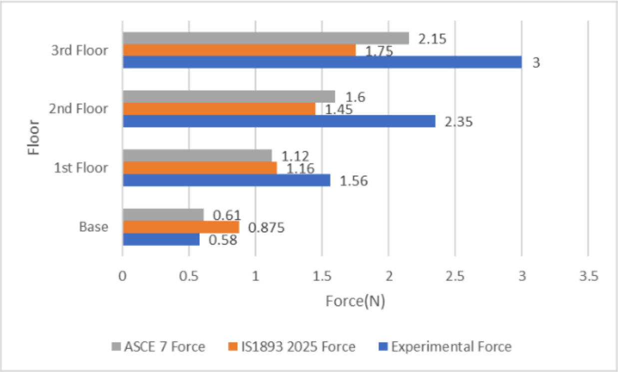


Figure 3.10 Experimental, Draft IS 1893(Part 1):2025 , & ASCE 7 lateral seismic forces acting on NSEs at each floor

The experimental force exceeded the Draft IS 1893(Part 1):2025 predicted value by approximately 71%.

ASCE 7 provisions produced results closer to the experimentally observed seismic demand because they include floor amplification effects, dynamic amplification factors, flexibility considerations

The comparison indicates that the simplified equivalent static approach of Draft IS 1893(Part 1):2025 may underestimate seismic force demand for suspended utility systems subjected to resonance amplification.

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE

5.1 GENERAL

This chapter presents the major conclusions obtained from the experimental investigation on the seismic response of cable tray systems installed in a three-storey RC frame subjected to shake table excitation. The study was carried out in accordance with the newly introduced Architectural Elements and Utilities (AEUs) provisions of Draft IS 1893(Part 1):2025 and included comparison with ASCE 7 methodologies.

The experimental program evaluated the seismic performance of flexible and rigidly supported cable tray systems under varying excitation frequencies. Acceleration responses were measured at the base, floor levels, and cable tray locations to study floor amplification, resonance behaviour, and anchorage response.

The study also investigated the applicability of current Indian seismic provisions for non-structural utility systems and assessed the influence of support flexibility on seismic force transfer and dynamic amplification.

5.2 CONCLUSIONS

Based on the experimental investigation and analytical interpretation, the following conclusions are drawn:

1. Significant Floor Amplification was Observed

The acceleration response increased considerably from the base level to upper floors of the RC frame. The maximum Peak Floor Acceleration (PFA) was observed at the first floor with an amplification factor of approximately 5.00.

This indicates that non-structural utility systems installed at elevated floor levels experience substantially higher seismic demand compared to the ground motion input.

2. Resonance Effects Strongly Influenced Cable Tray Response

A sudden increase in acceleration response was observed in the excitation frequency range of approximately 6.5 Hz to 8.5 Hz. This behaviour indicates resonance interaction between: excitation frequency, structural frequency, and cable tray support systems.

Near resonance conditions: acceleration amplification increased rapidly, tray vibration became severe, and anchorage demand increased significantly.

3. Flexible Supports Reduced Force Transfer

Flexible cable tray supports exhibited: lower direct force transmission, reduced anchorage demand, and improved vibration absorption behaviour.

The experimental results indicate that flexible supports behave similarly to vibration isolation systems under seismic excitation.

4. Rigid Supports Increased Anchorage Demand

Rigidly supported cable trays showed: lower displacement response, higher stiffness, and stronger inertial coupling with the structure.

Although rigid systems reduced tray movement, they transferred larger seismic forces directly to anchorage connections, increasing the possibility of: bolt stress concentration, anchorage failure, and support damage.

5. IS 1893:2025 Underestimated Experimental Force Demand

The experimentally observed seismic force exceeded the force predicted using Draft IS 1893(Part 1):2025 provisions. The comparison showed: IS 1893:2025 predicted force = 1.75 N and experimental force = 3 N

The experimental force was approximately 71% higher than the IS predicted value.

This indicates that simplified equivalent static procedures may underestimate seismic demand for suspended utility systems subjected to dynamic amplification.

ASCE 7 methodologies provided force predictions closer to the experimentally observed response because they include: floor amplification effects, dynamic amplification factors, and component flexibility considerations.

This demonstrates the importance of incorporating detailed dynamic response provisions into Indian seismic design standards for non-structural components.

6. Support Flexibility Plays a Critical Role

The study confirms that support flexibility significantly influences: acceleration amplification, force transfer, vibration response, and anchorage behaviour.

Therefore, support configuration should be considered as an important design parameter for seismic protection of utility systems.

5.3 CONTRIBUTIONS OF THE PRESENT STUDY

The present study provides the following important contributions:

1. Experimental validation of the newly introduced AEU provisions of Draft IS 1893(Part 1): 2025 .
2. Comparative evaluation of flexible and rigid cable tray support systems.
3. Experimental floor amplification data for RC frame structures.
4. Comparison between Draft IS 1893(Part 1):2025 and ASCE 7 provisions.
5. Design recommendations for seismic anchorage and bolting of cable tray systems.

The study also contributes towards improving seismic safety of non-structural utility systems in buildings.

5.3 FUTURE SCOPE

The present study provides experimental insight into seismic behaviour of cable tray systems; however, several areas remain available for further investigation.

1. Full-scale experimental testing may be conducted to validate the behaviour observed in scaled laboratory models.
2. Nonlinear numerical modelling may be incorporated for detailed dynamic response analysis.
3. Advanced finite element simulations may be used to study bolt failure and anchorage stress distribution.
4. Different utility systems such as HVAC ducts, suspended ceilings, and mechanical equipment may be investigated.
5. The influence of vertical seismic excitation on utility systems may be studied.
6. Various anchorage materials and bolt configurations may be experimentally evaluated.

7. Hybrid isolation systems and damped utility supports may be investigated for seismic vibration reduction.
8. Fragility curves for non-structural utility systems may be developed using probabilistic seismic analysis.
9. Future studies may evaluate seismic interaction between multiple utilities installed within congested service areas.
10. Further research may contribute toward development of detailed Indian guidelines specifically for seismic design of non-structural utility systems.

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