EFFECT OF PODIUM CONNECTED WITH BASEMENT WALLS IN TALL BUILDINGS

A DISSERTATION
SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY
IN
STRUCTURAL ENGINEERING

Submitted by:

DEEPANSHU GARG

2K19/STE/503

Under the supervision of

DR NIRENDRA DEV
(Professor)

DEPARTMENT OF CIVIL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

MAY, 2022

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CANDIDATE'S DECLARATION

I, Deepanshu Garg, 2K19/STE/503 of M.Tech (Structural Engineering), hereby declare that the project dissertation titled "Effect of Podium Connected with Basement Walls in Tall Buildings" which is submitted by me to the department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma, Associateship, Fellowship or other similar title or recognition.

Garg

Place: Delhi **DEEPANSHU GARG**

Date: 30.05.2022

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the project dissertation titled “Effect of Podium connected with Basement Walls in Tall Buildings” which is submitted by Deepanshu Garg, 2K19/STE/503 [Civil Engineering], Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students 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.

Nirendra Dev

Place: Delhi **(DR. NIRENDRA DEV)**

Date: 30.05.2022 **SUPERVISOR**

ABSTRACT

Sky-scrappers having basements or connected podiums surrounding by RCC walls are always beneficial in terms of the behavior of the structure under serviceability checks under earthquake or wind forces. It is shown in this dissertation by the help of number of models with podium and without podium for a type of structure. Podium may apply a restraint force called as strutting force on the slab connected with RCC walls which will result in reversing the effect of moments produced due to overturning of the building due to earthquake or wind forces. It is concluded in the report that the lateral deflection, drift and overturning moments are lesser in podium connected structures as compared to the structures without podium. Effect of outriggers addition to podium is also considered in the dissertation to find out the best possible configuration of building so that function-ability and economy may be achieved. Software using for analysis is ETabs 2020 and validation of models has been done using general checklist format given in IS 16700:2017. All analysis of the structures opted for dissertation has been completed using BIS codes.

ACKNOWLEDGEMENT

It gives me a great sense of pleasure to present the report of the M. Tech Project undertaken during M. Tech. Final Year. I owe special debt of gratitude to **Prof. Nirendra Dev**, Department of Civil Engineering, for his constant support and guidance throughout the course of the work. His sincerity, thoroughness and perseverance have been a constant source of inspiration for me. It is only his cognizant efforts that my endeavors have seen light of the day.

I also take the opportunity to acknowledge the contribution of **Prof. V. K. Minocha**, Head of Department of Civil Engineering, for allowing me to utilize the department facilities and his full support and guidance during the development of the project.

I also would not like to miss the opportunity to acknowledge the contribution of all faculty members of the department, Arun K Agarwal, Anil Agarwal & all AKB Consultants staff for their kind assistance and cooperation during the development of the project. Last but not the least, I would like to acknowledge my family, wife & friends for their contribution in the completion of the project.

DEEPANSHU GARG

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 General

Due to their fundamental behavior as imperative designs in current urban areas and cities, notwithstanding their significance as a maintainable arrangement from the social, financial and environmental points of view. Alternately to low-ascent structures, elevated structures are exceptionally mind boggling due to the enormous number of primary components and parts in the structure, also to numerous peculiarities which their effects will be huger on elevated structures than low-ascent structures. Specifically, the huge gravity loads in tall structures lead to the event of unwanted peculiarities like divergent pivotal shortening of segments and center walls, and base settle (divergent settlements of base) with impressive qualities. Also, the effects of horizontal forces, for example, seismic loads and wind loads, will be higher than short structures [20]. Consequently, the steadiness and rigidity rules will have an incredible importance contrasting and strength model, and they would result in controlling the end design because of structures extending to the sky.

The fast mechanical advancement in different viewpoints, (for example, building materials, damping frameworks, development innovations, improvement of modern primary investigation and configuration utilizing CAD software, and so forth) permits the elevated structure predominance in numerous nations particularly in arising economies nations, which are needing these designs due to the accompanying reasons:

1. The shortage of terrains in the urban communities notwithstanding the rising paces of urbanization over the most recent years (because of the quick development of populace and relocation of individuals from provincial regions to metropolitan) make elevated structures a suitable choice to take care of this issue.
2. The speed for developing the taller and famous structure in the world, locale, nation, or city, where a few elevated structures are viewed as a vacation destination focus moreover to the proud brought to the area and nation, e.g., Shangai Tower, Burj Khalifa, and so forth [20]. Consequently, complex-molded tall structures pervasively utilized for the present elevated structures, for example, twisted, tapered, deflected, and aerodynamically supported structures.
3. Denser metropolitan regions with tall structures are ideal according to the natural perspective as a result of their productivity as far as land use and energy utilization. Wherein more modest and denser urban areas, the power matrix is more modest, prompting an effective exchange of energy. Additionally, the requirement for car decreases that is viewed as huge supporter of the issues of contamination and productive energy utilization. Additionally, there is plausible of the re-formation of a ground like normal biological system and climate (vertical nursery sub-urban areas) in these structures at confounding levels. Thus, by making denser metropolitan regions with elevated structures, practical and shrewd urban communities are accomplished, and more regular green spaces and environments can be saved.

The underlying polish and effectiveness of outriggers have additionally become key components in the proficient and financial plan of elevated structures. While outriggers have just been integrated into tall structures from most recent forty years, the outrigger as an underlying component has a significantly longer history. The cruising boats at various times have utilized outriggers to assist with opposing the breeze powers in the sails, making the reception of tall and thin poles conceivable. In tall structures, the center can be connected with the pole of the boat, the outrigger to the spreader, and the outside sections to the stays or covers.

In elevated structures, this equivalent advantage is acknowledged by a decrease of the base center upsetting minutes and the related decrease in potential center inspire powers. The upsetting second opposed through a couple between the windward stay and the pole is like the second moved to gravity-stacked outside sections in elevated structures.

Outriggers are rigid horizontal structure which connect centrally placed core and exterior columns of the building resulting in betterment of building strength, overturning stiffness, lateral deflection, story drift, etc. Outrigger system may be understood as a structural behavior which is formed from an overhang horizontal element connected to central shear walls and peripheral columns by the means of concrete wall, truss, links, etc. When the lateral loads are applied on the building elements, the outrigger trusses may tend to rotate and resulting in compressive force in the opposite side of wind columns and tension in same side of wind columns and the pivotal stresses generated due to twisting results in overcoming the effect of rotation in core walls.

The outrigger framework is ordinarily utilized as one of the underlying framework to actually control the unnecessary drift because of horizontal forces, either hurricane or seismic load, the gamble of primary and non-basic harm may be limited. For elevated towers in seismically dynamic zones or wind predominant zones, this framework might be picked as a successful and fitting primary framework.

High-rise buildings that are more vulnerable to lateral pressures arise as a result of increased industry, economic reasons, population, and people's lifestyles in urban areas. Structural designers have been attempting to counteract these horizontal stresses and provide enough strength by including ‘‘moment resistant frames, cross braced, slab action, and RCC walls into the strengthening of a structure. RCC walls are built to counteract the effects of horizontal loads and provide the necessary strength and stiffness when a building is likely to act any seismic activity. Shear walls are the most effective lateral force-resisting approach when compared to all other lateral force-resisting methods, especially for elevated towers and lift scenarios.

1.2 Behavior of Outrigger System under Lateral loads

The primary course of action for this framework comprises of a super substantial center associated with outside segments by solid even individuals, for example, a one story deep walls or trusses normally alluded as outriggers. The center might be centrally placed put with outriggers stretching out on the two sides or it could be found erratically on one side of the structure with outriggers reaching out to the structure sections on one side (Figure-1).

Outrigger go about as a solid arm connecting with external sections, when focal center attempts to shift its revolution at outrigger level outcomes in actuating a strain pressure couple in external segments and acting in inverse to that second which goes about as restoring moment following up on the center at that level. Thus, the successful profundity of the design for opposing bowing is expanded when the center twist as an upward cantilever by the presentation of strain in windward and pressure in leeward segments.

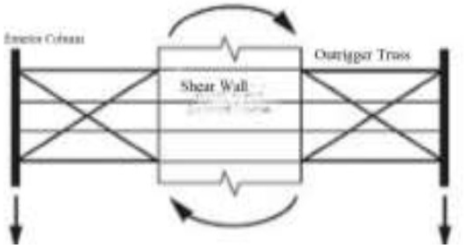


Figure 1: Behavior of an Outrigger system

While the outrigger configuration is successful in boosting the structural bending strength, it does not increase its resistance to shear, which must be handled primarily by the core in all of these circumstances.

1.3 Behavior of Outrigger System in Vertical loads

The essential capacity of outrigger framework is to expand the lateral stiffness of the structures under horizontal loads. In any case, because of peculiarity connected with tall structures, for example, differential shortening and base dishing or because of losing of a nearby element or associated strength, the towers with cantilever outrigger will expose to vertical force.

1.3.1 Load Path in Differential Axial Shortening

Small changes in strain between columns and core or between neighboring columns in a tall building can be caused by a variety of factors, including time-conditional changes such as elastic changes, changes due to creep, shrinkage and thermal effects [20]. It causes large changes in axial shortening across the building's height. This axial shortening causes outriggers to be displaced by differential movements, creating significant strains inside the outriggers that will create huge forces into the tower outrigger and transfer a portion of dead and live loads from columns to RCC walls placed centrally.

1.3.2 Load Way in Base Settlement

Differential settlements such as foundation dishing can occur for a variety of causes, including load concentration under a tall building's central core. This phenomena can result in varying vertical heights between the perimeter columns and the core, causing enormous forces through the outrigger configuration and will transfer the portion of the vertical loads from the RCC walls to the columns by the outriggers [20].

1.4 Types of Outrigger System

On the basis of connection with the RCC wall, there are two types of outrigger configurations:

- Core Outrigger System
- Peripheral Outrigger System

1.4.1 Core Outrigger System

Outrigger rafters or walls are being directly connected to RCC walls at the core and external members in a traditional outrigger arrangement. Over the height of the building, the number of outriggers might range from one to three or more. The outrigger rafters that are connected to the RCC walls and externally positioned vertical elements, prevent the walls from rotating and conversion of a portion of the moment in the walls to a vertical moment couple at the columns [13]. The outrigger will allow some rotation of the core by shortening and elongating the columns and deforming the trusses.

When a structure containing outrigger is being loaded horizontally, the walls will experience an over-turning flexure and twisting, and these loads will attempt to move the outrigger rafters up and down. The outriggers, which are controlled by columns, put resistance on the movement and generate pressures from opposite side [20]. These stresses will cause the outrigger rafters to turn in the other direction and will create opposite story shear stresses in the core, causing the deflection curve to invert. By introducing compressive force in opposite side of columns and tension in same side of columns, this change in curvature will reduce the over-turning forces, rotations, and lateral changes at the top, improving the overall design depth of the structure when it will be deflected like a cantilever beam [20].

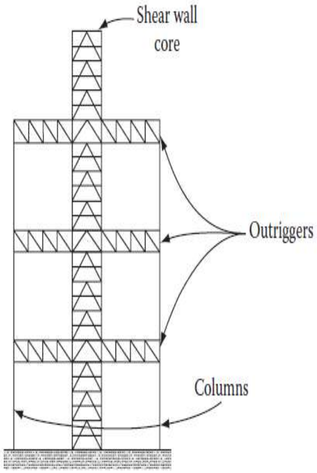


Figure 2: Core Outrigger System

1.4.2 Peripheral Outrigger System

Lateral stresses that cause the core to rotate and topple may shift floor center of stiffness at various belt element heights on separate stories. By shifting one face down and one face up, the belt truss that connects both levels tries to spin and follow itself. Peripheral vertical elements that will create opposite direction forces and limit the motions. The end bay columns usually create the greatest forces. These stresses on vertical elements will act by the belt rafters and will produce forces in horizontal directions in the story slab in the opposite direction and causing a opposite directional story shear in the center walls, reducing twisting and moments [20].

The virtual outrigger is viewed as the most practical kind of outrigger and utilized in skyscraper structures due for its various potential benefits over the regular one, for example, the extra free space coming about because of overlooking outriggers, likewise it assists with disposing of gravity powers moved through customary outriggers because of differential shortening.

In this type, the major and critical factor for economic performance of the system is slab strength and lateral stiffness.

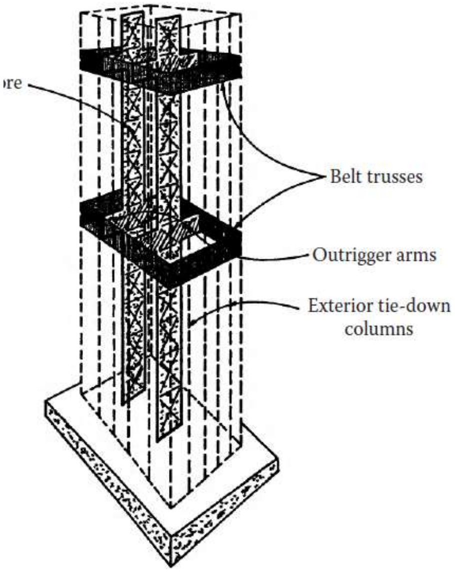


Figure 3: Peripheral Outrigger System

The fundamental idea driving the peripheral outrigger configuration is to utilize floor action, which are normally extremely firm areas of strength for and their own plane, leads to moment transfer as a lateral couple from the center that are not associated directly with core wall. The virtual outrigger's main principle is to apply slab diaphragms, which are normally quite stiffen and robust in the same plane, to transfer flexure moment in the way of a horizontal couple from the RCC wall to vertical components that aren't directly linked to the core. The rafters or walls then will change the force couples into vertical couples in segments or other primary components detachable to core. Belt brackets and basement walls are appropriate to use as virtual outrigger.

1.5 Peripheral Belt Truss Outriggers

The floor diaphragms at the top and bottom of the belt trusses resist rotation of the core, converting part of the moment in the core into a horizontal couple in the floor. The horizontal coupling is turned into vertical forces at the external columns by the truss, which is passed through the two floors to the truss chords.

Forces may be carried through the concrete-to-concrete connection when the core is a concrete shear wall, with reinforcing steel extending to the connection. Shear studs on the chords are used to transmit horizontal stresses between the floor diaphragms and the chords of the belt trusses.

1.6 Peripheral Basement Walls as Outriggers

A tall building's basement can also act as a virtual outrigger, creating a foundation with a wider effective width to prevent overturning. This can lessen or eliminate uplift caused by lateral stresses on foundation components. Basement walls are sufficiently strong and rigid to serve as outriggers.

When the core has a soft support, the basement wall's usefulness as an outrigger may be maximum. Because of the firm support, the majority of the moment in the core may travel straight to the core foundation rather than the outrigger walls.

1.7 Components of Outrigger system

The outrigger configuration is collected from 4 elements:

- Internal configuration: It may be of a steel linked central portion, RCC wall or modified core.
- External configuration: These may be of framed tubular configuration, moment opposing vertical elements and beam system.
- Outrigger Rafters: These are stiff connections that connect the inside and outside structural systems. It might be a concrete wall, a truss with various geometries, a deep beam, and so on.
- Peripheral Belt: It's a connector that connects all or part of the perimeter columns. A wall, truss, or deep beam might be involved.

1.8 Merits and Demerits of Outrigger System

1.8.1 Merits of Outrigger System

- In high-rise structures, the outrigger system may readily be coupled with various structural systems.

- In addition to a significant decrease in core overturning moment, the outrigger system effectively lowers building distortions from flexural bending and the consequent in-plane displacements at above levels [20].
- The overall flexural behavior of outrigger-braced tall structures reduces the impacts of dynamic fragility in dynamic excitation of the outrigger panel and broad perimeter columns significantly.
- The traditional outrigger system aids in the reduction of unequal elongation and base dishing.
- Outriggers or peripheral trusses give an alternate approach to combat the quick loss of local members owing to explosion in the event of a catastrophe.
- Outrigger systems may be made from a variety of materials, including concrete, steel, and modified composite material.
- It reduces net tensile stresses and upward pressures across the substructure system and vertical elements, as well as high shear requirement in foundations.
- Floor plan freedom, in which the location of external vertical elements are not affected by structural issues but rather by esthetic and functional factors.
- External framework may be done using simple beam interconnections rather than stiff frame connections, resulting in cost savings.
- The outriggers in a combination system comprising solitary tube or number of multi-level outrigger system will not only boost stiffness but will also smooth the axial pressure distribution in tube columns, reducing shear deformation effects.
- If the outrigger system is planned and developed correctly, it will give the best structural stiffness and strength, leads to better equilibrium between acceleration as well as inter-story movement needs.

1.8.2 Demerits of Outrigger System

- The most significant disadvantage of using cantilever systems is the possibility of obstructing occupation and leasable space.
- While the system's remarkable effectiveness in boosting the structure's flexural stiffness, it is unable to raise the structure's resistance to shear, that is mostly borne by the core.
- Outrigger floors cause inconsistencies in a high-rise building's stiffness distribution, and they can contribute to the emergence of weaker storeys close the

outrigger floors in the event of an earthquake or wind, which is against mandatory code requirements.

- The influence of the outrigger construction on the execution of the work is another possible negative. Because of the lifting, welding, and fitting of outrigger sections and components, standard building methods take 3 to 4 days per floor for core wall construction, but almost a month required for outrigger levels. To expedite construction and avoid delaying the core wall, the center at outrigger levels were partially blocked off during construction.
- Shrinkage, lateral displacement, temperature changes, and creep are the principal causes of peripheral frame and core shrinkage. Due to the high stiffness of outrigger parts, a minor vertical displacement causes very substantial axial forces in them.
- If the axial stresses caused by shortness cannot be released, the size of the outriggers must be doubled (costly design).
- Between the points of the outriggers and the columns, special connectors are employed. These connections may be adjusted during and perhaps after construction, making the outrigger system operational during that time.

1.9 Factors Affecting Outrigger System Performance

Outrigger system performance is influenced by a number of elements, as listed below:

- Positions and number of outriggers, as well as the stiffness of outrigger rafters.
- The corresponding stiffness of rafter parts of the system, like the centrally placed walls and rafter stiffness and the center walls and perimeter columns' relative stiffness [20]. As a result, these elements are:
    (i) Core outrigger and peripheral truss bending and shear stiffness
    (ii) The bending or axially loaded member stiffness of the peripheral elements
    (iii) Inner central flexural strength.
- Complete building configuration: In order to attain aesthetic purpose, complex architectural form such as twisted, slanted, and tapered geometries are replacing simple architectural features in modern tall building designs. The outrigger system's contribution to total building rigidity is influenced by these complicated geometries.
- Floor slab strength, likely in peripheral outriggers.

- The maximum gravity forces that may be delivered by outriggers (due to unequal shortening).
- The building's height, floor height, and layout measurements between central walls and rafters of outrigger centroids, as well as lateral force patterns.
- Selecting the right outrigger configuration based upon the main horizontal loads, floor layout, and other factors. For example, when wind loads are dominant, rigid outrigger systems are preferred; when seismic loads are dominant, flexible outrigger systems are preferred; when enough free space is required or gravitational attraction stresses transferred by traditional outriggers are eliminated, virtual outrigger systems are preferred; when both wind and earthquake forces are dominant, damped outrigger systems are preferred [20].

1.10 Backstay effect imposed due to Common Slab connected with Elevated Structures Tower

Podiums are supplemental floor sections at the lower levels of high-rise buildings that are typical in urban areas with low-to-moderate seismicity. Moment resistant frame and shear (or core) walls make up the lateral force resisting system for such structure layouts. Because the building's tower walls are offset from the podium's core, significant twisting moments can be forced on the podium.

When exposed to strong earthquake ground shaking, high shear stresses can be created on structural walls, jeopardizing their structural integrity. Despite the possibility for poor behavior in a rare seismic event, recommendations against this type of building have not been imposed in many design standards of practice.

Horizontal forces are transmitted from the tower to the floor at the podium-tower contact. To resist overturning operations, reactive pressures are created at the podium-tower contact. The rearward span of a suspension is analogous to the responding mechanism. In theory, the stated backstay mechanism can provide a high-intensity shear stress in the podium's structural (tower) wall. The in-plane stiffness of the floor slab linking the two walls determines the magnitude of the produced shear force.

The inside wall, that is close to the podium's center, is subject to greater moment restrictions from the podium construction than the external wall. To preserve compatibility, strong strutting forces are created in the connected structural element (beam and slab). The horizontal in-plane displacement of the floor diaphragm must be included in the modelling to appropriately depict this strutting movement. As a result, the assessments that use the (typical) stiff floor diaphragm (common slab action) assumption may distort the scope of such activities and leads to an economic structure.

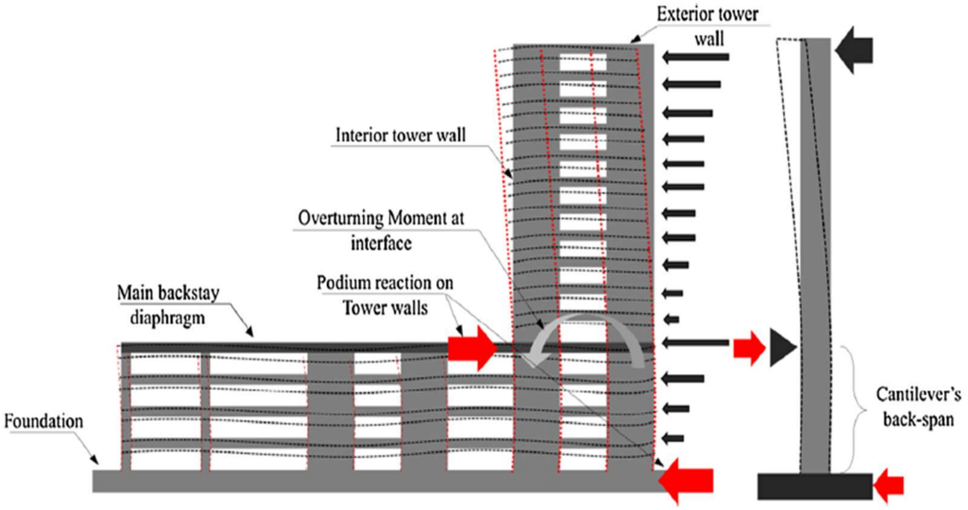


Figure 4: General Arrangement of Podium connected with Tower

As per structural geometry, the lateral resisting system is considered as a suspension system overhang from an intermediate support, which is given by the above ground, at-ground, and below ground diaphragms, as well as peripheral shear (basement walls). The Backstay Effect is a collection of lateral forces that occur inside a plinth structure to balance the lateral pressures and moments of a tower that extends above it.

The so-called "Backstay Effect" can result in massive force transfers and a significant shift in the redistribution of base shear and bending moments below the podium diaphragm. Because of the overturning resistance supplied mostly by plinth to the tower, the lateral force resistant parts of the tower notice a shift in direction of the Base shear at the ground - floor interface level and below, the Back-Stay effect is also known as Shear-Reversal [2].

- Through diaphragm action, the backstay distributes stresses from the lateral forces resisting elements in the tower to extra components provided inside the podium and basement [2].
- Backstay effect, also known as shear reversal, occurs when the shear force reverses within podium levels but same lateral force resisting part assists in resisting the transition [2].

1.11 Sensitivity Analysis

When an earthquake occurs, the fissures in the sections will develop. Because the true scope of crack formation cannot be determined, and because once cracks form, the element starts to lose its original stiffness, varying rigidity modifiers are adapted to various structural elements to consider the effect of rupturing on section stiffness, and thus on the behavior and evaluating results of a structure of the building [10].

Sensitivity Method is a tool for evaluating a building's behavior under various situations by progressively altering the stiffness attributes of its structural parts. The below-grade podium receives the Top Bound and Under Bound modifiers. Structural elements alone, with RC Cracked section parameters added to the building structural elements as per Table 6 of IS 16700:2017, page no. 7 [2].

CHAPTER 2

LITERATURE REVIEW

Kush Shah et al. (2020), this paper illustrates the lateral load resisting system supported by ground and below ground level diaphragms connected with basement walls. To achieve the objective, several models with different geometrical conditions are considered to review the actual behavior of the building under backstay effect. Models are prepared using lower and upper bound stiffness values given in IS 16700:2017 and a stiffness analysis has been done to check the serviceability of building. As per this analogy, model having shear wall on periphery of podium has maximum shear reversal and thus resulting in decreasing displacement of the building. It is also evaluated in the paper that axial forces created in beams near podium cutouts are almost 3 times higher than actual which needs to be checked during design of building. The main output of this study is that during modelling of tower with podium, one should model the podium completely with tower to analyze the actual results and this practice may achieve better strength, serviceability and economy [10].

Mehair Yacoubian et al.(2017), this paper illustrates the interference of non-tower structure to tower. It is found in this study that structure surrounding tower portion, i.e. podium, can exert considerable differential restraints on reinforced concrete walls. Wall-slab action is acting as strutting forces that are transferred in the other stories up and down grade level. These wall-slab acting forces are then distributed in inner and external walls and a equilibrium above the podium level formed. A study on models are done to quantify the serviceability factors of building. Rigid diaphragms action is basically considered to review the actual behavior of building. The increment of shear forces in coupling beams are examined by push-over analysis on simplified models. It is reviewed that shear force collection in coupling beams resulting in brittle failure of ductile walls. The wall curvature changes drastically at podium level resulting in decrement of lateral displacement, drift and overturning moments resulting in building with better serviceability checks [15].

Bungale S. Taranath, this reference books illustrate the concept of outrigger system analytically and in practical aspects and helps in understanding the various types of structural systems and their advantages and disadvantages as compared to outrigger system. It also solves the mathematical modelling of various outrigger systems and suggest the optimum location of outrigger with respect to the strength and deflection parameters using American codes of design. It also suggest core bracing to be used in addition to the outriggers for much better results [4].

Amit R. Chotalia, this paper introduced an analytic definition of perimeter bound system in summation to the various preparation of models of a 35, 50 and 70 stories by using belt truss at single, double and triple levels with different types of bracings used. Based on various model results a conclusion have been made to conclude out the most economical configuration, shape and story of outrigger [1].

Wael Alhaddad, the paper illustrated a natural meaning of outrigger system as well as the various grouping of this system. Resulting from various grouping and materials, this paper shows the response behavior of outrigger system with for and against of the belt truss system based on various aspects [20].

IS 16700:2017, as per clause 8.1.3.3.1, which states that transferring the podium generated forces from lateral load resisting members in super structure to the additional basement walls connected with the common slab and the basement through one or more floor diaphragms and lateral load resisting members at podium story with induced forces transferring way through slab action will help tall building to overcome the effects of overturning moments induced due to lateral loads. The podium slabs are to be checked for forces came from sensitivity analysis. The floor slab of upper and lower levels are to be modelled to capture possible cracking in diaphragm by assuming an upper bound and lower bound axial stiffness [2].

CHAPTER 3

METHODOLOGY & VALIDATION

3.1 Geometric parameters

One building layout is investigated in this study, which includes structures that are positioned on flatland. The number of stories taken into account for each type of setup is 40. The building is square in geometry with podium area greater than tower area plate. Different models have been prepared with podium at different levels to review the serviceability effects on the structure. All variants of the building frame have the same plan arrangement. To prevent complications like orientation, the columns are assumed to be square and shear walls are being assumed in the lift & staircase core. The podium at all levels are assumed to be connected with basement walls to serve the purpose of collector wall.

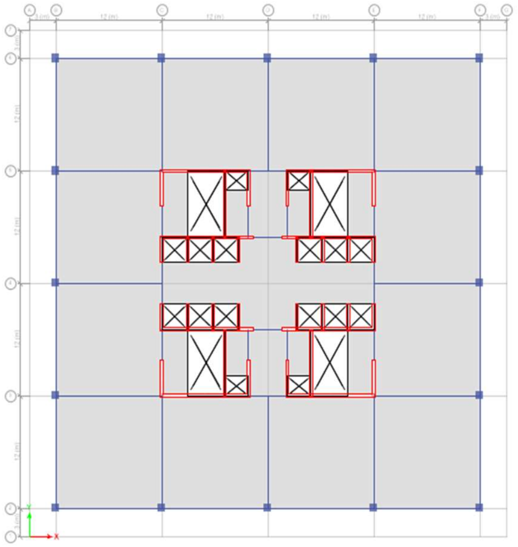


Figure 5: Typical Floor Plan

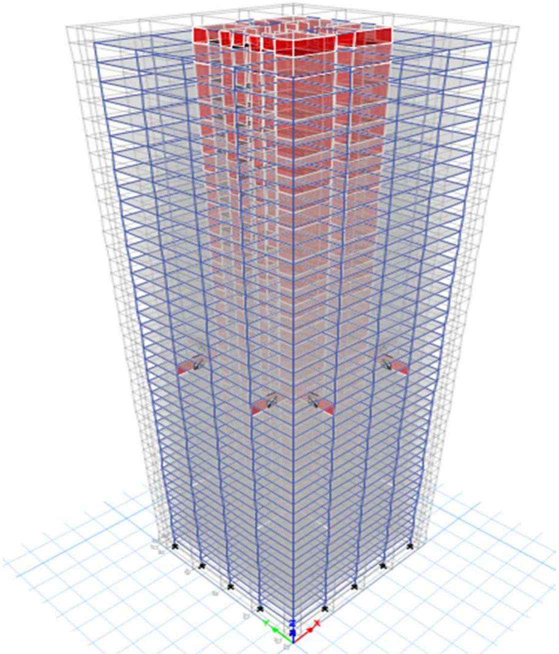


Figure 6: Typical Tower Elevation

3.2 Modelling

The building is planned with ductile shear walls, columns & beam-slab system. After assuming dimensions of various members, a computer CAD model of the frame of structure is produced for resulting out CAD analysis for the effects of vertical and horizontal loads that are to be applied on the elements chosen. The structure is being analyzed using ETabs 2020. Geometrical sizes, element properties and member & node connectivity, including eccentricities is being modeled in the CAD analysis. The allowable values of the load and resulting stresses is being utilized within the code compliance of the Indian standards. The computer aided analysis evaluated the individual member forces, base forces at founding level and displacement pattern of the entire building structure and in the elements. The outcomes of the CAD model is then to be used to verify adequacy of the element sizes assumed and further possibilities to be carried out as required to rationalize the system and sizes of structural members. The whole structure is idealized as a space frame. Beams, columns and shear walls in the structure are modeled as line members. The slabs are modelled as plate elements. The structure is analyzed for all possible loads i.e. gravity loads and lateral loads likely to be applied on the structure.

3.3 Design Data Consideration

Table 1: Design Data of Statement Problem

Number of stories	**G+39**
Strength of Concrete	M30
Reinforced Steel Strength	Fe500D
Horizontal Members Dimension	600mm*900mm
Vertical Member Dimension	900mm*900mm
Slab Thickness	300mm
Zone factor (Z)	0.24
Damping ratio	2%
Typical Floor height	4.0m
Ground floor height	4.0m
Importance factor	1.2
Response reduction factor (R)	5
Soil type	II (Medium Soil)
Shear Wall Dimension	300 mm thick
Typical Floor Live load	4 kN/m^2
Finishing Load	2.5 kN/m^2
Wind Speed	47 m/s
Risk Factor, k_1	1.0
Terrain Factor, k_2	1.0
Topography Factor, k_3	1.0
Cyclonic Importance Factor, k_4	1.0
Retaining Wall Thickness	450mm
Podium Slab Thickness	300mm
Podium Level Live Load	4 kN/m^2

3.4 Models Pertaining to Statement Problem

Number of models are being prepared for achieving the objective of the dissertation to valid the results of tall building including a connected podium to the basement walls. Models prepared are with podium and without podium and additionally included outrigger at mid height level to check the more effectiveness of the structural system so that a most desirable configuration of structure may be concluded. Below are the table containing models prepared for the statement problem.

Table 2: Model Description of Statement Problem

Model No.	**Description**
1	Building with No Podium and No Outrigger
2	Building with 1 Podium and No Outrigger
3	Building with 2 Podium and No Outrigger
4	Building with 3 Podium and No Outrigger
5	Building with 4 Podium and No Outrigger
6	Building with No Podium and Mid Height Core Outrigger
7	Building with 1 Podium and Mid Height Core Outrigger
8	Building with 2 Podium and Mid Height Core Outrigger
9	Building with 3 Podium and Mid Height Core Outrigger
10	Building with 4 Podium and Mid Height Core Outrigger

3.5 Methodology of Analysis

The building is analyzed having 40 stories with different numbers of basements with RCC wall connected rigidly with ductile shear walls, columns & beam-slab system. A analysis is carried out to evaluate the behavior of building due to backstay effect of podium and to evaluate the effect of backstay for varying number of basements.

Also, a core-outrigger is analyzed with backstay effect of podium to check the dual behavior on the tall buildings. Building is assumed to be situated in Delhi zone with seismic zone-IV.

Ten number of models stated in 3.4 are prepared to evaluate the desired effect of podium on the tall buildings.

3.6 Validation of Models

The building is analyzed having 40 stories with different numbers of basements with RCC wall connected rigidly with ductile shear walls, columns & beam-slab system. A analysis is carried out to evaluate the behavior of building due to backstay effect of podium and to evaluate the effect of backstay for varying number of basements.

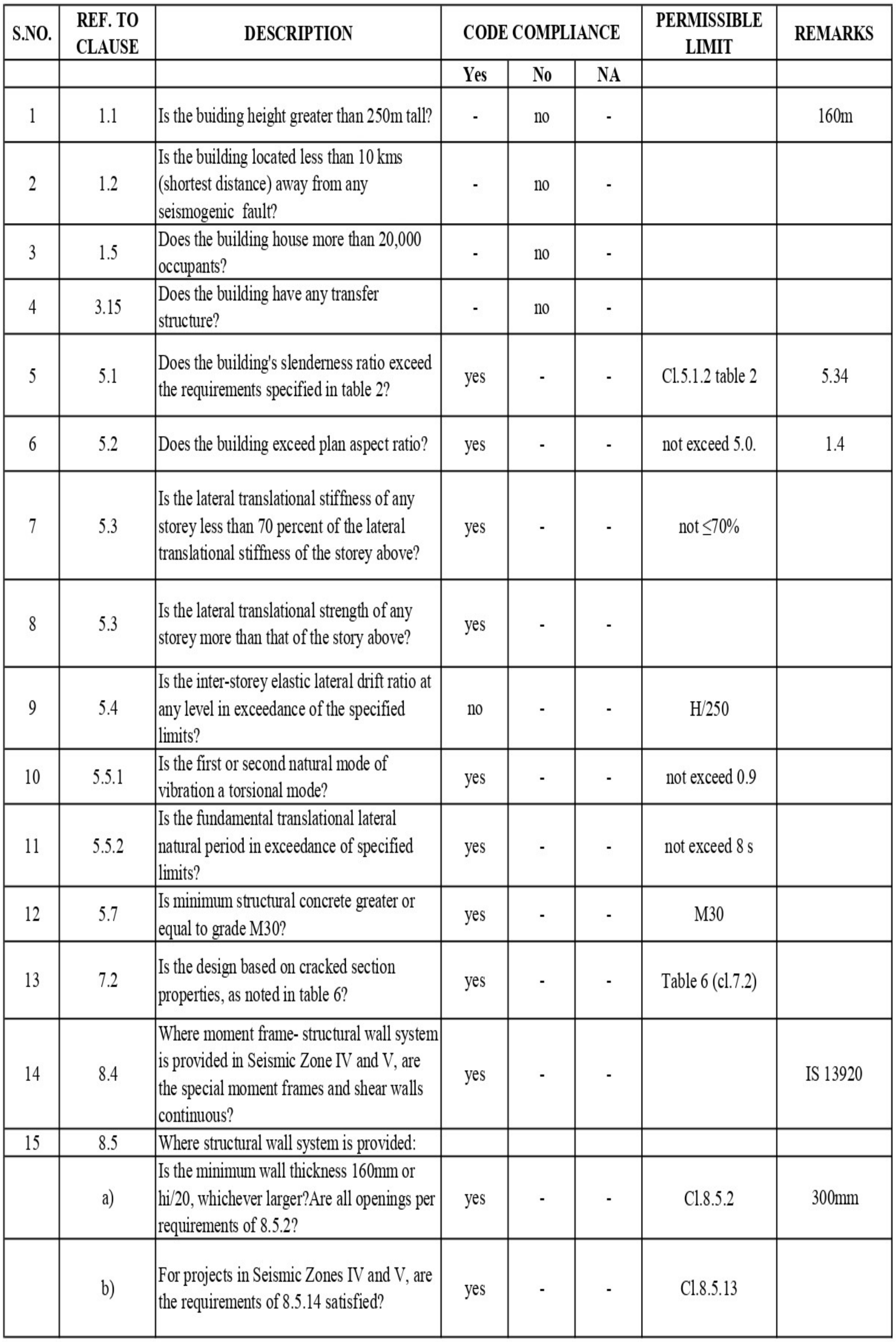
Model validation is the important step of the analysis by which one may check the validity and correctness of the model which is used in the analysis for the purpose of outcomes required to fulfill the need of the project.

Model validation may be done by using different checklists prepared by the help of data collected from CAD analysis results of the models. Firstly, static check of the model is required to perform by which loads applied on the model, i.e. Dead loads, Live loads, Wind loads, Seismic loads, Base shears, Time period of the model, may be reviewed and may check the correctness of the model in view of BIS codes.

As the structure chosen for analysis is a tall building of height greater than 50m but less than 250m. A different checklist format has been chosen to check the validity of the model and to verify the correctness of the model.

A generic checklist format given at page 18 of IS 16700:2017 [2] has been used to validate the models prepared for the fulfillment of objectives of the project. Checklists of all the models are prepared below to check the correctness of the model and it is reviewed that the models are meeting all code compliances and hence it can be concluded that the models opted for the CAD analysis are then may be used for final results so that a brief conclusion may be prepared to achieve the objectives.

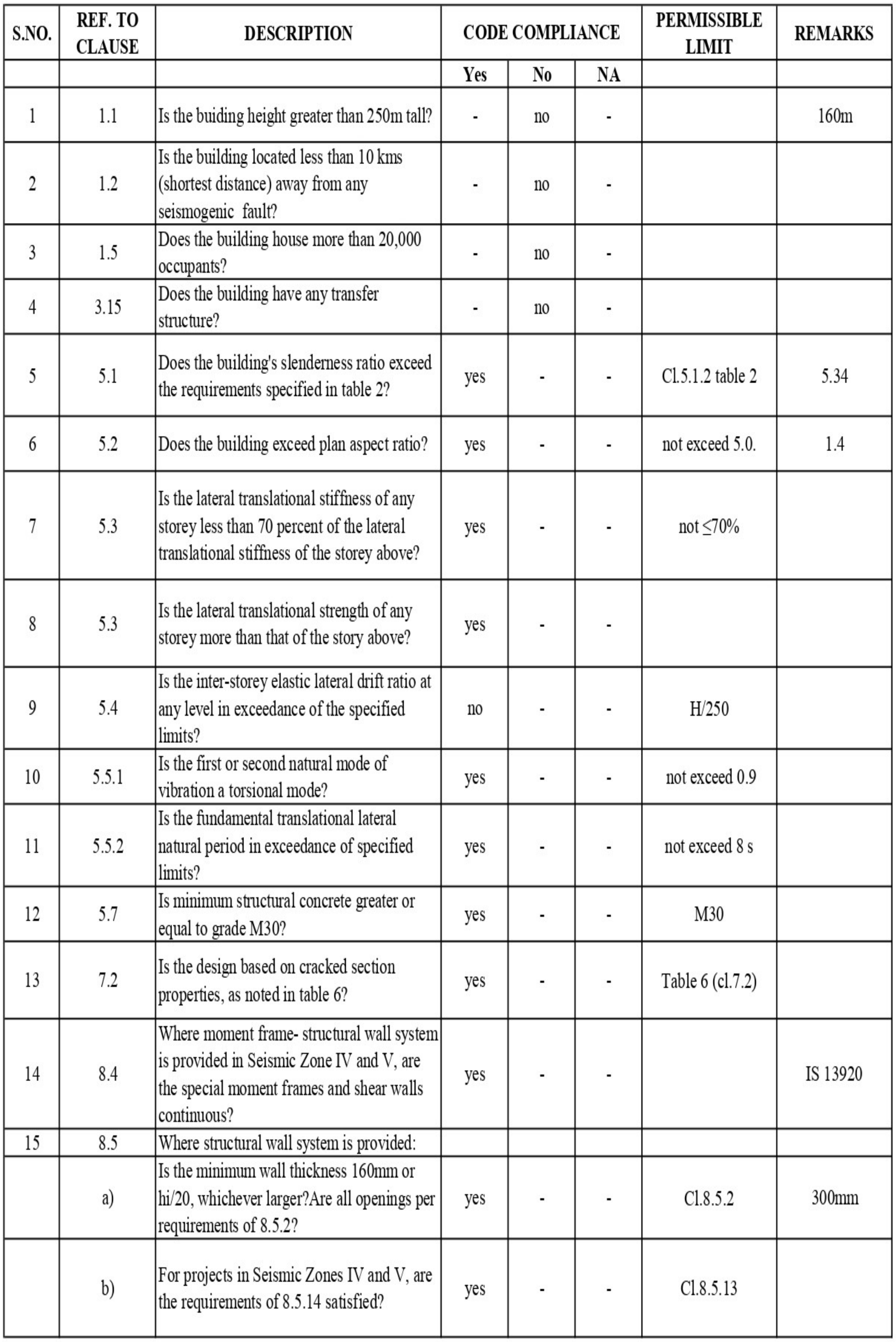
Table 3: Validation of Model-1



S.NO.	REF. TO CLAUSE	DESCRIPTION	CODE COMPLIANCE			PERMISSIBLE LIMIT	REMARKS
			Yes	No	NA		
1	1.1	Is the buiding height greater than 250m tall?	-	no	-		160m
2	1.2	Is the building located less than 10 kms (shortest distance) away from any seismogenic fault?	-	no	-		
3	1.5	Does the building house more than 20,000 occupants?	-	no	-		
4	3.15	Does the building have any transfer structure?	-	no	-		
5	5.1	Does the building's slenderness ratio exceed the requirements specified in table 2?	yes	-	-	Cl.5.1.2 table 2	5.34
6	5.2	Does the building exceed plan aspect ratio?	yes	-	-	not exceed 5.0.	1.4
7	5.3	Is the lateral translational stiffness of any storey less than 70 percent of the lateral translational stiffness of the storey above?	yes	-	-	not ≤70%	
8	5.3	Is the lateral translational strength of any storey more than that of the story above?	yes	-	-		
9	5.4	Is the inter-storey elastic lateral drift ratio at any level in exceedance of the specified limits?	no	-	-	H/250	
10	5.5.1	Is the first or second natural mode of vibration a torsional mode?	yes	-	-	not exceed 0.9	
11	5.5.2	Is the fundamental translational lateral natural period in exceedance of specified limits?	yes	-	-	not exceed 8 s	
12	5.7	Is minimum structural concrete greater or equal to grade M30?	yes	-	-	M30	
13	7.2	Is the design based on cracked section properties, as noted in table 6?	yes	-	-	Table 6 (cl.7.2)	
14	8.4	Where moment frame- structural wall system is provided in Seismic Zone IV and V, are the special moment frames and shear walls continuous?	yes	-	-		IS 13920
15	8.5	Where structural wall system is provided:					
	a)	Is the minimum wall thickness 160mm or hi/20, whichever larger?Are all openings per requirements of 8.5.2?	yes	-	-	Cl.8.5.2	300mm
	b)	For projects in Seismic Zones IV and V, are the requirements of 8.5.14 satisfied?	yes	-	-	Cl.8.5.13	

(Source: IS: 16700:2017)

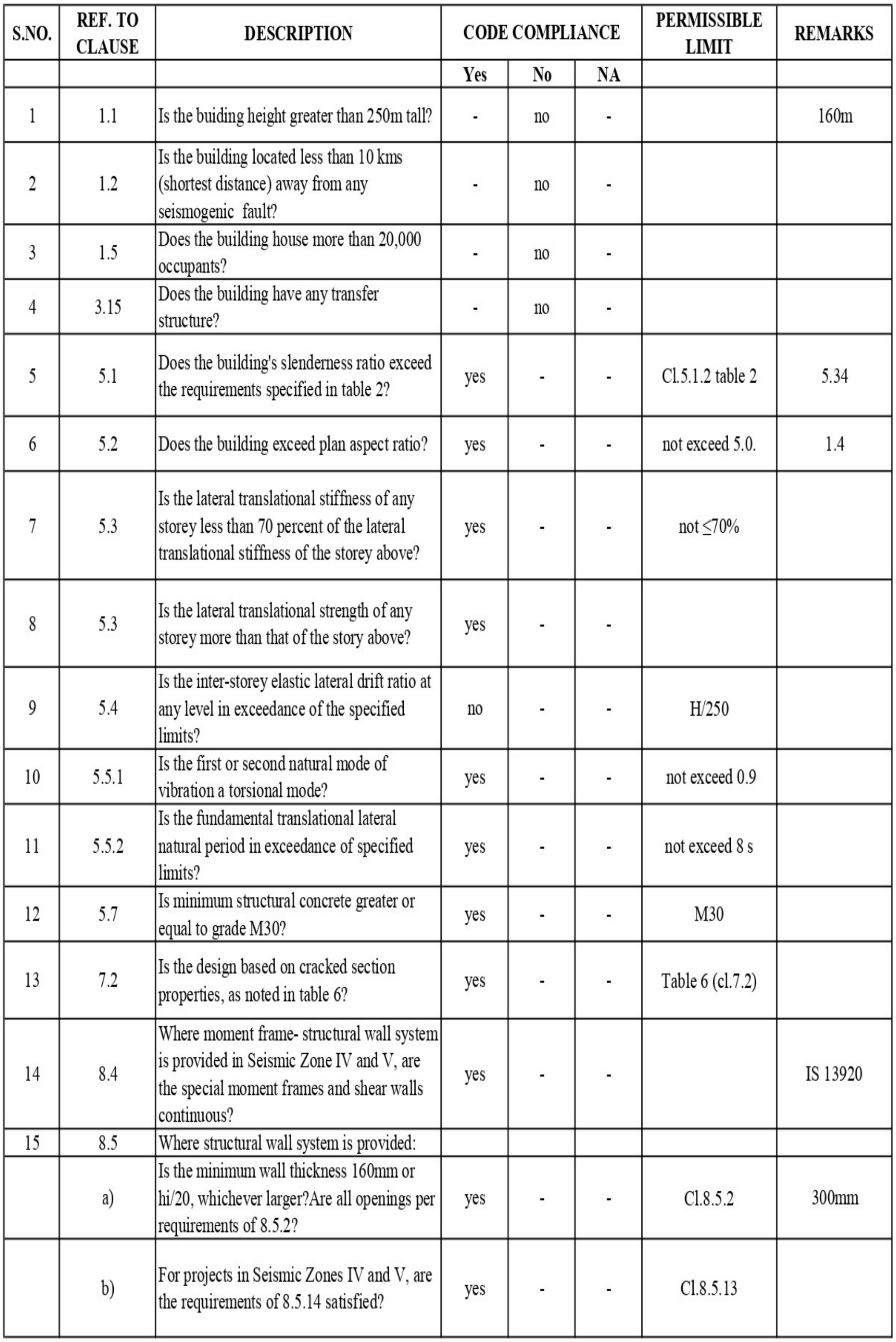
Table 4: Validation of Model-2



S.NO.	REF. TO CLAUSE	DESCRIPTION	CODE COMPLIANCE			PERMISSIBLE LIMIT	REMARKS
			Yes	No	NA		
1	1.1	Is the buiding height greater than 250m tall?	-	no	-		160m
2	1.2	Is the building located less than 10 kms (shortest distance) away from any seismogenic fault?	-	no	-		
3	1.5	Does the building house more than 20,000 occupants?	-	no	-		
4	3.15	Does the building have any transfer structure?	-	no	-		
5	5.1	Does the building's slenderness ratio exceed the requirements specified in table 2?	yes	-	-	Cl.5.1.2 table 2	5.34
6	5.2	Does the building exceed plan aspect ratio?	yes	-	-	not exceed 5.0.	1.4
7	5.3	Is the lateral translational stiffness of any storey less than 70 percent of the lateral translational stiffness of the storey above?	yes	-	-	not ≤70%	
8	5.3	Is the lateral translational strength of any storey more than that of the story above?	yes	-	-		
9	5.4	Is the inter-storey elastic lateral drift ratio at any level in exceedance of the specified limits?	no	-	-	H/250	
10	5.5.1	Is the first or second natural mode of vibration a torsional mode?	yes	-	-	not exceed 0.9	
11	5.5.2	Is the fundamental translational lateral natural period in exceedance of specified limits?	yes	-	-	not exceed 8 s	
12	5.7	Is minimum structural concrete greater or equal to grade M30?	yes	-	-	M30	
13	7.2	Is the design based on cracked section properties, as noted in table 6?	yes	-	-	Table 6 (cl.7.2)	
14	8.4	Where moment frame- structural wall system is provided in Seismic Zone IV and V, are the special moment frames and shear walls continuous?	yes	-	-		IS 13920
15	8.5	Where structural wall system is provided:					
	a)	Is the minimum wall thickness 160mm or hi/20, whichever larger?Are all openings per requirements of 8.5.2?	yes	-	-	Cl.8.5.2	300mm
	b)	For projects in Seismic Zones IV and V, are the requirements of 8.5.14 satisfied?	yes	-	-	Cl.8.5.13	

(Source: IS: 16700:2017)

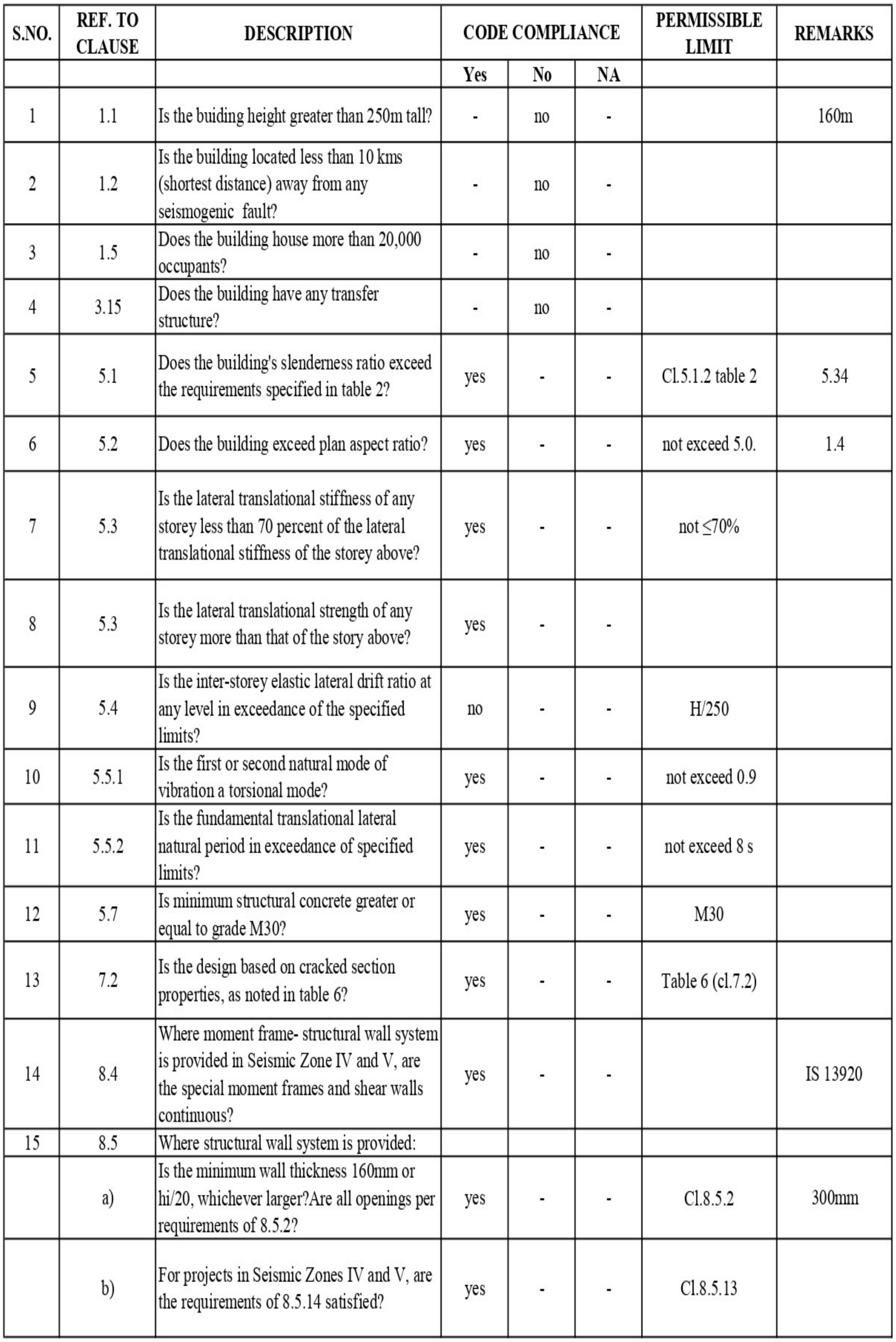
Table 5: Validation of Model-3



S.NO.	REF. TO CLAUSE	DESCRIPTION	CODE COMPLIANCE			PERMISSIBLE LIMIT	REMARKS
			Yes	No	NA		
1	1.1	Is the buiding height greater than 250m tall?	-	no	-		160m
2	1.2	Is the building located less than 10 kms (shortest distance) away from any seismogenic fault?	-	no	-		
3	1.5	Does the building house more than 20,000 occupants?	-	no	-		
4	3.15	Does the building have any transfer structure?	-	no	-		
5	5.1	Does the building's slenderness ratio exceed the requirements specified in table 2?	yes	-	-	Cl.5.1.2 table 2	5.34
6	5.2	Does the building exceed plan aspect ratio?	yes	-	-	not exceed 5.0.	1.4
7	5.3	Is the lateral translational stiffness of any storey less than 70 percent of the lateral translational stiffness of the storey above?	yes	-	-	not ≤70%	
8	5.3	Is the lateral translational strength of any storey more than that of the story above?	yes	-	-		
9	5.4	Is the inter-storey elastic lateral drift ratio at any level in exceedance of the specified limits?	no	-	-	H/250	
10	5.5.1	Is the first or second natural mode of vibration a torsional mode?	yes	-	-	not exceed 0.9	
11	5.5.2	Is the fundamental translational lateral natural period in exceedance of specified limits?	yes	-	-	not exceed 8 s	
12	5.7	Is minimum structural concrete greater or equal to grade M30?	yes	-	-	M30	
13	7.2	Is the design based on cracked section properties, as noted in table 6?	yes	-	-	Table 6 (cl.7.2)	
14	8.4	Where moment frame- structural wall system is provided in Seismic Zone IV and V, are the special moment frames and shear walls continuous?	yes	-	-		IS 13920
15	8.5	Where structural wall system is provided:					
	a)	Is the minimum wall thickness 160mm or hi/20, whichever larger?Are all openings per requirements of 8.5.2?	yes	-	-	Cl.8.5.2	300mm
	b)	For projects in Seismic Zones IV and V, are the requirements of 8.5.14 satisfied?	yes	-	-	Cl.8.5.13	

(Source: IS: 16700:2017)

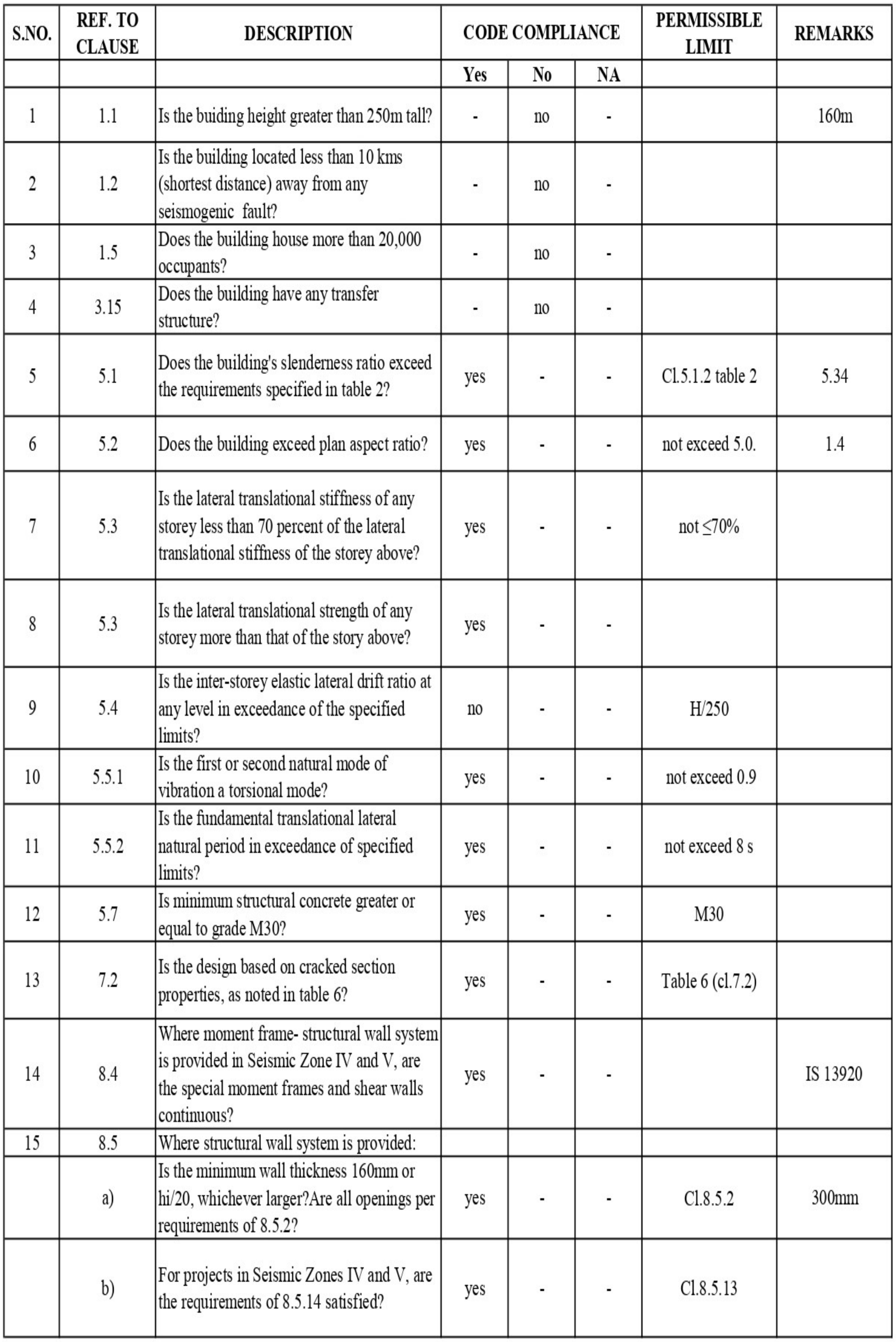
Table 6: Validation of Model-4



S.NO.	REF. TO CLAUSE	DESCRIPTION	CODE COMPLIANCE			PERMISSIBLE LIMIT	REMARKS
			Yes	No	NA		
1	1.1	Is the buiding height greater than 250m tall?	-	no	-		160m
2	1.2	Is the building located less than 10 kms (shortest distance) away from any seismogenic fault?	-	no	-		
3	1.5	Does the building house more than 20,000 occupants?	-	no	-		
4	3.15	Does the building have any transfer structure?	-	no	-		
5	5.1	Does the building's slenderness ratio exceed the requirements specified in table 2?	yes	-	-	Cl.5.1.2 table 2	5.34
6	5.2	Does the building exceed plan aspect ratio?	yes	-	-	not exceed 5.0.	1.4
7	5.3	Is the lateral translational stiffness of any storey less than 70 percent of the lateral translational stiffness of the storey above?	yes	-	-	not ≤70%	
8	5.3	Is the lateral translational strength of any storey more than that of the story above?	yes	-	-		
9	5.4	Is the inter-storey elastic lateral drift ratio at any level in exceedance of the specified limits?	no	-	-	H/250	
10	5.5.1	Is the first or second natural mode of vibration a torsional mode?	yes	-	-	not exceed 0.9	
11	5.5.2	Is the fundamental translational lateral natural period in exceedance of specified limits?	yes	-	-	not exceed 8 s	
12	5.7	Is minimum structural concrete greater or equal to grade M30?	yes	-	-	M30	
13	7.2	Is the design based on cracked section properties, as noted in table 6?	yes	-	-	Table 6 (cl.7.2)	
14	8.4	Where moment frame- structural wall system is provided in Seismic Zone IV and V, are the special moment frames and shear walls continuous?	yes	-	-		IS 13920
15	8.5	Where structural wall system is provided:					
	a)	Is the minimum wall thickness 160mm or hi/20, whichever larger?Are all openings per requirements of 8.5.2?	yes	-	-	Cl.8.5.2	300mm
	b)	For projects in Seismic Zones IV and V, are the requirements of 8.5.14 satisfied?	yes	-	-	Cl.8.5.13	

(Source: IS: 16700:2017)

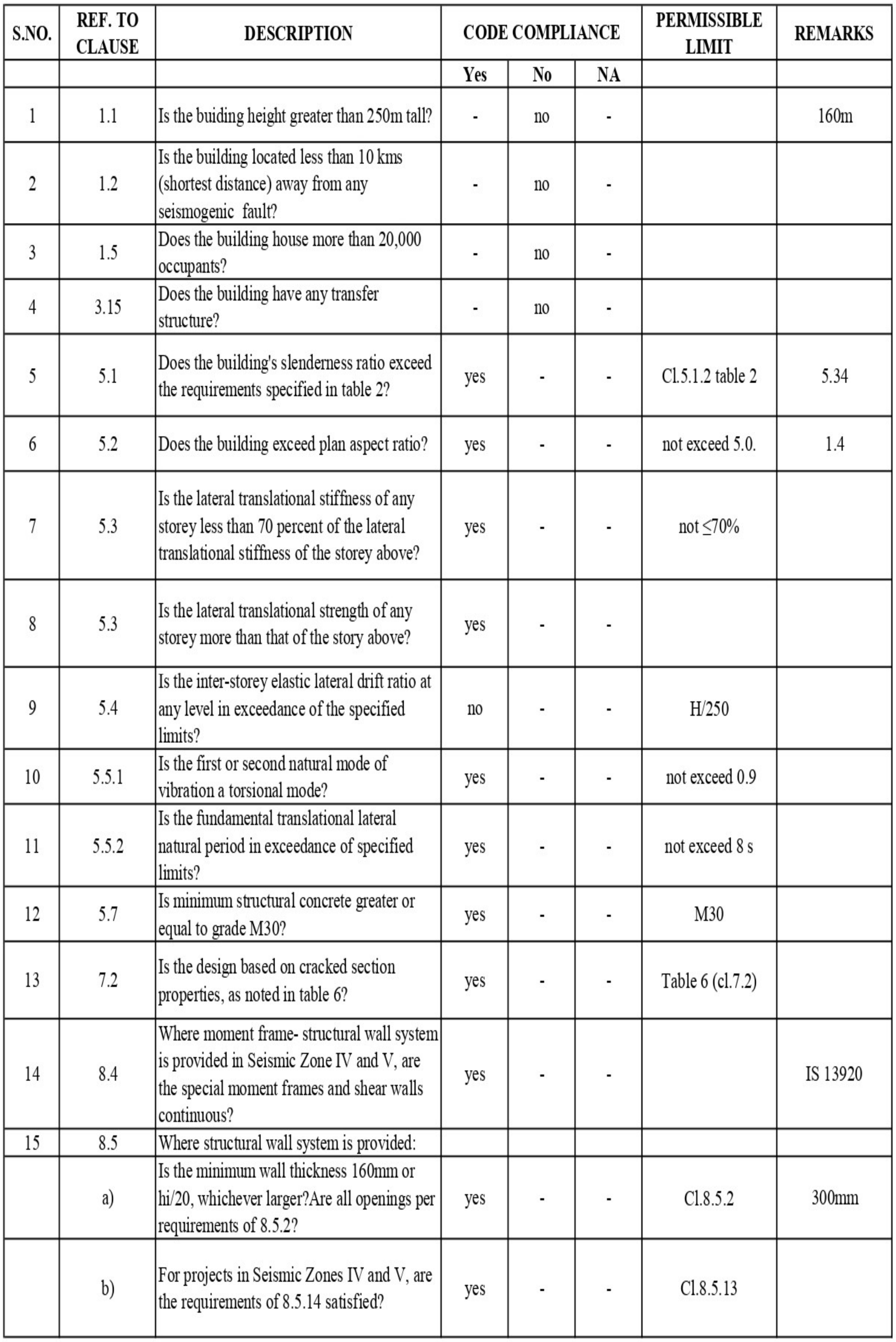
Table 7: Validation of Model-5



S.NO.	REF. TO CLAUSE	DESCRIPTION	CODE COMPLIANCE			PERMISSIBLE LIMIT	REMARKS
			Yes	No	NA		
1	1.1	Is the buiding height greater than 250m tall?	-	no	-		160m
2	1.2	Is the building located less than 10 kms (shortest distance) away from any seismogenic fault?	-	no	-		
3	1.5	Does the building house more than 20,000 occupants?	-	no	-		
4	3.15	Does the building have any transfer structure?	-	no	-		
5	5.1	Does the building's slenderness ratio exceed the requirements specified in table 2?	yes	-	-	Cl.5.1.2 table 2	5.34
6	5.2	Does the building exceed plan aspect ratio?	yes	-	-	not exceed 5.0.	1.4
7	5.3	Is the lateral translational stiffness of any storey less than 70 percent of the lateral translational stiffness of the storey above?	yes	-	-	not ≤70%	
8	5.3	Is the lateral translational strength of any storey more than that of the story above?	yes	-	-		
9	5.4	Is the inter-storey elastic lateral drift ratio at any level in exceedance of the specified limits?	no	-	-	H/250	
10	5.5.1	Is the first or second natural mode of vibration a torsional mode?	yes	-	-	not exceed 0.9	
11	5.5.2	Is the fundamental translational lateral natural period in exceedance of specified limits?	yes	-	-	not exceed 8 s	
12	5.7	Is minimum structural concrete greater or equal to grade M30?	yes	-	-	M30	
13	7.2	Is the design based on cracked section properties, as noted in table 6?	yes	-	-	Table 6 (cl.7.2)	
14	8.4	Where moment frame- structural wall system is provided in Seismic Zone IV and V, are the special moment frames and shear walls continuous?	yes	-	-		IS 13920
15	8.5	Where structural wall system is provided:					
	a)	Is the minimum wall thickness 160mm or hi/20, whichever larger?Are all openings per requirements of 8.5.2?	yes	-	-	Cl.8.5.2	300mm
	b)	For projects in Seismic Zones IV and V, are the requirements of 8.5.14 satisfied?	yes	-	-	Cl.8.5.13	

(Source: IS: 16700:2017)

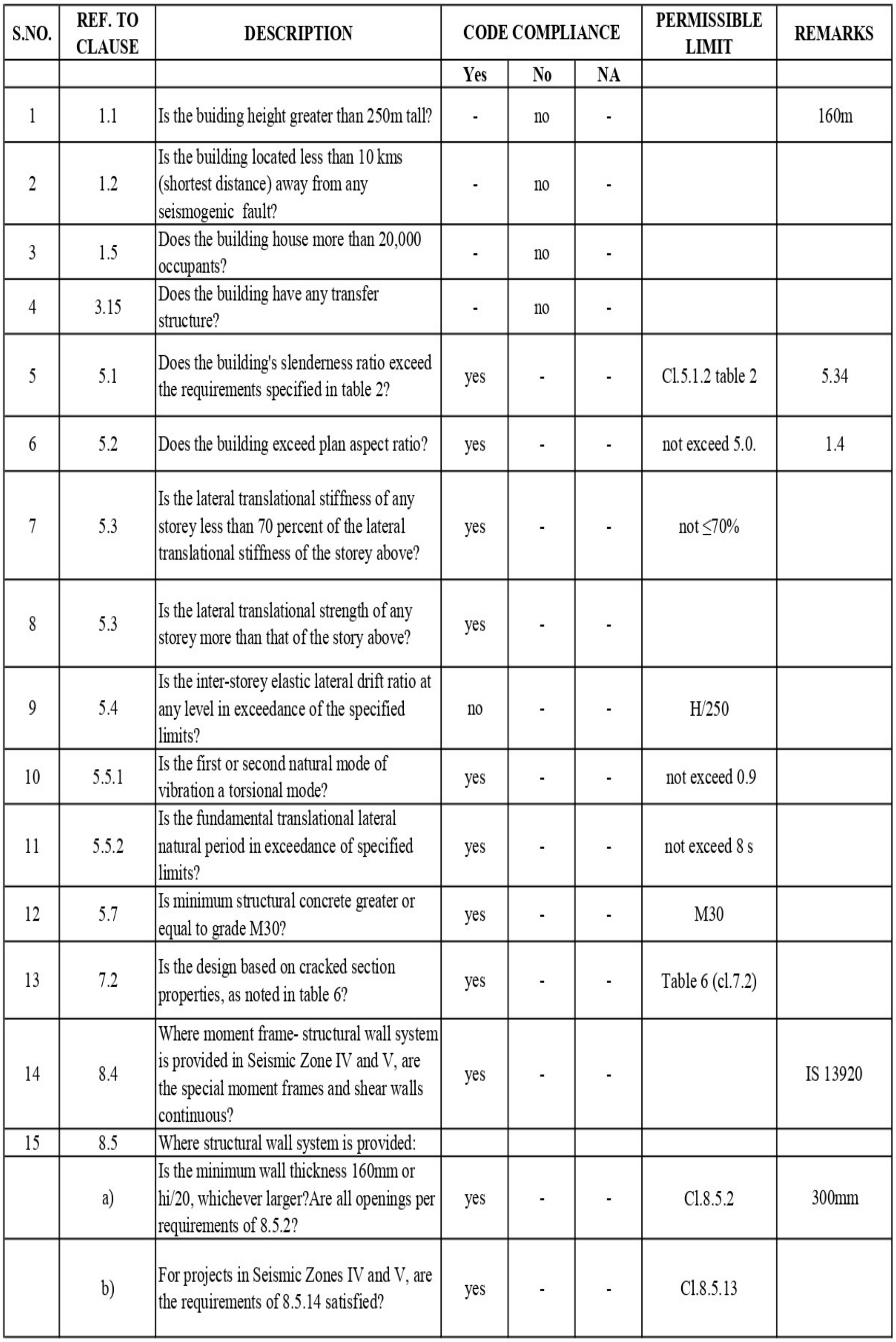
Table 8: Validation of Model-6



S.NO.	REF. TO CLAUSE	DESCRIPTION	CODE COMPLIANCE			PERMISSIBLE LIMIT	REMARKS
			Yes	No	NA		
1	1.1	Is the buiding height greater than 250m tall?	-	no	-		160m
2	1.2	Is the building located less than 10 kms (shortest distance) away from any seismogenic fault?	-	no	-		
3	1.5	Does the building house more than 20,000 occupants?	-	no	-		
4	3.15	Does the building have any transfer structure?	-	no	-		
5	5.1	Does the building's slenderness ratio exceed the requirements specified in table 2?	yes	-	-	Cl.5.1.2 table 2	5.34
6	5.2	Does the building exceed plan aspect ratio?	yes	-	-	not exceed 5.0.	1.4
7	5.3	Is the lateral translational stiffness of any storey less than 70 percent of the lateral translational stiffness of the storey above?	yes	-	-	not ≤70%	
8	5.3	Is the lateral translational strength of any storey more than that of the story above?	yes	-	-		
9	5.4	Is the inter-storey elastic lateral drift ratio at any level in exceedance of the specified limits?	no	-	-	H/250	
10	5.5.1	Is the first or second natural mode of vibration a torsional mode?	yes	-	-	not exceed 0.9	
11	5.5.2	Is the fundamental translational lateral natural period in exceedance of specified limits?	yes	-	-	not exceed 8 s	
12	5.7	Is minimum structural concrete greater or equal to grade M30?	yes	-	-	M30	
13	7.2	Is the design based on cracked section properties, as noted in table 6?	yes	-	-	Table 6 (cl.7.2)	
14	8.4	Where moment frame- structural wall system is provided in Seismic Zone IV and V, are the special moment frames and shear walls continuous?	yes	-	-		IS 13920
15	8.5	Where structural wall system is provided:					
	a)	Is the minimum wall thickness 160mm or hi/20, whichever larger?Are all openings per requirements of 8.5.2?	yes	-	-	Cl.8.5.2	300mm
	b)	For projects in Seismic Zones IV and V, are the requirements of 8.5.14 satisfied?	yes	-	-	Cl.8.5.13	

(Source: IS: 16700:2017)

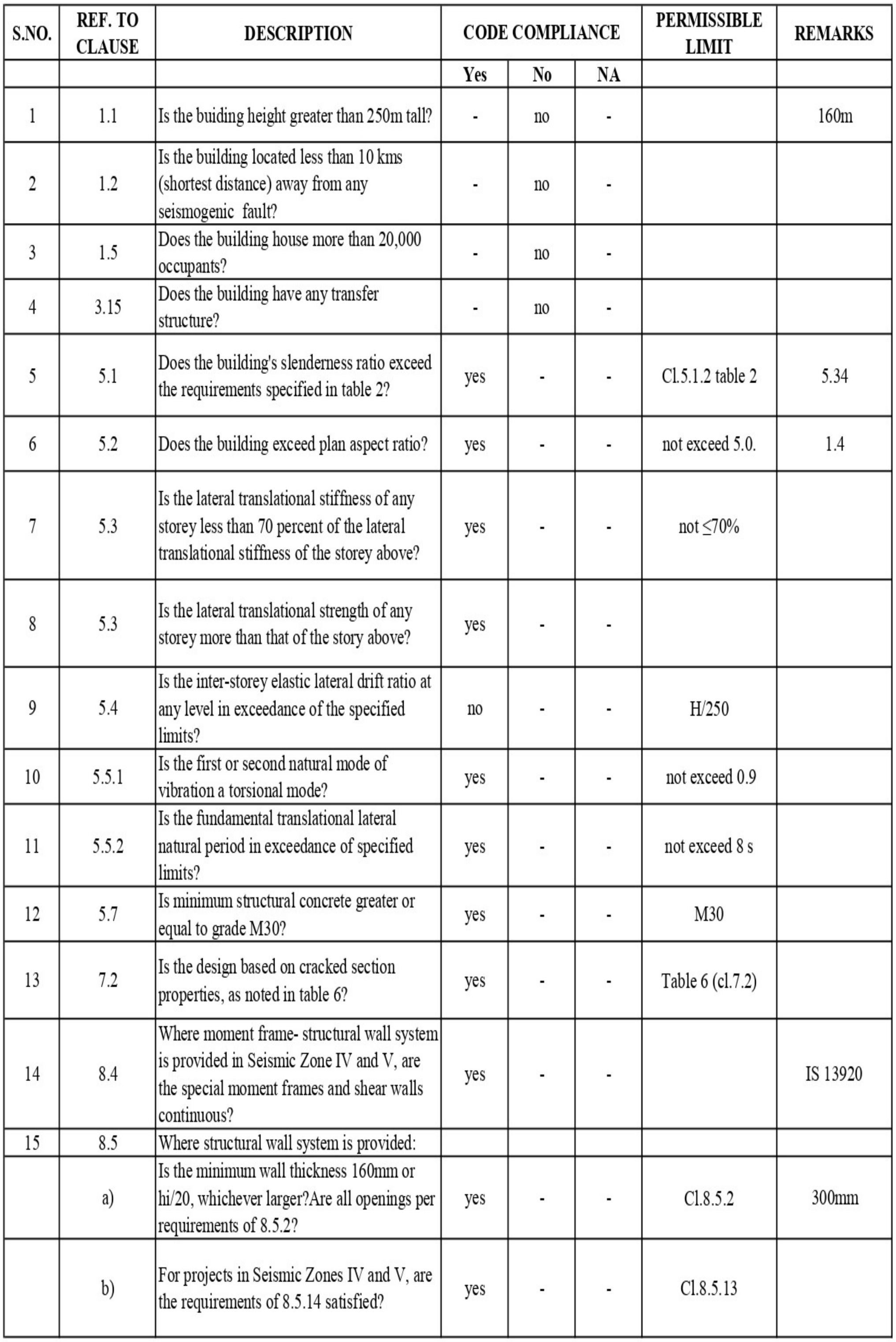
Table 9: Validation of Model-7



S.NO.	REF. TO CLAUSE	DESCRIPTION	CODE COMPLIANCE			PERMISSIBLE LIMIT	REMARKS
			Yes	No	NA		
1	1.1	Is the buiding height greater than 250m tall?	-	no	-		160m
2	1.2	Is the building located less than 10 kms (shortest distance) away from any seismogenic fault?	-	no	-		
3	1.5	Does the building house more than 20,000 occupants?	-	no	-		
4	3.15	Does the building have any transfer structure?	-	no	-		
5	5.1	Does the building's slenderness ratio exceed the requirements specified in table 2?	yes	-	-	Cl.5.1.2 table 2	5.34
6	5.2	Does the building exceed plan aspect ratio?	yes	-	-	not exceed 5.0.	1.4
7	5.3	Is the lateral translational stiffness of any storey less than 70 percent of the lateral translational stiffness of the storey above?	yes	-	-	not ≤70%	
8	5.3	Is the lateral translational strength of any storey more than that of the story above?	yes	-	-		
9	5.4	Is the inter-storey elastic lateral drift ratio at any level in exceedance of the specified limits?	no	-	-	H/250	
10	5.5.1	Is the first or second natural mode of vibration a torsional mode?	yes	-	-	not exceed 0.9	
11	5.5.2	Is the fundamental translational lateral natural period in exceedance of specified limits?	yes	-	-	not exceed 8 s	
12	5.7	Is minimum structural concrete greater or equal to grade M30?	yes	-	-	M30	
13	7.2	Is the design based on cracked section properties, as noted in table 6?	yes	-	-	Table 6 (cl.7.2)	
14	8.4	Where moment frame- structural wall system is provided in Seismic Zone IV and V, are the special moment frames and shear walls continuous?	yes	-	-		IS 13920
15	8.5	Where structural wall system is provided:					
	a)	Is the minimum wall thickness 160mm or hi/20, whichever larger?Are all openings per requirements of 8.5.2?	yes	-	-	Cl.8.5.2	300mm
	b)	For projects in Seismic Zones IV and V, are the requirements of 8.5.14 satisfied?	yes	-	-	Cl.8.5.13	

(Source: IS: 16700:2017)

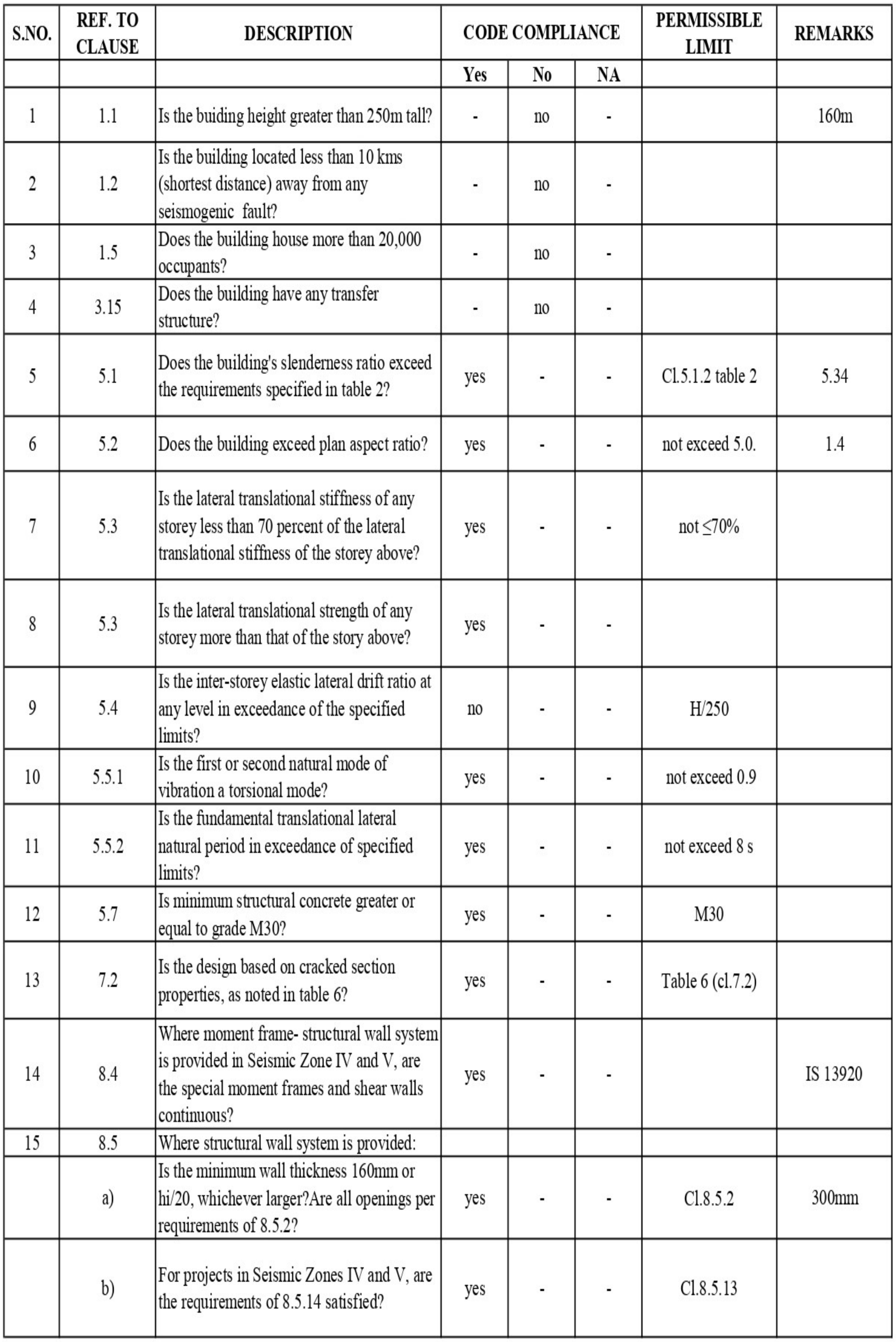
Table 10: Validation of Model-8



S.NO.	REF. TO CLAUSE	DESCRIPTION	CODE COMPLIANCE			PERMISSIBLE LIMIT	REMARKS
			Yes	No	NA		
1	1.1	Is the buiding height greater than 250m tall?	-	no	-		160m
2	1.2	Is the building located less than 10 kms (shortest distance) away from any seismogenic fault?	-	no	-		
3	1.5	Does the building house more than 20,000 occupants?	-	no	-		
4	3.15	Does the building have any transfer structure?	-	no	-		
5	5.1	Does the building's slenderness ratio exceed the requirements specified in table 2?	yes	-	-	Cl.5.1.2 table 2	5.34
6	5.2	Does the building exceed plan aspect ratio?	yes	-	-	not exceed 5.0.	1.4
7	5.3	Is the lateral translational stiffness of any storey less than 70 percent of the lateral translational stiffness of the storey above?	yes	-	-	not ≤70%	
8	5.3	Is the lateral translational strength of any storey more than that of the story above?	yes	-	-		
9	5.4	Is the inter-storey elastic lateral drift ratio at any level in exceedance of the specified limits?	no	-	-	H/250	
10	5.5.1	Is the first or second natural mode of vibration a torsional mode?	yes	-	-	not exceed 0.9	
11	5.5.2	Is the fundamental translational lateral natural period in exceedance of specified limits?	yes	-	-	not exceed 8 s	
12	5.7	Is minimum structural concrete greater or equal to grade M30?	yes	-	-	M30	
13	7.2	Is the design based on cracked section properties, as noted in table 6?	yes	-	-	Table 6 (cl.7.2)	
14	8.4	Where moment frame- structural wall system is provided in Seismic Zone IV and V, are the special moment frames and shear walls continuous?	yes	-	-		IS 13920
15	8.5	Where structural wall system is provided:					
	a)	Is the minimum wall thickness 160mm or hi/20, whichever larger?Are all openings per requirements of 8.5.2?	yes	-	-	Cl.8.5.2	300mm
	b)	For projects in Seismic Zones IV and V, are the requirements of 8.5.14 satisfied?	yes	-	-	Cl.8.5.13	

(Source: IS: 16700:2017)

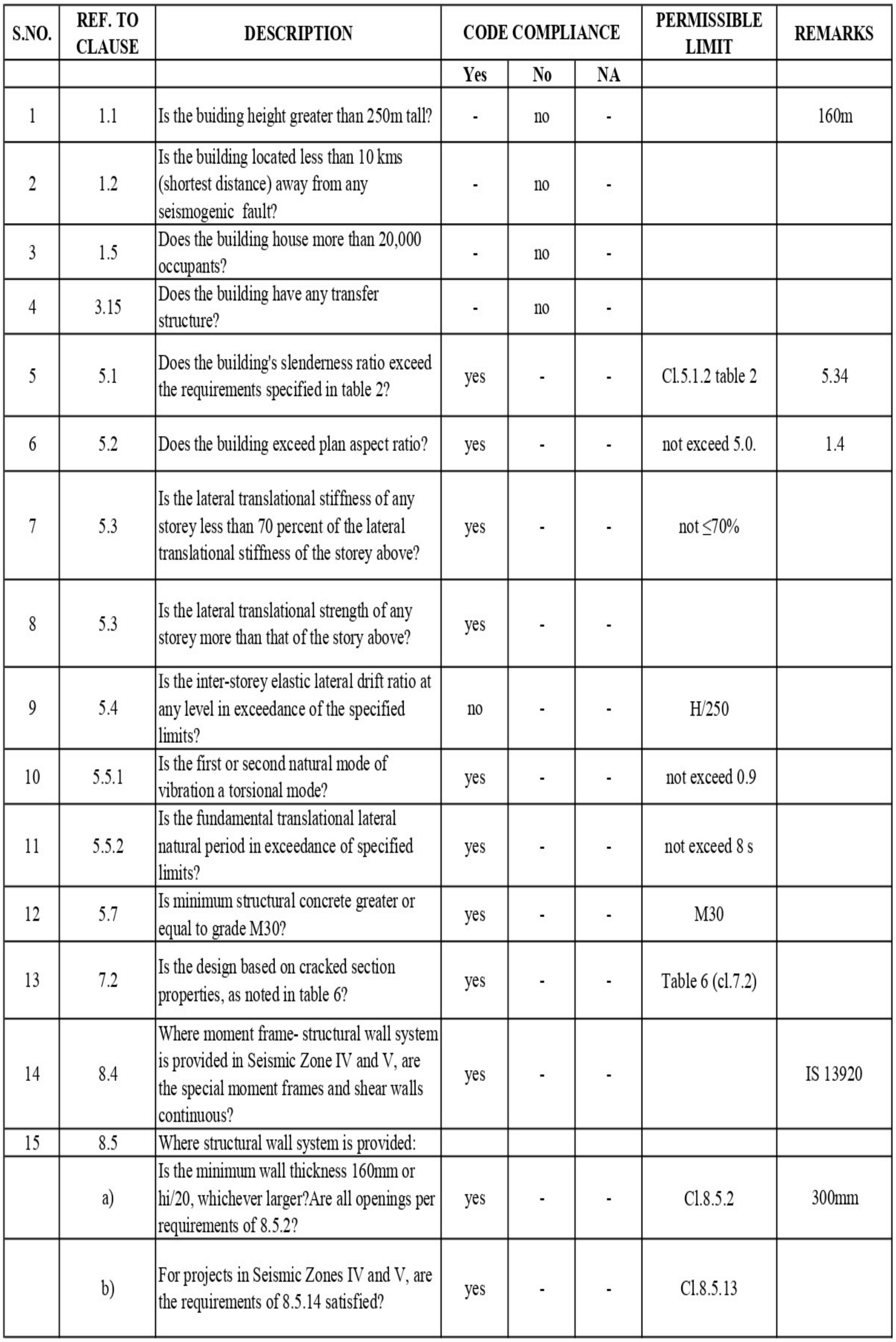
Table 11: Validation of Model-9



S.NO.	REF. TO CLAUSE	DESCRIPTION	CODE COMPLIANCE			PERMISSIBLE LIMIT	REMARKS
			Yes	No	NA		
1	1.1	Is the buiding height greater than 250m tall?	-	no	-		160m
2	1.2	Is the building located less than 10 kms (shortest distance) away from any seismogenic fault?	-	no	-		
3	1.5	Does the building house more than 20,000 occupants?	-	no	-		
4	3.15	Does the building have any transfer structure?	-	no	-		
5	5.1	Does the building's slenderness ratio exceed the requirements specified in table 2?	yes	-	-	Cl.5.1.2 table 2	5.34
6	5.2	Does the building exceed plan aspect ratio?	yes	-	-	not exceed 5.0.	1.4
7	5.3	Is the lateral translational stiffness of any storey less than 70 percent of the lateral translational stiffness of the storey above?	yes	-	-	not ≤70%	
8	5.3	Is the lateral translational strength of any storey more than that of the story above?	yes	-	-		
9	5.4	Is the inter-storey elastic lateral drift ratio at any level in exceedance of the specified limits?	no	-	-	H/250	
10	5.5.1	Is the first or second natural mode of vibration a torsional mode?	yes	-	-	not exceed 0.9	
11	5.5.2	Is the fundamental translational lateral natural period in exceedance of specified limits?	yes	-	-	not exceed 8 s	
12	5.7	Is minimum structural concrete greater or equal to grade M30?	yes	-	-	M30	
13	7.2	Is the design based on cracked section properties, as noted in table 6?	yes	-	-	Table 6 (cl.7.2)	
14	8.4	Where moment frame- structural wall system is provided in Seismic Zone IV and V, are the special moment frames and shear walls continuous?	yes	-	-		IS 13920
15	8.5	Where structural wall system is provided:					
	a)	Is the minimum wall thickness 160mm or hi/20, whichever larger?Are all openings per requirements of 8.5.2?	yes	-	-	Cl.8.5.2	300mm
	b)	For projects in Seismic Zones IV and V, are the requirements of 8.5.14 satisfied?	yes	-	-	Cl.8.5.13	

(Source: IS: 16700:2017)

Table 12: Validation of Model-10



S.NO.	REF. TO CLAUSE	DESCRIPTION	CODE COMPLIANCE			PERMISSIBLE LIMIT	REMARKS
			Yes	No	NA		
1	1.1	Is the buiding height greater than 250m tall?	-	no	-		160m
2	1.2	Is the building located less than 10 kms (shortest distance) away from any seismogenic fault?	-	no	-		
3	1.5	Does the building house more than 20,000 occupants?	-	no	-		
4	3.15	Does the building have any transfer structure?	-	no	-		
5	5.1	Does the building's slenderness ratio exceed the requirements specified in table 2?	yes	-	-	Cl.5.1.2 table 2	5.34
6	5.2	Does the building exceed plan aspect ratio?	yes	-	-	not exceed 5.0.	1.4
7	5.3	Is the lateral translational stiffness of any storey less than 70 percent of the lateral translational stiffness of the storey above?	yes	-	-	not ≤70%	
8	5.3	Is the lateral translational strength of any storey more than that of the story above?	yes	-	-		
9	5.4	Is the inter-storey elastic lateral drift ratio at any level in exceedance of the specified limits?	no	-	-	H/250	
10	5.5.1	Is the first or second natural mode of vibration a torsional mode?	yes	-	-	not exceed 0.9	
11	5.5.2	Is the fundamental translational lateral natural period in exceedance of specified limits?	yes	-	-	not exceed 8 s	
12	5.7	Is minimum structural concrete greater or equal to grade M30?	yes	-	-	M30	
13	7.2	Is the design based on cracked section properties, as noted in table 6?	yes	-	-	Table 6 (cl.7.2)	
14	8.4	Where moment frame- structural wall system is provided in Seismic Zone IV and V, are the special moment frames and shear walls continuous?	yes	-	-		IS 13920
15	8.5	Where structural wall system is provided:					
	a)	Is the minimum wall thickness 160mm or hi/20, whichever larger?Are all openings per requirements of 8.5.2?	yes	-	-	Cl.8.5.2	300mm
	b)	For projects in Seismic Zones IV and V, are the requirements of 8.5.14 satisfied?	yes	-	-	Cl.8.5.13	

(Source: IS: 16700:2017)

CHAPTER 4

RESULTS AND CONCLUSION

4.1 Model Results

Based on the models analyzed for achieving the objective of the dissertation, various results have been taken out with the help of tables and charts prepared in the next segments. The results have been carried out using serviceability checks, i.e. rotation participations, story drift under seismic and wind loads, overturning moments, deflection of tower under lateral loads, stiffness of building in various models. These results will help in reviewing the effect of common slab action on the elevation structure and conclude to check the most economical configuration of the structure including podium effect and mid height outrigger.

1. Rotation Participation in Orthogonal Directions (%)
2. Deflection in Wind X (mm)
3. Deflection in Wind Y (mm)
4. Deflection in Spec X (mm)
5. Deflection in Spec Y (mm)
6. Drift in Seismic Load (mm)
7. Stiffness in X-Direction at First Floor (kN/sqm)
8. Stiffness in Y-Direction at First Floor (kN/sqm)
9. Story Drift in SpecX
10. Story Drift in SpecY
11. Story Drift in WindX
12. Story Drift in WindY
13. Overturning Moment in Seismic Loads
14. Overturning Moment in Wind Loads

4.1.1 Rotation Participation in Orthogonal Directions (RP), %

Table 13: Model Outcomes of Rotation Participation (%)

Model	1	2	3	4	5	6	7	8	9	10
RP(%)	47	42	45	39	30	25	21	22	20	15

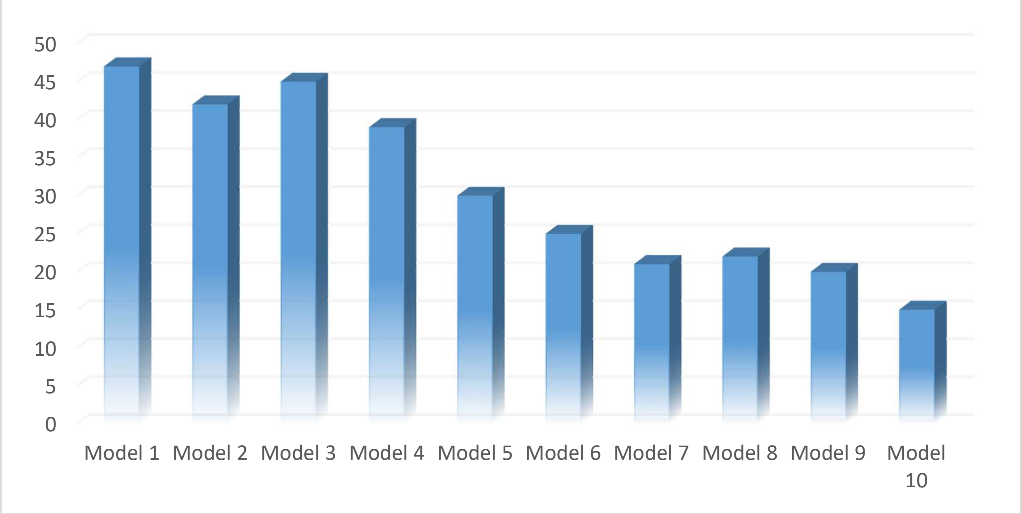


Figure 7: Graph showing Rotation Participation in Orthogonal Direction

Table 13 and Figure 7 are showing rotation participation in both orthogonal directions and it is clearly seen in the results that maximum rotation participation factor is in Model 1 and minimum rotation participation factor is in Model 10. From the results, it may be discussed that due to presence of podium in tall structures, a lateral force acting from the inner core to the basement walls which is resulting in decrement of rotation in the building due to lateral loads. It is also reviewed from the results that due to addition of an outrigger at mid-height of the tower, as resisting couple force will act from the inner core to the slab with maximum force distribution at podium level resulting in minimum rotation factor in Model 10.

4.1.2 Deflection in Wind X U_{WX}, mm

Table 14: Model Outcomes of Deflection in Wind X (mm)

Model	1	2	3	4	5	6	7	8	9	10
U_{WX}	114	109	95	89	80	98	93	82	75	65

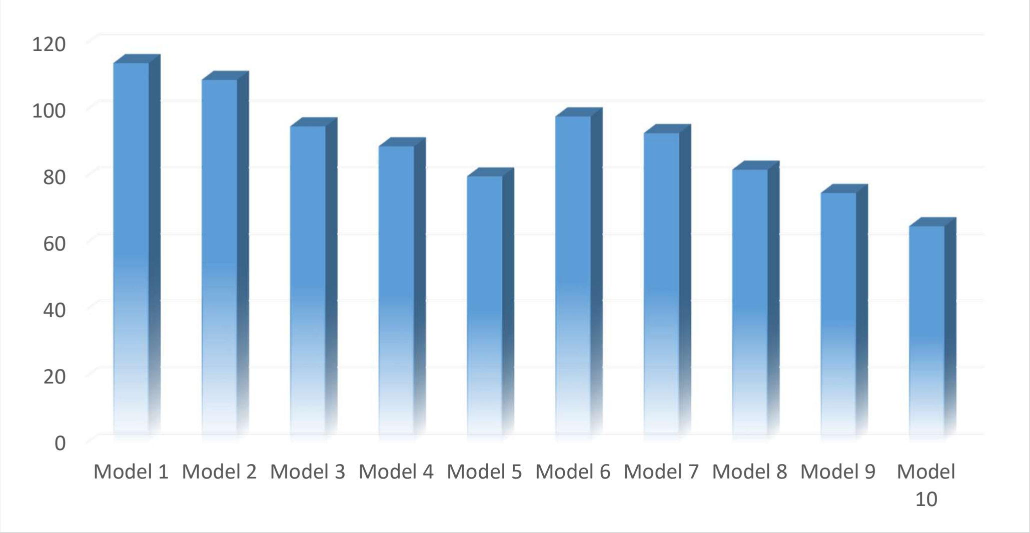


Figure 8: Graph showing Deflection in Wind X Load

Table 14 and Figure 8 are showing deflection in wind load in X direction and it is clearly seen in the results that maximum deflection is in Model 1 and minimum deflection in Model 10. From the results, it may be discussed that due to presence of podium in tall structures, a lateral force acting from the inner core to the basement walls will tie the structure from the podium level which results in decrement of deflection in the building due to wind loads. It is also reviewed from the results that due to addition of an outrigger at mid-height of the tower, structure get tied on one more level and will experience a resisting couple moment in leeward direction which results in minimum deflection in Model 10.

4.1.3 Deflection in Wind Y U_{WY}, mm

Table 15: Model Outcomes of Deflection in Wind Y (mm)

Model	1	2	3	4	5	6	7	8	9	10
U_{WY}	114	109	95	89	80	98	93	82	75	65

Table 15 and Figure 9 are showing deflection in wind load in X direction and it is clearly seen in the results that maximum deflection is in Model 1 and minimum deflection in Model 10. From the results, it may be discussed that due to presence of podium in tall structures, a lateral force acting from the inner core to the basement walls will tie the structure from the podium level which results in decrement of deflection in the building due to wind loads. It is also reviewed from the results that due to addition of an outrigger at mid-height of the tower, structure get tied on one more level and will experience a resisting couple moment in leeward direction which results in minimum deflection in Model 10.

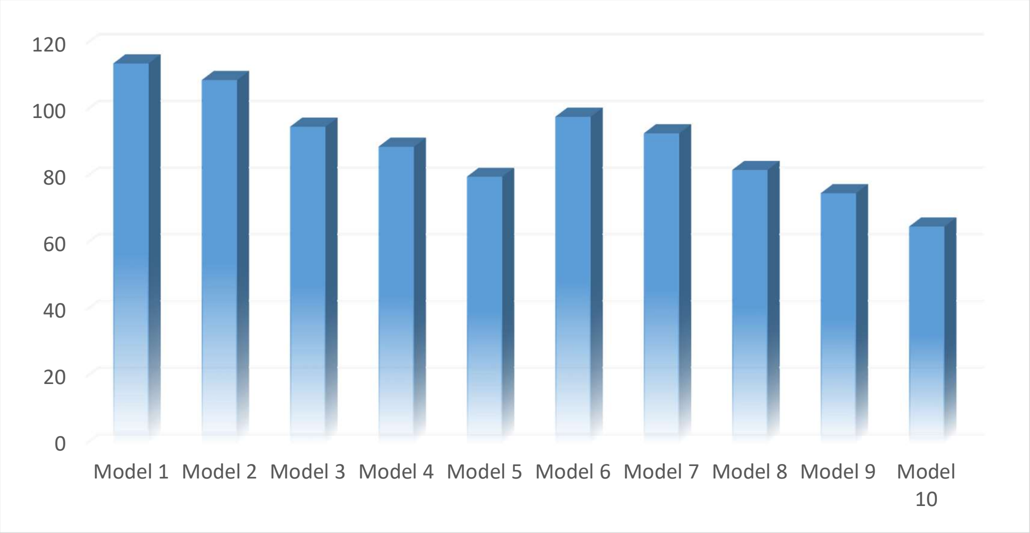


Figure 9: Graph showing Deflection in Wind Y Load

4.1.4 Deflection in Spec X U_{SX}, mm

Table 16: Model Outcomes of Deflection in Spec X (mm)

Model	1	2	3	4	5	6	7	8	9	10
U_{SX}	150	142	135	120	115	135	120	114	105	99

Table 16 and Figure 10 are showing deflection in Spec X load and it is clearly seen in the results that maximum deflection is in Model 1 and minimum deflection in Model 10. Due to increase in seismic weight of the structure due to addition of outrigger, deflection in Model 6 is more than Model 4 and Model 5. It may be discussed that due to presence of podium in tall structures, a lateral force acting from the inner core to the basement walls will tie the structure from the podium level which results in decrement of deflection in the building due to wind loads. It is also reviewed from the results that due to addition of an outrigger at mid-height of the tower, structure get tied on one more level and will experience a resisting couple moment in leeward direction which results in minimum deflection in Model 10.

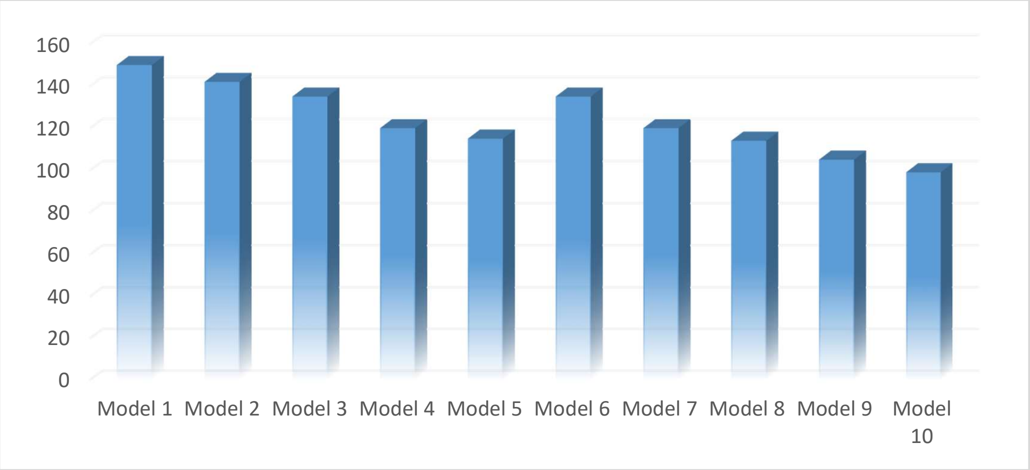


Figure 10: Graph showing Deflection in Spec X Load

4.1.5 Deflection in Spec Y U_{SY}, mm

Table 17: Model Outcomes of Deflection in Spec Y (mm)

Model	1	2	3	4	5	6	7	8	9	10
U_{SY}	160	140	150	135	120	146	138	120	108	101

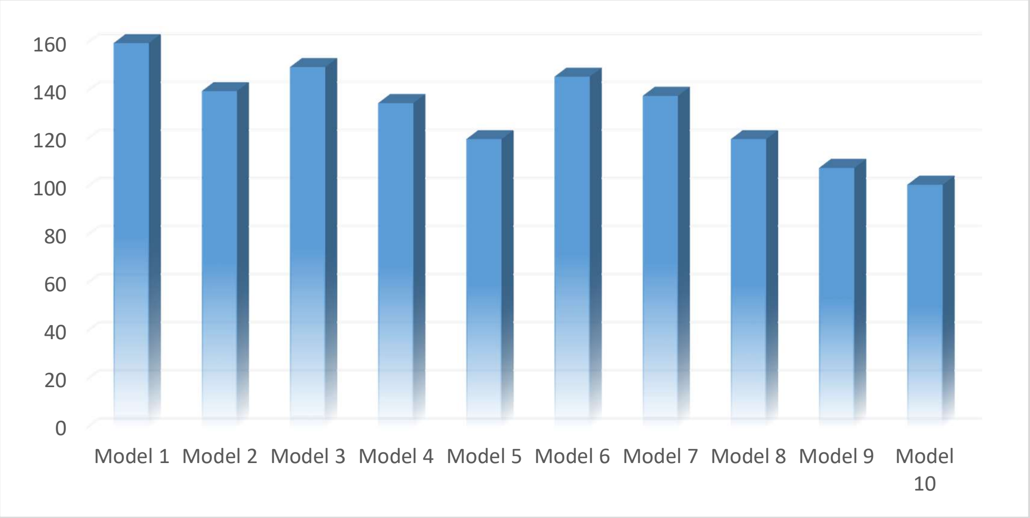


Figure 11: Graph showing Deflection in Spec Y Load

Table 17 and Figure 11 are showing deflection in Spec Y load and it is clearly seen in the results that maximum deflection is in Model 1 and minimum deflection in Model 10. Due to increase in seismic weight of the structure due to addition of outrigger, deflection in Model 6 is more than Model 4 and Model 5. It may be discussed that due to presence of podium in tall structures, a lateral force acting from the inner core to the basement walls will tie the structure from the podium level which results in decrement of deflection in the building due to wind loads. It is also reviewed from the results that due to addition of an outrigger at mid-height of the tower, structure get tied on one more level and will experience a resisting couple moment in leeward direction which results in minimum deflection in Model 10.

4.1.6 Story Drift in EQ Load Case, Deq

Table 18: Model Outcomes of Story Drift in EQ Load Case

Model	1	2	3	4	5	6	7	8	9	10
D_{eq}	0.210	0.196	0.206	0.210	0.180	0.210	0.200	0.178	0.187	0.160

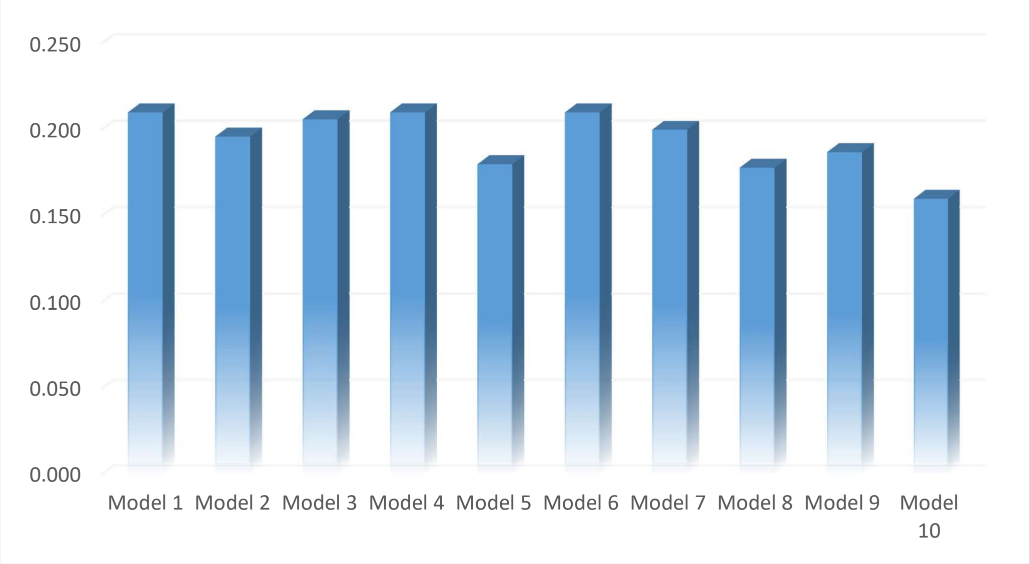


Figure 12: Graph showing Story Drift in EQ Load Case

Table 18 and Figure 12 are showing drift factor in seismic load case and it is clearly seen in the results that maximum drift is in Model 1 and Model 4 and minimum deflection in Model 5 and Model 10. Due to increase in seismic weight of the structure due to addition of outrigger, deflection in Model 6 is more than Model 5. It may be discussed that due to presence of podium in tall structures, a lateral force acting from the inner core to the basement walls bound the structure at the podium level which results in decrement of drift in the building due to seismic loads. It is also reviewed from the results that due to addition of an outrigger at mid-height of the tower, structure get tied on one more level and will experience a resisting couple moment in leeward direction which results in minimum drift in Model 10. The drift outcome from the models are well in the permissible limits of BIS codes.

4.1.7 Stiffness of Structure in X-Direction at First Floor Level, X_1

Table 19: Stiffness (X) of Structure at First Floor Level

Model	1	2	3	4	5	6	7	8	9	10
X_1	5E+07	8E+07	1E+08	2E+08	3E+08	1E+08	2E+08	3E+08	4E+08	4E+08

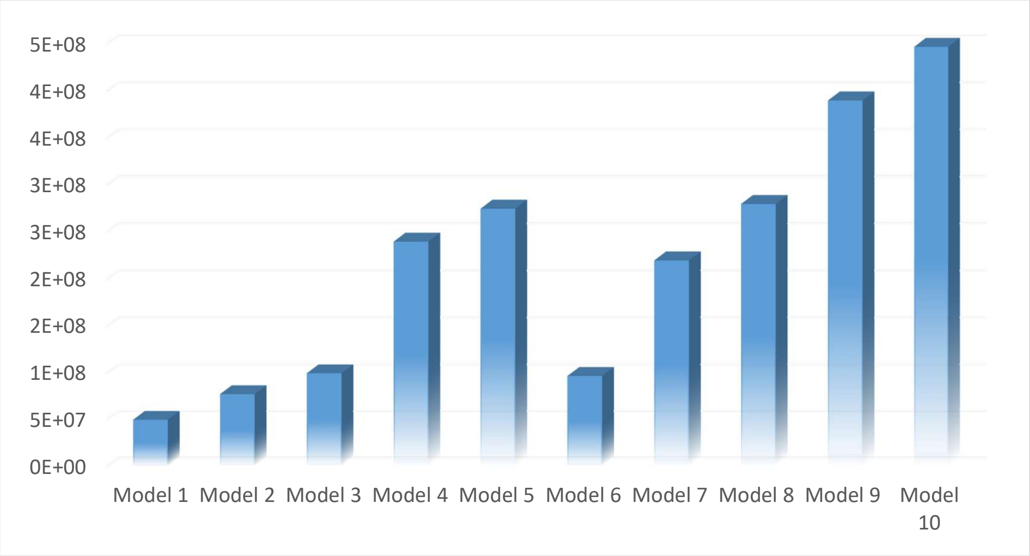


Figure 13: Graph showing Stiffness (X) of Structure at First Floor Level

Table 19 and Figure 13 are showing story stiffness at 1st floor level and it may be reviewed here that due to addition of number of basements story stiffness under lateral loads increases with minimum story stiffness in Model 1 and maximum story stiffness in Model 10. Here we can also reviewed that due to addition of outrigger in the tall structures, story stiffness increases by a significant number and can be concluded that addition of basements and outrigger is better for the structure. Due to addition of lateral load resisting elements, force generated in the inner core transfer to the collector wall, here basement wall, by the means of slab action results in increasing the stiffness of floor to a great extent which leads to decrement of drift, deflection and overturning moments, etc.

4.1.8 Stiffness of Structure in Y-Direction at First Floor Level, Y_1

Table 20: Stiffness (Y) of Structure at First Floor Level

Model	1	2	3	4	5	6	7	8	9	10
Y_1	4E+07	8E+07	1E+08	2E+08	3E+08	1E+08	2E+08	3E+08	4E+08	4E+08

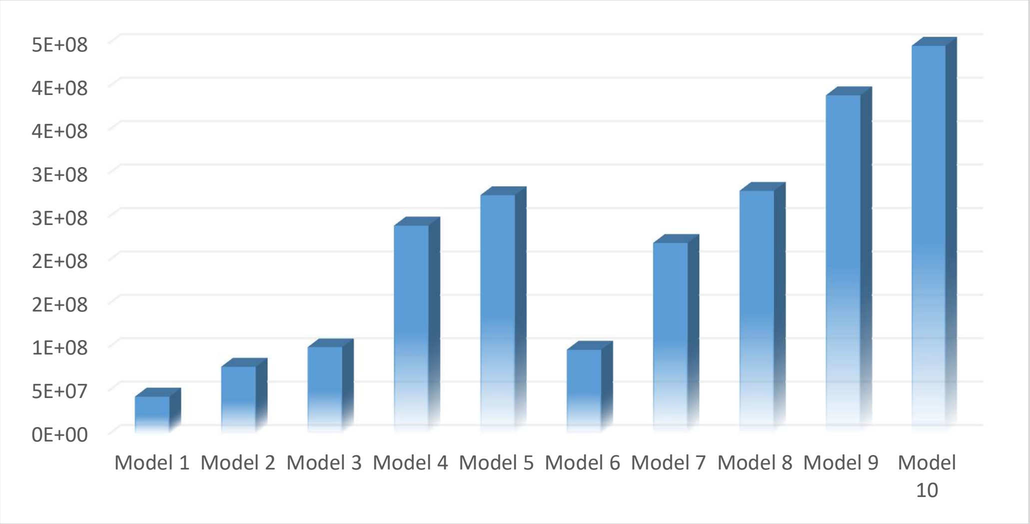


Figure 14: Graph showing Stiffness (Y) of Structure at First Floor Level

Table 20 and Figure 14 are showing story stiffness at 1st floor level and it may be reviewed here that due to addition of number of basements story stiffness under lateral loads increases with minimum story stiffness in Model 1 and maximum story stiffness in Model 10. Here we can also reviewed that due to addition of outrigger in the tall structures, story stiffness increases by a significant number and can be concluded that addition of basements and outrigger is better for the structure. Due to addition of lateral load resisting elements, force generated in the inner core transfer to the collector wall, here basement wall, by the means of slab action results in increasing the stiffness of floor to a great extent which leads to decrement of drift, deflection and overturning moments, etc.

4.1.9 Story Drift due to Wind Load, Dw

Table 20 and Figure 15 are showing drift factor in seismic load case and it is clearly seen in the results that maximum drift is in Model 1 and Model 4 and minimum deflection in Model 5 and Model 10. Due to increase in seismic weight of the structure due to addition of outrigger, deflection in Model 6 is more than Model 5. It may be discussed that due to presence of podium in tall structures, a lateral force acting from the inner core to the basement walls bound the structure at the podium level which results in decrement of drift in the building due to seismic loads. It is also reviewed from the results that due to addition of an outrigger at mid-height of the tower, structure get tied on one more level and will experience a resisting couple moment in leeward direction which results in minimum drift in Model 10. The drift outcome from the models are well in the permissible limits of BIS codes.

Table 21: Model Outcomes of Story Drift in Wind Load Case

Model	1	2	3	4	5	6	7	8	9	10
D_w	0.19	0.18	0.165	0.16	0.15	0.17	0.155	0.15	0.143	0.132

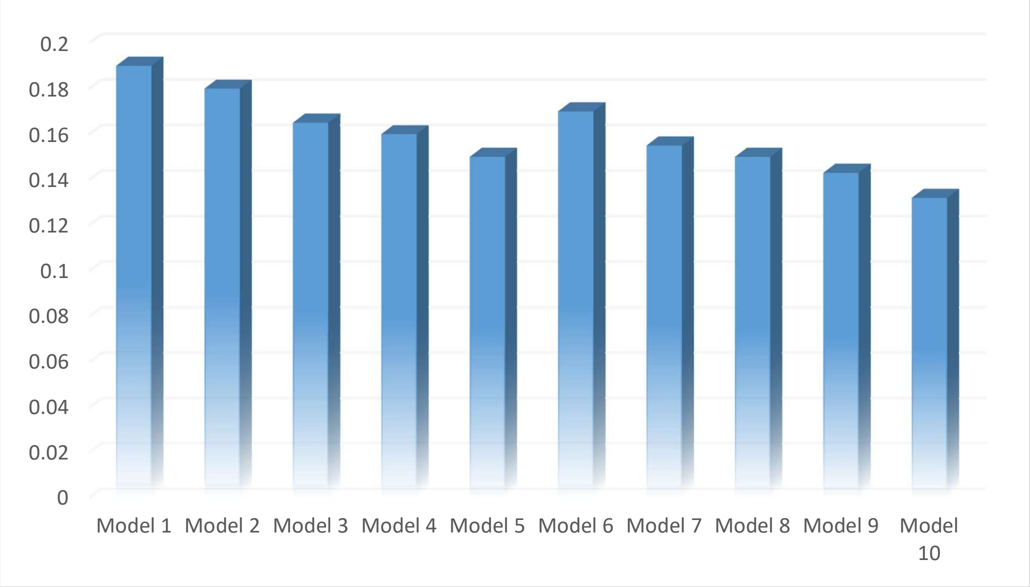


Figure 15: Graph showing Story Drift in EQ Load Case

4.1.10 Overturning Moment due to Seismic Load

Figure 16 are showing overturning moment due seismic load case and it is clearly seen in the results that maximum moment is in Model 1 and minimum moments in Model 5 and Model 10. It may be discussed that due to presence of podium in tall structures, a lateral force acting from the inner core to the basement walls bound the structure at the podium level creating a different path of load distribution which results in decrement of moment in the building due to seismic loads. It is also reviewed from the results that due to addition of an outrigger at mid-height of the tower, structure get tied on one more level and will experience a resisting couple moment in leeward direction which results in minimum overturning moments in Model 10.

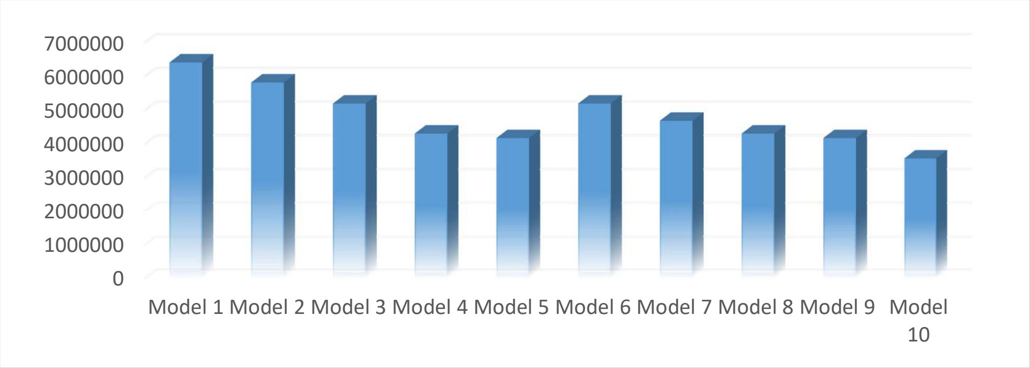


Figure 16: Graph showing Overturning Moment in EQ Load Case

4.1.11 Overturning Moment due to Wind Load

Figure 17 are showing overturning moment due seismic load case and it is clearly seen in the results that maximum moment is in Model 1 and minimum moments in Model 5 and Model 10. It may be discussed that due to presence of podium in tall structures, a lateral force acting from the inner core to the basement walls bound the structure at the podium level creating a different path of load distribution which results in decrement of moment in the building due to seismic loads. It is also reviewed from the results that due to addition of an outrigger at mid-height of the tower, structure get tied on one more level and will experience a resisting couple moment in leeward direction which results in minimum overturning moments in Model 10.

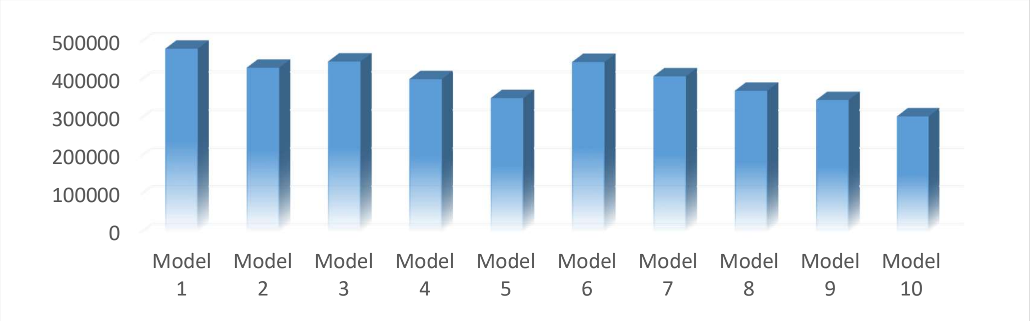


Figure 17: Graph showing Overturning Moment in EQ Load Case

4.2 Conclusion

With the help of models mentioned in Chapter 3 and results reviewed in 4.1.1 to 4.1.11, some conclusions may be listed on the basis of serviceability check, that is, rotation participation factor, displacement of top story under lateral loads, story drift under lateral loads, overturning moments under wind and seismic loads, stiffness at first floor, etc. that is required to check the actual behavior of the building and to comment on the more economical or structurally better configuration by adding basement or podium in the tall structure and additionally behavior of outrigger with basement or podium to achieve our objective.

As per figure 7, the rotation participation of the model containing 4 basements and outrigger at mid-height level is minimum which shows that transitional participations of the elevated structure is better in Model 10 and especially the outrigger is resisting the twisting moment and showing better results than a building without outrigger. As the level of basements increasing, the stiffness of the collector wall is increasing, as shown in figure 13, 14 and that leads to resist more twisting moments generated due to lateral loads.

As per figure 16, 17, the overturning moments due to wind and seismic loads are decreasing with increasing the basement levels and also decreasing with addition of outrigger in the elevated structure. As clearly shown in figure 16 & 17, the overturning moments is decreased by 40% and that results in reduction of displacements and story drift of the building as shown in figure 8 to 12, 15 by a great extent leading to the achieve some economy in the structure and will be able to save some of our national resources. As shown in figure 13 & 14, the stiffness of the podium level is increasing with increasing with increasing number of basements, maximum overturning moment is attracting on podium slab and a designer needs to design the podium level slab accordingly as per strength required.

A finite element analysis of the problem statement using ETabs 2020 helps us to design the requisite slab as per the forces being transferred from core to the basement wall and also basement wall may be designed as per the forces transmitted to walls from core.

From this study, a combined behavior of basement walls and outrigger is reviewed and found that outrigger is element which transfer the forces evenly on the slab and due to creation of resisting moment couple, deflection and drift may be controlled to a great extent. Number of combinations of structural configuration of a building may be planned with varying number of podium slabs and number and level of outrigger to achieve the ultimate economy in the project.

As per results in previous sections, it may be concluded that building without basements have comparably low stiffness and strength in compared to the buildings with basements or required strength. As per our study, serviceability behavior of Model 10 is better than any other configuration and behavior of Model 5 is better than Model 1, which shows that by addition of backstay effect in the elevated structures, maximum of the overturning moments are catered on the podium level itself due to its high stiffness and help in resisting displacement of the building.

Additionally, installing an outrigger in the building is a costly job and will also require a great time due to which project completion time may increase and leads to a virtual loss to the contractor, client. Due to this, it may be included that for 40 storied towers, tower with connected podium or basement walls are the better configuration than basement with outrigger due to high cost and more time consuming. If cost and time are not a considerable factor then the tower with connected basement with outrigger is the most preferable configuration to be adopted by a designer to resist the effects generated due to lateral loads. With increasing number of basements leads to increase the overall stiffness but the excavation of that number of basements will be a challenging job and one has to assist shoring consultant to design the shoring properly so that no accident will occur at site till the ground floor level slab.

REFERENCES

[1] A. R. Chotalia and H. Solanki, "Optimum shape of outrigger system for high-rise reinforced concrete buildings under earthquake loadings," *International Journal of Advance Engineering and Research Development,* vol. 4, no. 5, pp. 1101-1104, May 2017.

[2] B.o.I Standards, IS:16700:2017 - *Criteria for Structural Safety of Tall Concrete Buildings, India, Bureau of Indian Standards, 2017.*

[3] B. Pang, F. Wang, J. Yang, S. Nyunn and I. Azim, "Performance of slabs in reinforced concrete structures to resist progressive collapse," *In Structures,* vol. 33, pp. 4843-4856, 2021.

[4] B. S. Taranath, Structural Analysis and Design of Tall Buildings: Steel and Composite Construction, Washington DC: International Code Council, 2012.

[5] D. M. Patil and K. K. Sangle, "Seismic behaviour of outrigger braced systems in high rise 2-D steel buildings," *In Structures,* vol. 8, pp. 1-16, 2016.

[6] G. W. Ho, "The evolution of outrigger system in tall buildings," *International Journal of High-Rise Buildings,* vol. 5, no. 1, pp. 21-30, Marh 2016.

[7] J. Premalatha and M. Mrinalini, "Seismic behaviour of a multi-storeyed reinforced concrete irregular building with outrigger belt truss system," *International Journal of Engineering and Advanced Technology (IJEAT),* vol. 8, no. 2, pp. 181-187, 2018.

[8] K. Kamath, "Seismic performance of a tall multi storey tower connected by a large podium," *International Journal of Recent Technology and Engineering,* vol. 8, no. 2, pp. 3545-3551, 2019.

[9] K. S. Moon, "Structural design of double skin facades as damping devices for tall buildings," *Procedia Engineering,* vol. 14, pp. 1351-1358, 2011.

[10] K. Shah, H. Desai and D. Shah, "Effect of backstay on 3B+G+20 storey R.C.C building," *National Conference on Structural Engineering,* vol. 6, no. 9, Aug 2020.

[11] K. Zhou, X. W. Luo and Q.-S. Li, "Decision framework for optimal installation of outriggers in tall buildings," *Automation in Construction,* vol. 93, pp. 200-213, May 2018.

[12] L. Xing, P. Gardoni, Y. Zhou and M. Aguaguina, "Optimal outrigger locations and damping parameters for single-outrigger systems considering earthquake and wind excitations," *Engineering Structures,* vol. 245, pp. 112868-112884, July 2021.

[13] M. M. Parekh and K. J. Dhandha, "Study on position of outrigger system in tall structure," *Journal of Emerging Technologies and Innovative Research (JETIR),* vol. 3, no. 5, pp. 236-242, May 2016.

[14] M. Samadi and N. Jahan, "Determining the effective level of outrigger in preventing collapse of tall buildings by IDA with an alternative damage measure," *Engineering Structures,* vol. 191, pp. 104-116, March 2019.

[15] M. Yacoubian, N. Lam, E. Lumantarna and J. L. Wilson, "Effects of podium interference on shear force distributions in tower walls supporting tall buildings," *Engineering Structures,* vol. 148, pp. 639-659, Oct 2017.

[16] N. Y. Mithbhakare and P. D. Kumbhar, "Review on behavior of outrigger system in high rise building," *International Research Journal of Engineering and Technology (IRJET),* vol. 07, no. 04, pp. 1990-1994, April 2020.

[17] O. A. Mohamed and O. Najm, "Outrigger systems to mitigate disproportionate collapse in building structures," *Procedia Engineering,* vol. 161, pp. 839-844, Jan 2016.

[18] P.-C. Lin, T. Takeuchi and R. Matsui, "Optimal design of multiple damped-outrigger system incorporating buckling-restrained braces," *Engineering Structures,* vol. 194, pp. 441-457, Sept 2019.

[19] R. Tavakoli, R. Kamgar and R. Rahgozar, "Seismic performance of outrigger–belt truss system considering soil–structure interaction," *International Journal of Advanced Structural Engineering,* vol. 11, no. 1, pp. 45-54, 2019.

[20] W. Alhaddad, H. Yahia, X. Hu and L. HongGang, "A comprehensive introduction to outrigger and belt-truss system in skyscrappers," *In Structures,* vol. 27, pp. 989-998, Oct 2020.

[21] Z. Bayati, M. Mahdikhani and A. Rahaei, "Optimized use of multi-outriggers system to stiffen tall buildings," in *The 14th World Conference on Earthquake* Engineering, Beijing, China, 2008.