The Seybold Report

ISSN 1533-9211

DOI: 10.5281/zenodo.8363012

DYNAMIC SOIL STRUCTURE INTERACTION ANALYSIS OF HIGH-RISE BUILDING SUPPORTED ON FINNED PILE-MAT FOUNDATION

Dr. BASAVANAGOWDA.G.M

Assistant Professor, Department of Civil Engineering, MSRIT, Bangalore, India.

M ROSHANA*

P.G Research scholar, Department of Civil engineering, MSRIT, Bangalore, India.
*Corresponding Author Email: roshana.manjunath0702@gmail.com

PRADEEP C R

Assistant Professor, Department of Civil Engineering, Bangalore Institute of Technology, Bangalore, India.

Abstract

In a process known as Soil-Structure Interaction (SSI), the motion of the structure is impacted by the soil reaction and vice versa. It has been believed that SSI enhances a building's capacity to respond to earthquakes. In order to transfer building loads from shallow soil strata with poor bearing capacity to deeper soil strata with high bearing capacity and stiffness, pile foundations are often employed. Compared to vertical loads, lateral loads are often only partially resisted by piles. Thus, it is also necessary to enhance the lateral load bearing capability of piles. In general, fins make the pile more rigid, which helps piles to resist greater lateral stresses than the typical approach. It is exceedingly challenging to fully understand the behavior of fin piles using conventional soil pile theories since they have various fin configurations. The purpose of the current study is to understand how regular pile mats (RP-Mat) and finned pile mat foundations with different fin lengths of 6m & 18m behave under saturated and unsaturated soil conditions when they are subjected to 1940 El-Centro earthquake ground motion. The three-dimensional Finite element analysis ABAQUS 6.17 software was used to model these foundations. At various floor levels, the peak acceleration, storey lateral displacement and Inter-storey drift values are compared for both fin lengths under different soil conditions. Results of the study showed that when compared to RP mat, using a finned pile mat proved more effective in decreasing the structural response. A better performance with respect to reducing the seismic effects on the building and improving its stiffness was observed when the fin length was increased Further, the 0.6Lp is proved to be the effective fin length which were shown satisfactory performance when compared to other fin lengths.

Keywords: Earthquake, Acceleration, lateral displacement, Inter-storey drift, Soil Structure interaction, Finned Pile-Mat.

1. INTRODUCTION

Every civil construction has foundations and other supporting elements that are either buried in the ground or depends on it. Due to the challenges in modelling the mechanical behavior of soils and the high level of variability in their characteristics, structural engineers sometimes totally neglect the influence of soil on the structural system [1]. Conventional design of structures ignores the effects of soil-structure interaction and is predicated on the assumption that the structure is firmly supported. Recent research, however, suggests that taking SSI into account might enhance a building's seismic performance. For increasing the natural period can be achieved by decreasing the stiffness of the soil-structure system and increasing the degrees of freedom. Second, the kinematic interaction and inertial interaction effects [2] because the

The Seybold REPORT

ISSN 1533-9211

DOI: 10.5281/zenodo.8363012

foundation input motion to diverge from the free field motion. When unbraced constructions lies on relatively soft soils, soil-structure interaction, in particular, may greatly enhance storey lateral displacements and inter-storey drifts [3]. The most popular foundation options for bridges and other structures are drilled shafts and pile foundations. Such structure-foundation systems have come under examination for their performance in Kobe (1995) and Northridge (1994) earthquake [4].

Piles are usually used to transmit large vertical loads from the superstructure through weaker subsoil into the underlying bearing strata. Due to their size being far less than that of the vertical loads, the horizontal loads operating on pile foundations are frequently disregarded. Under various ground conditions, the behavior of piles subjected to static and cyclic loads has been evaluated. To forecast the maximum lateral load borne by the pile head and the soil pile reaction throughout its length, several empirical formulae have been developed[5].The foundation-structure interaction may be assessed taking into account inertial interactions between the foundation and structure given the nonlinear reaction of the soil to diverse ground motions, dynamic interactions between the foundation and the soil beneath are also possible[6].In order to avoid negative consequences from high-intensity vibrations, due to the disastrous impact of elevated levels of horizontal resistance during an earthquake, it is essential to employ an innovative strategy while building the substructure for multi-storey structures. According to recent research, for both onshore and offshore foundations, finned piles can offer better levels of lateral support than traditional pile types. [7].

The soil properties and pile shaft hardness are the primary determinants of the increase in lateral resistance caused by piles with wings connected at their heads. For recalcitrant soils to achieve equivalent advantages owing to inserting a piece into the pile, stronger wings are required than for weak soils [8]. Finned piles have demonstrated more efficacy in enhancing lateral load resistance than standard methods like increasing pile diameters or fortifying shallow soil. A range of factors, including fin length and width, position on a structure, and unique morphologies, can all have a substantial impact on overall fin efficiency, according to study. As a result, we may say that the fins' behavior is connected to their surface area [9, 10].

The levels of resistance offered by rectangular-fin piles exceed those provided by their triangular counterparts. Additionally, it's not just added strength that finned piles provide to the structure with their increased lateral resistance, they also help to lower the lateral deformation which makes them ideal for fulfilling the dual requirement of limit state designs [7].When regular piles are strengthened at the pile head with plates to boost the foundation system's lateral load-carrying capacity, they become finned-piled foundations. Piles often encounter shock, such as earthquake-related vibrations. Since this is the case, piles must have the capacity to absorb energy in order to maintain the structure. Fin piles can absorb enormous quantities of energy without losing any strength, as compared to regular piles, which can usually only absorb a little amount of energy [11].Peng and Rouainia [12] the lateral load capacity of model tests conducted on a monopole equipped with fins was drastically increased according to 3D analysis performed on laterally loaded fin piles. When fins are attached to a pile, the rise in lateral resistance that results may be evaluated against the movement of the pile head. Numerical

The Seybold REPORT
ISSN 1533-9211
DOI: 10.5281/zenodo.8363012

analysis demonstrates that an increase in fin length results in an increase in lateral resistance.

For Soil-Structure Interaction (SSI) study, the decision between a rectangular pile and a circular pile depends on a number of variables, such as the structural system, design specifications, and modelling choices. Both pile designs have benefits and drawbacks, and the choice ultimately comes down to the requirements of the particular project and technical expertise. Structural system: The type of structure being analysed may have an impact on the pile form selection. When the load distribution calls for a broader pile section or in constructions with rectangular footprints, rectangular piles are frequently utilized. Also, circular piles are more often utilized in various applications because of their simplicity and symmetry. Load distribution: The pile form that is chosen can be influenced by the structure's load distribution characteristics and the interaction between the pile and the earth. In general, circular heaps distribute loads more evenly, which might be helpful in some circumstances. When there is an uneven weight distribution or when certain load patterns must be taken into account, rectangular piles may be selected.

In the present study, an attempt is made to model the 25-storey high rise structure with finned pile–mat foundation from which the response of structure in terms of peak acceleration, storey lateral displacement and inter-storey drift is studied under both saturated and unsaturated condition with varying fin length (L_f=6m & 18m). Based on the thorough review of literature, it is considered clearly that finned pile mat foundation is more effective under unsaturated condition. The performance of FP-Mat under saturated condition needs to be explored.

2. VALIDATION OF 3D NUMERICAL MODEL

In order to validate the data present in the literature, a unique and improved soil-structure numerical model is built in the present part using the finite element programme ABAQUS 6.17, the structure properties are as mentioned in table 1. Fixed Analysis was conducted for the 25-storey building resting in regular pile-mat foundation and the outcomes are displayed as in Figure 3. The findings of the current investigation are well in line with those found in the literature by Bariker et al. (2022) [7].

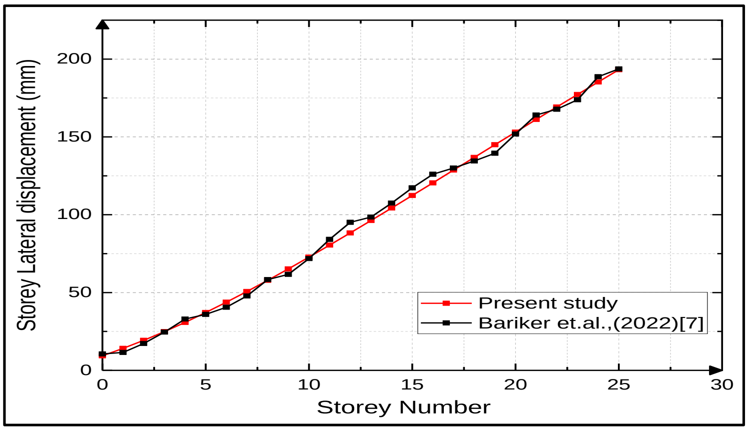


Figure 1: Comparison of Storey Lateral displacement with storey number

The Seybold REPORT

ISSN 1533-9211

DOI: 10.5281/zenodo.8363012

2.1 Present Study

The building model was subjected to the ground motion of the 1940 El-Centro earthquake with a magnitude of M_w=6.9 having a duration of 53.74s and peak acceleration of 0.349g, as shown in figure 2. An analysis of the dynamic relationship between soil and structure for a 25-story building resting on Finned Pile-Mat was done by varying fin lengths (L_f=6m & 18m) under saturated and unsaturated soil conditions.

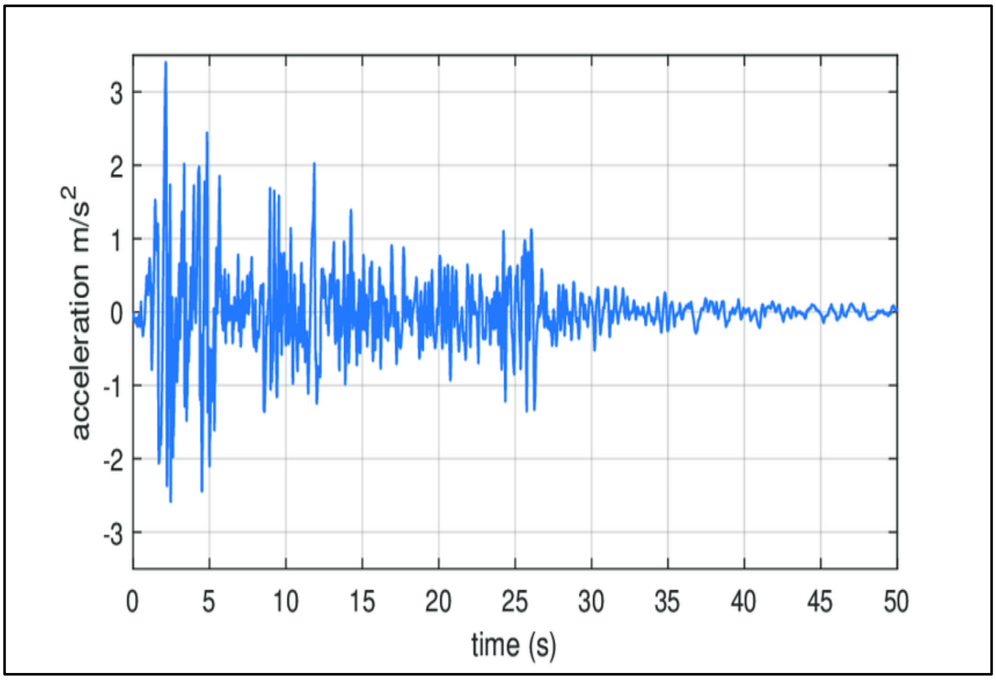


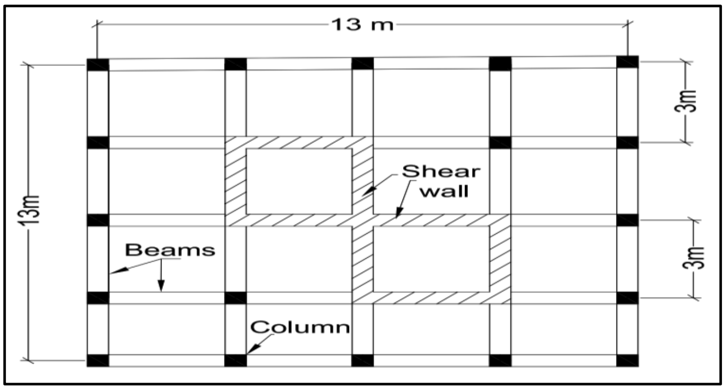
Figure 2: 1940 El-Centro earthquake groundmotion considered for the present study (Source: [13])

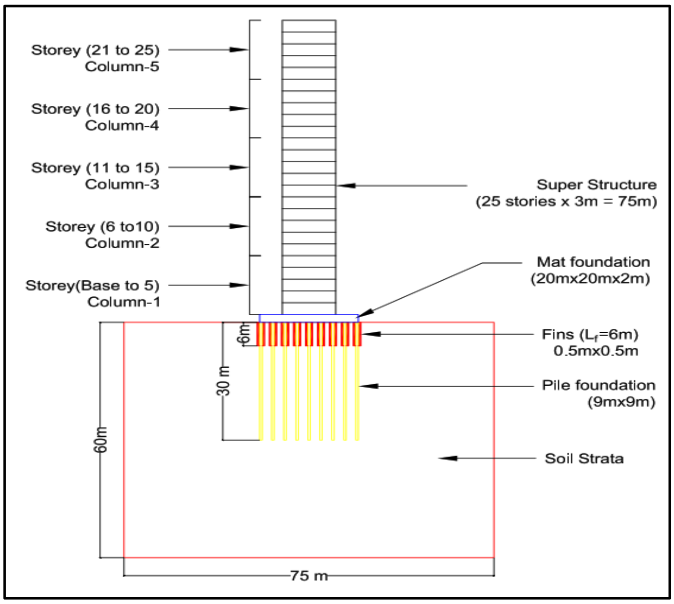
2.1.1 Super Structure Details

According to height, four categories were used to group tall structures. by the International Conference on Tall Buildings in 1972 (Mukand et al. 1973 [14]): (1) 9-16 storeys (up to 50 m); (2) 17- 25 floors (up to 75 m); (3) 26-40 stories (up to 100 m); and (4) more than 40 stories (ultra tall buildings). In this study, a 25-story building with a maximum height of 75 metres has been chosen, and a 3m centre-to-centre spacing between each column has been studied using ETABS software [15] as per the codal provision of IS 456:2000[16] figure 3(a) shows the plan view of 25-storey building with position of shear wall, column and beams.

ISSN 1533-9211

DOI: 10.5281/zenodo.8363012





(a) (b) Figure 3: (a) Plan &(b) Elevation of 25 storeybuilding

Table 1: Details of C/S of structural element with reinforcement details [7]

Section Type	Column -1	Column-2	Column-3	Column-4	Column-5	Shear wall	Slab	Beam
Storey-level	1 to 5	6 to 10	11 to 15	16 to 20	21 to 25	1 to 25	1 to 25	1 to 25
Dimensions (m)	0.5x0.5	0.45x 0.45	0.4x0.4	0.35x 0.35	0.3x0.3	0.5m thick	0.25m thick	0.3x0.4
Cross section area(m^2)	0.25	0.202	0.16	0.1225	0.09	0.5	0.25	0.12
Longitudinal reinforcement (no. & dia of bars)	12#24	12#24	12#24	12#20	12#20	#12@ 150	#16@ 250	3#12 (top) 4#16 (bottom)
Tie reinforcement (Diabar @spac, mm)	#10@75	#10@12 5	#10@18 0	#10@ 200	#10@ 225	#10@ 200	-	#10@ 180

ISSN 1533-9211
DOI: 10.5281/zenodo.8363012

The dimensions and position of the beams, columns cross-section and shear wall are selected from literature i.e., Bariker.et.al (2022) [7]. The reinforcement details are obtained through structural design using ETABS software for beams, column and shear wall. Compressive strength of 35Mpa was considered while opting for M35 grade cement which was used to form all the structure components. The determination of properties obtained from analysis relied on specified factors found within references [15] and [16]. The resulting values showed that concrete has an E=29,580 Mpa with density being roughly equivalent to around about 25000 N/m³ while using Fe500 grade of steeland the structural elements are given as Visco-elastic material property. Table 1 showcases both the dimensions of structural components as well as the corresponding reinforcement details after taking into account a 5% dampening observed in them during dynamic analysis All of the characteristics and dimensions are taken into account from the research Bariker et al. (2022) [7] As the load lowers at higher storey levels during the structural study, we lowered the column dimensions, as can be seen in Table 1,which also shows that the column dimensions are smaller as the storey level increases.

2.2 Substructure Details

According to the literature Bariker et al. (2022) [7], silty-soil is used for unsaturated conditions and clayey-soil is used for saturated conditions when considering the soil mass for the foundation. Both Tables 2 and 3 provide the characteristics of the soil bulk. Based on the column response and type of soil, an ETABS structural analysis was conducted for both a traditional piled-mat foundation and a FP-Mat foundation.

2.2.1 Materials properties

The qualities of the soil and the structural components made of M35 concrete used in the structural design were analyzed in this study. For the FEM investigation, a dilation angle of 1° was employed to prevent any potential separation. For the Mohr-coulomb model, the soil layers are simulated. The analysis with a 5% structural damping value was taken into consideration using the Rayleigh coefficients of α= 0.2015 and β= 0.012. To achieve the saturated soil layers, the densities are reduced and are shown in Table 3 based on research by Mohammed Yadgar et al. (2022) [17].

Table 2. Properties of Soil-Structural Elements for Unsaturated Finned Pile-Mat Condition [7]

Characteristic Properties	Soil	Structural Elements
Material model	Mohr-Coulomb Model	Visco-elastic Model
Unit weight, γ (kN/m³)	15.5	25
Density(kg/m³)	1580	2548
Modulus of Elasticity, E (MPa)	28	29,580
Poisson's ratio, μ	0.33	0.2
Friction angle, $\phi(^0)$	22	-
Dilation angle, $(^0)$	1	-
Cohesion, C(kPa)	24	-
Void ratio, (e)	0.882	-
Permeability, K (m/s)	$4.8\text{x}10^{-9}$	-

The Seybold REPORT

ISSN 1533-9211

DOI: 10.5281/zenodo.8363012

Table 3: Properties of Soil-Structural Elements for Saturated Finned Pile-Mat Condition [17]

Characteristic Properties	Soil	Structural Elements
Material model	Mohr-Coulomb Model	Visco-elastic Model
Density(kg/m³)	1575	2548
Modulus of Elasticity, E (MPa)	45	29,580
Poisson's ratio, μ	0.42	0.2
Friction angle, ϕ (^{0})	30	-
Dilation angle(^{0})	15	-

2.3 Analysis of Building resting on Regular Pile-Mat and Finned Pile-Mat

In this analysis the building resting on Finned pile-mat by varying the Fin length of L_f=6m & 18m under saturated and unsaturated soil condition. The purpose of this study was to compare how effective two different pile-mats regular vs. finned pile-mat were at protecting a multi-story superstructure with respect to seismic activity when placed on different soil conditions. Our investigation employed the ground motion from the 1940 El Centro earthquake. The foundation system of this structure was designed using both solid and shell element models. When analysing the mass and stiffness dampening components in the current investigation, dynamic soil structure interaction must be taken into consideration; literature-based Rayleigh damping coefficient parameters such as α & β were assessed with final values being calculated at 0.758 and 0.012 respectively. The listed structural components in Table 1 above were separately modelled before being assembled into their proper places. After that, they were combined to create the building's multi-storey superstructure. The piles below are extruded to replicate the piled mat as a single piece, and the piled-raft is specified as being 2 m thick.

Through analysis of the surface-to-surface contact between every pile-mat and the surrounding soil it was possible to gain insight into the nature of their interaction. When referring to instances where soft earth separated constructions from firmer ground it was known as the slave surface. Furthermore, in scenarios where there is a combination of both interactions between soils piles, and mats, they are referred to as dominant surfaces respectively. Specifying tangential or friction-based contacts required us to construct a frictional behaviour that relied heavily on existing data pertaining to the associated pressure points [18, 19]. It was determined that the pile's usual degree of hardness in contact with the ground was sufficient to avoid any piercing of the soil strata.

For a quicker computation in our analytical method, a sensitivity test on mesh size has been carried out. The meshing procedure was successfully completed using multiple element distributions categorised as different sizes ranging from extremely coarse to refined. The refined option was chosen for model meshing because it was the most effective choice among the various element distribution options as measured by computation time and accurate outcomes. Moreover, the application of a coarse mesh technique is carried out farther away from locations with high concentration of stresses while a finely tuned method is used at locations with highly concentrated spots. Both the earth and the structural components were made solid against seismic shaking by being classified as solid components. For preventing

The Seybold Report
ISSN 1533-9211
DOI: 10.5281/zenodo.8363012

translational errors in soil base across all three dimensions we specified boundary conditions (UX=UY=UZ=0) during our initial phase. In order to carry out a time-history analysis with an applied earthquake load along the x-direction we allowed for translation along this axis (UX). For all phases considered here (UX = UY = 0), movement along either the x or y direction was restricted for the soil models. However, the total three-dimensional model employed in conducting a time-history analysis is illustrated in Figure 4.

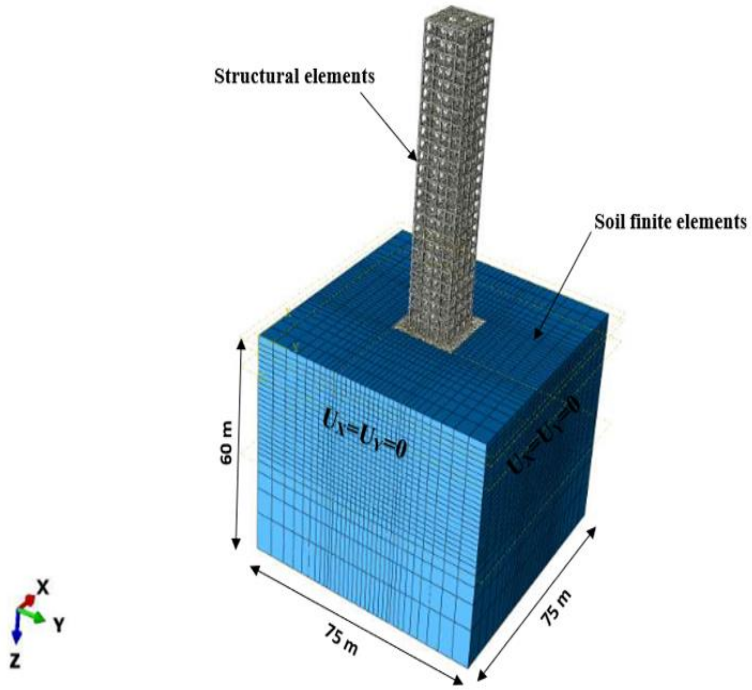


Figure 4: Three-dimensional Finite element SSI meshed model developed using ABAQUS

2.4 Numerical Analysis Program

Numerous investigations [20] found that the Pile Mat methodology is a novel strategy to prevent the potentially disastrous impacts on structure because of the SSI effect. Finned piles, a novel technique, successfully replaces conventional piles in a system's lateral reaction. A 25-story building sitting on a finned pile-mat system was subjected to a number of time-history assessments in the search for such a novel method to use as a corrective remedy. The responsiveness of the conventional pile-raft system and the finned pile-mat system was compared. Figure 5 depicts the schematic perspective of the conventional piled-raft and the finned pile raft. Each pile used in the study was Lp (30 m) and BxB (0.5 m x 0.5 m) in size. Additionally, finned with assumed fin widths (Wf) of 0.5 m, estimated fin thickness of 0.15 m, and assumed fin lengths (Lf) of those in normal pile.

ISSN 1533-9211
DOI: 10.5281/zenodo.8363012

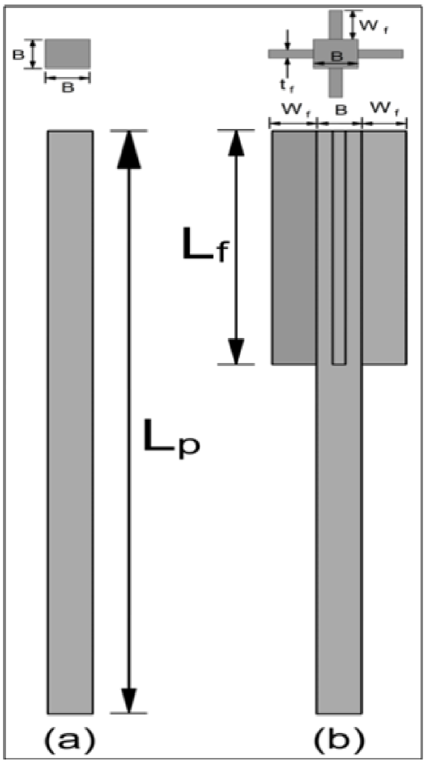


Figure 5: Schematic representation of the pile models: (a) Regular pile-mat & (b) Finned pile-mat

In the present analysis, numerical SSI analyses were completed using the ABAQUS programme, and a thorough analysis was conducted across many sets, including Series I, which contained responses from a regular pile mat (RP-Mat). Series II looked at a Finned Pile-Mat operating under unsaturated and saturated soils condition at Fin length 6m to evaluate the impact of fins on dynamic loading performance. Series III contained responses of finned pile-mat under different soil conditions with Fin length 18m.Three crucial were assessed in order to accurately record the seismic damage levels: the peak acceleration level, the peak storey lateral displacement, and the peak inter-story drift. The storey-drift and Inter-storey drift are calculated using equation (1) & (2) from IS 1893:2016[21]

Storey drift = $\{u_{(i+1)} - u_{i}\}$ …… (1)

Inter storey drift = (storey drift/ storey height) x100…… (2)

Where $u_{(i+1)}$ represents the lateral displacement of the upper floor, and u_i represents the lateral displacement of the lower floor.These equations allow for the assessment of seismic loads on a building's reaction to lateral forces and the determination of whether or not the displacements are within acceptable limits for the structure's design and safety criteria.

ISSN 1533-9211

DOI: 10.5281/zenodo.8363012

3. RESULTS AND DISCUSSIONS

3.1 Regular Pile-Mat (RP-Mat)

The response parameters of analysis of 25 storied building such as acceleration vs time, inter-storey drift at different floor levels is as presented below.

3.1.1. Peak Acceleration and Peak Inter-Storey Drift

The acceleration time-history charts are depicted in Figure 6 at various floor levels. The building's maximum acceleration varied between 0.012g at ground level and 0.24g on the top floor (25th floor), as observed. More acceleration was experienced on higher floor levels. It has been observed that the acceleration values in the building have been amplified, thus. By analysing Figure 7, we can infer that there exists a positive relationship between greater inter-story drift and elevated floor levels, which is caused by strong vibrations that the building experiences. Hence, it is crucial to take into account this aspect while designing tall structures. In addition, a calculation yielded a value of approximately 6.82s, with the maximum measurement of story-drift being roughly 0.0084m. Nonetheless, there were no issues that emerged since this stayed within the satisfactory thresholds according to the directives of IS: 1893(2016).

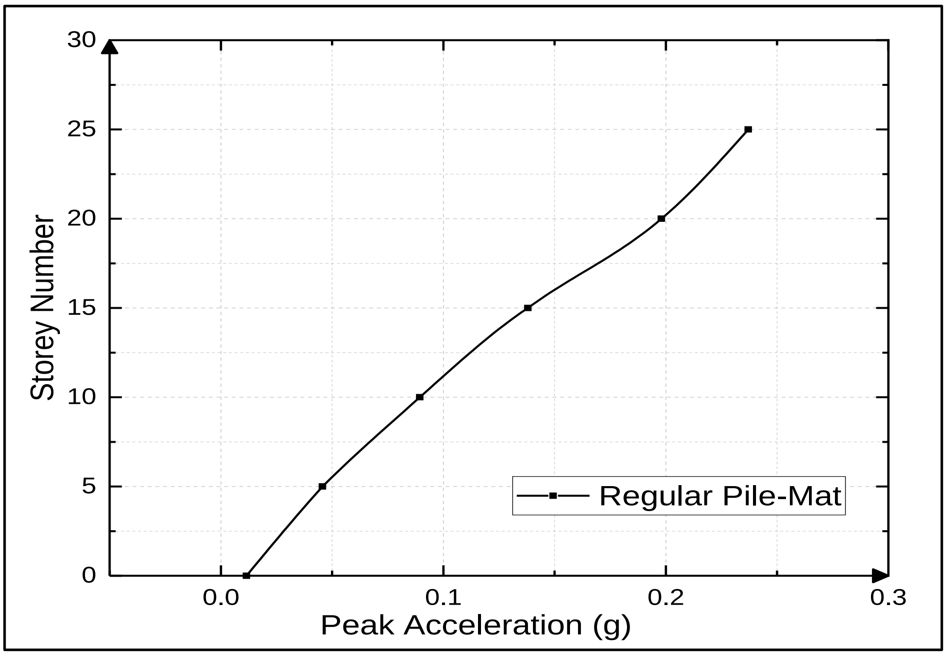


Figure 6: Acceleration time–history plots at differentstorey level of the building

ISSN 1533-9211
DOI: 10.5281/zenodo.8363012

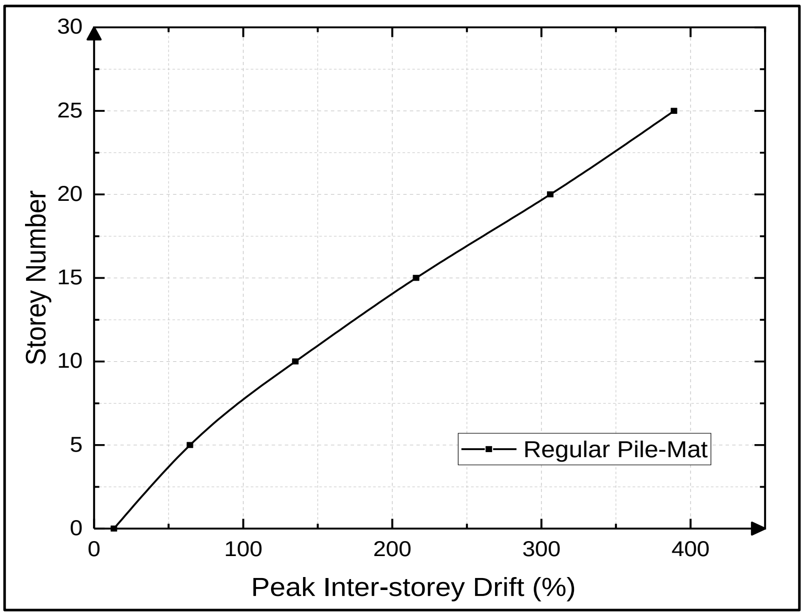


Figure 7: Peak Inter-storey drift at differentstorey level of the building

3.1.2. Peak Storey Lateral displacement

Figure 8 shows how the structure responded, which was determined by measuring the storey lateral displacement at various story levels of the buildings. The building's lateral displacement increased as it increased in floors, with the peak displacement varying from 9.24 mm at the first floor to 191 mm at the top floor (25th storey) of the structure.

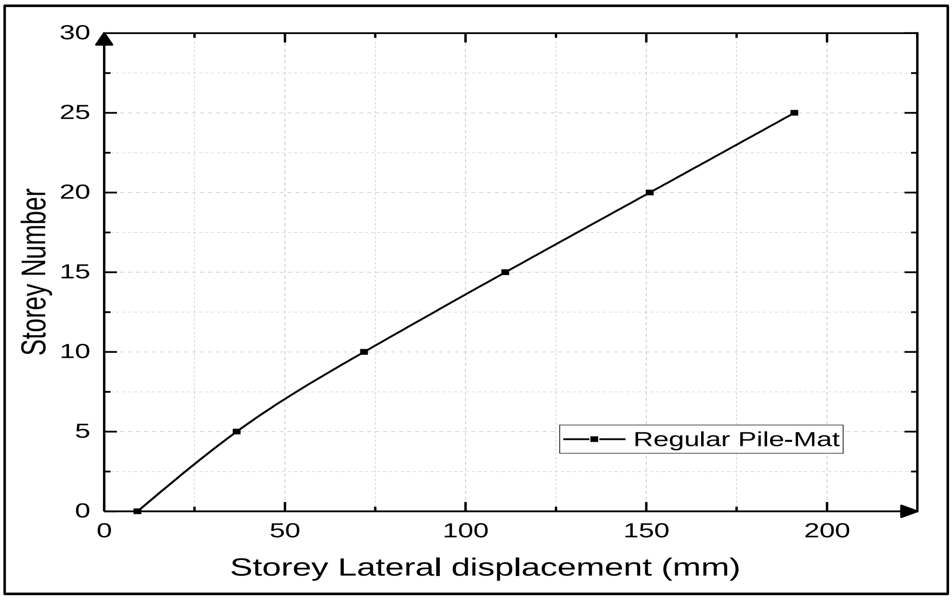


Figure 8: Storey Lateral displacement plots at different storey levels of the building

ISSN 1533-9211
DOI: 10.5281/zenodo.8363012

3.2 Finned Pile-Matwith Fin Length L_f=6m under Unsaturated Soil Conditions

To investigate how the finned pile-mat (FP-Mat) affects a multi-storey building's ability to respond to earthquakes. Finned pile Mat foundations are used in place of traditional pile foundations. Figure 9 depicts the 3D model of the FP-Mat that was created for this investigation. The FP-Mats exposed to the ground motion of the 1940 El Centro earthquake underwent time-history analysis (Figure 2). Furthermore, the fin length was considered to be L_f=6m or 20% of the total Pile length under unsaturated Soil conditions.

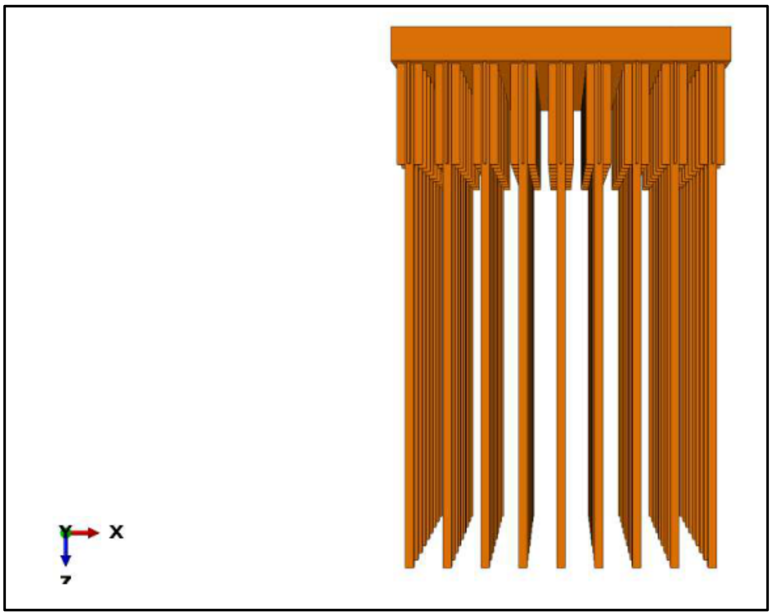


Figure 9: Three-Dimensional Finned pile-mats with Fin length L_f=6m developed in the present study

3.2.1 Peak Acceleration and Peak Inter-Storey drift values

Figures 10 and 11 for a 25-storey structure illustrate the acceleration history plots for various storeys together with their associated inter-Storey drifting values. With a 6m-long fin, FP-Mats support the structure. The findings show that an FP-Mat can significantly lessen the seismic behaviour of a multi-story structure. In the absence of an RP-Mat, the top floor's inter-storey drift and maximum peak acceleration both decreased.

As a result, the structure was less affected by vibrations. The piled-mat system's greater flexural stiffness boosted passive resistance to the applied seismic stress. The inter-story drift was tentatively determined to be 2.10×10^{-7}% at the base and 1.16×10^{-8}% on the 25thlevel, respectively, when compared to regular pile mat.

Acceleration values range from 1.52×10^{-10} g at the base of the skyscraper to 8.15×10^{-12} g on its 25th storey. The building's acceleration readings have been seen to be enhanced as a result.

ISSN 1533-9211

DOI: 10.5281/zenodo.8363012

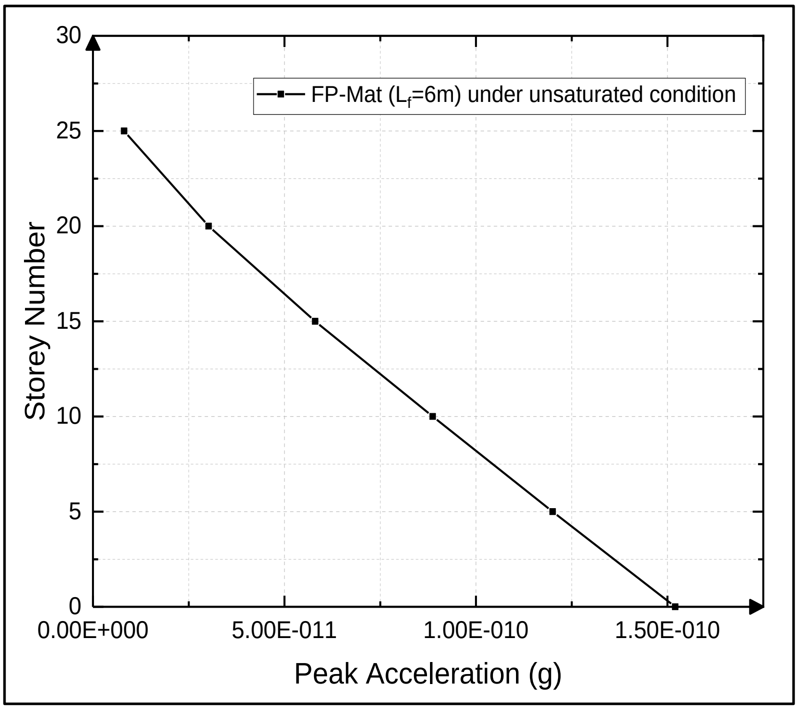


Figure 10: Acceleration time–history plots at differentstorey level of the building

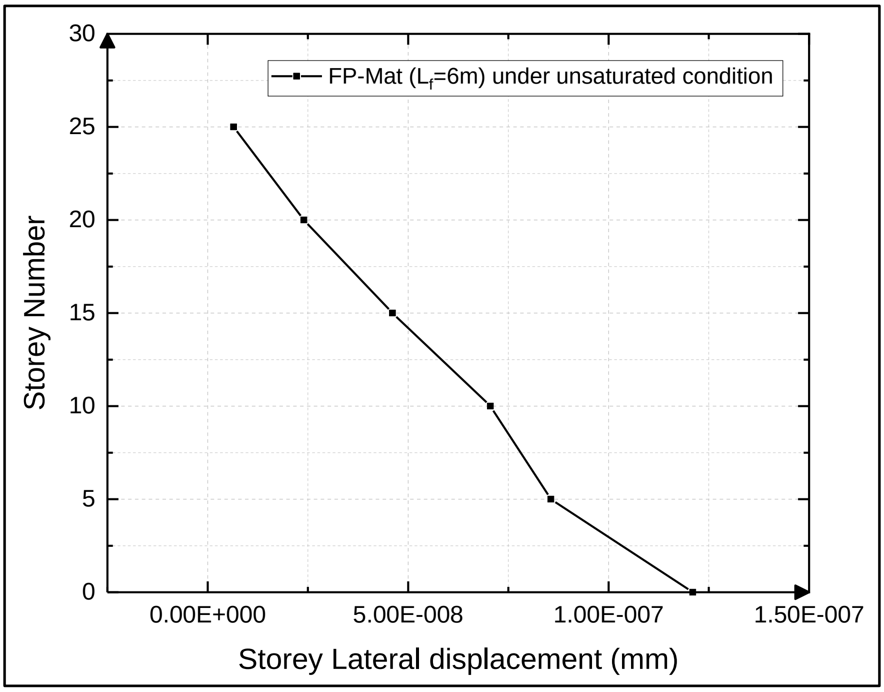


Figure 11: Peak Inter-storey drift at differentstorey level of the building

ISSN 1533-9211

DOI: 10.5281/zenodo.8363012

3.2.2 Peak Storey Lateral displacement

Figure 12 shows how the peak of the high-rise structure varies. When storey lateral displacement was examined for all storey levels between finned pile-mat and RP-Mat, in case of RP-Mats the top storey's lateral displacement was found to be more than the base floors and under FP-Mat foundation, at top storey the displacement value was $6.48x10^{-9}$mm and at base floor it was $1.21x10^{-7}$ mm the lateral displacement was found to be lower.

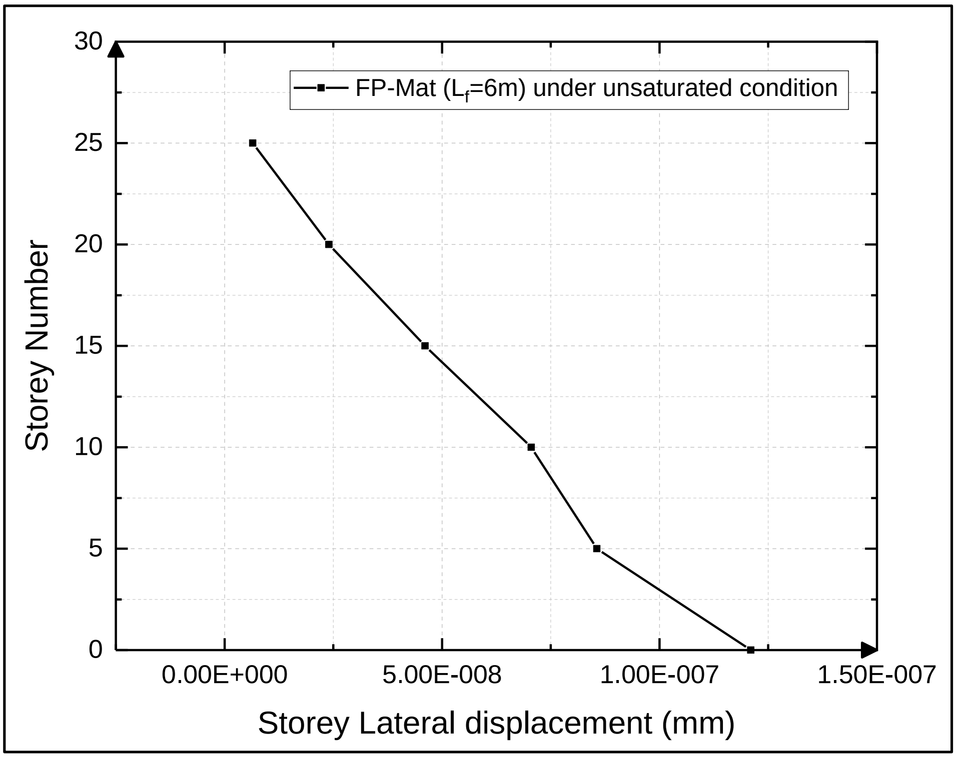


Figure 12: StoreyLateral displacement plots at different storey levels of the building

3.3 Finned Pile-Mat with Fin Length L_f=6m under Saturated Soil Conditions

3.3.1 Peak Acceleration and Peak Inter-Storey drift

The building model was subjected to the ground motion of the 1940 El-Centro earthquake to do the analysis on the FP-mat to determine the effect of finned pile-mat in saturated conditions. According to Figure 13& 14, the acceleration and inter-storey drift for the finned pile mat foundation in saturated conditions vary over time. The results show that adding an FP-Mat to a multi-storey building in a saturated condition significantly reduces seismic behaviour. As a result, the peak acceleration and inter-storey drift of the top floor were decreased in comparison to the RP-Mat, reducing the effects of vibrations on the building.Peak acceleration values were around $3.90x10^{-11}$g at the base and $2.14x10^{-12}$g at the top level. The inter-storey drift was reduced compared to RP-mat at the base it was $9.06x10^{-8}$%, and at the top it was $4.97x10^{-9}$%.

ISSN 1533-9211
DOI: 10.5281/zenodo.8363012

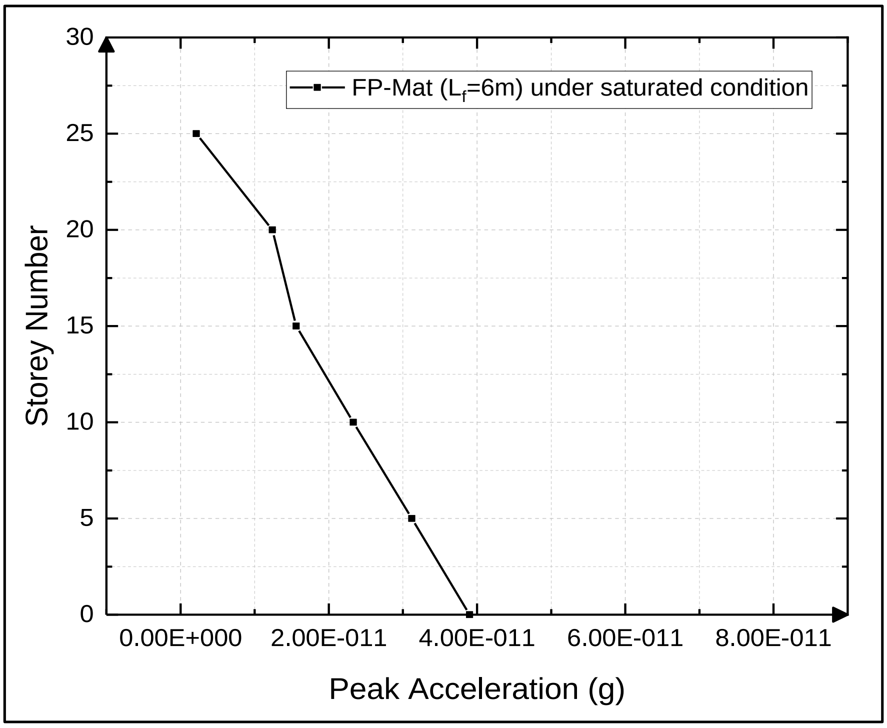


Figure 13: Acceleration time–history plots at differentstorey level of the building

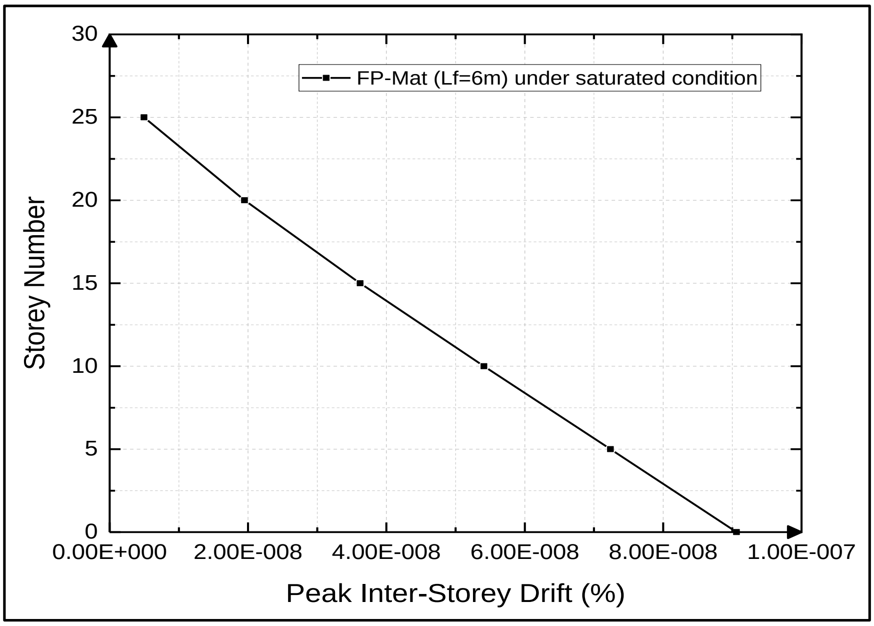


Figure 14: Peak Inter-storey drift at differentstorey level of the building

ISSN 1533-9211
DOI: 10.5281/zenodo.8363012

3.3.2 Peak StoreyLateral displacement

Figure 15 shows that the lateral displacement was examined for all storey levels between finned pile-mat and in RP-Mat the top storey's horizontal displacement was found to be more than the base floors, however under FP-Mat foundation,at top storey the displacement value was 3.34×10^{-9} mm and at base floor it was 6.09×10^{-8} mm the lateral displacement was found to be lower.

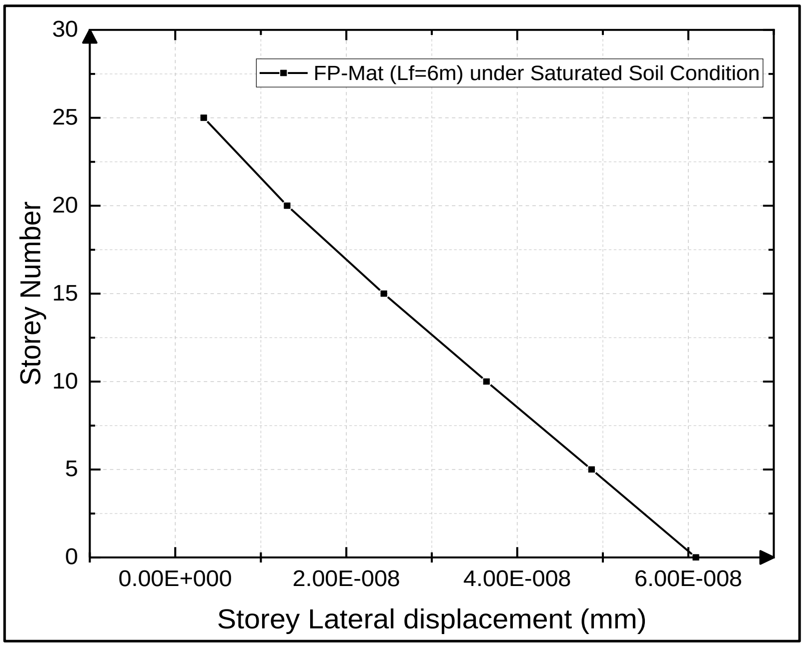


Figure 15: StoreyLateral displacement plots at different storey levels of the building

3.4 Finned Pile-Mat with Fin Length L_f=18m under Unsaturated Soil Conditions

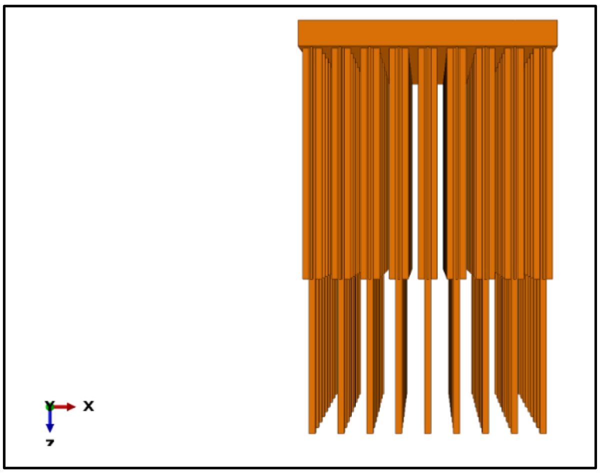


Figure 16: Three-Dimensional Finned pile-mats with Fin length L_f=18m developed in the present study

ISSN 1533-9211
DOI: 10.5281/zenodo.8363012

3.4.1 Peak Acceleration and Peak Inter-Storey drift

Figures 17 and 18 show the acceleration time-history plots and inter-storey drift values at different storey levels of the 25-storey building, supported by the FP-Mats with Fin length L_f=18m.

The results show that an FP-Mat beneath a multi-storey building significantly reduces seismic behaviour. As a result, the top floor's maximum peak acceleration and inter-storey drift were lower than that of RP-Mat, Also it was observed the effects of vibrations on the structure was reduced.

The increased flexural stiffness of the piled-mat system resulted to higher passive resistance being created against the applied seismic stress. The inter-storey drift at the base was approximately $8.15x10^{-9}$ % and at the 25th floor the value was approximately $3.93x10^{-10}$ % when compared to regular pile mat.

The acceleration values at the base were $5.79x10^{-12}$g and at the 25th floor they were $2.79x10^{-13}$g, and as we can see the acceleration values were decreased compared to regular pile-mat foundation.

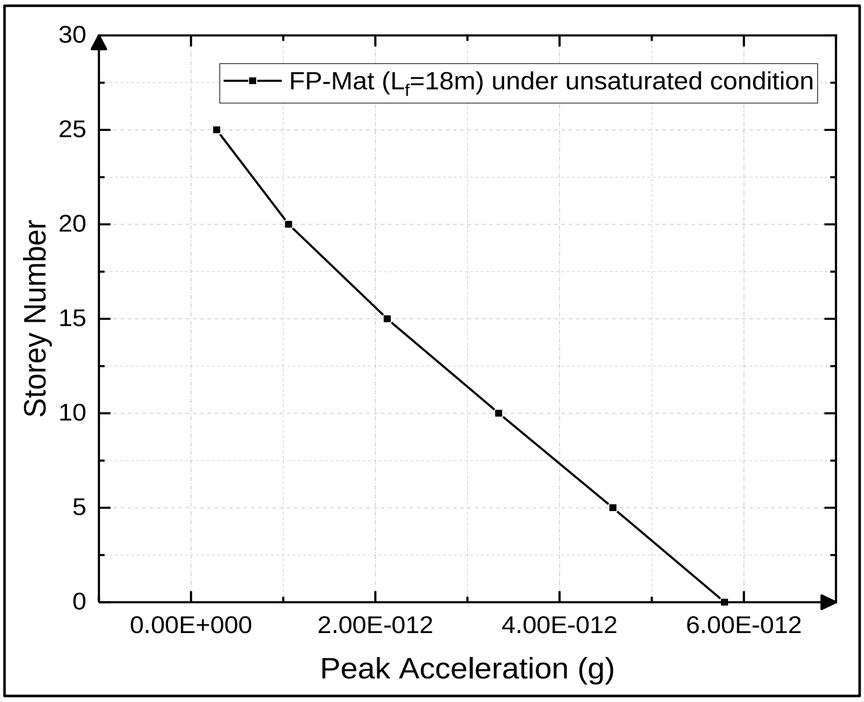


Figure 17: Acceleration time–history plots at differentstorey level of the building

ISSN 1533-9211
DOI: 10.5281/zenodo.8363012

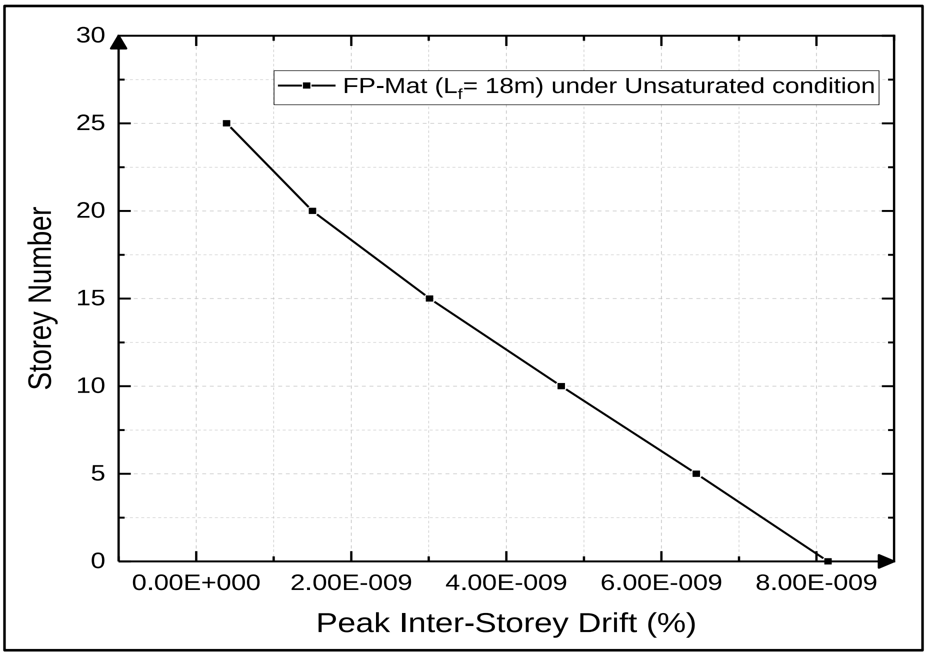


Figure 18: Peak Inter-storey drift at differentstorey level of the building

3.4.2 Peak Storey Lateral displacement

From the Figure 19when lateral displacement was examined for all storey levels between finned pile-mat and in RP-Mat the top storey's lateral displacement was found to be more than the base floors and also under FP-Mat foundation, at top storey the displacement value was $6.48x10^{-10}$and at base floor it was $1.21x10^{-9}$the lateral displacement was found to be lower than the RP-mat.

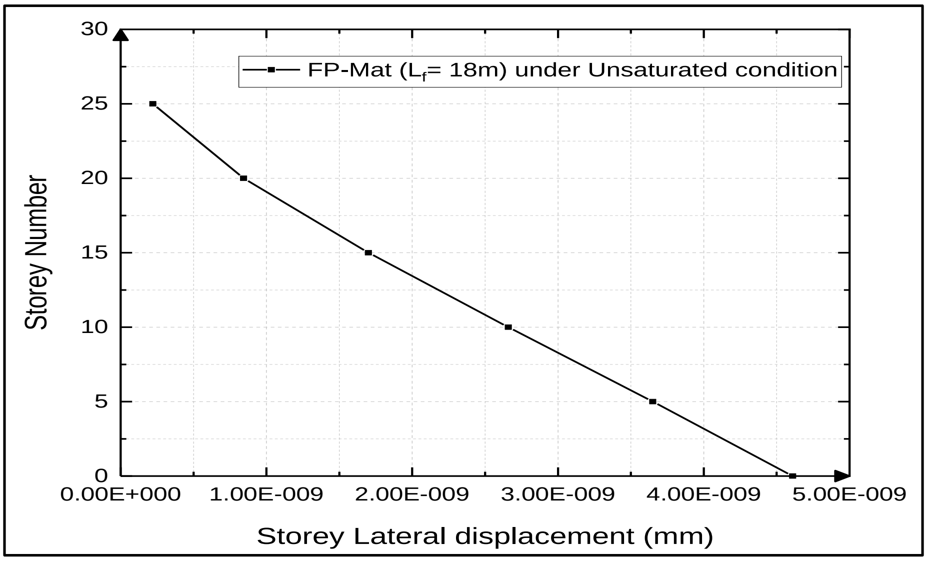


Figure 19: Storey Lateral displacement plots at different storey levels of the building

ISSN 1533-9211

DOI: 10.5281/zenodo.8363012

3.5 Finned Pile-Mat with Fin Length L_f=18m under Saturated Soil Conditions

3.5.1 Peak Acceleration and Peak Inter-Storey drift

The building model was subjected to the 1940 El-Centro earthquake ground motion to conduct the analysis on the FP-mat to determine the effect of finned pile-mat in saturated conditions. According to Figure 20 & 21, the acceleration and inter-storey drift for the finned pile mat foundation in saturated conditions vary over time. The results show that by adding FP-Mat to a multi-storey building with the soil is in saturated condition it reduces the seismic behaviour. As a result, the peak acceleration and inter-storey drift of the top floor were decreased in comparison to the RP-Mat, reducing the effects of vibrations on the building. Peak acceleration values were around $7.57\text{x}10^{-13}$g at the base and $5.22\text{x}10^{-15}$g at the top level. The inter-storey drift was reduced compared to regular pile mat at the base, where it was $1.51\text{x}10^{-9}$ %, and at the top it was $1.30\text{x}10^{-11}$ %.

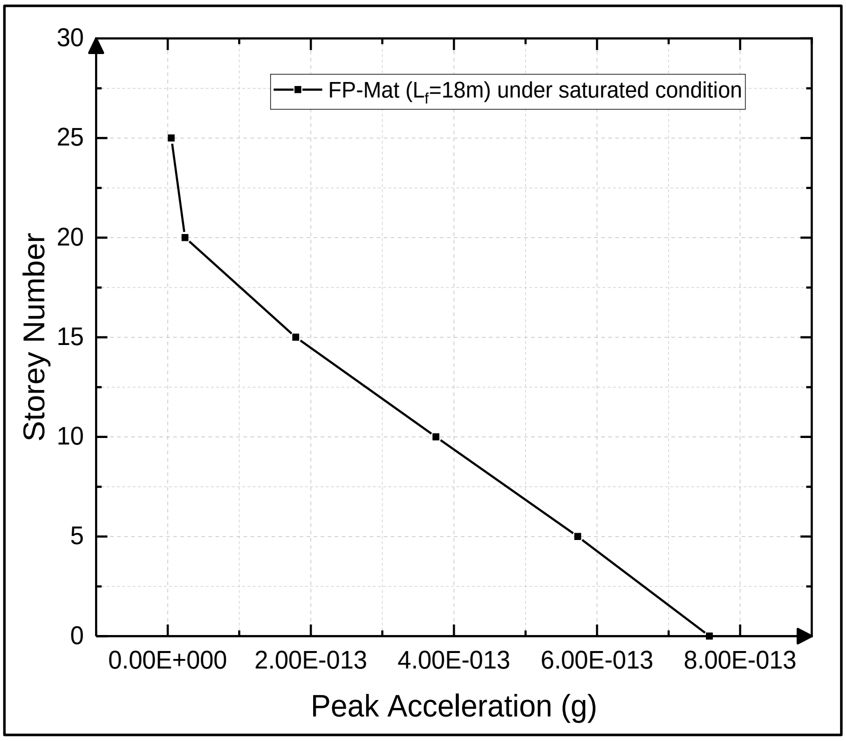


Figure 20: Acceleration time–history plots at differentstorey level of the building

ISSN 1533-9211
DOI: 10.5281/zenodo.8363012

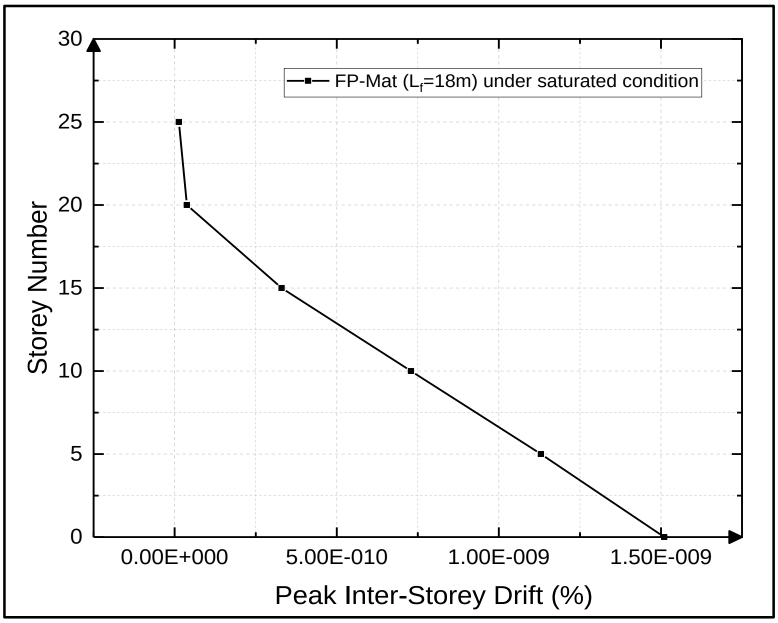


Figure 21: Peak Inter-storey drift at differentstorey level of the building

3.5.2 Peak Storey Lateral displacement

Figure 22 shows how the high-rise building varies. When lateral displacement was examined for all storey levels between finned pile-mat and RP-Mat, in case of RP-mats the top storey's horizontal displacement was found to be more than the base floors, however under FP-Mat foundation,at top storey the displacement value was $8.89x10^{-12}$ and at base floor it was $1.02x10^{-9}$the lateral displacement was found to be lower.

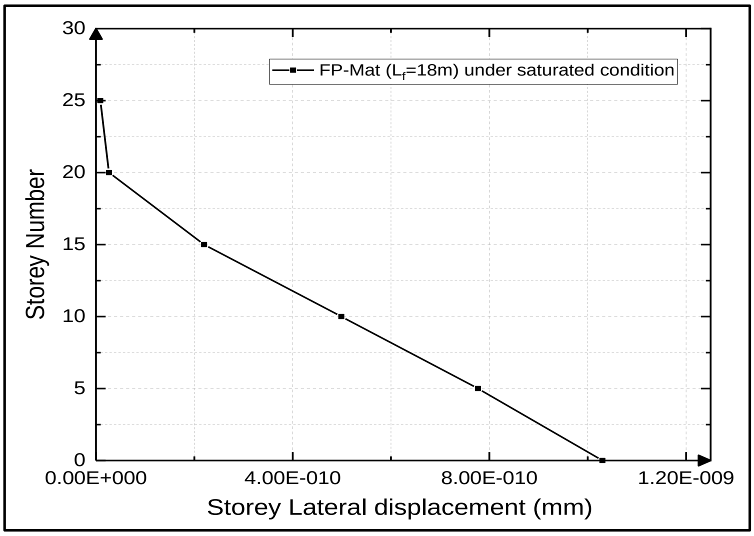


Figure 22: Storey Lateral displacement plots at different storey levels of the building

The Seybold REPORT

ISSN 1533-9211

DOI: 10.5281/zenodo.8363012

4. CONCLUSIONS

Based on numerical investigation seismic response was carried out for **Regular Pile-Mat** and **Finned Pile-Mat** with different **fin lengths (L_f = 6m, 18m) i.e., 0.2L_p and 0.6L_p under both unsaturated and saturated soil conditions** was conducted and the effect of fin length on the seismic response by using 1940 earthquake ground motions were studied.

The following conclusion were drawn.

- Peak acceleration and maximum lateral storey displacement do not significantly increase for all floors supported by Regular Pile-mats as the storey levels increases and also variation is found to be linear.
- The fin length has greater influence on the effect of seismic response hence by increasing the fin length the variation between inter-storey drift was reduced for about 96% in saturated soil condition with fin length 18m.
- The addition of Fin to pile mat helps to decrease the response of the structure caused by seismic activity. Using fin length 0.2L_p and 0.6L_p can significantly reduce the building's seismic response by over 98% when compared to other fin lengths.
- The seismic response of high-rise building constructed over FP-mat are significantly reduced when compared to building constructed on RP-mat.
- FP-Mat with varying fin length i.e., 6m and 18m under unsaturated and saturated soil condition it was observed that under fin length 18m for both soil condition better performance was achieved and Also 6m fin length gives better performance in the case of saturated soil condition than unsaturated condition. Hence, considering the seismic performance and economical construction 18m fin length may be considered the optimum for reducing the seismic response for both soil conditions.

References

1) Zhang, Wenyang & Seylabi, Elnaz & Taciroglu, Ertugrul. "An ABAQUS toolbox for soil-structure interaction analysis". Computers and Geotechnics. 114. 103143. 10.1016/j.compgeo.2019.103143.

2) Zhang, Xiaofeng & Far, Harry, "Seismic behaviour of high-rise frame-core tube structures considering dynamic soil–structure interaction". Bulletin of Earthquake Engineering. 20. 10.1007/s10518-022-01398-9.

3) Far, Harry & Fatahi, Behzad & Ghabraie, Kazem & Zhou, Wan-Huan. "Evaluation of numerical procedures to determine seismic response of structures under influence of soil-structure interaction". Structural Engineering, Mechanics.56.27,47.10.12989/sem.2015.56.1.027.

4) Guin, Jayanta and P. K. Banerjee. "Coupled Soil-Pile-Structure Interaction Analysis Under Seismic Excitation." *Journal of Structural Engineering-ace* 124 (1998): 434-444.

5) Peng, J.R. Behaviour of Finned Piles in Sand under Lateral Loading. Ph.D. Thesis, University of Newcastle, Newcastle upon Tyne, UK, 2005.

6) Qaftan& Omar Shareef Sadq."Response of Soil – Foundation – Structure Interaction of Tall Building (Frame - Wall)" Structural System Under Seismic Effect, University of Salford (United Kingdom) ProQuest Dissertations Publishing.

ISSN 1533-9211

DOI: 10.5281/zenodo.8363012

7) Bariker, P.; Kolathayar, S. Dynamic Soil Structure Interaction of a High-Rise Building Resting over a Finned Pile Mat. *Infrastructures* 2022, *7*,142. https://doi.org/10.3390/infrastructures7100142

8) Saha, Rajib & Dutta, Sekhar & Haldar, Sumanta & Kumar, Sumit. Effect of soil-pile raft-structure interaction on elastic and inelastic seismic behaviour. Structures. 26. 378-395. 10.1016/j.istruc.2020.04.022.

9) Babu, K. & Viswanadham, B V. “Numerical Investigations on Lateral Load Response of Fin Piles”. 317-329. 10.1007/978-3-319-61905-7_27.

10) Albusoda, Bushra & Al-saddi, Anmar.“Experimental study on performance of laterally loaded plumb and battered piles in layered sand”. Journal of Engineering 23. 23-37.

11) Ambi, Rekha & P K, Jayasree & N Jayashree, Unnikrishnan. “Study of fin shape on the behaviour of finned piles under combined loading conditions”. IOP Conference Series: Earth and Environmental Science. 491. 012051. 10.1088/1755-1315/491/1/012051.

12) Peng, J.-R & Rouainia, M. & Clarke, B. Finite element analysis of laterally loaded fin piles. Computers & Structures - COMPUT STRUCT. 88. 1239-1247. 10.1016/j.compstruc.2010.07.002.

13) PEER Ground Motion Database. Available online: https://ngawest2.berkeley.edu/

14) Mukand J, Padmanabhan P, Arya AS, (1973) National conference on tall buildings. New Delhi

15) CSI Computers and Structures INC. CSI Analysis Reference Manual, 18th ed.; CSI: Berkeley, CA, USA, 2017.

16) IS 456-2000 (2000) Indian Standard Plain and Reinforced Concrete Code of Practice. Bureau of Indian Standards, New Delhi.

17) Mohammed Yadgar Ahmed, Iran Keskin A Simulation on Soil Structure Interaction with Abaqus; Effect on the Behavior of a Concrete Building of Soil Layers and Earthquake Properties. Journal of Polytechnic (2022). Doi:10.2339/Politeknik.1059138

18) M.A. Nasr, Ahmed. Experimental and theoretical studies of laterally loaded finned piles in sand. Canadian Geotechnical Journal. 51. 10.1139/cgj-2013-0012.

19) Yaghobi, Mohammad & Hanaei, Faezeh & Fazel Mojtahedi, Farid & Rezaee, Milad. (2019). Numerical finite element analysis of laterally loaded fin pile in sandy soil. Innovative Infrastructure Solutions. 4. 14. 10.1007/s41062-019-0200-9.

20) Han, Yingcai“Seismic response of tall building considering soil-pile-structure interaction”. Earthquake Engineering and Engineering Vibration. 1. 57-64.

21) IS 1893-2016; Criteria for Earthquake Resistant Design of Structures, Part 1: General Provisions and Buildings [CED 39: Earthquake Engineering]. 6th ed. Bureau of Indian Standards: New Delhi, India, 2016; Volume 1893.

22) Far, Harry & Clifton, Timothy. “Significance of Considering Soil-Structure Interaction Effects on Seismic Design of Unbraced Building Frames Resting on Soft Soils”. Australian Geomechanics Journal. 51. 55-64.

23) Matinmanesh, H., & Asheghabadi, M. S. “Seismic analysis on soil-structure interaction of buildings over sandy soil”. Procedia Engineering, 14, 1737–1743.