

Soil Effect on the Seismic Response of Reinforced Concrete Multi Story Structures

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Abstract: In terms of the importance of establishing mega multi-story constructions that considers the impact of seismic action, this research was initiated with the objective of verifying the soil ability to stabilize such structures, while considering the impact of changing the natural frequency of the structure itself, in view of soil type. After setting the research objectives, a methodology was set to encompass 5 investigations. Throughout the Theoretical Investigation, literature in the field of multi-story structure response to seismic action and the numerical models that simulates such structures. During the Numerical Investigation, the available numerical models were scrutinized, from which PLAXIS 2D was selected to be implemented. Moreover, a numerical analysis technique was elaborated. Furthermore, the representation of the various elements was expounded for both the soil and the structure. All through the Analytical Investigation, PLAXIS 2D investigated the structure response to the cases of soil presence and soil absence. During modeling the soil absence, several soil variables were considered (i.e. soil elasticity and soil depth) and many structure variables were taken into account (i.e. height to width ratio and the structure foundation).

During the Inferential Investigation, conclusions were deduced, where the research results highlighted the importance of considering the foundation rigidity. Moreover, the research suggested recommendations for future research, where it was advised to investigate the soil data experimentally. Moreover, the research suggested some recommendations for the Engineering Practice, where it was advised to implement three-dimensional Finite Element Models "FE" to simulate structures with surrounding soil.

Keywords: Soil-structure dynamics, structure frequency, periodic time, Soil Modulus of elasticity

I. Introduction

Soil Structure Interaction (SSI) determines the response of structures during seismic activity, which is the mechanism in which the response of soil particles to earthquake ground movement affects the movement of the structure and the structure response affects the movement of soil mass. The collective response of the structure, the base, is evaluated by a seismic soil-structure interaction analysis. Interactions between three related structures influence the response of a building to earthquake shaking: the structure, the base of structure (foundation), and the soil underneath and surroundings of the foundation. For the theoretical state of a rigid base sustained on rigid soil, soil structure interaction impacts are absence. The discrepancy between the structure's real reaction and the response of the imaginary, static base case is then accounted for by SSI. The foundation forms the supportive basis of the whole structure, which transmits the superstructure's load to the ground. It is therefore necessary to build the foundation in such a way that, apart from being economical, it is both secure and efficient. The results of SSI are influenced not only by the structural configuration, but also with the properties of the foundation and soil. The foundation has been built in recent years to bear additional loads from superstructures such as high-rise towers, bridges, power stations or other civil structures and to avoid excessive settlement. Both structural and geotechnical.

This thesis performs a detailed seismic analysis of a multi-story structure, first with shallow foundations using the FE program PLAXIS 2D under different soil parameters, the superstructure is fully modeled to study the mutual effect between superstructure, surrounding soil, and foundations to achieve more accurate results.

Effects of soil properties, depth of underneath soil, superstructure properties, on the seismic response of structures have been studied to investigate their effect on the natural frequency of structures. The challenge that confronted the researcher was the presence of a knowledge gap in SSI. Accordingly, his main objective was to augment this gap by verifying the capability of the soil to stabilize structures, while considering natural frequency of the structure, in view of soil type.

II. Literature Review

Based on the amassed literature, apparent was that there are many researchers investigated the structural authenticity and seismic protection. Among them, for example are (H. L. WONG and J. E. LUCO), who documented that terrestrial fractures are caused by microseism bursts that caused fatalities over thousands, while the enhancement of technology decreased their risky consequences (i.e. fatalities and property loss) and engineers that imposed their solutions. They further added that seismic protection is an increasing challenge for structural engineers, where many researches are involved in the promotion of seismic-isolators to enhance the behavior of structures during earthquakes. However, they added that considering SSI in the seismic analysis will most probably promote the structure performance during earthquakes. Moreover, they advocated that SSI was not seriously considered until 1971, in spite of the fact that many journals provided design guidelines in 1970s.

Likewise, (H. Bolton SEED, J. LYSMER) [1] suggested a finite element approach as a robust tool for designing nuclear plants with their included structures, where they concluded that implementing such technique in conjunction to engineering experience could assess the level of accuracy of the engineering design.

Similarly, (Spyrakos C, Beskos D 1986, Wolf JP at 1985) [2] investigated SSI during 1980 and 1990. However, many researchers investigated SSI analysis impact.

Moreover, (Lou Menglin, Wu Jingning) investigated 3 major impacts on the structure dynamic response at soft soil, in 1998. They advocated that the SSI dynamic characteristics (i.e. frequencies so as vibrating forms) will decrease and the body motion will be enhanced. They further added that damping of vibrating energy (i.e. radiation damping) will be transferred to the soil, which would dominate the ground motion and consequently, the frequencies are also significant factors that need to be considered.

In the same context, (Kramer 1996, Gazetas et al. 1998 [3], Abdel-Motaal 1999 [4], Day 2002 and Babalola 2011) documented that many researchers investigated the Dynamic Soil Structure Interaction “DSSI” by different analysis methods to obtain accurate structure analysis, under lateral dynamic action. They further stated that the design of these structures should match the requirements, where the deflections should not exceed the assigned limits, soil stress is smaller than the bearing capacity and foundation-structural reliability is preserved. They further stated that the structure response is dependent on several factors (i.e. loading, soil mechanical identities and foundation type). Moreover, they advocated that the structure response to seismic load is dominated by the interaction between the structures so as foundation together with soil beneath the foundation. Moreover, they documented that there are some methods that can assess the impact of SSI by splitting it into direct-analysis and substructure-approaches, where in the 1st method, both soil and structure are considered in the model and are analyzed as one system. However, this approach the soils are modeled by finite element and the boundary conditions are the surrounding soil; figure 1. On the other hand, the 2nd method divides SSI impacts into portions that are then combined to provide the final results; figure 2.

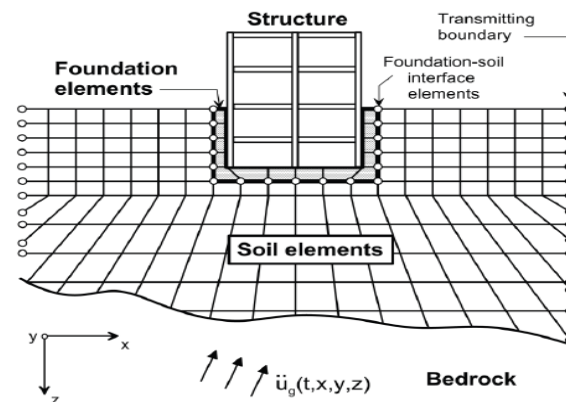


Figure 2.1 Direct-Analysis approach of SSI

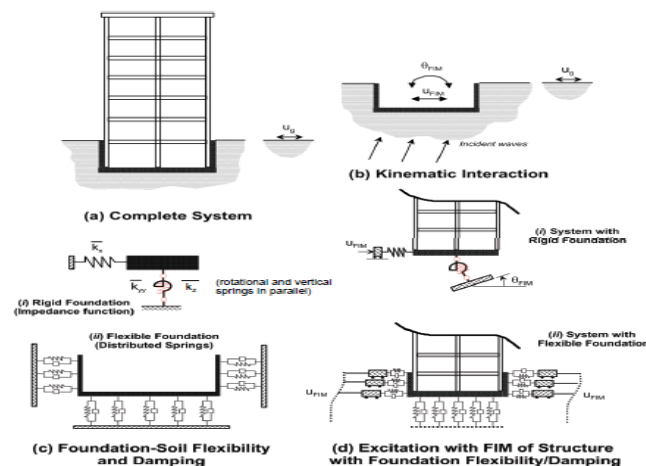


Figure 2.2 SSI substructure theoretical approach

(Dowrick 1987, Kramer 1996, Abdel-Motaal 1999, Gandomzadeh 2011, Abdel-Motaal et al. 2014 [5] , & Alfach 2019) documented that SSI is the process with a relationship between reaction and soil mobility and structure, where the structure

responds in a different way to a similar simulation, depending on the soil type and site conditions, figure 2.3. They further added that Large-scale studies were achieved to investigate the soil-structure system dynamic features.

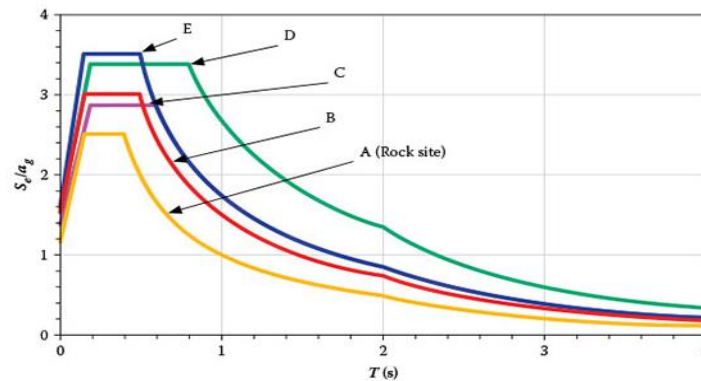


Figure 2.3 Response-spectrum curve for various sites (EC8 2004, Worku, 2014)

Clough and Penzien [6] documented that FE concept is a very flexible numerical technique that solves any complicated problem. Many researchers studied the impact of SSI on seismic structure performance. However, it is common to analyze fixed-base structure response by ignoring SSI effect.

They further added that imposing a natural period “T” is a major identity in mimicking wind so as generated seismic forces. In practice, the period “T” is assumed from empirical formulae codes or it could be designated from numerical or analytical models, where the impact of SSI is neglected in practice so as in analytical models.

Moreover, they elaborated that in Earthquake-Engineering, the soil type has 2 major impacts, as follows:

- The 1st impact affects the vibratory wave that is transferred from basement to surface, where in Uniform-Building-Code “UBC” [7]. They simulated this impact by soil profiles “SA” till “SF”, where “Ca” is the coefficient based on acceleration and “Cv” is the coefficient based on velocity.
- The 2nd impact affects the structure natural period “T”, which changes its dynamic reaction. It is worth wise mention that their study considered the 2nd impact, which possesses important aspects in seismic loads and dynamic loads (i.e. machine vibration and so as flow).

However, [7] advocated that physically, “T” of building frame lateral vibration signifies the required time for a complete cycle of the structure, when it vibrates liberally due to initial displacement or initial velocity. They designated that this is a significant factor in building reaction against wind so as seismic and other lateral forces.

Similarly, [8] stated that in regular design, T is obtained from empirical relations; Eq. (1)

$T = Ct(h)^{3/4}$ Where: Ct: value in metric system for structural resisting (i.e. 0.075 for concrete frames resisting moment, 0.085 for steel frames resisting moment so as eccentrically-braced frames and 0.05 for any building) and H: building height

Moreover, Hokabadi and Fatahi [9] carried out a 3-D FEM to inspect the impact of mimicking foundations exposed to seismic characteristics acting on the natural frequency of frames. They modeled 15-story building, where they concluded that different models alter the seismic performance dramatically.

However, Bhojgowda and Subramanya [10] constructed FEM for multistory buildings with various heights (i.e. 5-story, 10-story and 15-story). Such models have different base-fixity so as soil type (i.e. soft to hard soil), where they inspected the impacts of such parameters on the structure reaction, in terms of base-shear, bending-moment and “T”. They assumed that these buildings have pile foundations that could be treated with fixed base, as the response was negligible. They further documented that “T” of flexible footing model was more than fixed footing models, while bending moments so as displacements were less.

Similarly, Guerdouh and Khalfallah [11] conducted a numerical analysis to the impact on SSI on seismic performance to of 1-story frame (i.e. 3 m high and 5 m span). The concrete frame section was 0.4 mx0.4m, which rests on soil with three layers: (i.e. top soft-soil, middle medium-soil and bottom hard-soil with a layer depth of 10, 20 and 50 m, respectively). The frame was exposed to low or medium or strong seismic excitations. Their study objectives were to examine multiple-response aspects (i.e. impact of SSI for the soil so as frame); designate the changes in frame lateral displacement, in terms of earthquake intensity. They obtained different results, where they emphasized that soil type governs the seismic response and frames. They further stated that soft soils indicated lateral displacement more than harder soils. Other researchers presented work, as an attempt to inspect many parameters (i.e. SSI and seismic response) Similarly, Aqeel T. Fadhil, Salah

R. Al-Zaidee and Mustafa M. Jasim [12] tooled complicated FFM, where they conducted 6 case studies (i.e. fixed-base foundation) and simulated soil mass beneath the foundation. They mimicked the interior of a building frame by a frame element. They implemented variable sandy soils and modeled the soil-structure, where they utilized the value of Standard-Penetration-Test “SPT” and considered it as an identification index for the soil. Their results designated that the modeled frames with fixed-base foundation natural period is 22% more than in the case that neglected modeling of the soil mass, where the structure “T” of 5 case studies considered the SSI. These 5 cases represent 81% of the cases, where the base foundation was assigned to be fixed. This is attributed to the fact that the soil mass was considered during modeling. In spite of the fact, that fixity escalates the system stiffness. However, adding soil mass to system indicated higher influence on the system, which resulted in increasing “T” and decreasing the frequency; figure 2.4.

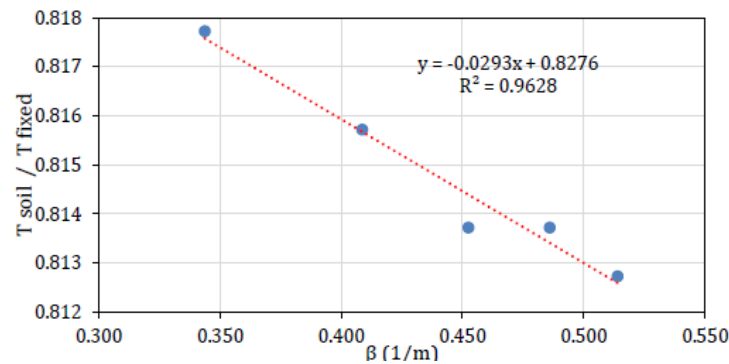


Figure 2.4 Relative natural period vs soil-foundation stiffness coefficient

Within the same context, in 2016, Maher A. Adam, Osama A. Kamal, Mohamed El-Hoseny [13] carried out an extensive numerical study to investigate and analyze the seismic reaction of mid-rise concrete structure under seismic action by PLAXIS V8.2 software, where a full-nonlinear SSI was employed. Three (3) 2-D mid-rise frames (i.e. 5-stories “S5”, 10-stories “S10” and 15-stories “S15”) were considered. Each structure was founded on 3 types of soil (i.e. “class A”, medium soil “class C” and loose soil “class D”). They were investigated under 3 shear-wave-velocities “Vs” of 1000, 270, and 90 m/s. For comparison purposes, each intermediate frame was analyzed under 3 base boundary-conditions (i.e. fixed base, equivalent soil-springs and flexible base), while considering a full SSI. Their results highlighted the significance of considering SSI impacts in the concrete seismic design of mid-rise moment-resisting frames. The scrutinized assembled literature, clear was that the following parameters have a special impact on the concrete seismic reaction, where they encompass the following:

1. **Soil properties**, which includes:
 - a. Soil type
 - b. Depth of soil underneath the structure
 - c. Soil modulus of elasticity
2. **Structure geometry**, which encompasses:
 - a. Height over width ratio
 - b. Number of stories
 - c. Type of foundations

III. Method of analysis

After setting the research objectives, the research methodology was planned to encompass 4 studies (i.e. Theoretical Study, Numerical Study- Analytical Study- Inferential Investigation). These studies are elaborated, as follows:

The Theoretical Study assembled the literature in the domain of multi-story buildings retort to seismic actions so as the numerical tools that mimic such buildings.

The Numerical Study scrutinized the numerical models, where PLAXIS 2D was chosen to be tooled. Moreover, the analysis technique was expounded. Furthermore, the elements’ representation was elaborated for the soil so as the structure. Additionally, the suitability of the results was inspected by contrasting them against previous results.

The Analytical Study investigated the results of the parametric study that was achieved by PLAXIS 2D, in terms of structure retort under the condition of soil absence so as soil presence, where during modeling the case of soil absence, the soil variables were

accounted for (i.e. soil elasticity so as soil depth) and many structure parameters were considered (i.e. height to width ratio and foundation).

The Inferential Study deduced conclusions and suggested recommendations for future research and Engineering Practice.

This main objective will be achieved, as follows:

- 1- Implement FE-analysis to evaluate the parameters affecting the seismic response by conducting PLAXIS 2D simulations, while considering the SSI dynamic analysis. Tool HS-small strain model to consider the soil non-linearity, where it modeled the dynamic boundary conditions.
- 2- Study the natural periodic time of buildings with shallow foundations under different soil type, modulus of elasticity and depth parameters.
- 3- Study the impact of changing building geometry under different soil types on the natural periodic time of structures by changing the number of floors, height over width ratios.
- 4- Study structure natural periodic time of structures for different types of foundations

Parametric study

The 2-D FE is modeled by utilizing PLAXIS software and an extensive parametric investigation to the structural reaction was achieved, where mesh-geometry so as grid-spacing together with finite-size of modeled domain, as well as, wave-radiation and soil- material were considered during the analyses.

The soil performance during non-linear dynamic stress-strain with large forced vibrations amplitude (i.e. earthquake loading) is very complicated. Accordingly, in order to simulate soil seismic response, the employed model should be aware of the structure identities and soil identities.

However, for simplicity reasons, the soil plasticity is simulated by Mohr-Coulomb-failure-criterion under plane-strain con The considered soil parameters were investigated by PLAXIS; results were obtained; analyzed and presented, as follows:

Analyzing and Discussing Soil Modulus of elasticity

The parametric study was achieved to capture SSI under different soil type, where its impact on the structure periodic-time was numerically investigated.

As an exemplar, PLAXIS was applied to an RC 2-D frame, where the frames are spaced by 5 meters with 5 stories with a basement at a depth of 2 m, below the soil surface, the frame is 15 m high, above ground level, and is 20 m wide with column's spacing taken as 5 m, where the mechanical properties of the modeled structure are listed in table 4.1

Moreover, many exemplars were created above different soil types with different modulus of elasticity "E" (i.e. 25 and 400 Mpa). This was achieved to represent loose soil to firm soil for the same structure exemplar, where the periodic time is captured for each exemplar.

PLAXIS was operated on the established exemplars and results were obtained; analyzed and presented on figures 4.1 to 4.11, where figure 4.1 represents the modeled structure and soil by 2-D PLAXIS.

On the other hand, figure 4.2 presents the measurements points of the reaction, where the response measuring points, in the model, are the roof at an elevation of 15 m, as signified on figure 4.2.

It is noted worthy to mention that SAP2000 was employed to compute the fundamental frequency of the created structure exemplars, where the structure was fixed at its base or hinged or hinged with ground beams; figures 4.3, 4.4 and 4.5. They signify the periodic time, while ignoring SSI, where figure 4.3 embodies the structure with hinged supports modeled by 2-D SAP, figure 4.4 characterizes the structure with fixed supports modeled by 2-D SAP, while figure 4.5 symbolizes structure with hinged supports and ground beams modeled by 2-D SAP.

However, the results of the periodic time are presented following figures 4.6, 4.7 and 4.8, where figure 4.6 denotes the natural periodic time of a structure with hinged support, figure 4.7 exemplifies the natural periodic time of a structure with fixed support, while figure 4.8 embodies the natural periodic time of a structure with hinged supports and ground beams.

Moreover, figure 4.9 signifies the deformed shape of SSI by 2-D PLAXIS; identically, figure 4.10 symbolizes the soil periodic time ($E=100 \text{ KN/m}^2$) and figure 4.11 exemplifies the Natural-periodic-time versus E soil.

Table 4.1 Identities of the modeled exemplar

Parameter		Symbol	Unit	Magnitude
Columns	Normal stiffness	EA	Kn	7.920×10^6
	Flexural rigidity	EI	Kn.m^2	237.6×10^3

	Weight	w	Kn/m ²	9
Beams	Normal stiffness	EA	Kn	25.3x10 ⁶
	Flexural rigidity	EI	Kn.m ²	45.86x10 ⁶
	Weight	w	Kn/m ²	28.75
Foundations	Normal stiffness	EA	Kn	61.6x10 ⁶
	Flexural rigidity	EI	Kn.m ²	82.13x10 ⁶
	Weight	w	Kn/m ²	70

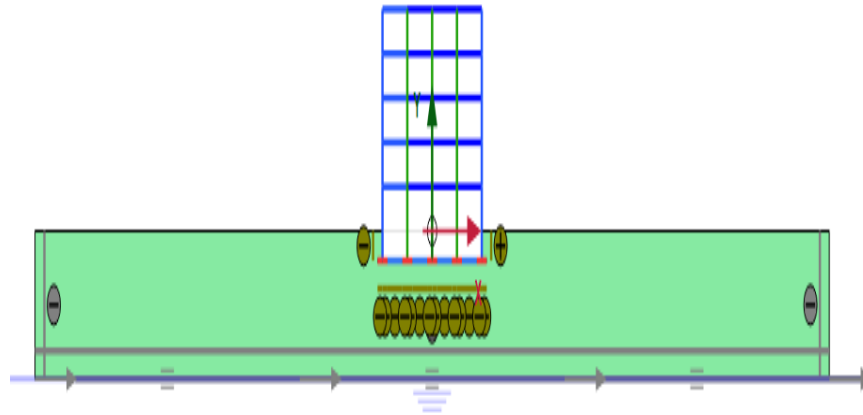


Figure 4.1. Modeling structure and soil by 2-D PLAXIS

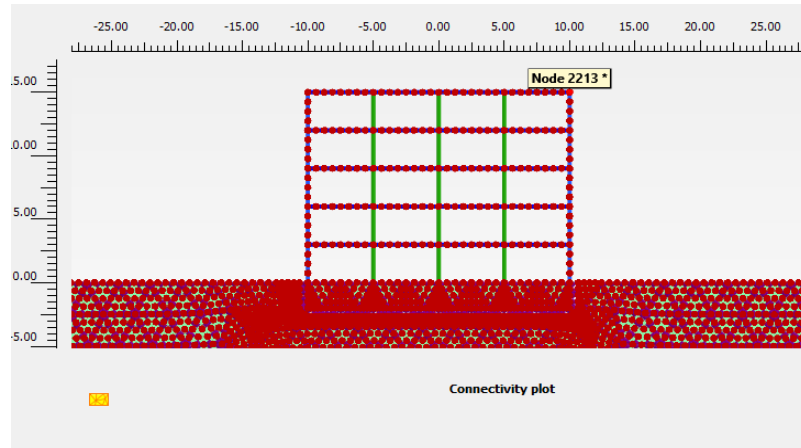


Figure 4.2. Measurements points of the reaction

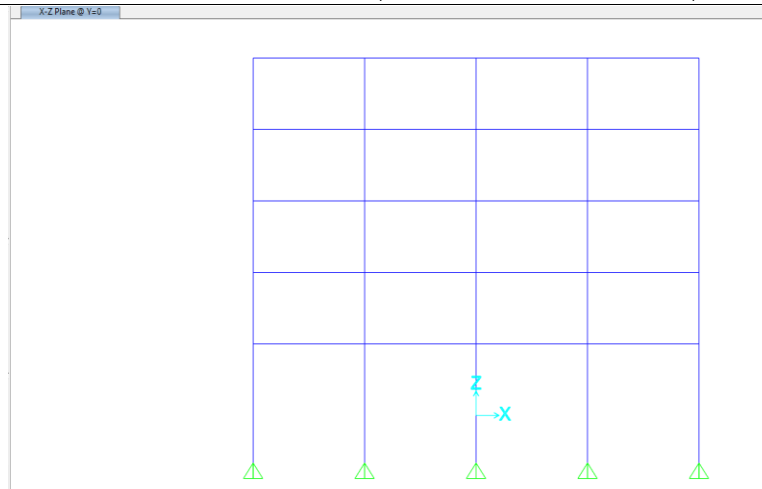


Figure 4.3. Structure with hinged supports modeled by 2-D SAP

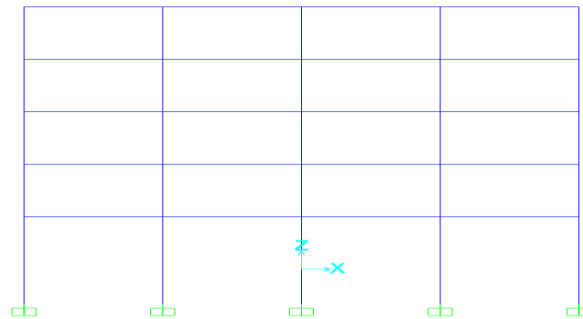


Figure 4.4. Structure with fixed supports modeled by 2-D SAP

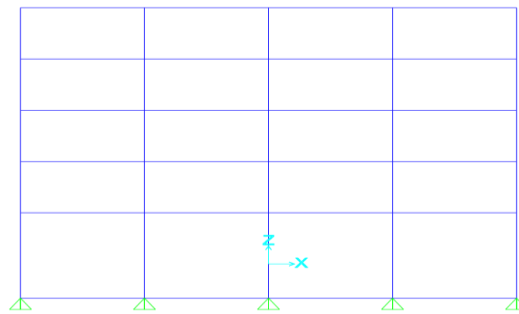


Figure 4.5. Structure with hinged supports and ground beams modeled by 2-D SAP

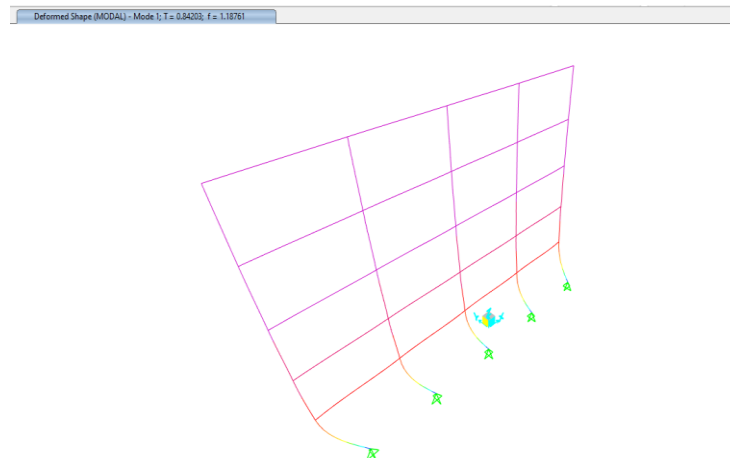


Figure 4.6. Natural periodic time of a structure with hinged support

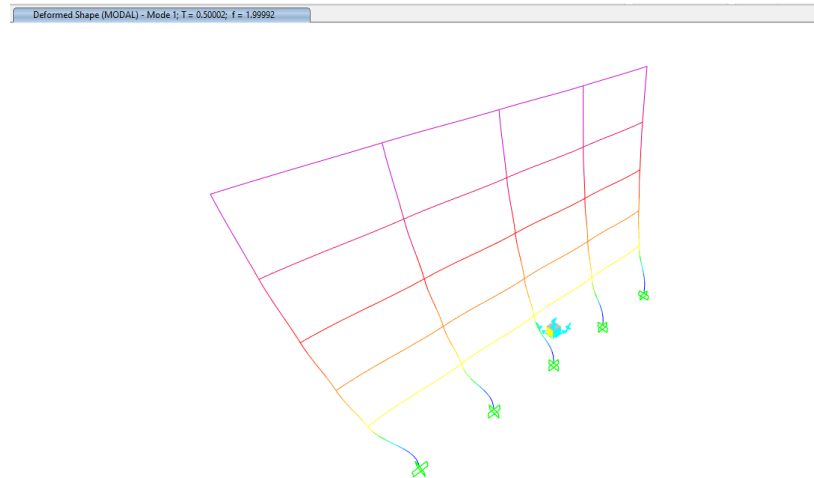


Figure 4.7. Natural periodic time of a structure with fixed support

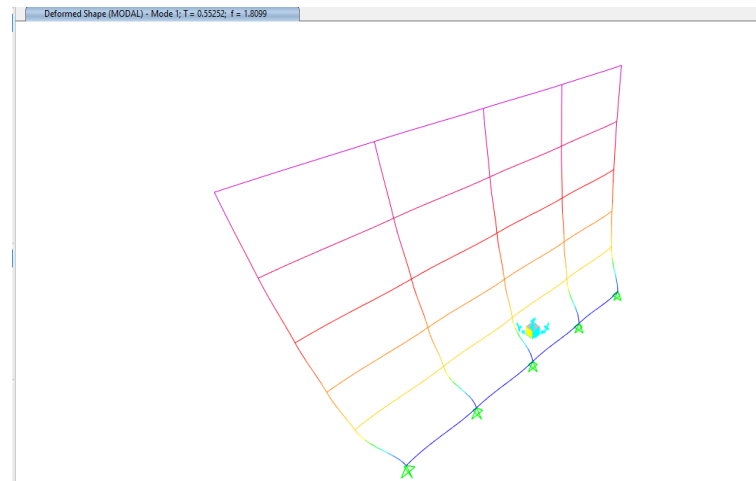


Figure 4.8. Natural periodic time of a structure with hinged supports and ground beams

From figures 4.6, 4.7 and 4.8, apparent was the following:

- 1- Regarding the hinged supports, the periodic time was 0.85 sec.
- 2- As for the fixed supports, the periodic time was 0.5 sec.
- 3- Focusing on the hinged supports with ground beams, periodic time was 0.55 sec.

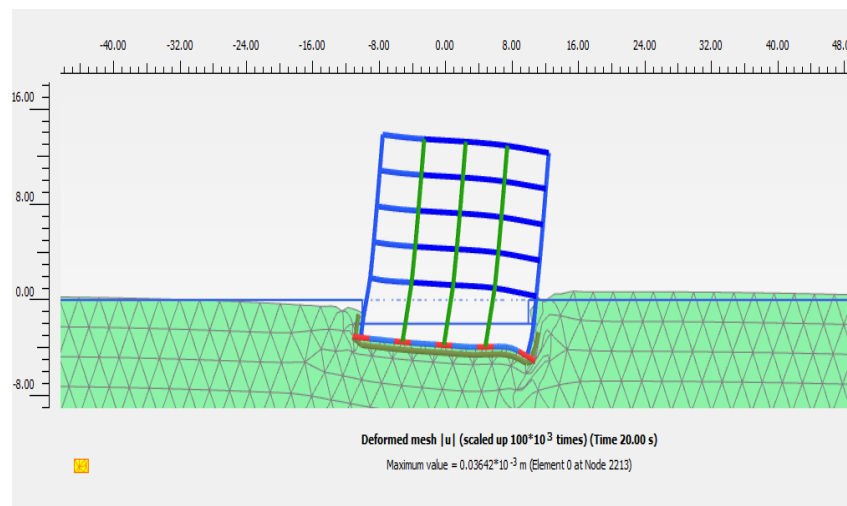


Figure 4.9. Deformed shape of SSI by 2-D PLAXIS

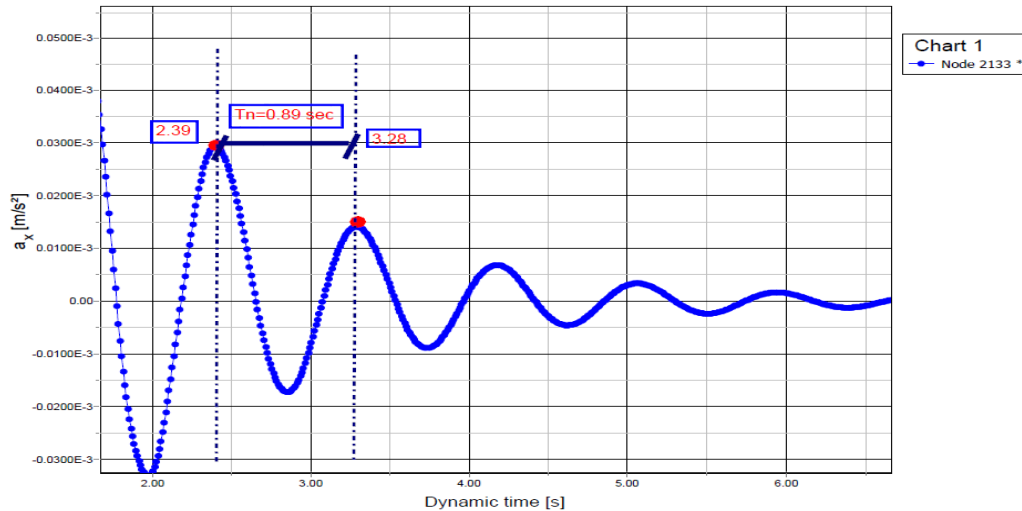


Figure 4.10. Soil periodic time ($E=100 \text{ KN/m}^2$)

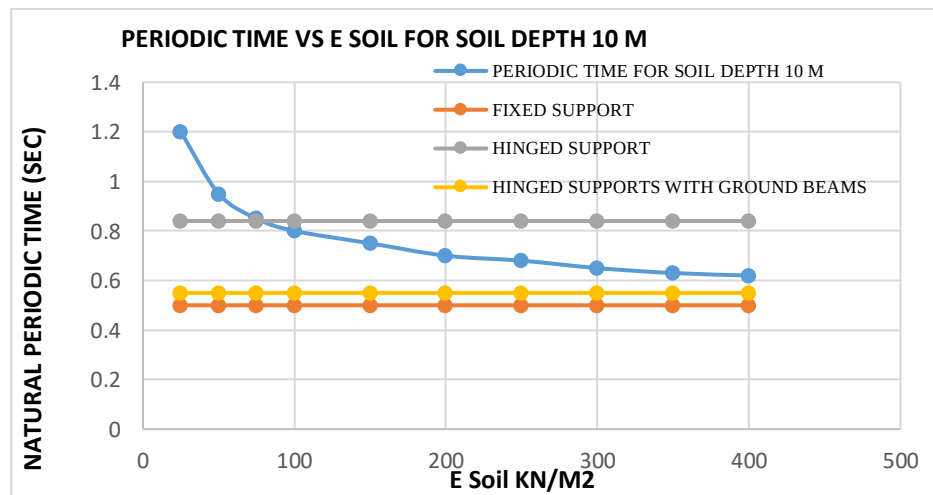


Figure 4.11. Natural-periodic-time vs E soil

From figures 4.10 and 4.11, obvious was the following:

- 1- Considering SSI indicated that soil has an impact on the periodic time, where table 4.2 represents the soil identities.
- 2- Periodic time is longer for loose soil and lower E
- 3- Periodic time decreases by increasing E.
- 4- Increasing E beyond 75 Mpa, moves the periodic time curve to lie between the periodic time curve of hinged support and that of the fixed supports, which signifies the partial fixation between foundations and soil.

Analyzing and Discussing Soil depth impact

PLAXIS was applied to the same created exemplar to investigate different soil depths (i.e. 10, 20 and 40 m) on its periodic-time.

PLAXIS was operated; results were obtained; analyzed and presented on figure 4.12 which represents the natural-periodic-time versus E for soil depths 10, 20 and 40 m, respectively.

From figure 4.12, apparent was the following:

- 1- For the soil with E less than 100 Mpa, the depth has a significant impact on the structure periodic-time, while at E higher than 100 Mpa, the depth has an insignificant impact on the structure periodic-time.
- 2- For soil with E of 25000 KN/m^2 , the periodic-time decreases by 4 and 9%, at soil depths of 20 and 40 m, respectively.

- 3- For soil with E of 50000 KN/m², the periodic-time decreases by 2 and 4%, at soil depths of 20 and 40 m, respectively.
- 4- As depth increases, SSI promotes the foundations rigidity and structure stiffness, especially for the case of loose soil.
- 5- The depth has a minor impact on firm soil.

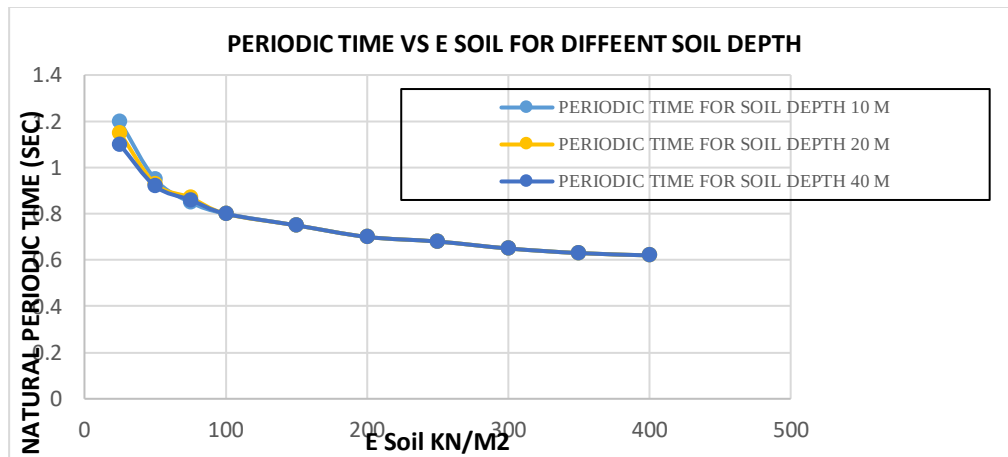


Figure 4.12. Natural-periodic-time vs E soil (Different soil depths)

Analyzing and Discussing Building geometry & periodic time

PLAXIS was applied to the same created exemplar to investigate structure height over width (i.e. H/B) on its periodic-time, where H/B was 0.85, 0.92 and 1.15.

PLAXIS was operated; results were obtained; analyzed and presented on figure 4.13 which represents the natural-periodic-time versus H/B 0.85, 0.92 and 1.15 m, respectively. Figure 4.13 shows that the natural-periodic-time versus E, soil all investigated soil depths, where it denotes that as H/B increases, the periodic-time increases, for all soil depths.

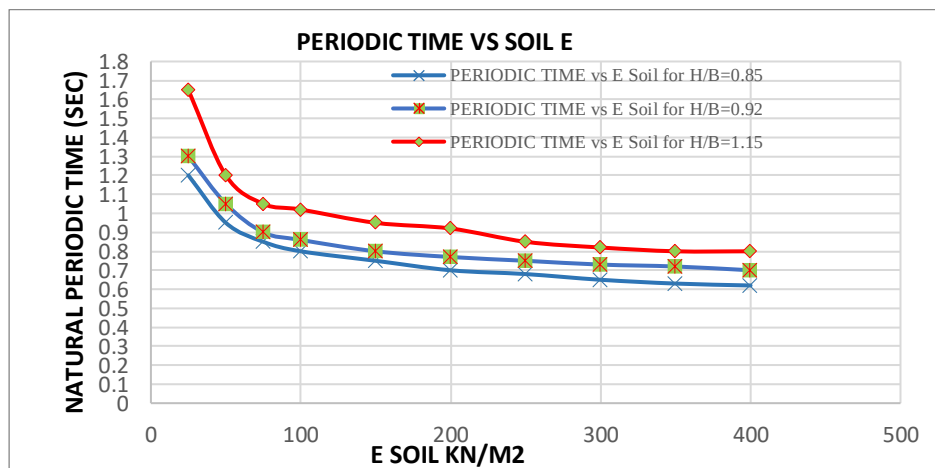


Figure 4.13. Natural-periodic-time vs E of the soil (different H/B)

IV. Further analysis and discussion

The calculated structure nature-period conforms to Paulay and Priestley (1992) suggestion, where they estimated the structure periodic time by Eq. 4.1 that ignores the soil impact during calculating the periodic-time.

$$T = 0.075 * H^{0.75} \quad (4.1)$$

Where:

H: structure height

This formula provides a periodic time similar to that estimated by SAP, where SSI is ignored. However, when soil impact was taken by PLAXIS into consideration, apparent was that periodic-time varies according to the soil modulus of elasticity.

Accordingly, based on the analyzed data, an expression was proposed, Eq (4.2), to designate the increased period due to considering SSI and soil modulus of elasticity; figure 4.20 and table 4.3

$$T = 0.075 * H^{0.75} * Y \quad \text{where } Y = 3.7414 * E^{-0.226} \quad (4.2)$$

Where:

H: structure height

E: soil modulus of elasticity

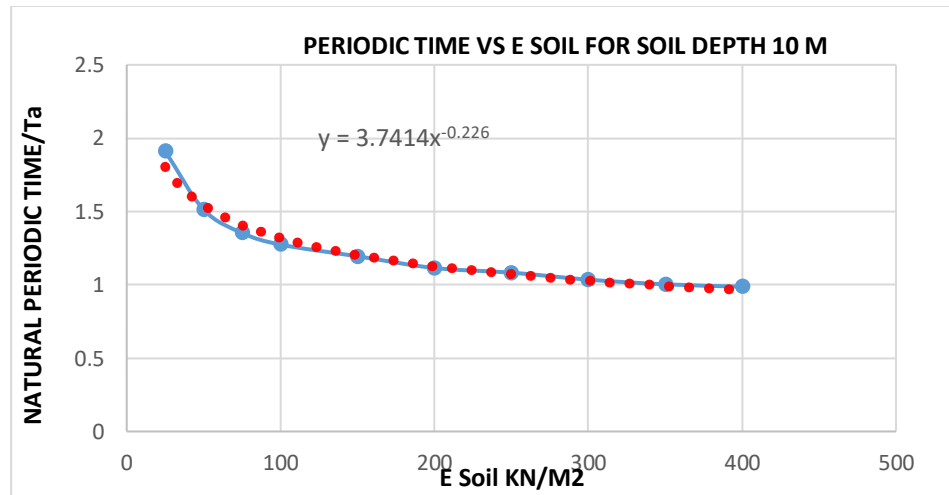


Figure 4.14. Calculated natural period while considering E value of the soil

Table 4.3 Calculated natural period while considering E value of the soil

E (Kn/m2)	Plaxis Tn (sec)	Proposed eqn. Tn (sec)
25	1.2	1.14
50	0.95	0.97
75	0.85	0.89
100	0.8	0.83
150	0.75	0.76
200	0.7	0.71
250	0.68	0.67
300	0.65	0.65
350	0.63	0.63
400	0.62	0.61

V. Conclusions

Summary

Within the framework of constructing super multi-story structures that might be subjected to earthquakes, this research was originated with the impartial of authenticating the soil capability to carry such constructions during altering the structure natural-frequency, in terms of the soil sort.

After establishing the research goals, an approach was designed to encircle 5 studies (i.e. Theoretical, Numerical, Analytical and Inferential Studies).

In the Theoretical Study, literature in the domain of multi-story construction's reaction to earthquakes and in the domain of numerical models that mimic such structures.

In the Numerical Study, the accessible numerical models were inspected, where PLAXIS 2D was chosen to be employed. Furthermore, a numerical analysis approach was expounded. Additionally, elements representation was set for the soil so as the structure. Moreover, confidence in the numerical results was attained and the simulation results were verified against measured results of preceding research.

In the Analytical Study, PLAXIS 2D inspected the structure reaction to the case of soil existence and soil inexistence, where during modeling the soil inexistence, several soil parameters were considered (i.e. soil elasticity so as soil depth) and other structure variables were considered (i.e. height/width ratio and structure base).

Conclusions

Based on the carried out studies, some conclusions were deduced, as follows:

- 1- The research results highlighted the importance of considering the foundation rigidity.
- 2- Multi-story structures are affected, when soil-structure natural-frequency and periodic-time were considered to be between hinged case and the fixed case, as they represent partial fixation (i.e. fixed and hinged supports).
- 3- Structure seismic reaction is inversely proportional with foundation rigidity, where this rigidity is affected by:
- 4- Soil stiffness (i.e. higher soil stiffness increases the structure rigidity and decreases the periodic time)
- 5- Soil depth (i.e. It has a minor impact on seismic reaction of the structure)
- 6- Soil type (i.e. loose soil increase, increases the rigidity)
- 7- Seismic response analysis was carried to the studied structure, supported on different soil layers, considered several shear moduli to evaluate the impact of soil layer, where the results of this analysis emphasized the following:
- 8- Assured the positive impact of increasing the stiffness that decreased the seismic reaction.
- 9- Confirmed the impact of foundation type on the periodic time of the building, where it cleared it. Especially, in the case of weak surface soil layer and dense surface layer provided similar values.
- 10- Indicated that structure height to width ratio affected the structure periodic time (i.e. as H/B increases, the periodic time increases).
- 11- Designated that foundation stiffness has a major impact on the structure seismic reaction, where the raft foundation e was similar to isolated footing with rigid ties.

Recommendations

Based on the deduced conclusions, recommendations for future studied and Engineering Practice were suggested, as follows:

The research provided some recommendations for future research, as follows:

- 1- Scrutinize soil data, experimentally.
- 2- Carry out further investigations with experimental soil data by employing 3-D FEM to consider both the structure and the soil.
- 3- Employ recent coupling tool in PLAXIS to attain a facility that could combine PLAXIS 3D and SAP 2000, where this will allow users to carry out a coupled structural so as geotechnical analysis, in one.
- 4- Utilize different soil layers to indicate the impact on the periodic time and the structure reaction.

Furthermore, the research suggested some recommendations for Engineering Practice, as follows:

- 1- Employ 3-D FEM to simulate structures with neighboring soil.
- 2- Conduct full-scale experiments with reasonable information about material properties to validate the FEM against dynamic cases.

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