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Seismic Response of Diagrid system Building and Effect of Soil-Structure Interaction on Conventional Building: A Review

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ABSTRACT: During severe seismic events, the dynamic response of the structure is affected not only by the behavior of the superstructure but also by the nature and behavior of the soil present in and around the substructure. The conventional structural design process usually assumes the base of the foundation to be completely restrained, in a fixed condition. However, this assumption is inaccurate as it neglects the effect of flexibility offered by the interaction of the soil with the structure. There is no clear consensus on either the beneficial or detrimental effects of soil-structure interaction (SSI) on the seismic response of structures. The main objective of this paper is to study the effect of SSI on a multi-story building. Also, over the past research works have been carried out about diagrid buildings. Having established the importance of diagrid structures, researchers and practitioners have developed advanced design strategies to make diagrid structural systems efficient and economical. The structural efficiency and flexibility in architectural planning makes diagrid an innovative structural system for tall buildings. In this research paper study about “Seismic Response of Diagrid system Building and effect of Soil-Structure Interaction on conventional building”, this topic study in different Research paper. Comparison of analysis results in terms of time period, top storey displacement and inter-storey drift is presented in this paper.

KEYWORDS: Diagrid system, High-rise buildings, Seismic Response, Raft Footing, Finite Element Method, Winkler Method, ETABS, SAP2000, Abaqus, MIDAS/gen and SATWE, Tuned Mass Damper (TMD), structure soil structure interaction (SSI), Time History.

I. INTRODUCTION

The advancement in technology has made our life simpler and comfortable when compared to earlier times and has also led to the need for space for living for the growing population. According to the records, if we analyze our world population, it right now exceeds 7.88 billion, which mandates the need to fulfil the growing demands of the population. Due to the limited space and the need for environmental conservation, it has become important for a civil engineer to focus on stiffer, lighter and new technology savvy methods for the construction. The diagrid structure is one such method in which the vertical columns are eliminated, the frame carries the gravity load, as well as the lateral load and the usage of steel is also minimized when compared with the conventional building. Recently diagrid structural system is adopted in tall buildings due to its structural efficiency and flexibility in architectural planning. Compared to closely spaced vertical columns in framed tube, diagrid structure consists of inclined columns on the exterior surface of building. Due to inclined columns lateral loads are resisted by axial action of the diagonal compared to bending of vertical columns in framed tube structure. Diagrid structures generally do not require core because lateral shear can be carried by the diagonals on the periphery of building.

The increasing of population in urban cities, the creative methods of architects, the high cost of land, the lack of available land for construction, and the reduction of random building. All of these reasons led to increase the height of building. Therefore, it has been worked to find a solution to be safe under loads and more stability. Regardless the effect of soil, the procedure of design may generate some models can be uneconomical and unsafe. Especially when building is established on soft soil. Hence, there is a cooperation between structural engineers and geotechnical engineers in the field of Soil-structure interaction (SSI), which is a phenomenon that connects between structural engineering and geotechnical engineering. Moreover, seismic load may cause collapse during the life of building. Therefore, it must have been studied the building's seismic performance with soil effect. The term (SSI) refers to the actual performance with considering the effect of soil. SSI problem has become an interdisciplinary approach that is

connecting between structural and geotechnical engineering. Especially in sites where a soft soil and seismic activity are. However, with hard soil, the response of high-rise building is the same case like fixed base due to high stiffness. The dynamic response of a structure relies on the characteristics of underlying soil, structure and excitation. The behavior of foundations in a high-rise building differs from the behavior of the free field motion (the soil that is under and surrounding the foundations) due to the capability of foundations to resist deformations. Besides, the dynamic response increases the deformation of soil under foundation. The soil response gives rise to the deformation of structure and the response of the structure results to the soil behavior. This process generally refers to the dynamic interaction between soil and structure (SSSI). The seismic performance for low-and medium-rise building differs from the seismic performance for high-rise building. The structural system in a high-rise building plays a main role to how respond. In this paper study, on Seismic response of Diagrid Building and Soil Structure interaction effect in conventional building.

II. LITERATURE REVIEW

General

The present review concerned with Studies or development and application of Soil Structure Interaction and who reduce the response of structure to earthquake induce excitation. The review also about the parametric study and effectiveness of Diagrid Building.

Parametric study of Diagrid Building: -

This study summarizes the results of a parametric study performed to enhance the understanding of some important characteristics of Diagrid Building. The literature for this study is as follow:

Neha Tirkey, G.B. Ramesh Kumar [2019] : In this paper the case study on diagonal perimeter often known as the diagrid structure using software ETABS (Extended Three-Dimensional Analysis of Building System). The diagrid structure has emerged into an innovative method in the recent construction field and has led to the advancement of tall buildings and high-rise structures not only in the engineering field but also in the architectural field. It has also made the structure stiffer and lighter when compared to the normal conventional buildings. The diagrid structure is designed, analyzed and is compared with the conventional building using ETABS software mainly focusing on seismic and wind analysis parameters. As per IS 456:2000 and the Linear Static Method all the structural members of the diagrid model are designed and IS 1893 (PART 1): 2002 is considered for load combination of seismic analysis. The comparative study has been executed for different diagrid structures using ETABS software to find the stiffness and flexibility of the high raised structures and also for an asymmetrical structure through simple framework. The lateral load resisting system is better in resisting the gravity loads than the structural system when the structure height gets increased. The configuration and efficiency of the diagrid system has reduced the number of structural elements. The ETABS software is used to design and analyse the results such as axial, shear and bending moment. The possibility of failure is much lesser for diagrid structure when compared to the conventional structure by heavy vibration during an earthquake.

Kai Hua,b, Yimeng Yang a, Suifeng Mua, Ge Qua [2011] : In this paper, response spectrum, time history and linking slab in-plan stresses analysis were execute combine with a practical project by these programs. Also, the facing a large number of new-type complex structural system and progressively consummate earthquake-resistant theories, the conventional software can no longer meet the needs of calculation and analysis. Meanwhile, some international finite element programs, such as ETABS, SAP2000, MIDAS/gen and SATWE, were updating themselves but remain respective limitations. The response spectrum, time history and linking slab in-plan stresses analysis were execute combine with a practical project with inclined columns by several programs such as ETABS, SAP2000, MIDAS/gen and SATWE, and the main study are as follows:

1. All the results of response spectrum analysis calculated by different programs are basically similar, while ETABS may miss the statistic of oblique columns, which need to be paid attention to in future designs.
2. The results of time history analysis by SAP2000 and ETABS are roughly similar. However, SAP2000 does not have the concept of "storey", which made the post-processing much more complicated. Therefore, to the regular structure, ETABS is recommended; and to those gymnasium or space truss structures, SAP2000 has its irreplaceable advantages.
3. As for the slab stress analysis, ETABS and MIDAS/Gen have their respective advantages: ETABS/s good at pre-processing with automatically line constraint and area division; and MIDAS/Gen does well in the post-processing such as the stresses combinations.
4. Slab, as the important lateral force resistant component, should not be ignored in design works. Especially to those complex structures, the slabs stress analysis at weaken positions is really essential.

Khushbu D. Jani and Paresh V. Patel [2013] : In this paper, analysis and design of 36 storey diagrid steel building is presented in detail. A regular floor plan of 36 m×36 m size is considered. ETABS software is used for modeling and analysis of structure. All structural members are designed using IS 800:2007 considering all load combinations. Load distribution in diagrid system is also studied for 36 storey building and Dynamic along wind and across wind are considered for analysis and design of the structure Also, the analysis and design results of 50, 60, 70 and 80 storey diagrid structures is carried out. Comparison of analysis results in terms of time period, top storey displacement and inter-storey drift is presented in this study. In this paper is observed that most of the lateral load is resisted by diagrid columns on the periphery, while gravity load is resisted by both the internal columns and peripheral diagonal columns. So, internal columns need to be designed for vertical load only. Due to increase in lever arm of peripheral diagonal columns, diagrid structural system is more effective in lateral load resistance. Lateral and gravity load are resisted by axial force in diagonal members on periphery of structure, which make system more effective. Diagrid structural system provides more flexibility in planning interior space and facade of the building.

Premdas S. M. Sirajuddin [2019] : The developed advanced design strategies to make diagrid structural systems efficient and economical. The structural efficiency and flexibility in architectural planning makes diagrid an innovative structural system for tall buildings. Several studies have pointed out the design methodology and researches have been carried out about the joint connections. Hence, the purpose of this paper is to provide a systematic summary of the existing research achievements of the diagrid structural system for tall buildings. Also, analysis the mechanism of load transfer, structural style and aesthetic appearance of diagrid structures are very different form orthogonal structures. The design of safe joint connection is an important step in the design of diagrid structures. Better seismic resistance of the structure makes it ideal in seismic vulnerable areas as well. Many studies prove that diagrid not only enhances strength and stiffness but also improves the ductile capacity of the structure. Hence the potential of diagrids to become more popular in the construction of high rise and mid-rise buildings is high as the new technology in the field of construction will aid the complex construction to become easier. The flexibility of using diagrids to form architecturally complex shaped structures has been recognized all over the world. A limitation to this is the lack of specific design procedures for the safe and conservative design.

Faisal Mehraj Wani, Jayaprakash Vemuri, Chenna Rajaram, Dushyanth V. Babu R [2022] : The main objective of this paper is to study the effect of SSI on a multi-story (G + 10) building resting on a mat foundation. The building is modeled using Finite Element Method (FEM) software and SSI is incorporated using Winkler's (un-coupled) and pseudo-coupled approaches. In this paper study the dynamic response of the structure is affected not only by the behavior of the superstructure but also by the nature and behavior of the soil present in and around the substructure. The conventional structural design process usually assumes the base of the foundation to be completely restrained, in a fixed condition. However, this assumption is inaccurate as it neglects the effect of flexibility offered by the interaction of the soil with the structure. There is no clear consensus on either the beneficial or detrimental effects of soil-structure interaction (SSI) on the seismic response of structures. A case study is done to understand the non-linear dynamic response of building with different soil bearing capacities. The results are represented in terms of fundamental period, base shear, and story drift. Seismic evaluation of reinforced concrete structures typically considers only the superstructure and neglects the flexibility of foundations. However, the dynamic characteristics of structural response are affected by soil-structure interaction. This paper presented results from a nonlinear time history analysis of a G+10 reinforced concrete building considering the effects of soil-structure interaction. The soil-structure interaction is modeled using Winkler's approach. From the research paper results, is observed that using Winkler's hypothesis with a constant coefficient of subgrade reaction does not produce accurate estimates of settlements.

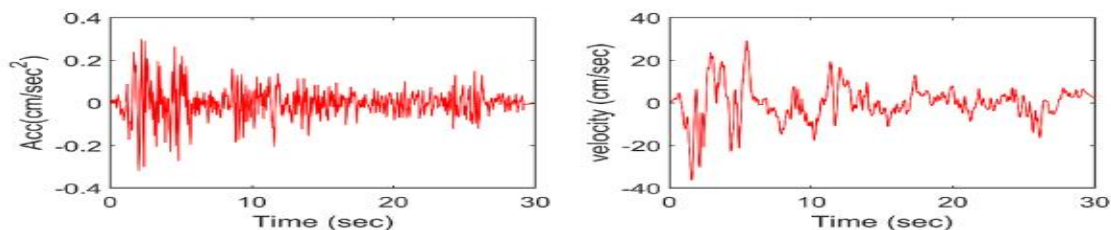


Fig. 1. Characteristics of El Centro ground motion May 18, 1940



Table 1: Building Description of the model.

| Description | Data |
|--------------------------|---------------|
| Length X Width | 16 m _ 16 m |
| No. of storeys | 11 |
| Height of similar storey | 3.2m |
| Thickness of slab | 0.150m |
| Beam dimension | 300mm X 500mm |
| Column dimension | 600mm X 450mm |

Table 2: Material specification.

| Properties | Data |
|---------------------|-----------------------------------|
| Grade of concrete | M25 fck = 30N/mm ² |
| Grade of steel | fy = 500N/mm ² |
| Density of concrete | Y concrete = 25 kN/m ³ |

Table 3: Soil properties.

| Soil Type | Soil type Shear modulus (kN/m ²) | Elastic modulus (kN/m ²) | Poisson ratio (μ) |
|-------------|--|--------------------------------------|-------------------|
| Hard soil | 30000 | 72000 | 0.2 |
| Medium soil | 20000 | 50000 | 0.25 |
| Soft soil | 10000 | 26000 | 0.3 |

Time Period result: -

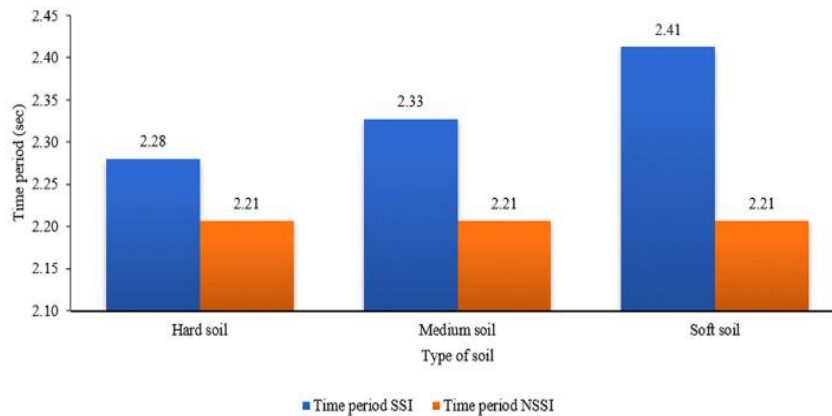


Fig. 2. Comparison of the Time period for different types of soil with fixed base and flexible base condition.

Base shear Result on various type of Soil: -

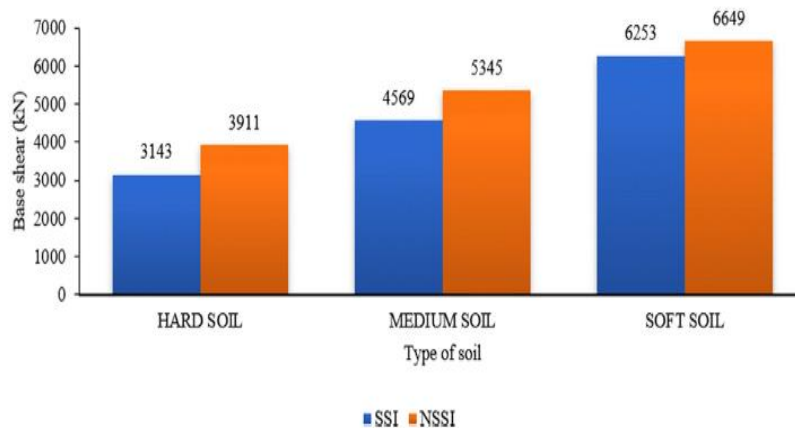


Fig. 3. Comparison of the base shear for different types of soil with fixed base and flexible base condition.

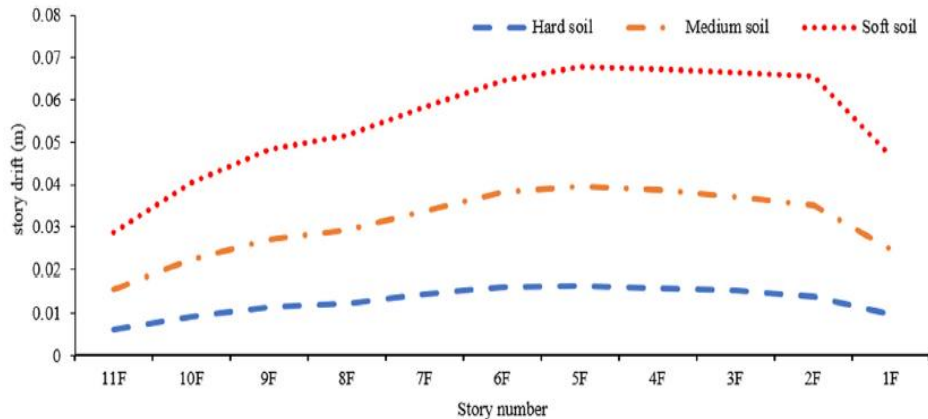
Story Drift Result: -

Fig. 4. Variation of story drifts for different types of soil with a fixed base.

It is also observed that the period of the building increases with an increase in the stiffness of springs. The period of the building is maximum in the case of soft soil as compared to the fixed base condition. The base shear or the case of a flexible base decreases by 10% when compared to the case of a fixed base. The story drifts due to medium and soft soil increases in the higher stories. The maximum drift was observed in the middle stories. These results were also compared with those obtained from the alternate pseudo-coupled approach. Overall, the observations indicate that the effect of SSI should be incorporated in the case of soft soil, otherwise, it could lead to reduced accuracy in our assessment of the overall structural safety under severe earthquakes. Further, the use of a single modulus of subgrade could be discontinued. It is further observed that a proper assessment of the modulus of subgrade reaction is important in Winkler's spring approach. The best way to estimate the modulus of subgrade reaction is by performing studies on determining SSI using geotechnical field investigations and geotechnical software and then performing the inverse analysis. Further, the parametric analysis by varying the height and shape of structure, with and without SSI, revealed that high-rise structures on soft soil are more affected by SSI than low-rise structures.

Wesam Al Agha, Waleed Alozzo Almorad, Nambiappan Umamaheswari, Amjad Alhelwani [2021]: In this research authors have considered SSI using the direct method (FEM soil medium) and studied the effect of changing soil type (soft soils and hard soils) on the performance of the tall building under consideration. The building was taken to be 16 stories, wall-framed dual system for seismic loading resistance. Semi-infinite elements from Abaqus (similia's Abaqus 6.14) solid element library were used to model the boundaries of soil media. The seismic loading input was El-Centro acceleration time-history record. Results of analysis showed differences between soft soil and hard soil types, especially on the displacements and base shear values. The factors that dominate tall buildings design is the dynamic soil-structure interaction (SSI) that differs significantly with the variation of several aspects. Soil type that incorporate the building's foundations, the height of the building, the type of lateral load resisting system, and many other factors. This paper presents analytical study of R.C High-Rise building under seismic loads in the case of fixed-base and the case of Soil Structure Interaction including the effects on displacement, shear base, and fundamental period values, the results showed: Increasing of displacement values in the case of Soil Structure Interaction. By comparing between soft and hard soil, the displacement values in hard one almost equal to the values from the case of Fixed-base. Decreasing of base shear values in the case of Soil Structure Interaction with soft soil comparing to hard one whereas the values in hard soil almost equal to the values from the case of Fixed-base. Increasing of time periods in the case of Soil Structure Interaction, especially with soft soil. The peripheral RC shear walls at the corners presented the smallest displacement and base shear comparing to the other position with hard soil. However, with soft soil the core RC shear wall was the best due to the smallest displacement and base shear value.

Halkude S.A, Kalyanshetti M.G. and Barelikar S.M. [2014] : In the propose of research paper study understand the effect of soil flexibility on the performance of building frames resting on raft foundation. The researcher investigates different approaches of considering soil flexibility in the soil structure interaction analysis (SSI) with regard to the response in the superstructure. The researcher study is focus on SSI analysis of symmetrical space frame of 2 bay in both x and y direction, 2 storey (2X2X2), 2 bays in both direction, 5 storey (2X2X5) and 2 bay in both direction, 8 storey (2X2X8) resting on raft foundation with fixed base and flexible base. Three types of soil i.e. Hard, Medium Hard

and Soft Soil are used for the SSI study. Dynamic analysis is carried out using the Response Spectra of IS: 1893-2002. The soil flexibility is incorporated in the analysis using Winkler approach (spring model) and elastic continuum approach (FEM model). SAP-2000 is used for developing these models. The effect of SSI on various structural parameters i.e. natural time period, base shear, roof displacement, beam moment and column moment are studied and discussed. The comparison is made between the approaches of SSI modeling i.e. Winkler approach (spring model) and elastic continuum approach (FEM model). The paper study reveals that the SSI significantly affects the response of the structure. Elastic continuum approach (FEM model) has proved to be the effective approach for consideration of elastic continuum beneath foundation. In this research paper study, the natural period of structure increases due to SSI effect. For soft soil the effect is more prominent. Thus, evaluation of this parameter without considering SSI may cause serious failure in seismic design. Increase in soil flexibility causes increase in the base shear. For soft soil base shear increases with higher rate. Base Shear shows a remarkable increment with increase in soil softness and storey height. Roof displacement is also observed to be increasing due to incorporation of SSI. For soft soil the roof displacement is higher and in Elastic continuum approach (FEM model) the increment is more than in Winkler approach (Spring Model). Beam Moment and Column Moment are observed to be increased due to SSI effect. For stiff soil the difference is about 1.5-2 times however for soft soil it is observed to be in the range of 2.5-3 times. Natural Period, Roof Displacement, Base Shear, Beam Moment and Column Moment are observed to be increasing more in case of Elastic continuum approach (FEM model) as comparative to Winkler approach (Spring Model). It is possible to incorporate variation in the soil properties, layered soil and boundary conditions in Elastic continuum approach (FEM model). Elastic continuum approach (FEM model) is more effective than Winkler approach (Spring Model) as it considers elastic continuum below foundation which assists to get realistic behavior of structure. Finite Element Method has proved to be more useful method for studying the effect of SSI. At least Winkler hypothesis should be employed to consider SSI instead of fixed base to decrease the complexity for practical purpose.

Ming-Yi Liu, Wei-Ling Chiang, Jin-Hung Hwang, Chia-Ren Chu [2007] : In this paper, a mathematical model is developed for predicting wind-induced oscillations of a high-rise building with a tuned mass damper (TMD) when the soil-structure interaction (SSI) is considered. This model is based on time-domain analyses. Numerical examples are used to assess the effectiveness of a TMD for vibration mitigation under wind loads. Results indicate that the proposed model can reasonably reflect soil characteristics. It can more accurately evaluate wind-induced responses of a building with a TMD than fixed-base models. Furthermore, structural oscillations will be overestimated and the effectiveness of TMDs will be underestimated if SSI is neglected. Our findings also confirm that TMDs are beneficial devices in reducing wind-induced vibrations of tall buildings. In particular, they are more effective for the higher soil stiffness. This paper study will help researchers better understand mechanisms of wind-induced responses for a building with a TMD when SSI is taken into account. It will also improve the understanding of wind-resistant designs for high-rise buildings. Numerical examples are used to assess the effectiveness of the TMD in reducing the structural oscillation. Several conclusions can be drawn from this investigation:

1. This model can reasonably reflect soil characteristics. In addition, it can more accurately calculate wind-induced responses of a building with a TMD than fixed-base models.
2. Across-wind vibrations are greater than along-wind oscillations for a variety of soil types. Furthermore, SSI can be ignored and TMDs have significant advantages for vibration control when the soil is stiff. On the other hand, SSI cannot be neglected for small soil stiffness. Otherwise, wind-induced responses will be overestimated and the effectiveness of TMDs will be underestimated. TMDs more effectively suppress structural oscillations for the higher soil stiffness and SSI is required for accurate predictions with low soil stiffness.
3. TMDs with greater mass are more useful in reducing structural responses under wind loads. They are also more beneficial in controlling across-wind vibrations than along wind oscillations. Moreover, TMDs are more advantageous for suppressing accelerations than displacements of buildings. Consequently, TMDs are effective devices for the wind-induced vibration mitigation of high-rise buildings.
4. This study will help researchers better understand mechanisms of wind-induced responses for a building with a TMD when SSI is taken into account. It will also improve the understanding of wind resistant designs for high-rise buildings.

Huang Li-Jeng and Syu Hong-Jie [2014] : In this paper study the finite element seismic response simulation of a typical tower crane frame using SAP2000. Three-dimensional beam elements and bar elements are employed for vertical and horizontal frames as well as the tie rods, respectively, to build up the numerical model. Then numerical example is considered and two kinds of earthquake ground accelerations are tested, i.e., 1940 NS component of the El Centro and 1995 Kobe accelerations. The dynamic responses of displacement, velocity and accelerations of a typical

node of the tower crane frame are illustrated and discussed. The numerical simulation results show that the maximal displacements might be large to over 1 meter and the associated maximal velocity and acceleration can be greater than 4 m/s and 40 m/s², respectively at the highest position of tower crane. The structural analysis software SAP2000 has been analyze the free vibration and seismic responses of a typical tower crane frame structure. Finite element model is first built up using three-dimensional beam elements for the vertical supporting column and the horizontal cantilever loading arm as well as bar elements for the tensile steel tendons. It is result found that the fundamental natural frequencies of the typical tower crane are generally lower than those of major RC buildings and the leading 12 natural frequencies range from 0.3 Hz to 6.5 Hz. After tested by 1940 NS component of El Centro and 1995 Kobe ground motions, the seismic response analysis depicted that the maximal displacements of the typical tower crane due to earthquake excitations can be large to more than 1 meter and the associated maximal velocity and acceleration can be greater than 4 m/s and 40 m/s², respectively.

Hui Long, Zicheng Wang, Chunshun Zhang, Haiyang Zhuang, Wenzhao Chen, Cheng Peng [2021] : In this research paper considering the high-rise buildings with pile-raft foundation, a series of building-site two-dimensional finite element analysis models with different building spacings is established. Then, considering the nonlinear characteristics of soil and structure, the static-dynamic coupled numerical simulations are conducted to study the structure-soil-structure interaction (SSSI) under different ground motion. Under actual engineering conditions, the dynamic SSSI effect of adjacent structures in earthquakes is highly complex. Based on the soil-structure system model that is too simplified or does not consider material nonlinearity, the numerical analysis of the SSSI effect of adjacent structures is carried out without considering the static state's influence. The paper results may deviate from the actual situation. To more accurately study the dynamic SSSI effects between adjacent structures, the finite element method is used to conduct a two-dimensional static-dynamic coupled numerical analysis of the seismic response of a single, two or three identical high-rise structures in the site. The finite element method is used to perform a static-dynamic coupling numerical analysis of the seismic response of single, 2 or 3 identical high-rise structures in the site. In the analysis, soil and structural material nonlinearity is considered and a contact method that can produce slippage and instantaneous separation between soil and structure is adopted. The purpose is to more realistically simulate the influence of the SSSI effect on the structure's seismic response when there are the same adjacent structures on one or both sides. In the paper result, the influence of the SSSI effect on the seismic response between adjacent structures cannot be ignored. The SSSI effect of adjacent structures should be fully considered in the seismic design of structures. The study of SSSI based on nonlinear conditions is closer to engineering reality, but it also increases the problem's complexity. Some conclusions obtained are similar to the previous research results, but there are many differences. Nevertheless, the study based on the two-dimensional plane problem is only applicable to the situation where the structures are aligned horizontally in a straight line in practical engineering.

III. CONCLUSION

From the literature review study, it is observed that most of the lateral load is resisted by diagrid columns on the periphery, while gravity load is resisted by both the internal columns and peripheral diagonal columns. So, internal columns need to be designed for vertical load only. Due to increase in lever arm of peripheral diagonal columns, diagrid structural system is more effective in lateral load resistance. Lateral and gravity load are resisted by axial force in diagonal members on periphery of structure, which make system more effective. Diagrid structural system provides more flexibility in planning interior space and facade of the building. In case Soil Structure Interaction conventional or RC Building it is observed that the period of the building increases. The period of the building is maximum in the case of soft soil as compared to the fixed base condition. The base shear or the case of a flexible base decreases by 10% when compared to the case of a fixed base. The story drifts due to medium and soft soil increases in the higher stories. The maximum drift was observed in the middle stories. the parametric analysis by varying the height and shape of structure, with and without SSI, revealed that high-rise structures on soft soil are more affected by SSI than low-rise structures.

This literature's deal with numerous numbers of papers that have been found helpful for carrying out work. An extensive literature review is done and interface noted down. Lots of literature are available on effect of SSI on only RC or conventional building. But No literatures papers are available in effect of SSI on Diagrid building and their effect with Various type of Soil. So, aim of this study is to find parameter such as displacement, storey shear, storey drift with effect of SSI on Diagrid building with Various type of Soil.

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