IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 18, Issue 3 Ser. II (May – June 2021), PP 24-37
www.iosrjournals.org

Effect of Transfer Floors on the Behaviour of Residential Buildings under Earthquake Loads

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Abstract:
The target of this research is to study the effect of adding a simple-girder supported transfer floor on the behaviour of a residential building. Numerical analyses of a 3-D model were conducted and the results was matched to Elawady 2012 model to ensure that the values of all factors used in the approved Elawady (2012) model were entered into the Etabs program with high accuracy, in order to obtain an approved model and make a modifications to achieve the objectives of the study with the best results that can be acquired and trusted.. Girder type system to the transfer system was illustrated; global performance was investigated in terms of displacement curves, storey-drift, shear and moment.

Seismic forces were inserted by implementing the linear response spectrum method, in order to determine the effect of earthquake loads on the building and to investigate the global seismic behavior of the structure. A transfer girder system which is lighter and more flexible than traditional floor slab system was utilized in order to study its effect on the structure under horizontal super imposed loads.

***Key Word**: Transfer Floors, High-Rise Buildings, Seismic Loads, Earthquake Loads, Nonlinear Analysis.*

Date of Submission: 02-06-2021 Date of Acceptance: 15-06-2021

I. Introduction

The importance of transfer floors in high-rise buildings emerged due to the need to gain maximum utility benefits from the same building through utilizing multifunctional construction systems (garages, commercial shops, administrative units, residential units, restaurants and hotels).

The discontinued vertical elements (columns and shear walls) within high-rise buildings are no longer considered as a design mistake. Subsequently, the architectural demands for high-rise buildings in which columns may have different arrangements between levels have become familiar; the transfer system transmits horizontal and vertical loads from the vertical elements above it to another structure system(s) below [1]. The interaction of transfer floor systems with the vertical elements can significantly affect the calculated straining actions in high rise building elements. Hence, it must be accounted for during structural building analyses. This raises the demand for accurate transfer floor modeling to improve the numerical 3-D model to demonstrate tall building behavior [2]. It is required to clarify the interaction between the transfer systems and the structure vertical supports. The study stated that the actual transfer system behavior simulation must be modeled in a global coordination system status. Parameters are varied in floor thickness mainly to study its effect.

II. Scope of Study

This research aims to study the effect of location of the girder system of the transfer floor on the behavior of a residential building, and the effect of double increase the number of floors of the building, under earthquake loads. The structures were analyzed using a linear response spectrum. The transfer system imposes a cumulative effect going down into the structural system.

III. METHODOLOGY

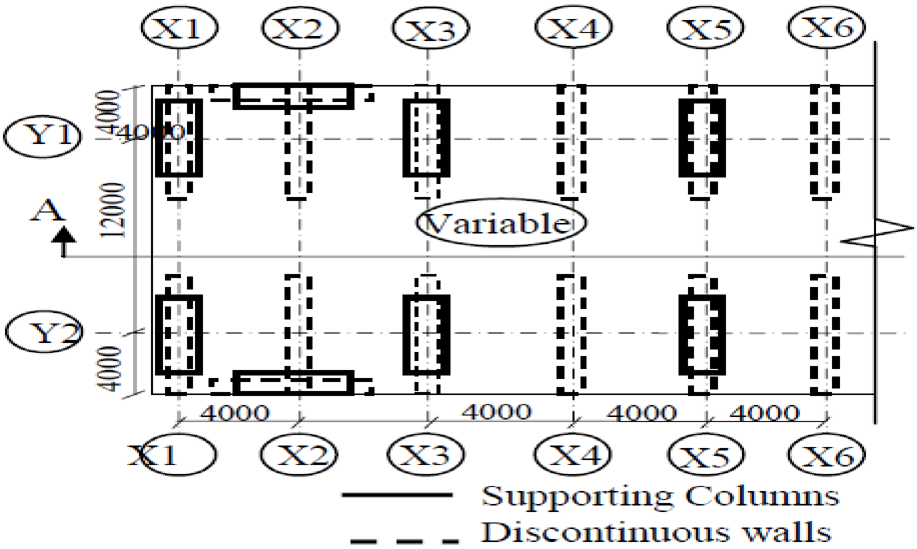
Model definition

A. Description of 3-D model

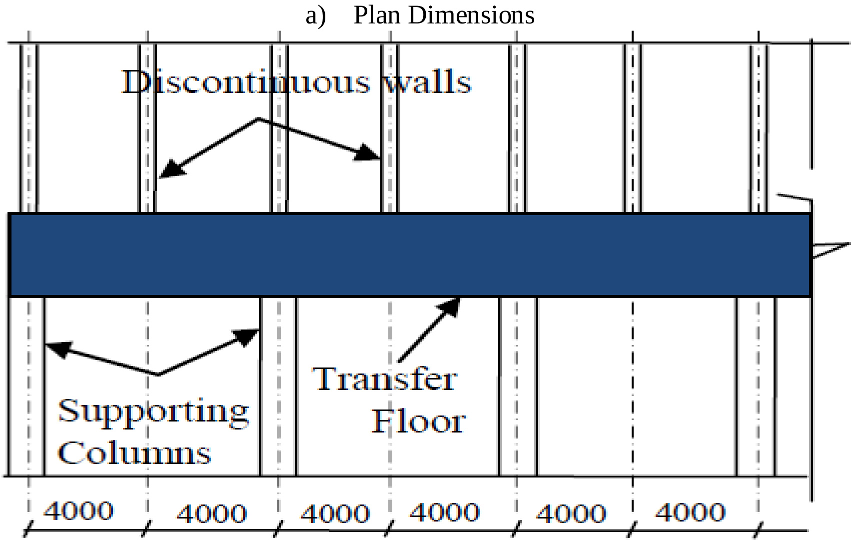
Figure 1 and 2; show the general dimensions of the analyzed building are as follows:

1. Foot print of the building is 20x48 m2.
2. Shear walls supported above the transfer floor are 0.225 m x 0.60 m.
3. Shear walls supported below the transfer floor are 0.70 m x 0.30 m.

4. Numbers of analyzed floors are 25.
5. Transfer floor thickness is 1.50 m.
6. Transfer system is located at 10% of the building height for the verification.
7. Buildings are 15, 30 floors high.
8. Transfer floor at 10%, 20% and 30%of total height.



a) Plan Dimensions



b) Elevation Dimensions

Figure (1): Finite Element Model with Transfer Floor: a) Plan Dimensions and Elevation Dimensions [3].

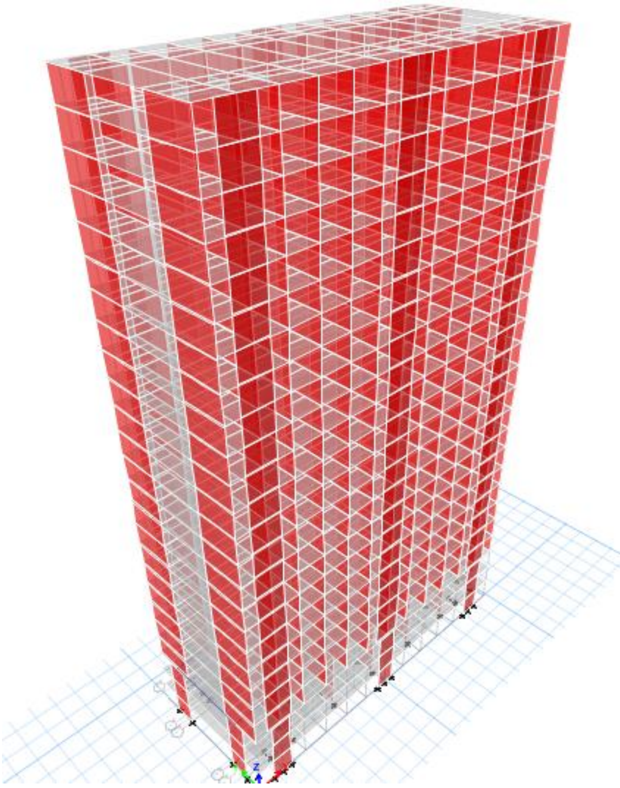


Figure (2): The Prototype Model with Transfer Floor at 10% of Building Height.

B. Linear Response Spectrum Analysis

The linear response spectrum from UBC illustrated in Figure 3 was applied to study the behaviour of the structure. Cairo (Egypt) was chosen to be the zone study. The seismic zone falls under zone (2A), soil type was selected (SC). (Very dense soil and soft rocks), the ductility is 5.50 and the reduction factor for live load is 0.50 for seismic mass.

The building loading was divided where the floors above the transfer floor are: the floor cover 3KN/m2 and live load 2KN/m2 the loads for the typical floors supporting the transfer level, the floor cover (4.50 KN/m2) and live load (5KN/m2) were selected [3].

For high rise and irregular structures should be analyzed by response spectrum method. There was a significant computational advantages using response spectrum method of seismic analysis for prediction of displacements and member forces in structural systems. The method involved only the calculation of the maximum values of the displacements and member forces, in each mode using smooth spectra that are the average of several earthquake motions. Sufficient modes to capture such that at least 90% of the participating mass of the building (in each of two orthogonal principle horizontal directions) had to be considered for the analysis. The analysis was performed to determine the base shear for each mode using given building characteristics and ground motion spectra, and then the storey forces, accelerations, and displacements are calculated for each mode, and were combined statistically using the SRSS combination [4].

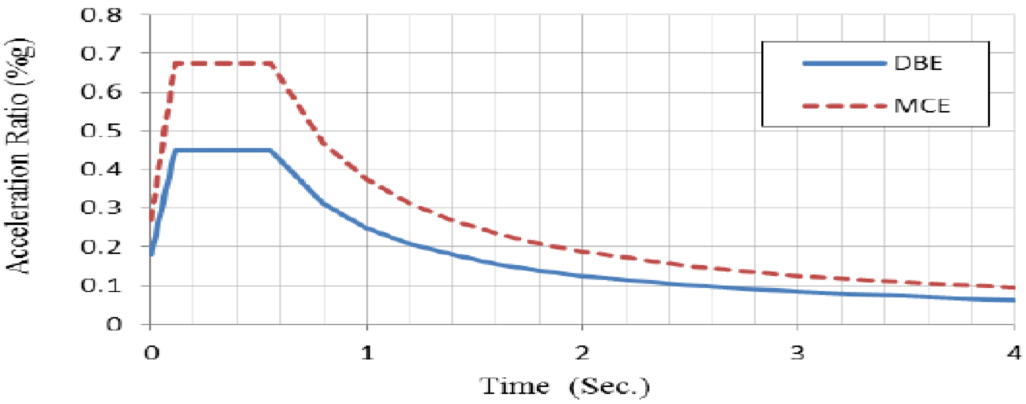


Figure (3): Response Spectrum According to UBC97 [3].

VI. Model verification

A comparison has been made between the results of the verified model Elawady 2012, in case of the building with 25 floors and the transfer floor at 10% of the total building height with thickness 1.50m. The prototype model were made to ensure the accuracy of the results, some of the parameters that were used to make 3D model were imposed and their accuracy was confirmed by trial and error. The finite element software package ETABS 17 is adopted in the current numerical analysis.

It is evident from figure 4 that a significant raise in the base shear magnitude is spotted in the structure with the lowest transfer floor located at 10% of total structure height. The floor shear force decreased significantly above the transfer position in all cases due to sudden reduction in the mobilized mass. The displacement distribution of each building had a flexural mode up to its transfer level. At this level a large inertial force affected the structure due to the large mass of the transfer floor which resulted in a maximum displacement at the transfer floor level. The drift decreased above this level as a result of the seismic energy dissipation that occurred at the position of discontinuity.

the drift value for the higher transfer floor (more than 30% of total height) reached its maximum value at the mid height between the foundation and the transfer floor. Above the transfer floor, the drift increases to its maximum value near the roof level. The storey moment were distributed over the total height of the building, the maximum moment values were located at the building base and increase gradually, whenever increased the transfer floor height [3].

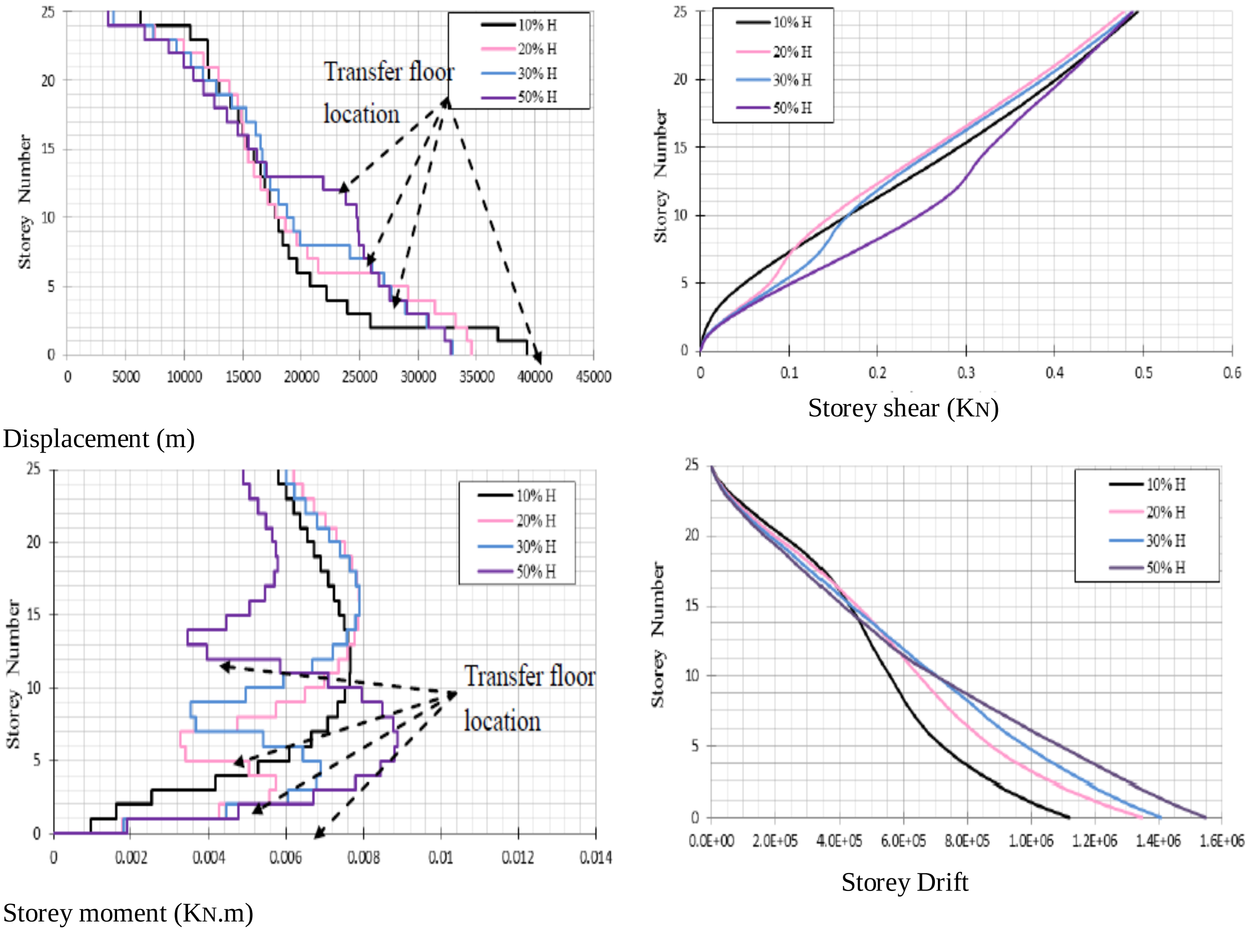


Figure (4): storey shear, displacement (above), storey drift and storey moment (below) for the building with 25 floors to the transfer at 10, 20, 30 and 50% of the total building height [3].

On average the prototype analyzed model results were within 96% conformity with the results by Elawady 2012, in Figure 5.

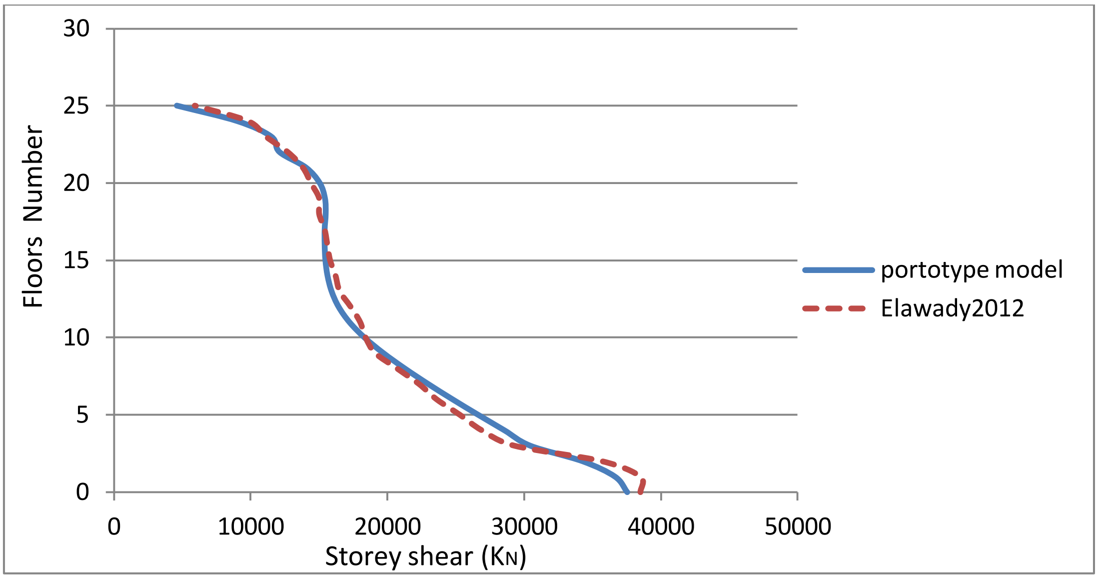


Figure (5): Verification of the Storey Shear Results for the Building with Transfer Floor at 10 % of the Total Height.

Figure 6 demonstrated that the displacement values of the prototype model comparison to Elawady 2012 are near identical 95.10%.

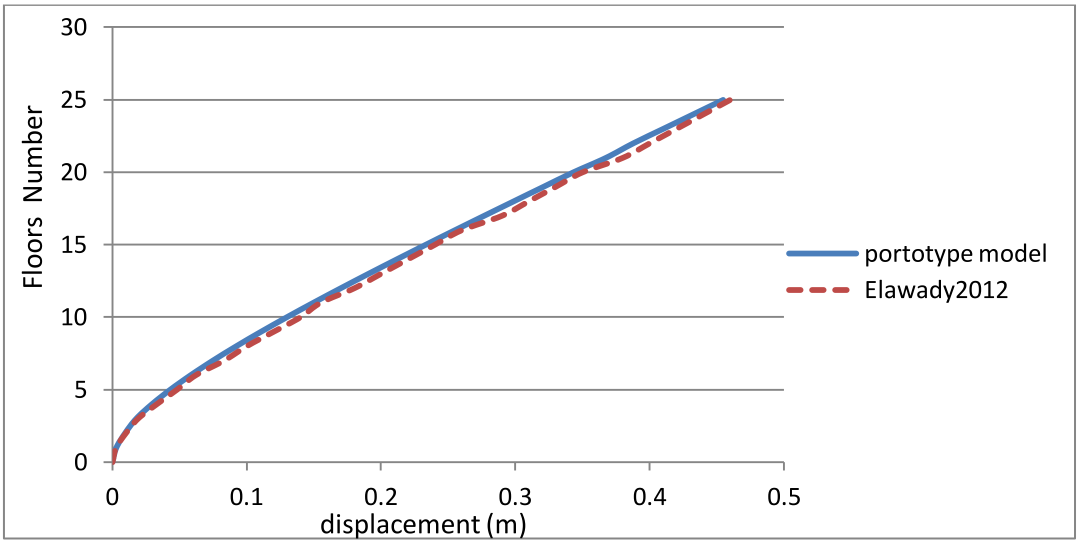


Figure (6): Verification of the Displacement Results for the Building with Transfer Floor at 10 % of the Total Height.

Figure 7 showed that the drift values for the prototype model in comparison to Elawady 2012 with an identical ratio about 96.00%.

Figure (8) illustrated that the storey moment values of the prototype model were compared to that of Elawady 2012 with an identical ratio about 95.50%.

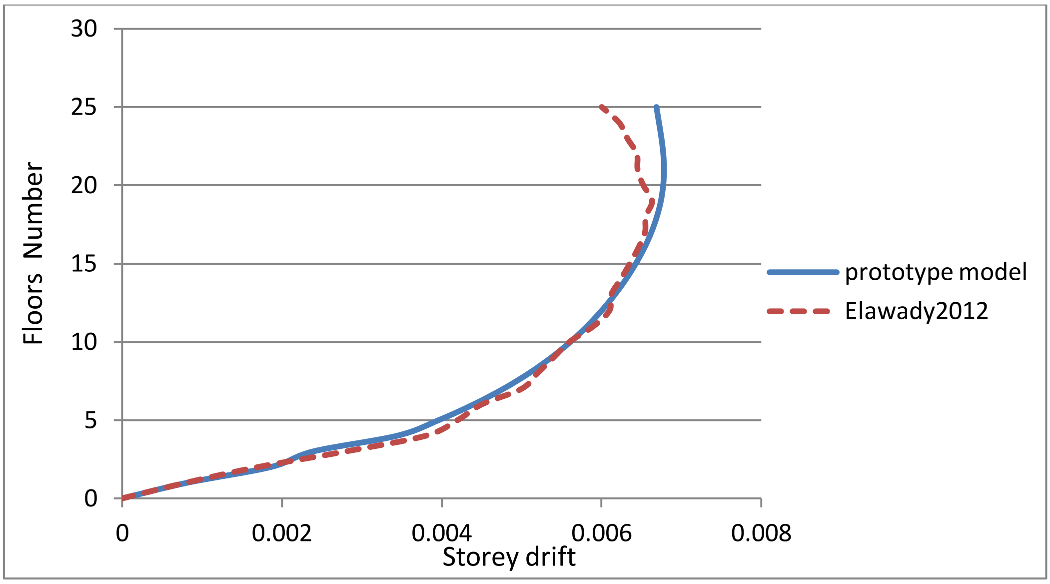


Figure (7): Verification of the Drift Results for the Building with Transfer Floor at 10 % of the Total Height.

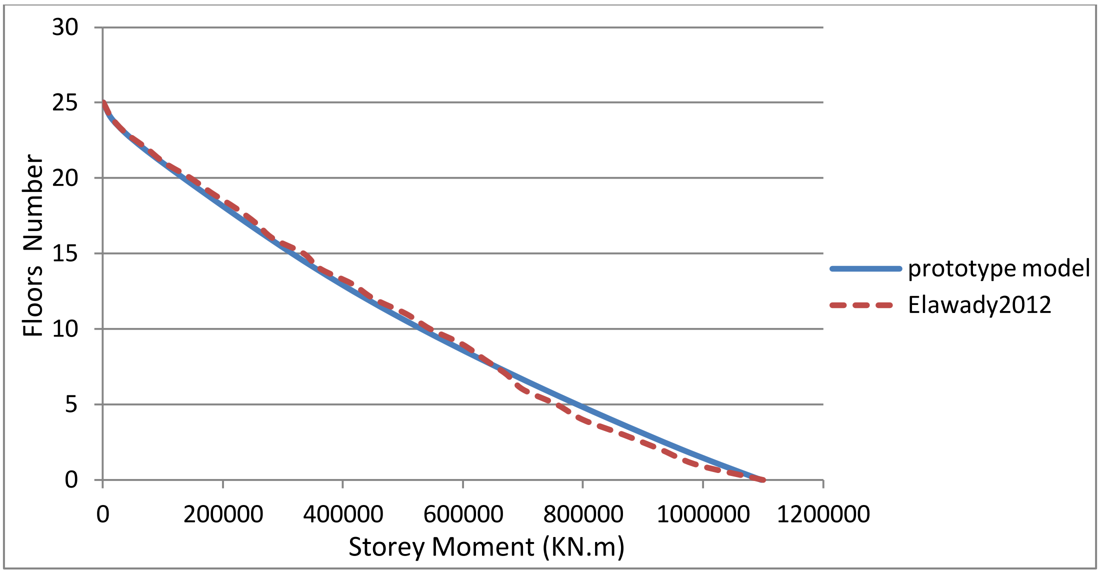


Figure (8): Verification of the Floor Moment Results for the Building with Transfer Floor at 10 % of the Total Height.

In summary, it is clearly revealed that the analysis of both models (prototype model and Elawady 2012) results are matched together with an average of an identical ratio of no less than 95% for all results.

V. Finite Element Simulation

The global behaviour for 3-D model will be presented in the Y direction of the building. A Prototype building which contains 15 floors in case 1 and 30 floors in case 2 instead of 25 floors, with fixed typical floor height 3.50m, the height of the building becomes 52.50m and 105.0m, respectively. Figure 9 showed that the plan dimension with girder system of the transfer floor, the floor area is 20.0m x 48.0m with slab thickness 16 cm, and the girder dimension 0.50m x 1.0m for building with 15 floors and 1.50m x 3.0m for building with 30 floors.

Figure 10 illustrated that the transfer floor was located on 2nd, 3rd and 5th floors in building with 15 floors, but the transfer floor was located on 3rd, 6th and 9th floors in the building with 30 floors at a ratio of 10, 20 and 30% of the total building height, respectively.

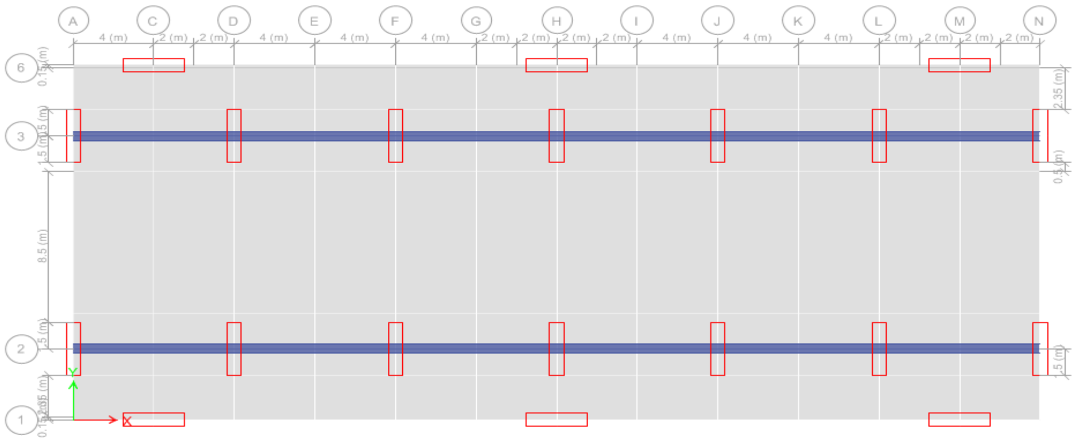


Figure (9): Plan of Girder System to Transfer Floor.

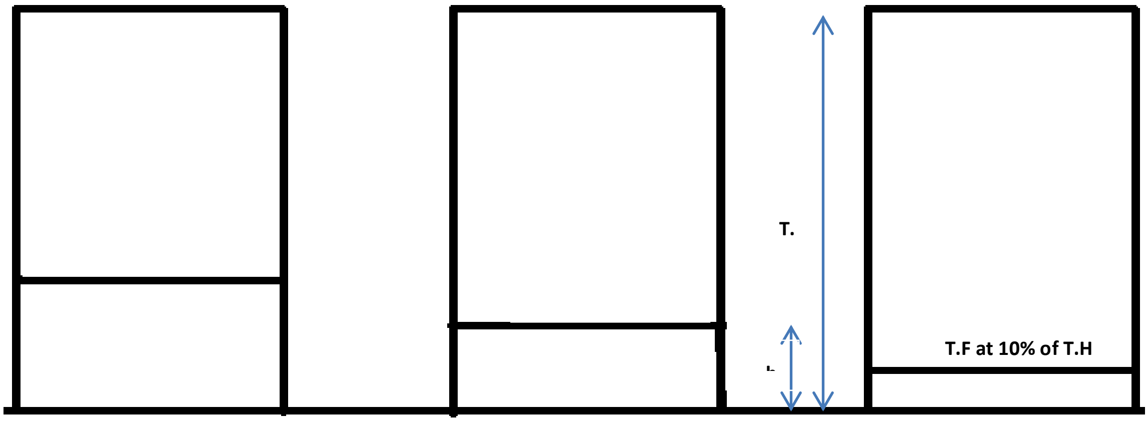


Figure (10): Elevation of Buildings with 15 or 30 Floors with Transfer Floor (T.F) at 10, 20 and 30% of the Total Building Height (T.H).

Seismic Response of Prototype Model

Seismic loads are the shaking of the surface of the Earth, resulting from the sudden release of energy in the Earth's lithosphere that creates seismic movements. Base shear, storey shear and base moment are the terms associated with the earthquake. Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. It depends upon the soil conditions at the site. Storey shear factor is the ratio of the story shear force when story collapse occurs to the story shear force when total collapse occurs. Through a series of dynamic analyses. Base moment is the moment produced at the base of structure due to different loading conditions on the structure [5].

The results which will be presented included the base shear and base moment at the level of the foundation, displacement distribution, storey-moment, storey-drift over the building height.

Case 1: Results and Analysis of 3-D Model with 15 Floors

Figure 11 showed that the building acts as a free cantilever with fixed base, the flexural behaviour appeared till the top of the building, the horizontal displacement was not significantly affected as a result of changing the position of transfer floor Where the maximum displacement value decreased by 2% when increased the height of the transfer floor from 10 to 30% of the total height of the building.

It is evident from figure 12 that the storey-shear distribution over the total building height, a significant decrease in the storey-shear value above the level of the transfer floor. As a result of the effect of the sudden change in the stiffness of the vertical elements above/below the transfer system, the base shear at the foundation level was affected significantly as the shear value increased by 12% as a result of the increase in the height of the transfer floor from 10 to 20%. Increase of 19% in the base shear value when the transfer floor height changed from 20 to 30% of the building total height, despite of the stability of the weight and the relatively lighter transfer system.

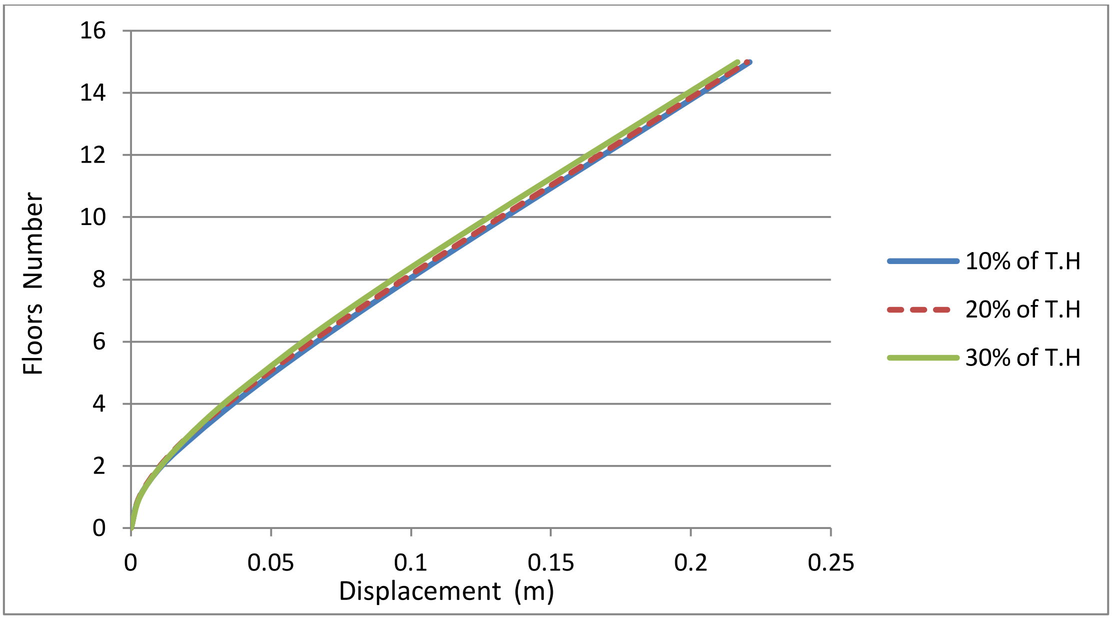


Figure (11): Displacement in Y Direction for a Building 15 Floors with Transfer Floor (Girder System) at 10, 20 and 30 % of the Total Height of the Building, respectively.

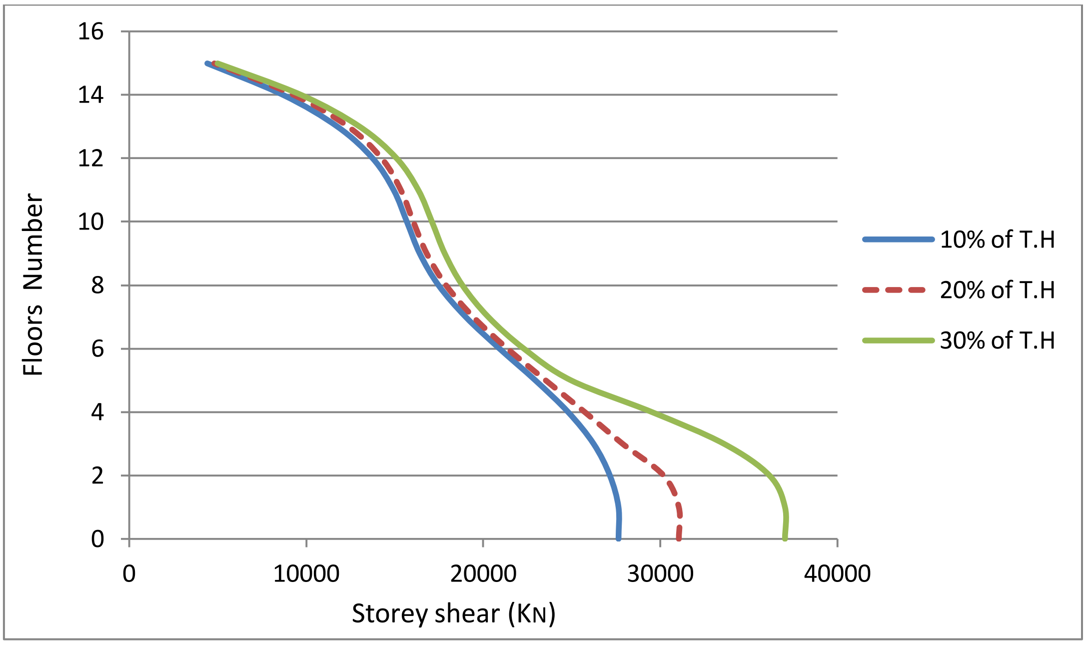


Figure (12): Storey-Shear in Y Direction for a Building 15 Floors with Transfer Floor (Girder System) at 10, 20, and 30 % of the Total Height of the Building, respectively.

Figure 13 illustrated that the inter-storey drift distribution over the building height. The figure showed that no significant decreased in the drift value occurred at the transfer floor level, as a result of using the transfer floor with girder system instead of slab system. The maximum drift values were not affected significantly, as a result of changing the position of the transfer system from 10 to 30%, the maximum drift increased by 3%.

Figure 14 demonstrated the storey-moment distribution over the building height, there was no effect in the storey-moment at the level of the transfer floor system, inspite of the sudden change in the stiffness above/below the transfer level. The values of the base moment which were affected by the change in the transfer floor position, the base moment value increased by 3% when the transfer floor height was raised from 10 to 20 %. Another increase of 9.50 % in the base moment occurred when the transfer floor position was raised from 20 to 30%.

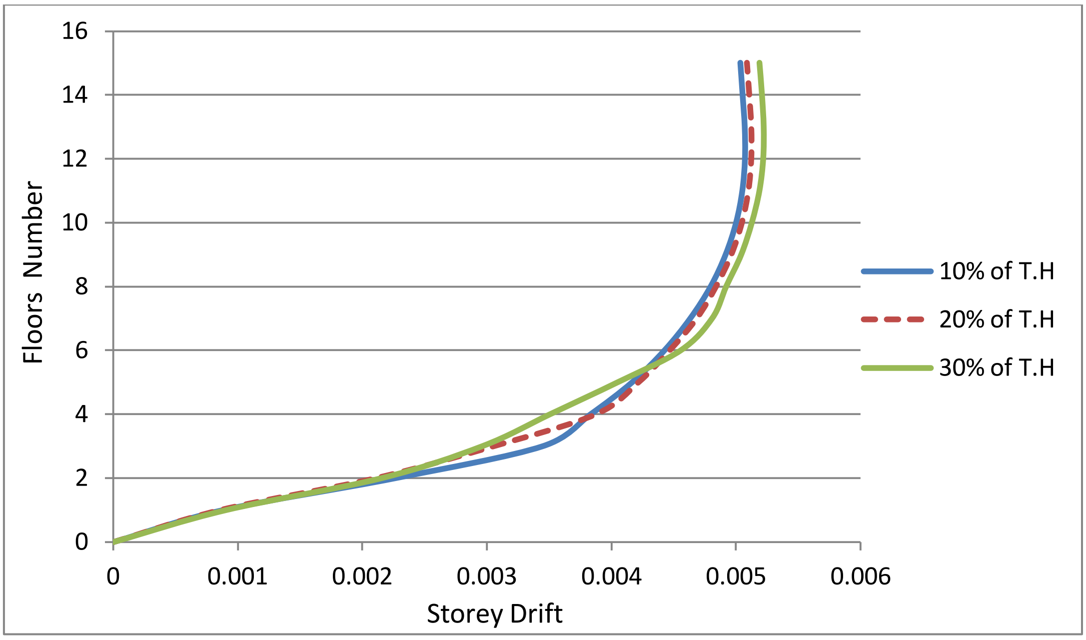


Figure (13): Storey-Drift in Y Direction for a Building 15 Floors with Transfer Floor (Girder System) at 10, 20, and 30 % of the Total Height of the Building, respectively.

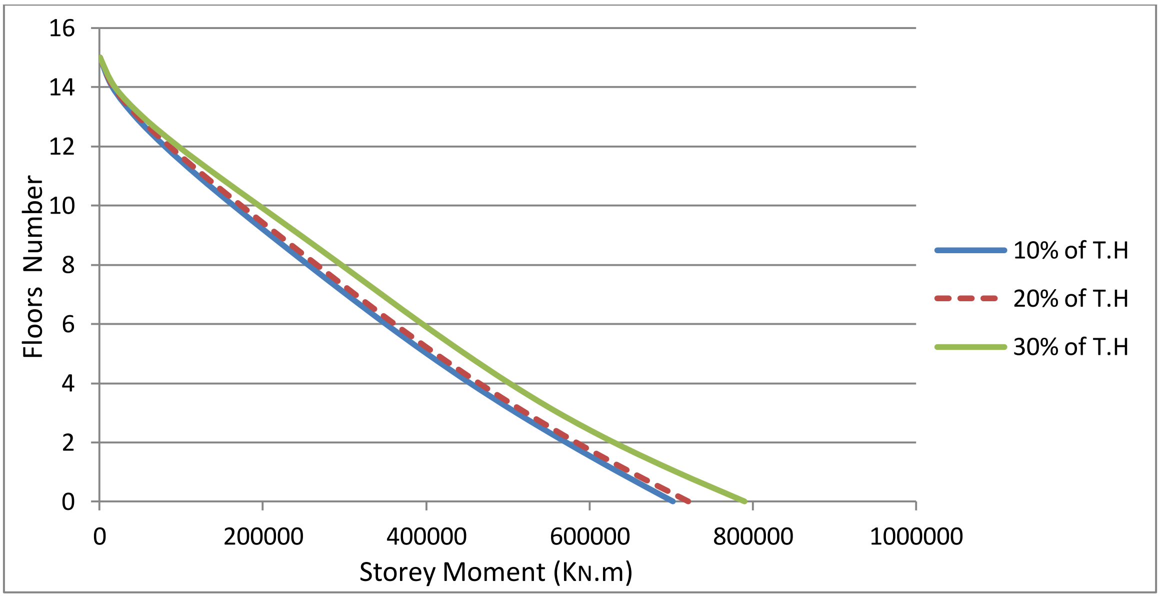


Figure (14): Storey-Moment in Y Direction for a Building 15 Floors with Transfer Floor (Girder System) at 10, 20, and 30 % of the Total Height of the Building, respectively.

Case 2: Results and Analysis of 3-D Model with 30 Floors

The number of floors has been increased from 15 to 30 floors implementary a girder system with transfer floor system, and a change in its height from 10 to 30% of the total height of the building was demonstrated.

From figure 15 to 21 gave the same behaviour for the building of 15 floors with transfer floor at 10, 20, and 30% of the total building height.

Figure 15 clarified that the horizontal displacement was not significantly affected as a result of changing the position of transfer floor, the displacement values decreased by 2.5% at building top, due to the increase in the transfer floor height from 10 to 30% of the total height of the building.

It's revealed from figure 16 that the value of base shear increased by 16%, when the transfer floor height is increased from 10 to 20%. The base shear increased when the height was raised from 20 to 30 % of the total height of the building by 0.8%.

Figure 17 demonstrated that the maximum value of drift for the building increased by up to 2% when the height of the transfer floor increased from 10 to 20%. The drift increased by 3% when the height of transfer floor changed from 20 to 30% of the total height of the building.
Figure 18 expressed an increase in the base moment value by 14%, when the height of the transfer floor increased from 10 to 30 % of the building height.

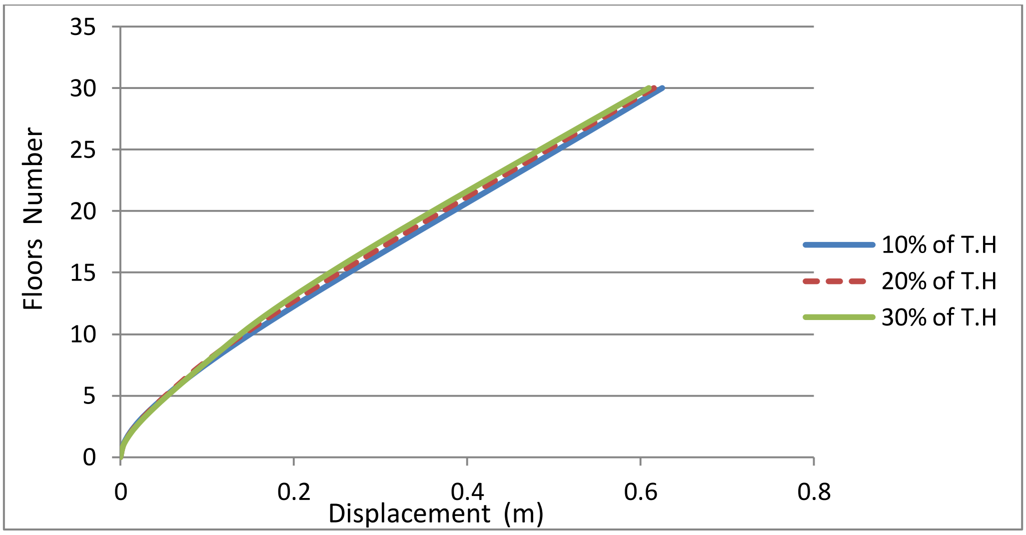


Figure (15): Displacement in Y Direction for a Building 30 Floors with Transfer Floor (Girder System) at 10, 20, and 30 % of the Total Height of the Building, respectively.

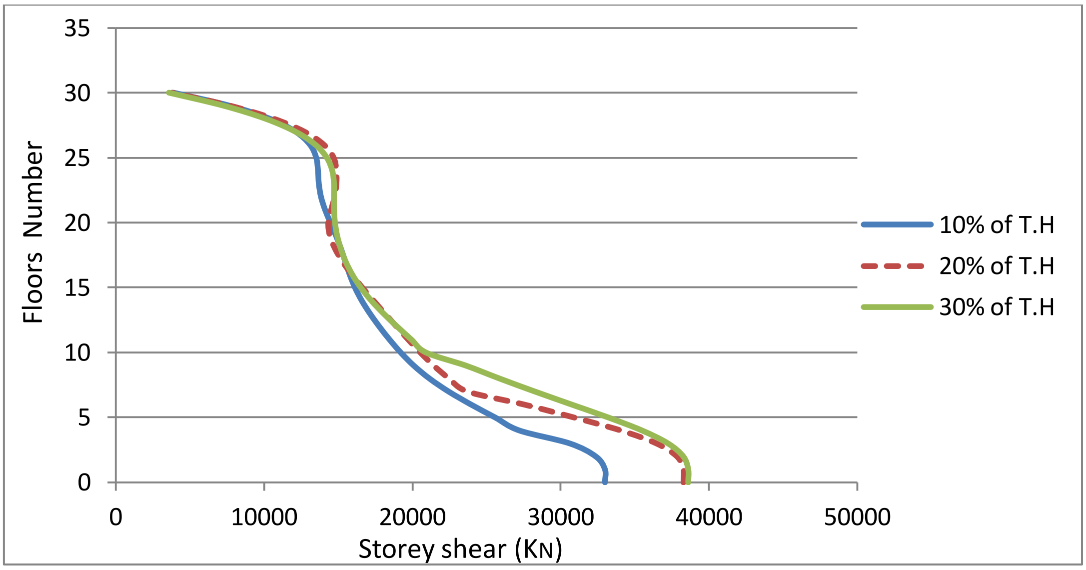


Figure (16): Storey-Shear in Y Direction for a Building 30 Floors with Transfer Floor (Girder System) at 10, 20, and 30 % of the Total Height of the Building, respectively.

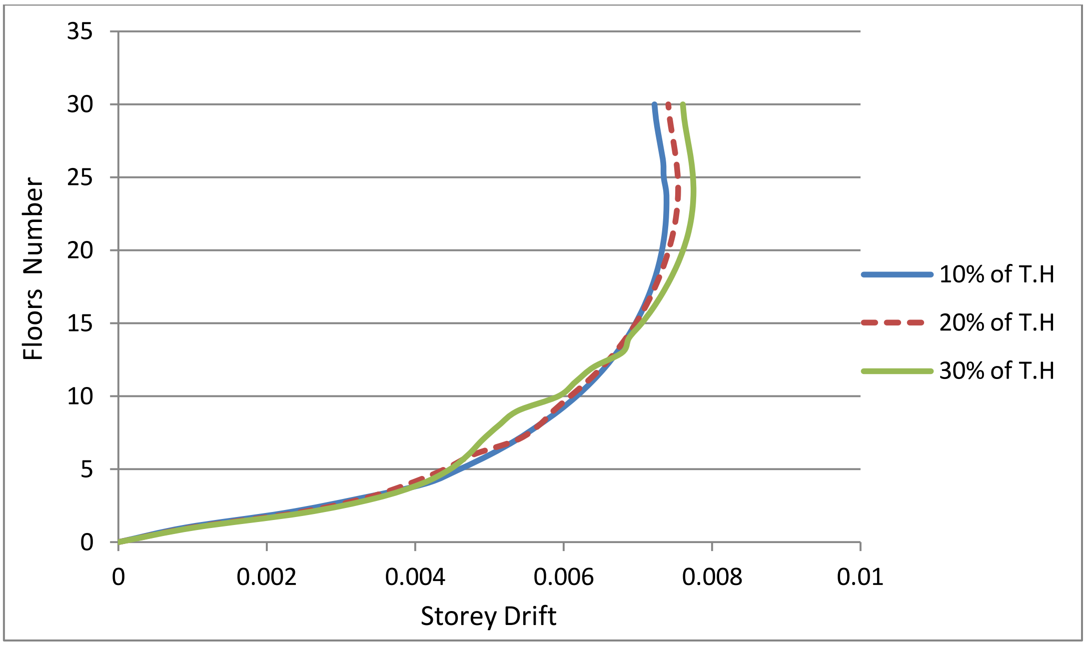


Figure (17): Storey-Drift in Y Direction for a Building 30 Floors with Transfer Floor (Girder System) at 10, 20, and 30 % of the Total Height of the Building, respectively.

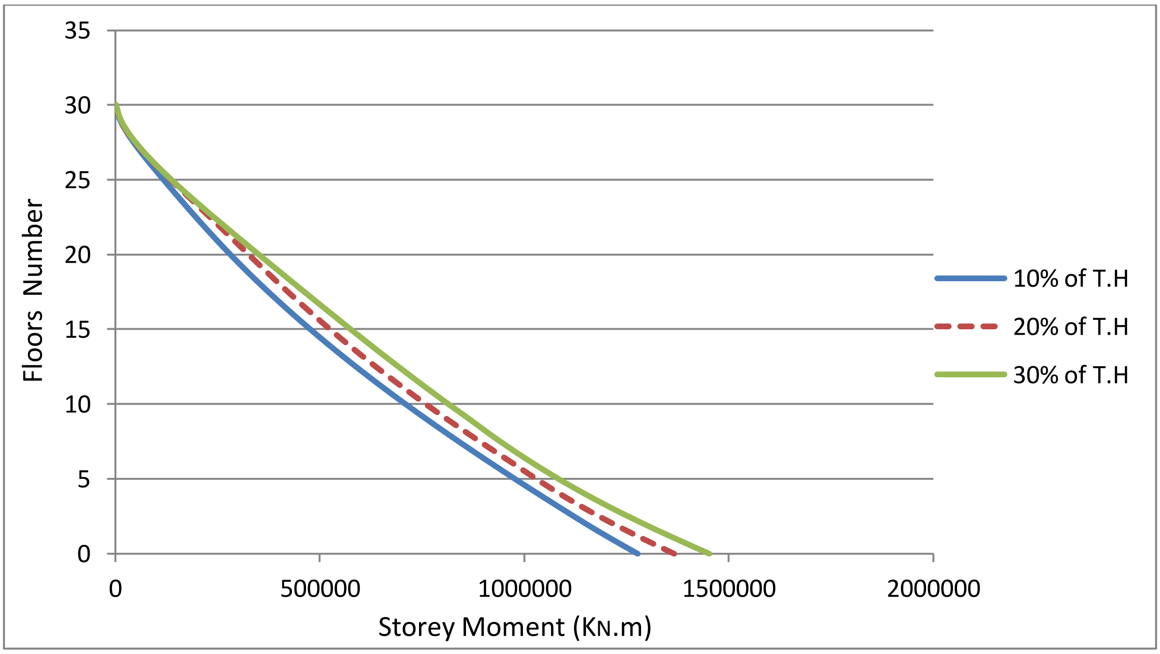


Figure (18): Storey-Moment in Y Direction for a Building 30 Floors with Transfer Floor (Girder System) at 10, 20, and 30 % of the Total Height of the Building, respectively.

IV. Comparison between Maximum Results of Straining Actions

A comparison between the results that were previously reported between 15 and 30 floors building, when the height of the transfer floor changed from 10, 20 and 30% of the total building height, with the aim to reveal the effect of the increase in the structure height with a relatively light weight (girder system) of the transfer floor.

It's evident from the figure 19 that the effect of the increase the number of floors on the maximum displacement was fixed ratio up to 180%.

Figure 20 showed that the value of the maximum base shear increased by 19, 23 and 4% respectively. A slight increase in the shear value appeared when increasing the height of the transfer floor to 30% of the total building height, despite the big difference in the number of floors. This confirms that it is possible to control the base shear values by increasing the height of the transfer floor.

Figure 21 clarified that the maximum value of the drift increased by 45, 47 and 32% respectively. A significant increase in maximum drift values occurred despite the use of a lightest weight transfer floor system (girder system). This indicates that the effect of increased the number of floors on drift is more effective than the weight of the transfer floor.

Figure 22 demonstrated that the maximum value of the base moment increased by 82, 89 and 84% respectively. There was a significant increase in base moment value, and it appeared to be more affected by the increase in the number of floors of the building than base shear.

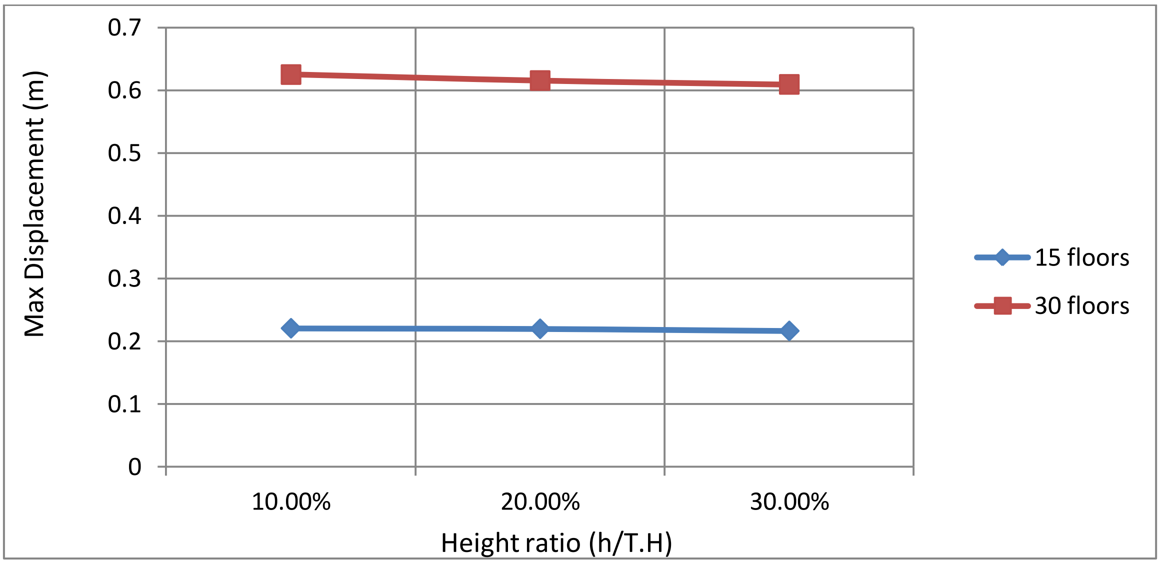


Figure 19: Comparison between the Maximum Displacement Values of 15 and 30 Floors Buildings with Transfer System.

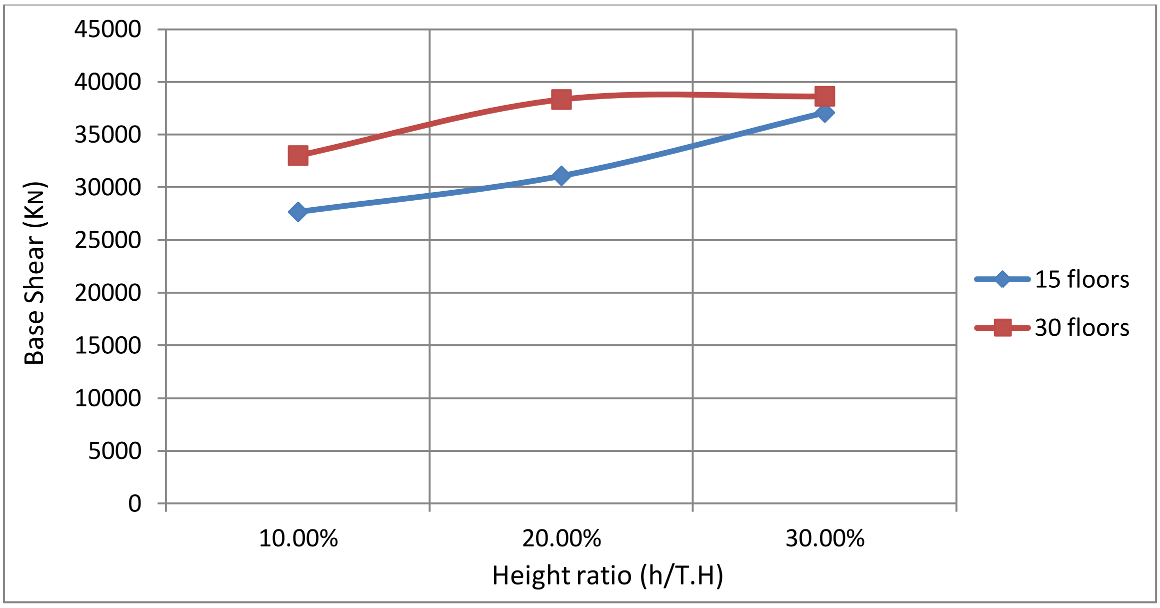


Figure 20: Comparison of the Base Shear Values in 15 and 30 Floors Buildings with Transfer System.

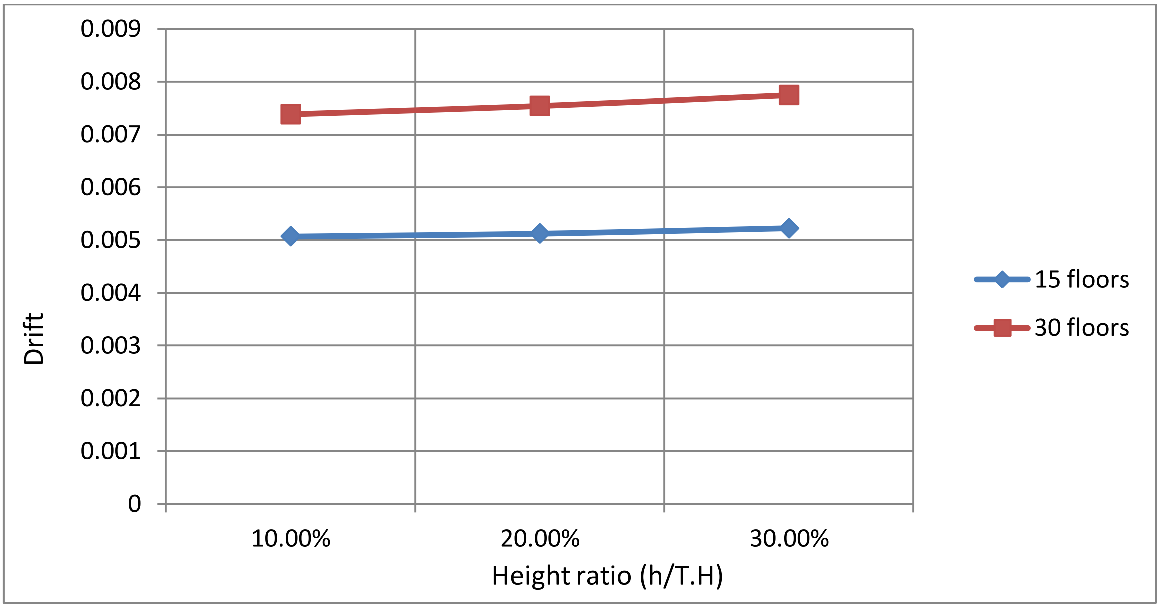


Figure 21: Comparison of the Drift Values in 15 and 30 Floors Buildings with Transfer System.

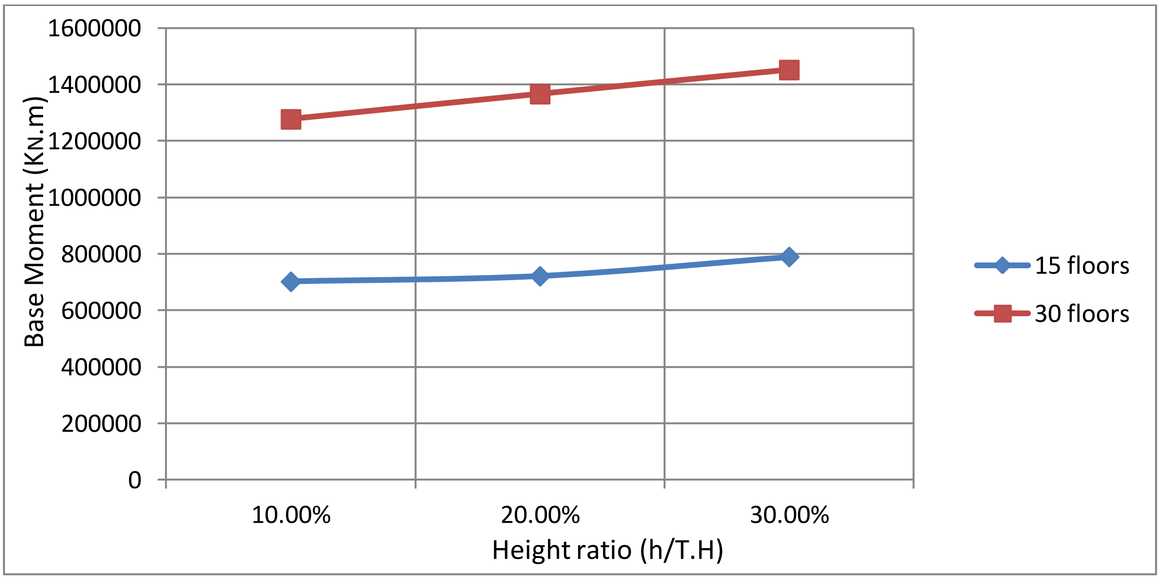


Figure 22: Comparison of the Base Moment Values in 15 and 30 Floors Buildings with Transfer System.

IIV. Conclusions

1. There was no effect of the level of the transfer floor on the displacement and drift due to the use of the light system of the transfer floor
2. It is possible to control the base shear values by increased the height of the transfer floor until 30% of the total building height.
3. For the girder system the straining actions (base shear and base moment), the effect of increased the number of floors of the building from 15 to 30 floors more effective on the base moment than base shear, as the values of increase reached (82, 89 and 84%) for base moment, while (19, 23 and 4%) for the base shear.
4. When increased the number of floors of the building from 15 to 30 floors, the transfer floor located at 30%, it gave the best results than located at 10 and 20% of the total building height.
5. The worst case when located the transfer floor at 20% of the total height of the building, where the values of the results increased by a large proportion of the base shear, maximum drift and base moment by 23, 47 and 89%, when increased the number of floors from 15 to 30.
6. The displacement increased by fixed ratio 180%, when increase the number of floors from 15 to 30 floors, despite the change in the height of the transfer floor from 10 to 30% of the total building height.

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Sameh Gebrail, et. al. "Effect of Transfer Floors on the Behaviour of Residential Buildings under Earthquake Loads." *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 18(3), 2021, pp. 24-37.