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# SEISMIC RESPONSE OF A SOFT GROUND STOREY REINFORCED CONCRETE STRUCTURE WITH DIFFERENT COLUMN ORIENTATIONS

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***ABSTRACT --- Open ground storey (OGS) is a typical feature in the modern construction throughout the world. Buildings having open ground storey are undesirable in seismically active areas as depicted by past earthquakes such as San Fernando 1971, Northridge 1994, Kobbe1995, Bhuj India 2001.Also the past studies have been done on open ground storeys without taking the orientation of columns into consideration. In this study, the objective is to check the best orientation of rectangular columns in a G+8 building with open ground storey which is a Soft Storey by observing the displacements, drift and Stiffness of the various models in X and Y direction. For this purpose, six models are created having different orientation of rectangular columns viz Model CCO (corner columns oriented), Model ECO (Exterior columns oriented), Model ACO (All columns oriented), Model ECOEC (External columns oriented excluding corner ones), Model AICO(All interior columns oriented) and the displacement, drift and stiffness of these models are compared . A reference model known as Model BM is considered for the study in which the stiffness and strength of the infill wall is not taken into account. The displacement, drift and stiffness of all the five models are compared to the reference model and it is observed that Model CCO has least difference in the displacement, drift and stiffness in X and Y direction. Hence the Model CCO is preferred.***

***KEYWORDS --- SAP 2000; Soft Storey; Column Orientation; Open Ground Storey; Stiffness.***

## I. INTRODUCTION

Buildings with open ground storey (Soft Storey) are considered as vertically irregular buildings as per IS 1893:2002 (Part 1), that requires static as well as dynamic analysis considering strength and stiffness of the infill walls. In this study, static analysis is done to see the effect column orientation on soft storey behaviour of Open Ground Storey in terms of Displacement, Drift and Stiffness. The objective of the present study is to check the best orientation of rectangular columns in a G+8 building with open ground storey /Soft Storey by observing the displacements, drift and Stiffness of the various models In X and Y direction. The structure (G+8) with open ground storey located in Seismic Zone-IV is analysed. A reference model known as Base Model (BM) is considered for the study in which the stiffness and strength of the infill wall is not taken into account. In order to study the behaviour of the Open Ground Storey building designed as per IS1893: 2002, various models are analysed. Five Models are designed viz Model CCO(corner columns oriented), Model ECO(External columns oriented) , Model ACO(All Columns Oriented), Model ECOEC(External columns oriented except corner ones), Model AICO(All interior columns Oriented). The ground storey columns are of 3.6m high while as upper storey columns are 3.1m high and these dimensions are selected by keeping the stiffness of the ground storey as 69.4% of the above columns.

Linear static and multimodal dynamic analyses of these models are carried out to compare the displacement, drift and stiffness of open ground storey. The support conditions considered are fixed-end conditions. The slab is considered to act as the diaphragm. In the analysis, various load combinations are applied. The worst load case is considered for the evaluation purpose.

## II. METHODOLOGY

The soft storey effect is introduced in the building by keeping the stiffness of the ground storey as 69.4% of the stiffness of the above stories. This is done by increasing the length of the columns of ground storey than other stories. The ground storey is kept open with height of the columns as 3.6m while as the columns of other stories are 3.1m long. For modeling the structure, the span in X direction is 25m with each bay equal to 5m and the span is y direction is 15m with each bay equal to 3m.

**Table I**

**Various parameters taken into consideration while modeling the G+8 structure**

| | |
|---|---|
| Thickness of the external walls | 230mm |
| Thickness of the internal walls | 150mm |
| Thickness of slab | 150mm |
| Zone | IV |
| Type of soil | Medium soil |
| Height of parapet | 1.5m |
| Live load on floors | 3 kN/m$^2$ |
| Live load on Roof | 1.5 kN/m$^2$ |
| Intensity of Floor finish | 1 kN/m$^2$ |
| Intensity of Roof treatment | 1.5 kN/m$^2$ |

*A. Materials Properties*

Different materials are used in the structural modeling of the building. The grade of concrete used is M25 and reinforcement used is Fe 415. The elastic properties of these materials are taken as per the IS 456:2000. As per clause 6.3.2.1 of the IS 456:2000 the modulus of elasticity of concrete is taken as:

$E_C = 5000\sqrt{f_{ck}}$ N/mm$^2$

Where $f_{ck}$ is the characteristic compressive strength of the concrete in N/mm$^2$ at 28 days. For present study value of $f_{ck}$ is 25. For the reinforcement, the yield stress ($f_y$) and modulus of elasticity ($E_s$) is taken as per IS 456:2000

Each model in this study is named according to the type of orientation of columns.

*B. Plan of the Models*

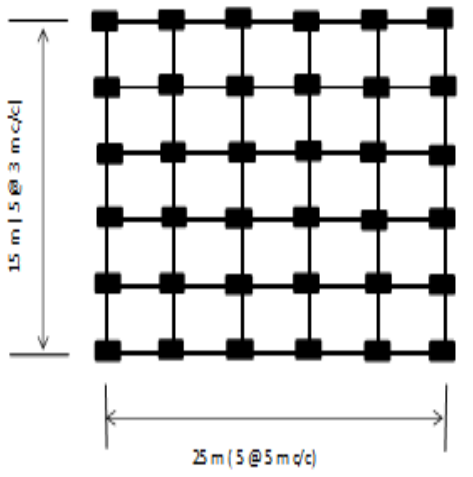


Fig.1 Plan of the structure (Base Model)

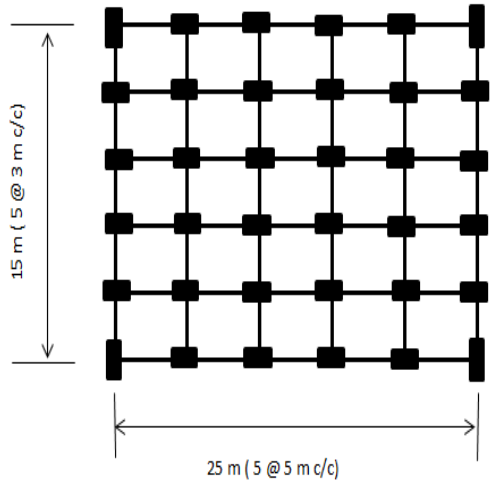


Fig.2 Plan of Model CCO

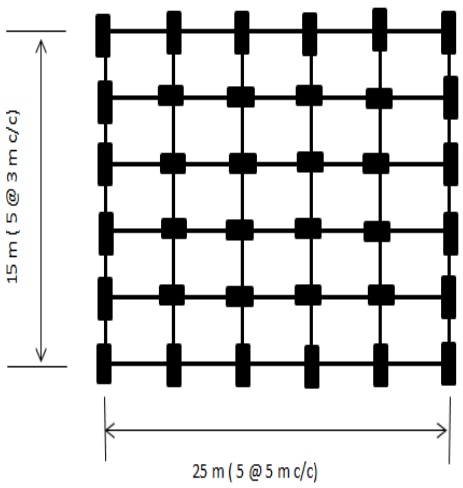


Fig.3 Plan of Model ECO

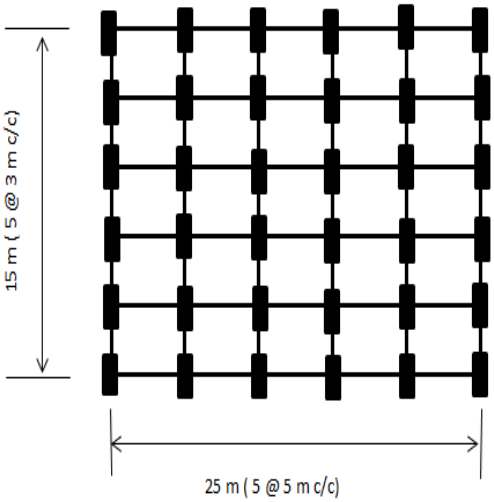


Fig.4 Plan of Model ACO

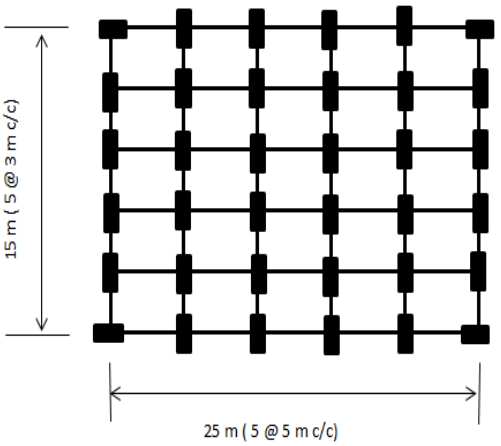


Fig.5 Plan of Model ECOEC

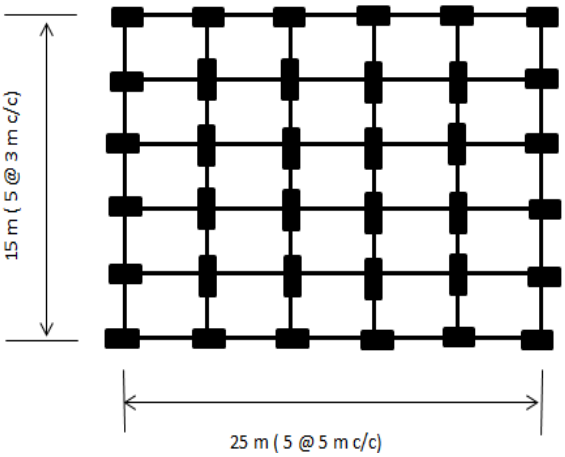


Fig.6 Plan of Model AICO

Response spectra for 5% damping for soil conditon medium as per IS 1893:2002(Part 1) is given in Figure 7.

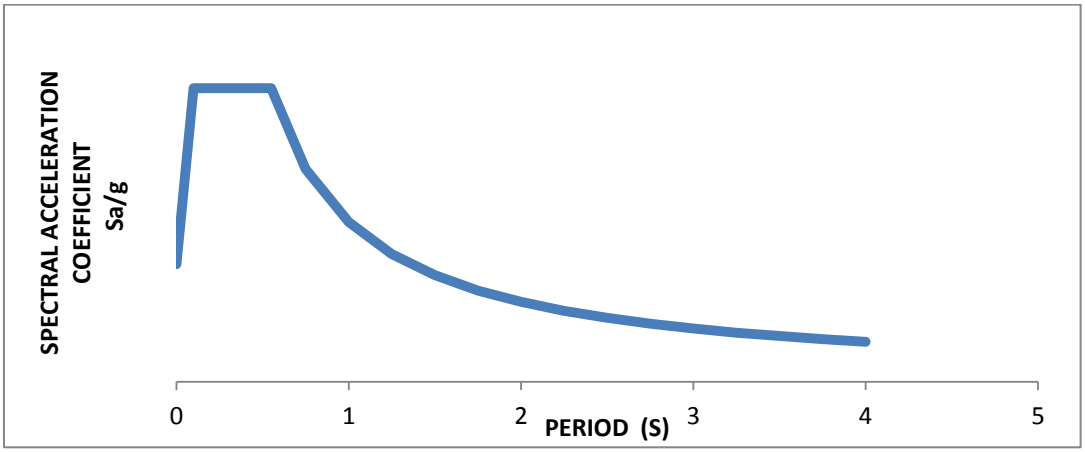


**Fig.7** Response spectra for 5% damping

*C. Load Combinations*

Load combination results when more than one load type acts on the structure. Design codes usually specify a variety of load combinations together with load factors (weightings) for each load type in order to ensure the safety of the structure under different maximum expected loading scenarios. In the limit state design of this RC building model the following load combinations are considered as per codal provisions provided in Clause 6.3.1.2, IS: 1893-2002(Part 1):

a) 1.5(DL+IL)
b) 1.2(DL+IL±EL)
c) 1.5(DL±EL)
d) 0.9DL±1.5EL

## III. RESULTS AND DISCUSSIONS

*1) Comparision of the displacement of all the Models in X direction.:*

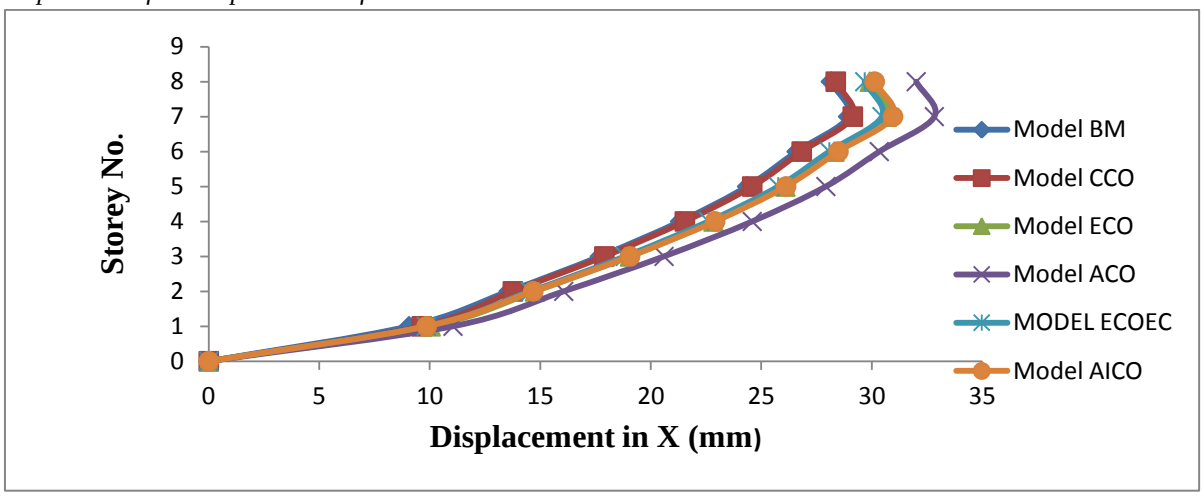


Fig.8 Comparision of the displacement of all the Models in X direction.

The graph in Figure 8 is plotted by taking displacement as abscissa and storey No. as ordinate for all the models. The figure shows displacement graph plotted for various frame models in X direction. From the graph it can be seen that all models show abrupt change in the displacement at storey No. 0.From the graph, it is found that model ACO is showing maximum displacement for all storey No's as compared to other models. Also the model BM is showing less displacement in X direction as compared to other models. All the other models namely model CCO, Model ECO, Model ECOEC and Model AICO are having their displacements in between the two models already discussed. As compared to BM the percentage increase in displacement for each storey No. as well as model increases .The percentage increase in displacement for model CCO at storey No. 1 is 6.40%, for model ECO at storey No. 1 is 10.82%, for model ACO at storey No. 1 is 21.96%, for model ECOEC at storey No. 1 is 8.61%,and for model AICO at storey No. 1 is 8.83%.Similiar trend is followed by at other storey No.'s with difference only in percentage increase in displacement. From the above graph we can find that Model CCO, ECO, ECOEC and AICO are showing almost similar percentages of increase in displacement. The displacement of other models has increased as compared to Model BM, the reason being the decrease in stiffness as compared to base model due to column orientations which has been considered in all models.

*2) Comparision of the displacement of all the Models in Y direction:*

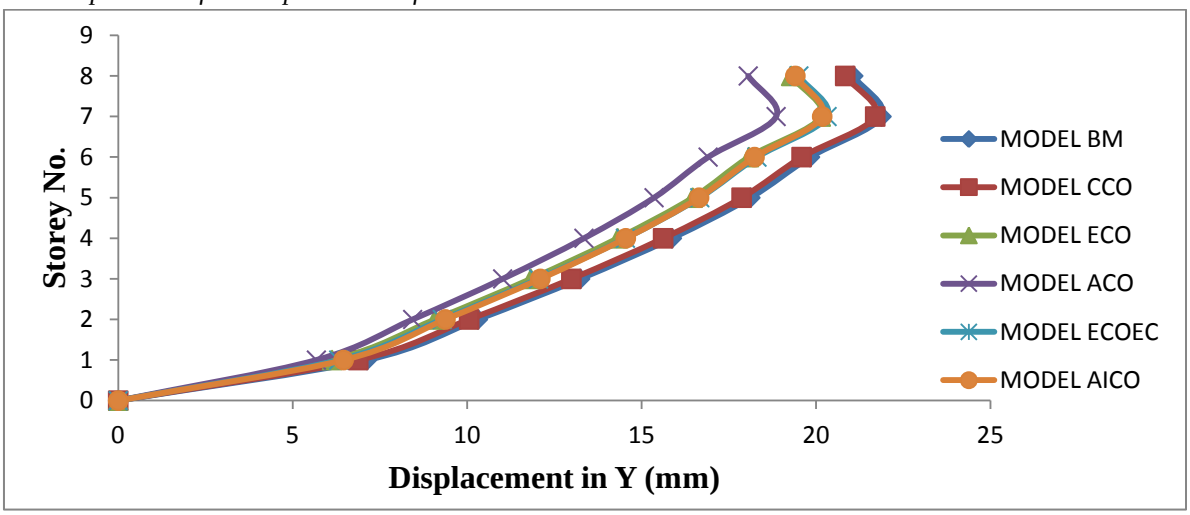


Fig.9 Comparision of the displacement of all the Models in Y direction.

The graph is plotted by taking displacement as abscissa and storey No. as ordinate for all the models. The figure 9 shows displacement graph plotted for various frame models in Y direction. From the graph it can be seen that all models show abrupt change in the displacement at storey No. 0.From the graph ,it is found that model CCO is showing maximum displacement for all storey No's as compared to other models. Also the model ACO is showing less displacement in Y direction as compared to other models. All the other models namely model CCO, Model BM, Model ECOEC and Model AICO are having their displacements in between the two models already discussed. As compared to BM, for all the models there is decrease in displacement percentage .For models CCO, ECO,ACO,ECOEC and AICO at storey No. 1 there is decrease in percentage of displacement by an amount of 3.5%, 14.02%,20.34%,11.36% and 9.40% respectively. From the above graph we can find that Models CCO is showing increase in percentage displacement because of decrease in stiffness due to column orientation which has been considered in the above models. For models ECO, ACO, ECOEC and AICO are showing decrease in percentage displacement because of increase in stiffness due to column orientation as considered

*3) Comparision of the Inter-Storey Drift of all the Models in X direction.*

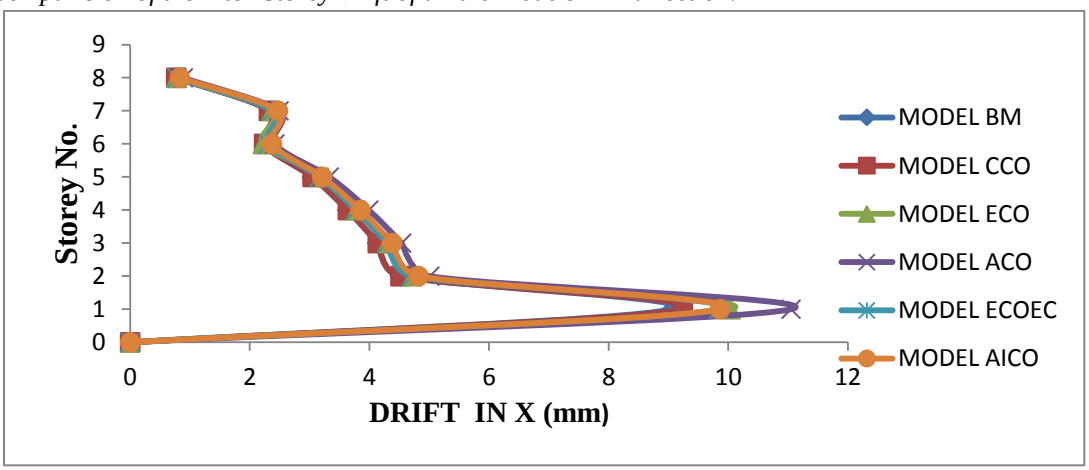


Fig.10 Comparision of the Inter-Storey Drift of all the Models in X direction.

The graph shown in figure 10 is plotted between Storey drift as abscissa and storey No. as ordinate for the models which have been considered for analysis .From the figure it can be observed that the maximum storey drift is found in all the models along X direction at storey No. 1.From the graph it is observed that storey drift at first storey as well at other stories is maximum for the model ACO. In all the other models, it can be seen that storey drift is showing little difference in their values at respective storey No.'s .For model CCO the percentage increase in drift as compared to Model BM at storey No. 1,2 are 1.98%,0.22% respectively and percentage decrease in Storey No. 8 is 1.28% . For model ECO the percentage increase in drift as compared to Model BM at storey No. 1 and 2 are 0.10% and 4.65% respectively but in storey No. 8 for the same model there is decrease in percentage drift by 1.28% as compared to Model BM. For model ACO, the percentage increase in drift as compared to Model BM at storey No. 1, 2 and 8 are 21.96%, 11.09% and 14.10% respectively. For model ECOEC the percentage increase in drift as compared to Model BM at storey No. 1, 2 and 8 are 8.61%, 4.43% and 0% respectively. For Model AICO, the percentage increase in drift as compared to Model BM at storey No. 1, 2 and 8 are 8.83%, 6.87%, and 6.41% respectively. From the percentage increase in drift of the models, it can be observed that Model CCO has minimum increase as compared to other models.

*4) Comparision of the Inter-Storey Drift of all the Models in Y direction.*

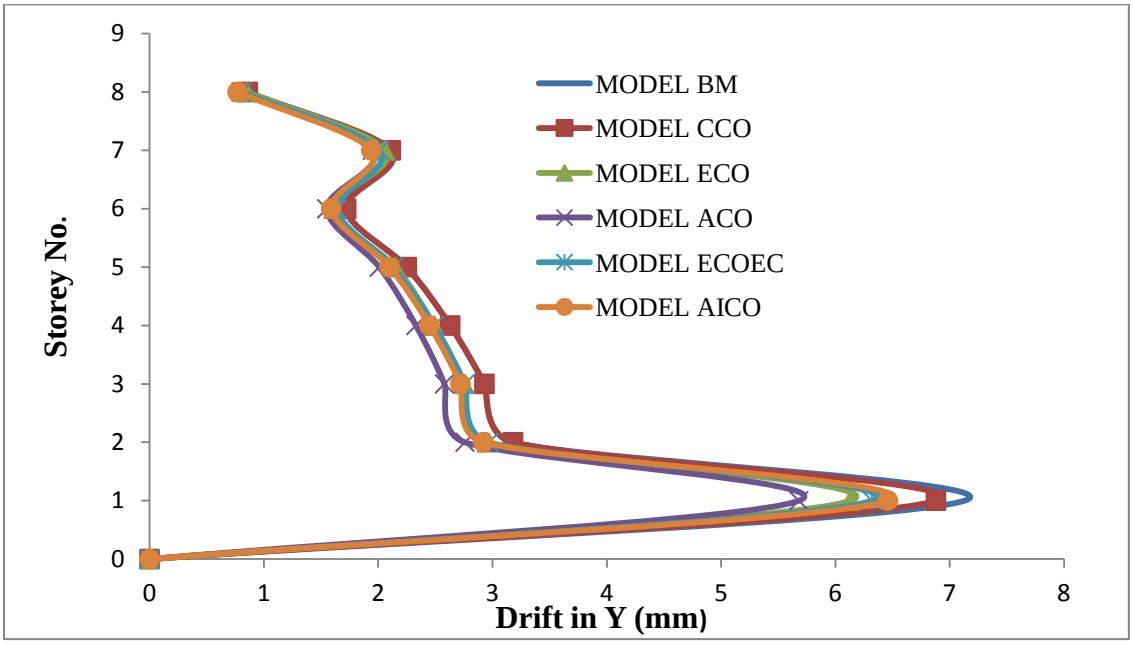


Fig.11 Comparision of the Inter-Storey Driftof all the Models in Y direction.

The graph is plotted between Storey drift as abscissa and storey No. as ordinate for the models which have been considered for analysis .From the figure 11 it can be observed that the maximum storey drift is found in all the models along Y direction at storey No. 1.From the graph it is observed that storey drift at first storey as well at other stories is maximum for the model CCO. In all the other models, it can be seen that storey drift is showing little difference in their values at respective storey No.'s .For model CCO the percentage decrease in drift as compared to Model BM at storey No. 1, 2 are 3.51% and 0 % respectively and percentage increase in Storey No. 8 is 6.17%s. For model ECO the percentage decrease in drift as compared to Model BM at storey No. 1 and storey No. 2 are 0.14%% and 7.23% respectively. For storey No. 8, the percentage increase in drift as compared to Model BM is 4.93%. For model ACO, the percentage decrease in drift as compared to Model BM at storey No. 1, 2 and 8 are 20.33%, 13.21% and 1.23%respectively. For model ECOEC the percentage decrease in drift as compared to Model BM at storey No. 1, 2 and 8 are 11.36%, 6.60% and 0% respectively. For Model AICO, the percentage decrease in drift as compared to Model BM at storey No. 1, 2 and 8 are 9.39%, 8.16 % and 4.93% respectively. From the comparision graph, it is observed that the percentage increase in drift of the model CCO is the highest .In Model ECO there is decrease in the drift but at storey No. 8 the drift increases as compared to Model BM. On the other hand for the models ECOEC and AICO, there is percentage decrease in drift at Storey No. 1 and 2 as compared to Model BM.

*5) Comparision of the Stiffness of all the Models in X and Y direction.*

Stiffness is the one of the main parameter which predicts the soft storey behavior of the particular structure. To evaluate the effect of the soft storey and column orientation on the storey stiffness various models are analysed by using SAP 2000. The results obtained are discussed as under:

**Table II**
**Stiffness of the models in X and Y direction.**

| | LATERAL STIFFNESS(KN/m) IN X DIRECTION | | LATERAL STIFFNESS (KN/m) IN Y DIRECTION | |
|---|---|---|---|---|
| **MODEL** | **GROUND STOREY** | **FIRST STOREY** | **GROUND STOREY** | **FIRST STOREY** |
| **BM** | 15000000 | 23491658.6 | 8437500 | 13214057.9 |
| **CCO** | 14270834.4 | 22349704 | 9166666.8 | 14356014.8 |
| **ECO** | 11354167.2 | 17781881.6 | 12083334 | 18923837.2 |
| **ACO** | 8437500 | 13214057.9 | 15000000 | 23491658.6 |
| **ECOEC** | 12083334 | 18923837.2 | 11354167.2 | 17781881.6 |
| **AICO** | 12083334 | 18923834 | 11354167.2 | 17781881.6 |

The **Table II** shows the comparision of the stiffness of all the models with respect to the base model in X and Y direction. The percentage decrease in the stiffness in the model CCO in ground floor and first floor in the X direction is 4.86% as compared to Model BM while as the percentage increase in stiffness in ground Floor in the Y direction as compared to Model BM is 8.64%. In Model CCO the percentage stiffness decreases in the X direction in ground and first floor as compared to Model BM while as in Y direction, the percentage stiffness increases in both ground and first floor in comparision to the Model BM. In Model ECO, the percentage decrease in stiffness in ground and first floor in X direction is 24.30% as compared to Model BM while as in Y direction there is increase in percentage stiffness by 43.20 % in ground and first floor as compared to Model BM. For models ACO, the percentage decrease in ground and first floor in X direction is 43.75% and percentage increase in Y direction in the ground and first floor is 77.8%.In Models ECOEC, AICO the trend followed by stiffness is same i.e. in X direction percentage decrease in stiffness is 19.4% and in Y direction, percentage increase in stiffness is 34.56%.

## IV. CONCLUSION

Followings are the main conclusions obtained from the present study:

1) The displacement of the Model ACO is highest as compared to other models in X while as in Y direction the same model has lowest displacement. Therefore Model ACO is not preferred. Model CCO has lowest displacement in X direction as compared to other models but in Y direction, the displacement of the same model increase. In Models ECOEC and AICO, the displacement in X direction is more as compared to Model BM but in Y direction the displacement is least of all the model which means the difference in X and Y direction is large for these models. In Model CCO, the displacement in X is least of all and in Y direction the displacement is higher than models ECOEC and AICO but lesser than Model BM. Hence model CCO is preferred since it has less difference in the displacement values in both X and Y direction.

2) The drift is highest in Model ACO in X direction but decreases in Y direction. Model ACO is not preferred as it has large difference in the drift. Model CCO has least drift in X direction. In Models ECOEC and AICO, the drift is more in X direction as compared to the Model BM but in Y direction, the drift decreases in these models. Model CCO has least drift as compared to other models in X direction but for the same model the drift increases in Y direction. Model CCO is preferred as it has small difference in the values of drift in X and Y direction.

3) The stiffness of the models decreases in X direction while as in Y direction, the stiffness of all the models increases as compared to Model BM. In Model CCO, the difference in the decrease in stiffness in X direction and the increase in the stiffness in Y direction is minimum as compared to other models. Hence model CCO is preferred as it will be able to resist almost lateral loads of equal magnitude in both the directions (X and Y) in case of an earthquake. In Models ECOEC and AICO, the stiffness in both X and Y direction remains same but the increase in X direction and decrease in Y direction is highest of all other models. Model ACO is not preferred since the difference is the stiffness in X and Y direction is large.

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