INFLUENCE OF DIAPHRAGM ACTION UPON THE SEISMIC RESPONSE OF HIGH RISE MOMENT RESISTING BUILDING FRAMES

Saeed Ahmad[1], Asim Gulzar[2], Huma Pervaiz[3]

Abstract

Diaphragm or horizontal bracing system is a horizontal system transmitting lateral forces to the vertical lateral load resisting elements. Under lateral loading floor slabs in reinforced concrete building perform as diaphragms to transfer lateral forces to load resisting frames. The objective of present study is to evaluate how a structure behaves when the reinforced concrete slabs are included in the structural analysis. In current study, two regular building model having 6 bays in each principle direction, each bay of 15ft length. In this way the plan dimensions become 90ft x 90ft.Total stories are 10, each having a height of 11ft except the plinth level which is 10ft in height .In this way the total height of the structure becomes 109ft. Diaphragms are modeled as rigid elements, thus the effect of their in plane movement relative to the vertical lateral load resisting system is neglected. It was found that the considering the effect of slabs in the structural analysis of case study buildings will give smaller values of storey displacements & storey shears, larger values of support reactions, column reinforcement & torsional forces transferred to beams, a mixed behavior for modal time period etc.

Keywords Diaphragm, Seismic response, Lateral forces

Introduction

The effect of the slab panels is not considered in reinforced concrete structural analysis because designers neglect their contribution in lateral load resistance. Their contribution is neglected in the structural analysis because they show large complexity in structural behavior. Mostly, the construction carried out in Pakistan is reinforced concrete with slabs providing the useable floor area. During an earthquake, these slabs will increase the lateral earthquake load resistance significantly. As they form a large part of structural system, therefore designers should get benefit from their large in plane stiffness. So in this study the response of two essentially same structures, with and without consideration of stiffness of slabs were evaluated and compared on the basis of different structural parameters listed in research objectives.

Research findings of this case study are model with slab gives higher values of modal time period for first three modes as compared to model without slabs (Table 1 & Figure 7). This means that for first three modes model without slabs will give the critical results whereas for higher modes model with slab will give the critical results. Lower values of displacements are observed in model with slab because of higher stiffness of slab panels (Table 3 & Figure 9). Higher values of storey shear are observed in model without slabs (Table 2 & Figure 8). Support reactions are more in the case of model with slab (Figure 10 & 11). True torsional forces are transferred to beams in case of model with slabs. Smaller storey displacements give rise to smaller end forces in beams which generates an economical design for the case of model with slabs. Higher percentage of reinforcement is observed in columns for the case of model with slab (Figure 12).

Diaphragm effects in rectangular reinforced concrete building is also dicussed by Joel M.Barron & Mary Beth D.Hueste [1].

[1]Department of Civil Engineering, University of Engineering and Technology Taxila, Pakistan
Tel: +923215216223Fax: +92519047650 Email: dr_sahmad@yahoo.com
[2]Nespak, Islamabad
[3]Department of Civil Engineering, University of Engineering and Technology Taxila, Pakistan

His objective of study was to evaluate how flexible diaphragm behaves in reinforced concrete design of building. As case study three story and five story buildings are evaluated using guidelines for seismic rehabilitation of buildings FEMA 273-nehrp. Models are then studied by assuming rigid diaphragm behavior and then by flexible diaphragm. He found that for low rise reinforced concrete building flexible design should be considered having an aspect ratio of 3:1 or larger.
Colin A. Rogers & Robert Tremblay studied the “impact of diaphragm behavior on the seismic design of low rise steel buildings [2].

This paper provides a description that how steel roof diaphragm behaves in low rise steel buildings. Diaphragm transfer lateral forces to vertical members. A vertical member yields in case of braced steel frames. Vertical bars behave as energy dissipating fuse element. To avoid failure of diaphragm special means must be taken to ensure that deformation capacity will be properly distributed over the diaphragm area.

Research Objectives
In this comparative evaluation study, the seismic performance of two multistory reinforced concrete building, one with modeled slabs to account for its stiffness and other without it, shall be investigated by Elastic Response Spectrum Analysis using UBC-97.The objectives of the study are summarized in following:

1. To study effect of slabs as diaphragm on the performance of high rise ductile moment resisting frames under seismic loads and to get a quantitative idea o this effect based on different structural parameters like, but not limited to:

    a) Time Period

    b) Base Shear

    c) Story Drifts

    d) Relative Story Displacements

    e) Support Reactions

    f) Member End Forces (Shears, Moments, Torsion etc)

2. By comparing it with another same structure but without modeling the slabs.
3. To understand the need to account the stiffness of slabs.
4. To understand how much it is important to consider the diaphragm action against lateral seismic forces in order to ensure its serviceable performance level without extensive cracking so that its stiffness contribution should remains there.

Case Study Buildings
Influence of diaphragm action upon the seismic response of high rise moment resisting building frames is determined by taking a regular building model having 6 bays in each principle direction, each bay of 15ft length. In this way the plan dimensions become 90ft x 90ft.Total stories are 10, each having a height of 11ft except the plinth level which is 10ft in height .In this way the total height of the structure becomes 109ft.

Two models are used in the research study. One modeled with slabs & the other one without slabs. Load is applied in the form of member load upon beams in the case of model without slabs. The brief description of these models and graphical views are given below.

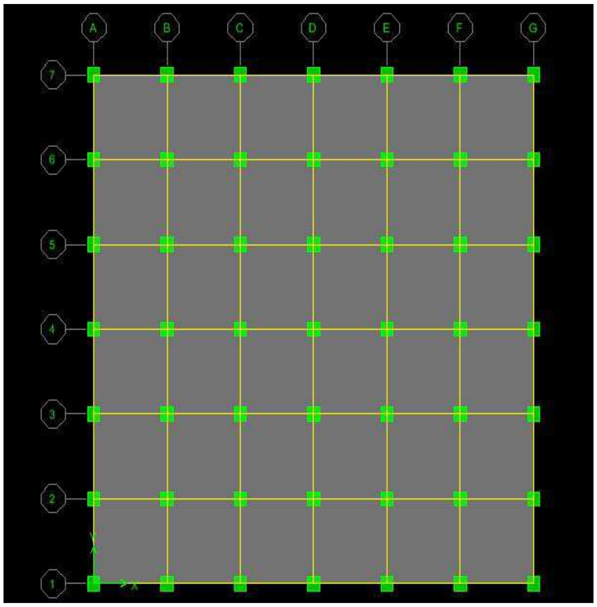


Figure 1. Plan of with slab

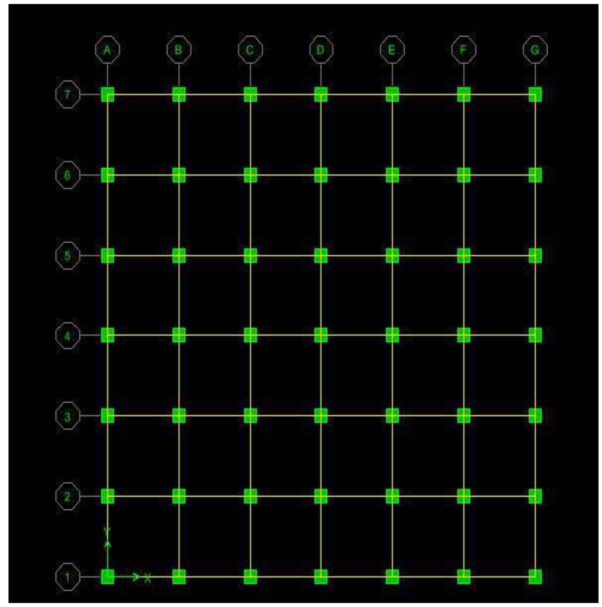


Figure 2. Plan of without slab

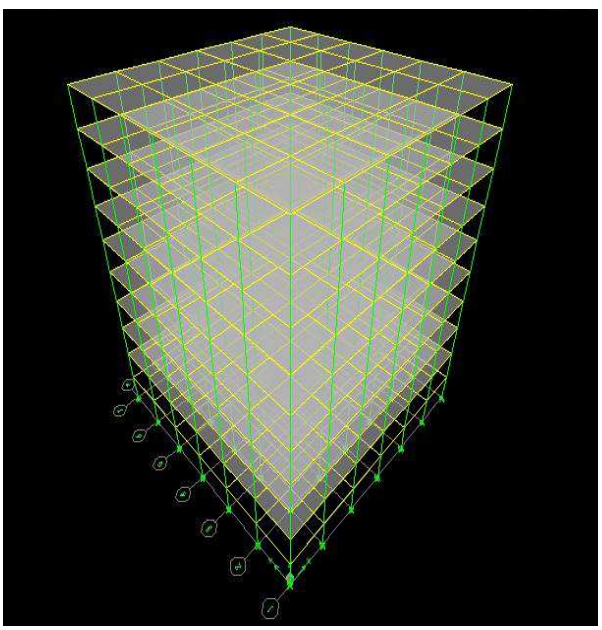


Figure 3. 3D view with slab

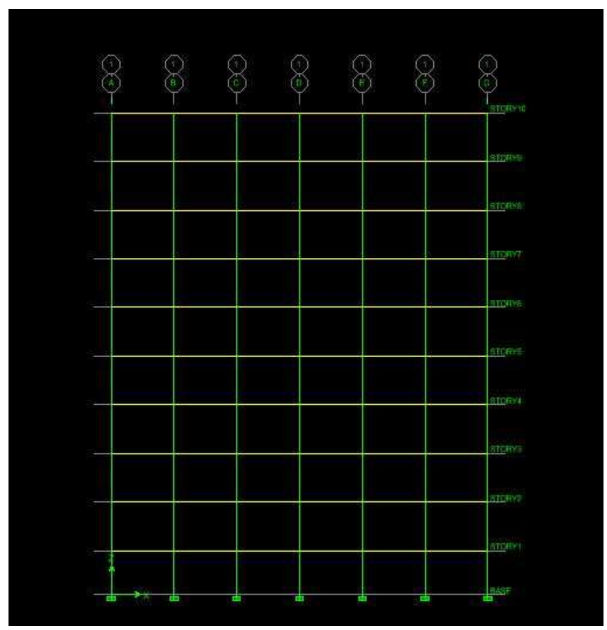


Figure 4. Elevation view without slab

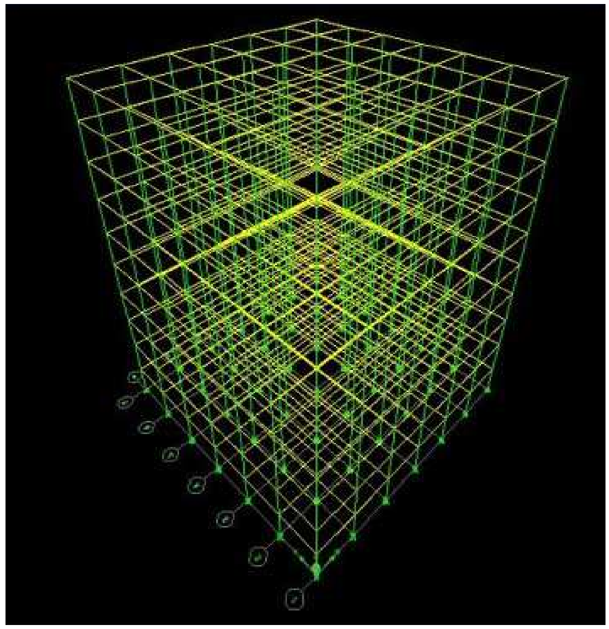


Figure 5. 3D view without slab

Method of Analysis

As prescribed earlier, dynamic analysis is performed response spectrum analysis method by using standard UBC response spectra whose peak values corresponds to Ca & Cv values zone 2B as per UBC. Eigen vector analysis type is used to generate different possible no of modes.

In modal analysis, SRSS (square root of sum of squares) technique is used for modal combinations in which 8 no of modes are considered since mass participation appears to be 99% for 8th mode in both principle directions. SRSS technique is also used for directional combinations.

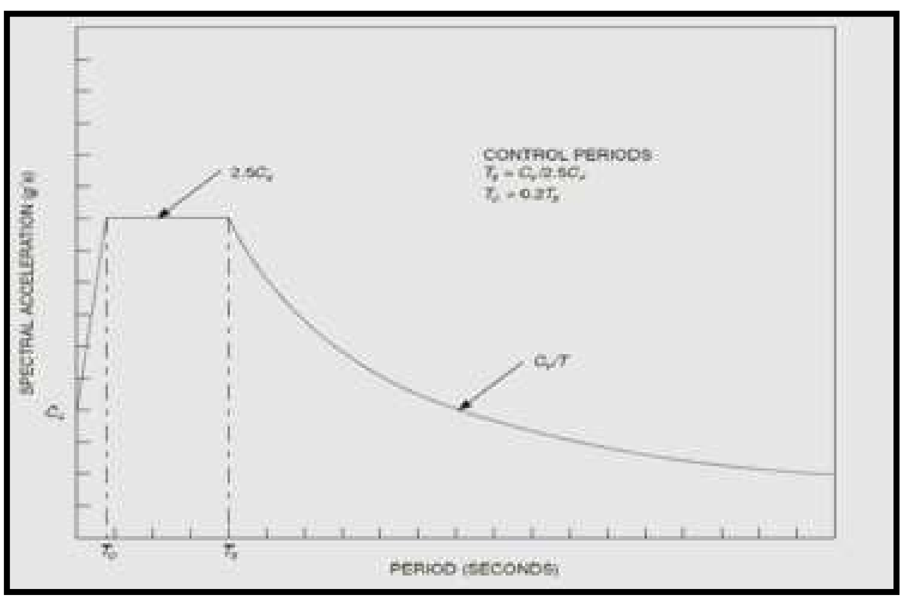


Figure 6. UBC response spectra

Results and Discussion

After performing the dynamic analysis of the two example models, their behavior will be analyzed & compared in terms of the following parameters.

1) Modal time period.
2) Storey shears.
3) Storey displacements.
4) Support reactions.
5) Reinforcement %age of columns

The comparison of results in terms of the above parameters will be given in terms of tables & graphs in the coming paragraph.

Modal Time Period

The time required to complete one complete cycle of vibration is called time period. Under free vibration the structure always vibrates in single mode called its fundamental mode and the corresponding time period is called fundamental period of the structure. The fundamental period is the longest period of the structure. The no of modes depends upon the no of degrees of freedom.

Table 1. Modal time periods of modeled slab and without slab

MODAL TIME PERIODS		
Mode	**Period(with slabs)**	**Period(without slabs)**
1	**1.43**	**1.34**
2	**1.43**	**1.34**
3	**1.33**	**1.26**
4	**0.50**	**0.88**
5	**0.50**	**0.68**
6	**0.47**	**0.68**
7	**0.30**	**0.49**
8	**0.30**	**0.47**

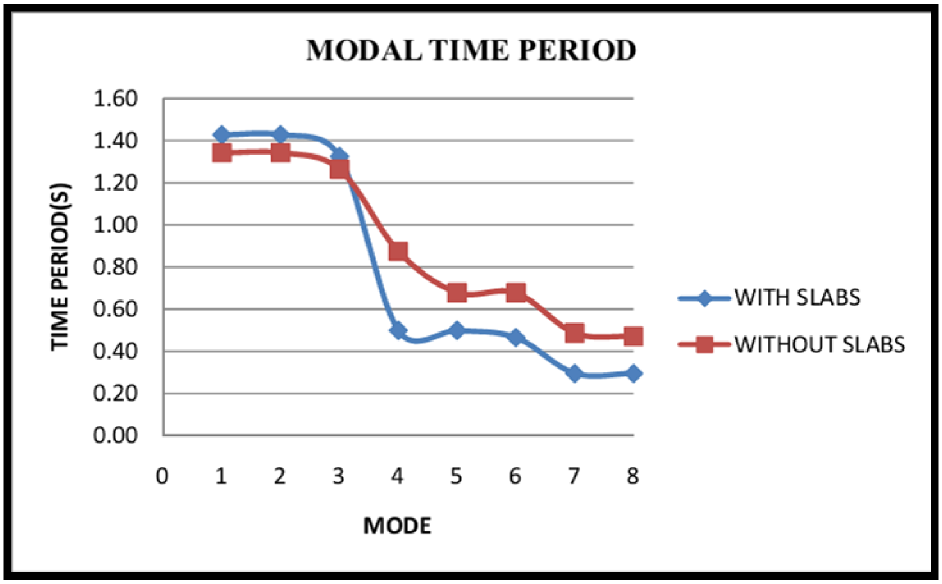


Figure 7. Comparison of time period against mode

Storey Shear

Values of acceleration due to gravity 'g' are being calculated for each mode from the Response Spectra defined at relative time modal time period values. This value of 'g' is then used to calculate seismic base shear for each mode. This calculated base shear is then distributed to each Storey relative to its mass and stiffness. This distributed base shear at each level is known as Storey shears.

Table 2. Storey shear of modeled slab and without slab

Storey	VX(with slabs)	VX(without slabs)
Storey1	7436	8298
Storey2	7361	8084
Storey3	6993	7700
Storey4	6453	7200
Storey5	5865	6600
Storey6	5234	5900
Storey7	4512	5171
Storey8	3673	4452
Storey9	2711	3283
Storey10	1377	1591

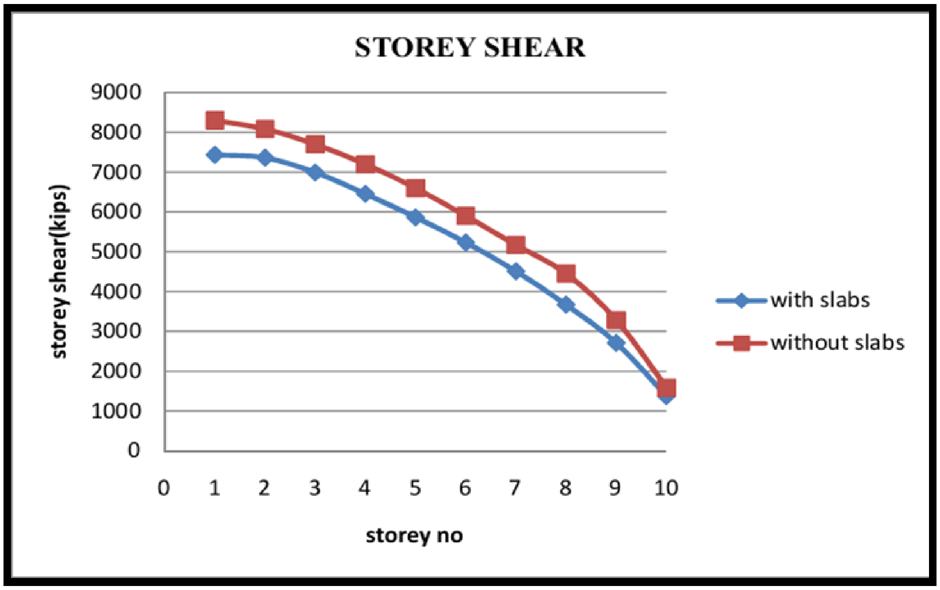


Figure 8. Comparison of storey shears against storey no.

Storey Displacements

Storey displacements depend upon the value of Storey shear at that Storey. Greater the value of Storey shear greater the value of Storey displacement & vice versa. Storey displacement comparisons will give an idea how the structure acts in two situations.

Table 3. Storey displacement of modeled slab and without slab

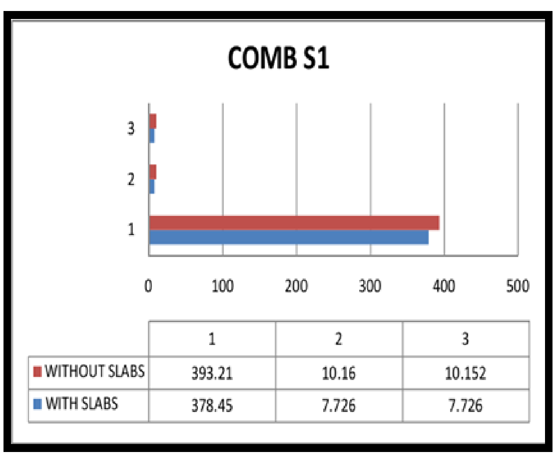
Storey	Ux(With Slabs)	Ux(With Out Slabs)
Base	0	0
Storey1	0.4063	0.4334
Storey2	1.3102	1.4096
Storey3	2.3045	2.4953
Storey4	3.2771	3.5269
Storey5	4.3173	4.5207
Storey6	5.2293	5.2813
Storey7	5.9976	5.8124
Storey8	6.6149	6.3807
Storey9	7.2581	7.233
Storey10	7.6039	7.6787

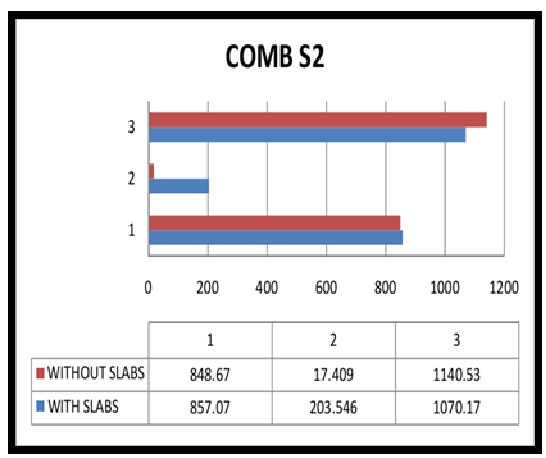
Figure 9. Comparison of storey displacement against storey

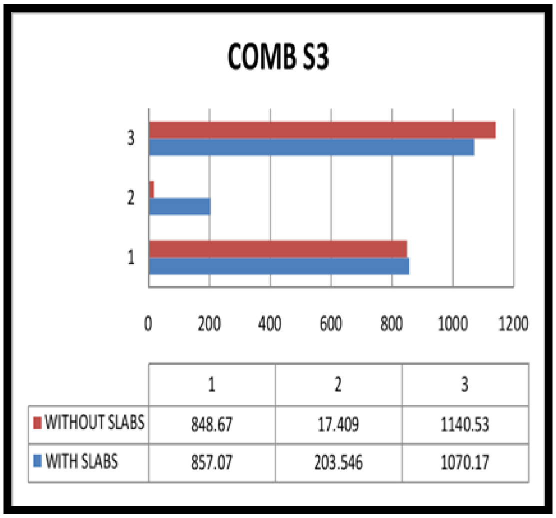
Support Reaction

The reactions at the base level of the building with fix supports are assigned to the structure, for each load combinations for which foundation has to be designed are called support reactions. Following graphs will represent the comparisons of the two structures for support reactions.

1=Axial force (kip), 2=Moment in x dir (kip.ft), 3=Moment in y dir (kip.ft)







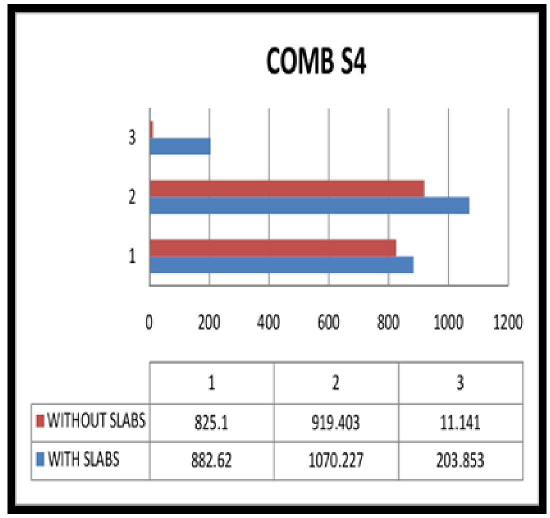
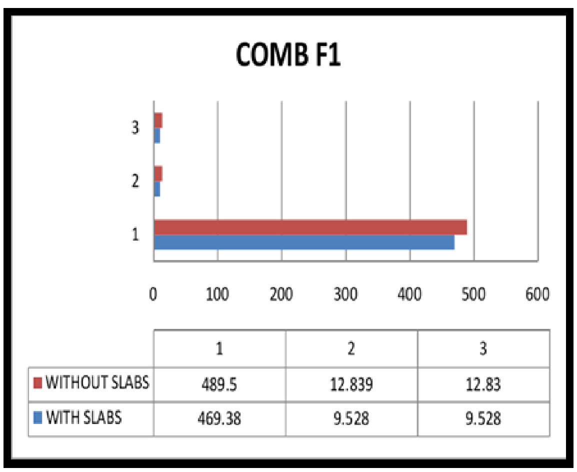
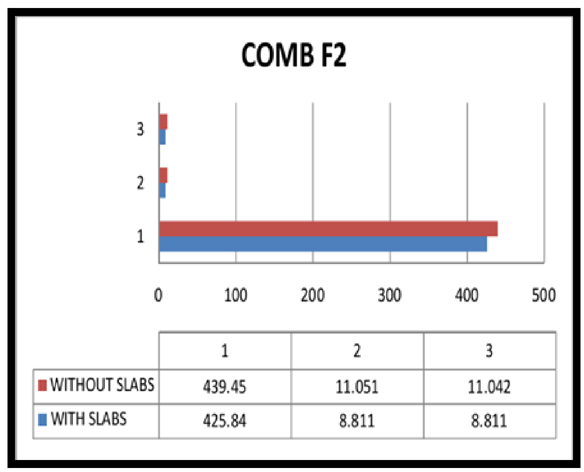
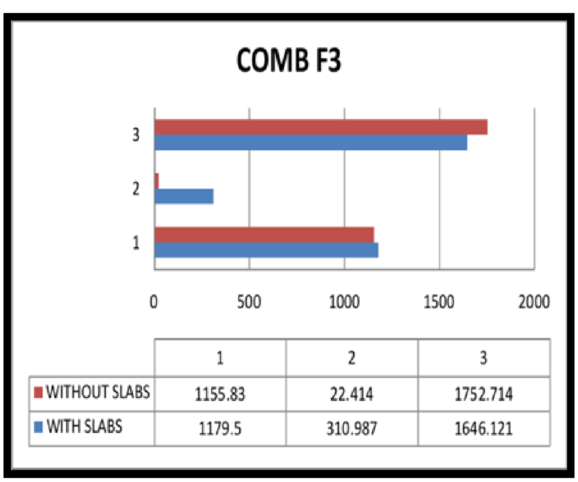
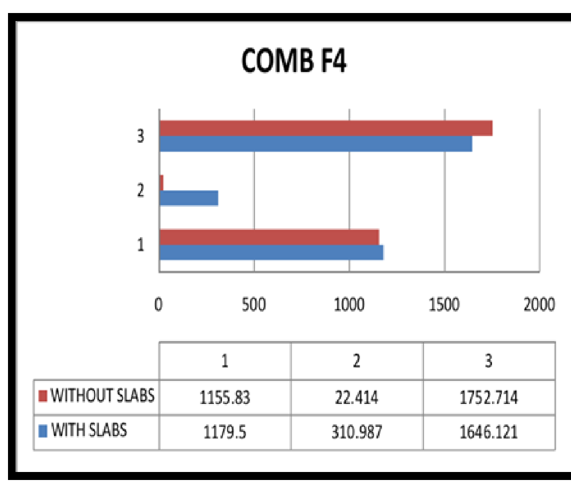


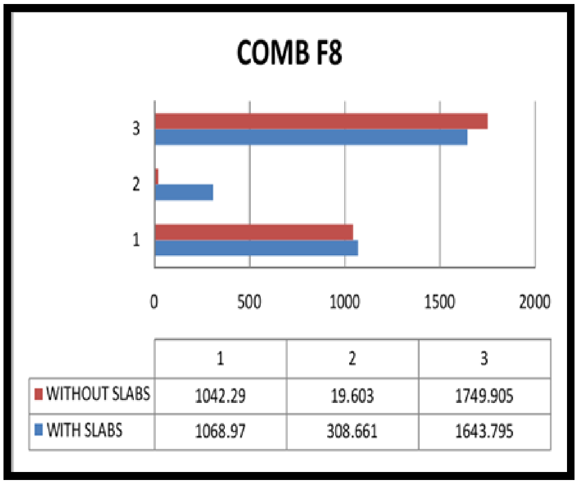
Fig. 10: Support reaction (service load cases) of modeled slab and without slab











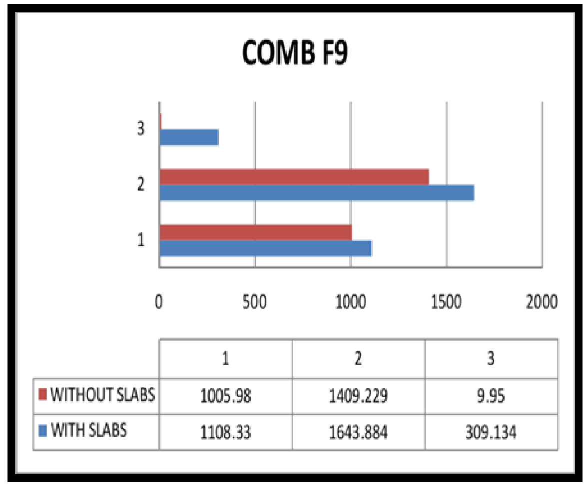


Figure 11. Support reaction (factored load cases) of modeled slab and without slab

Column Reinforcement

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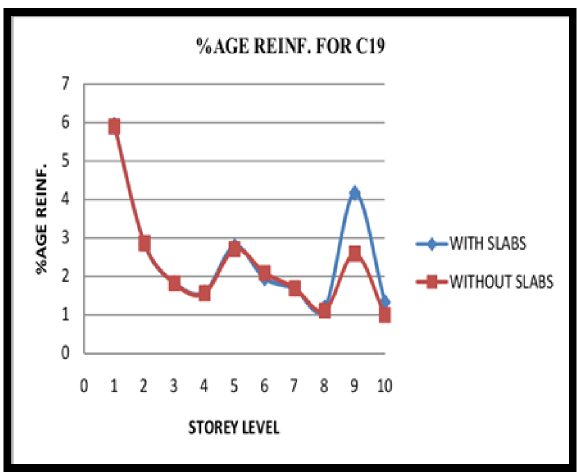

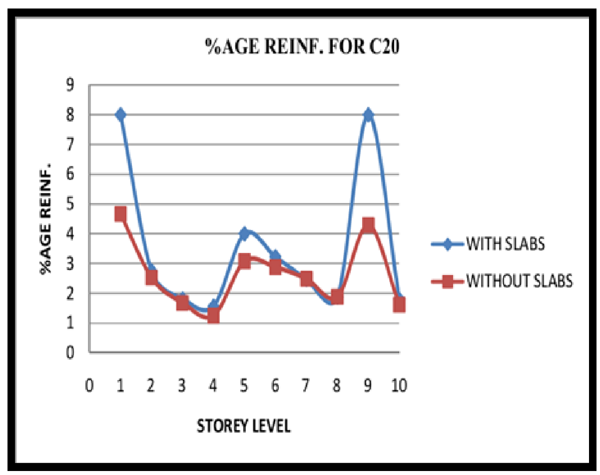

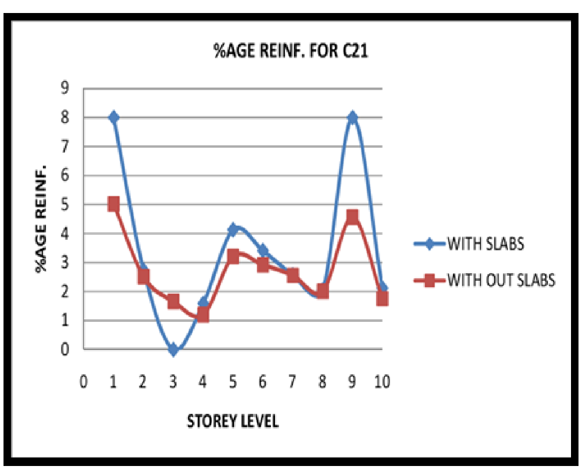

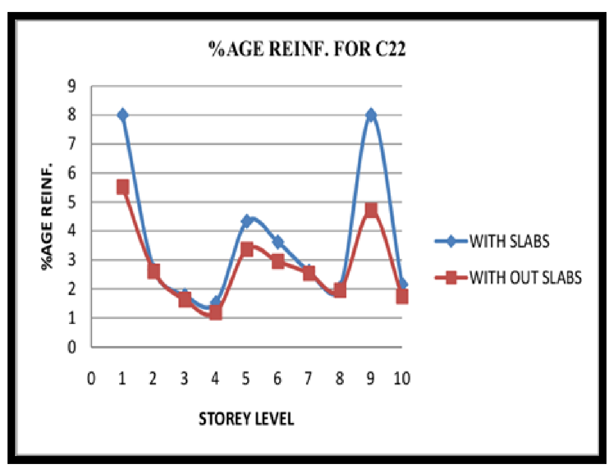

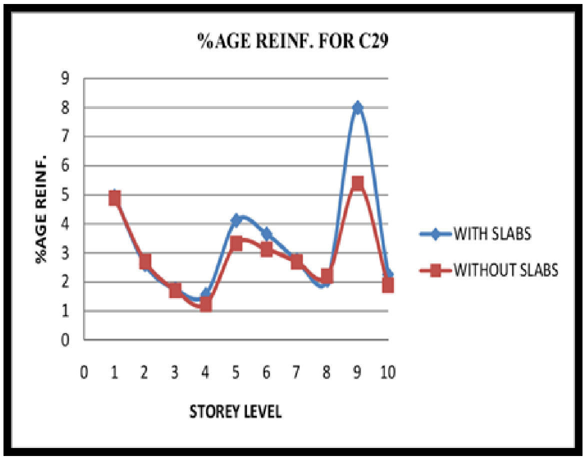

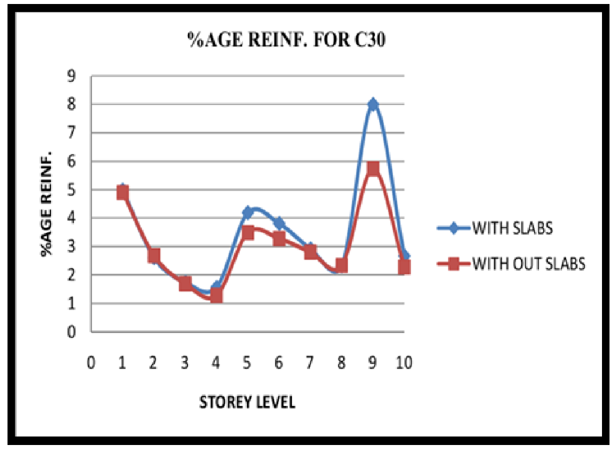

Figure 12. Column reinforcement of modeled slab and without slab

Conclusions

1) For the first three modes structure with slabs has higher periods as compared to without slabs. Whereas the condition is exactly opposite for the rest of the modes. By looking at response spectrum curve, it can be observed that lower the value of time period higher the value of g, which results in higher value of story shears. Hence, the structure should be analyzed for both cases in order to get the critical results.

2) Difference of time periods for the two cases is small for the first three modes, whereas the difference is large for the mode 4 & onward. This means that for higher modes the structural behavior becomes critical for models with slabs.

3) Story shear of the structure modeled without slabs are quite larger than that modeled with slabs. Thus, the model without slab will give the critical results.

4) Although the displacements for the structure with slabs are lower as compared to structure without slabs, but the difference can be ignored if some designer wants to. The lower value of displacements in the case of model with slabs indicates the effect of higher stiffness of slabs in structure. If designer consider their effect during the analysis & design phase of project, this will lead to economical design of structure.

5) For the case of model with slab the support reactions are more as compared to model without slabs. Therefore, for safe design of foundations slabs should be considered in the analysis & design of structure.

6) For all types of member forces, member end forces are generally of smaller value (although the %age decrease is of varying magnitude) in the structure in which stiffness of slabs are considered as compared to the other structure without slabs. The reason of smaller end forces are quite clear from the fact that since story displacements are smaller in the structure of modeled with slabs which in turns yields smaller value of end forces. Hence it can be concluded that the stiffness of slabs yield economical design.

7) However at floor level, the results of the torsional forces appears to be reversed which is certainly due to the effect of true torsional forces transferred to beams by the slabs. Hence it is necessary for the structural engineer to must consider its stiffness and must have a close look on the high torsion forces of

beams since this important aspect can be overlooked in case of analysis without slabs and yields unsafe design at floor levels.

8) Columns are critical for the case of structure modeled with slabs. As column is the critical & most important component of the structure, therefore it is of utmost importance to consider the effect of slabs in the structural analysis & design.

9) The critical reinforcement varies in the story levels due to dynamic model analysis while in static analysis the reinforcement decreases uniformly in the upper stories; hence it is necessary for the structural engineers to perform dynamic analysis to get the critical results.

References

[1] Joel M. Barron & Mary Beth D. Hueste, A technical paper titled “Diaphragm effects in rectangular reinforced concrete buildings”.

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[3] Uniform Building Code-1997.

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