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Seismic Analysis and Design of RCC Multi Storey Building Considering with and without Slab Diaphrahm Effect

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ABSTRACT

This experimental study encompasses the seismic analysis and design of multi storey RC building frames by considering different types of slab diaphragm. Two different type of slab diaphragm are considered namely without slab diaphragm i.e Flexible slab diaphragm and With slab diaphragm i.e Rigid slab diaphragm. These slab diaphragm systems are very efficient in resisting lateral forces. STAAD.Pro software has been used for analysis and design purpose. Results are collected in terms of maximum moments in Columns/beams, axial force, shear force, maximum displacement and storey displacement which are critically analyzed to quantify the effects of various parameters. This approach focuses on choosing the suitable slab diaphragm for a particular structure and their effectiveness in reducing the lateral displacement and moment thereby achieving economy in construction with similar structure..

Keywords: Seismic, Floor diaphragm, Maximum moment, Shear Force, Storey displacement, Peak storey displacement

1. Introduction

The vast devastation of engineered systems and facilities during the past few earthquakes has exposed serious deficiencies in the prevalent design and construction practices. These disasters have created a new awareness about the disaster preparedness and mitigation. Earthquake and its occurrence and its measurements, its vibration effect and structural responses have been continuously studied for many years in earthquake history and thoroughly documented in literature. Since then structural engineers have tried hard to examine the procedure, with an aim to counter the complex dynamic effect of seismically induced forces in structures, for designing earthquake resistant structures in a refined and easy manner. This reexamination and continuous effort has resulted in several revisions of Indian Standard 1893 code from 1962,1966,1970,1975,1984,2002 now recently 2016.While the recommended codes of practice for earthquake resistant design do exist but those only specifies the set of criteria for compliance. It is recognized that the complete protection against earthquakes of all sizes is not economically feasible and design based alone on strength criteria is not justified. Though the IS 1893-2016 itself mentioned about the rigid and flexible diaphragm its suitability over the structures is yet to be mentioned. nowadays it has been the designers discretion for considering the diaphragm effects on structures. Hence it is imperative to study the results obtained by considering the two different slab diaphragms effects on structures for getting the optimum design.

We commonly conceive of the seismic force-resisting system as being composed of vertical elements, horizontal elements, and the foundation. The vertical elements extend between the foundation and the elevated levels, providing a continuous load path to transmit gravity and seismic forces from the upper levels to the foundation. The horizontal elements typically consist of diaphragms,

Diaphragms transmit inertial forces from the floor system to the vertical elements of the seismic force-resisting system. They also tie the vertical elements together and thereby stabilize and transmit forces among these elements as may be required during earthquake shaking. Diaphragms are required to be designed as part of the seismic force-resisting system of every new building assigned to Seismic Design Category.

The role of Diaphragms are to a) resist gravity loads. b) to provide lateral support to vertical elements. c) to resist out-of-plane forces Resist thrust from inclined columns. d) to transfer lateral inertial forces to vertical elements of the seismic force-resisting system. e) to transfer forces through the diaphragm. f)to support soil loads below grade.

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Internal forces in a diaphragm are computed using approaches that range from simple idealizations to complex computer analysis. The analysis need only be as complex as necessary to represent how lateral forces flow through the building including the diaphragms. For regular buildings in which lateral resistance is provided by similar vertical elements distributed throughout the floor plan, simple models are often adequate for determining the diaphragm forces. For buildings with irregularities or with dissimilar vertical elements, significant force transfers may occur among the vertical elements at various levels, requiring more complex models to determine the diaphragm design forces. Hence STAAD.Pro software has been used for analysis purpose.

Mainly there are two types of slab diaphragms as listed below:

Rigid Diaphragms: A diaphragm may be considered rigid when its midpoint displacement, under lateral load, is less than twice the average displacements at its ends. Rigid diaphragm distributes the horizontal forces to the vertical resisting elements in direct proportion to the relative rigidities. It is based on the assumption that the diaphragm does not deform itself and will cause each vertical element to deflect the same amount. Rigid diaphragms capable of transferring tensional and shear deflections and forces are also based on the assumption that the diaphragm and shear walls undergo rigid body rotation and this produces additional shear forces in the shear wall. Rigid diaphragms consist of reinforced concrete diaphragms, precast concrete diaphragms, and composite steel deck.

Flexible Diaphragm: A diaphragm is considered flexible, when the midpoint displacement, under lateral load, exceeds twice the average displacement of the end supports. It is assumed here that the relative stiffness of these non-yielding end supports is very great compared to that of the diaphragm. Therefore, diaphragms are often designed as simple beams between end supports, and distribution of the lateral forces to the vertical resisting elements on a tributary width, rather than relative stiffness. Flexible diaphragm is not considered to be capable of distributing torsional and rotational forces.

The aim of this project is to make the comparative study of the design parameters of R.C.C buildings such as Column/Beam moments and its corresponding steel required, axial force, shear force and storey displacements etc by modeling with rigid slab diaphragm and flexible diaphragm effect. Thereby finding the suitable slab diaphragm to have a optimum R.C.C. seismic resistant structure.

2. Scope of the Study

The floors and roof of a building, in addition to resisting gravity loads, are also generally designed to act as diaphragms. In this respect, they are required both to distribute seismic forces to the main elements of horizontal resistance, such as frames and shear walls, and also to tie the structure together so that it acts as a single entity during an earthquake. The robustness and redundancy of a structure is highly dependent on the performance of the diaphragms.

In a ductile structure, diaphragms will almost always be required to remain elastic, so that they can sustain their function of transferring forces to the main lateral-resisting structure, and tying the building together. Diaphragms should in principle therefore have the strength to sustain the maximum forces that may be induced in them by the chosen yielding mechanism within the rest of the structure

Usually, the seismic analysis of buildings is carried out on the assumption that deflections in the diaphragms are so small compared with those in the main lateral load- resisting structure that the diaphragms can be treated as rigid. In most cases, this is quite satisfactory, because usually diaphragm flexibility affects neither overall structural stiffness (and hence natural period) nor the distribution of forces within a structure. Moreover, during a major earthquake, in ductile structures where the diaphragms are designed to remain essentially elastic, the superstructure deflections are likely to include large plastic deformations, increasing the disparity still further.

Therefore it is essential to study the behavior of the rigid diaphragm also for having effectiveness. Hence this study is being carried out to identify the suitable diaphragm for enhancing the economical design, by comparing the design parameter adopting the rigid as well as flexible diaphragm effects on same structure.

3. Literature Review

Some of the literature reviews connected with this project are:

Muto (1974) used a beam with bending and shear deformation effects to simulate the behavior of flexible floors in buildings.

Jain (1984) also used this beam including flexible and shear deformation effects to generate a solution to find the flexible-floor effect under the dynamic analysis.

Sashi K. Kunnath (1991) emphasized the in-plane flexibility of floor-slab systems has been observed to influence the seismic response of many types of reinforced concrete buildings. The assumption of rigid floor diaphragms is often used to simplify engineering analyses without significant loss in the accuracy of seismic response prediction for most buildings. However, for certain classes of structures, such as long and narrow buildings (especially with dual-braced lateral load- resisting systems), and buildings with horizontal (T or L-shaped) or vertical (setbacks or cross-walls) offsets, the effect of diaphragm flexibility cannot be disregarded. This paper presents an simplified macro-modeling scheme to incorporate the effect of inelastic floor flexibility in the seismic response analysis of RC buildings. The slab model includes effects of both in-plane flexure and shear. The inelastic behaviour of diaphragms is emphasized through a study of narrow rectangular buildings with end walls. The study shows that the in-plane deflections of floor slabs impose a larger demand on strength and ductility of flexible frames than predicted values using the assumption of rigid or elastic slabs. These demands may in turn lead to a failure of the gravity load supporting system. A quantitative estimate of this effect is presented in terms of the floor aspect ratios.

M.M. El- Hawary (1994) investigates the importance of including the effects of the flexibility of the horizontal diaphragms when using the P-delta method of analysis, especially when considering the loads applied to intermediate frames on trusses that are not part of the lateral force resisting system. Analyses were conducted for structural systems with a variable number of stories, number of bays and diaphragm stiffnesses and supported by rigid jointed plane frames or vertical trusses.

A. Dhiman Basu and Sudhir K. Jain

In this paper studied even though a rigid floor diaphragm is a good assumption for seismic analysis of most buildings, several building configurations may exhibit significant flexibility in floor diaphragm. However, the issue of static seismic analysis of such buildings for torsional provisions of codes has not been addressed in the literature. Besides, the concept of center of rigidity needs to be formulated for buildings with flexible floor diaphragms. In this paper, the definition of center of rigidity for rigid floor diaphragm buildings has been extended to unsymmetrical buildings with flexible floors. A superposition-based analysis procedure is proposed to implement code-specified torsional provisions for buildings with flexible floor diaphragms. The procedure suggested considers amplification of static eccentricity as well as accidental eccentricity. The proposed approach is applicable to orthogonal as well as no orthogonal unsymmetrical buildings and accounts for all possible definitions of center of rigidity.

Gardiner R. , D.K. Bull and A. J. Carr

In this paper studied simplistic design methods are commonly employed by design engineers to determine the approximate magnitude and distribution of inertial forces in reinforced concrete floor diaphragms of multi-storey buildings. Various researchers have identified that the commonly employed simplistic design method, the Equivalent Static Analysis method, in some cases, provides a poor representation of the true structural response. This research investigates the magnitude and trends of forces in concrete floor diaphragms, with an emphasis on transfer forces, under seismic loading. This research considers the following items: inertial forces which develop from the acceleration of the floor mass; transfer forces which develop from the interaction of lateral force resisting elements with different deformation patterns, such as wall and frame elements; and variation of transfer forces due to different strengths and stiffness of the structural elements. The magnitude and trends of forces in the floor diaphragms have been determined using 2-dimensional inelastic time history analysis. Trends have been identified which will aid the improvement of seismic floor diaphragm design methods.

D. K. Bull (2003) investigates the variety of layouts of lateral force resisting elements in structures, subjected to inelastic behaviour, make the design of diaphragms [4] significantly more complex than the traditional “simple beam" approach typically employed. Traditionally held views that diaphragms are inherently robustness and hence do not requires significant engineering input have been shown to be inappropriate by recent major earthquakes and recent laboratory studies. The simple beam method, at times, fails to recognize that the traditional load paths assumed are compromised by localized damage in the floor (diaphragms) due to incompatibility of deformation between the floors and the supporting structures (walls, beam and columns). "Strut and tie" methods are suggested as a means of tying these diaphragms into the lateral force resisting structures and as a way of dealing irregular floor plates and penetrations (stairs, lifts, atriums) through the floors. The focus of research in determining the seismic lateral forces into and through floor diaphragms has been on the magnitude of the floor inertias. However, it has been shown that primary structural elements interacting through the diaphragm, can cause stresses in the floors many more times than those of the inertia effects. These two sources of forces and stresses are interrelated.

Joel M. Barron and Mary Beth D. Hueste (2004) analyzed under seismic loading, floor and roof systems in reinforced concrete (RC) buildings act as diaphragms to transfer lateral earthquake loads to the vertical lateral force-resisting system (LFRS). In current practice, horizontal diaphragms are typically assumed to be rigid, thus neglecting the effect of their in-plane movement relative to the vertical LFRS. The objective of this study is to evaluate the impact on in- plane diaphragm deformation on the structural response of typical RC rectangular buildings using a performance - based approach. Three-story and five-storey RC buildings with end shear walls and two aspect rations (approximately2:1 and 3:1) were developed and designed according to current code procedures assuming rigid diaphragm behaviour. The performance-based design criteria outlined in the FEMA 273-NEHRP Guidelines for Seismic Rehabilitation of Buildings were used to assess the adequacy of the four case study buildings when diaphragm flexibility was including the structural response.

Ho Jung et al. (2007) discussed a simple method to more accurately estimate peak interstorey drifts that accounts for higher mode effects described for low-rise perimeter shear wall structures having flexible diaphragms or even for stiff diaphragms.

D. R. Gardineret al. (2008) research investigates the magnitude and trends of forces in concrete floor diaphragms, with an emphasis on transfer forces, under seismic loading. This research considers the following items: inertial forces which develop from the acceleration of the floor mass; transfer forces which develop from the interaction of lateral force resisting elements with different deformation patterns, such as wall and frame elements; and variation of transfer forces due to different strengths and stiffness of the structural elements. The magnitude and trends of forces in the floor diaphragms have been determined using 2-dimensional inelastic time history analysis.

Morteza Moeini, Behzad Rafezy:

All the seismic codes generally accept that in most cases the floor diaphragms may be modeled as fully rigid without in-plane deformability. Even though a rigid floor diaphragm is a good assumption for seismic analysis of the most buildings, several building configurations may exhibit significant flexibility in floor diaphragms. In these configurations, some codes like (EC8, NZS4203, GSC-2000) set certain qualitative criteria related to the shape of the diaphragm, while some others (ISC-2800, UBC-97, SEAOC-90, FEMA-273) set quantitative criteria relating the in-plane deformation of the diaphragm with the average drift of the associated story.

For the majority of buildings, floor diaphragms offer the most economical and rational method of resisting the lateral forces, since they are ordinarily included in the buildings to support the vertical workloads. It is thus, of the utmost importance, that they must be provided with sufficient in-plane stiffness and strength, together with efficient connections to the vertical structural elements.

4. Methodology

In this study there are two buildings having different utility aspect namely a Hospital and a Residential Building have been chosen for better understanding the behavior of slab diaphragm effects. The chosen building details are listed below.

- Type of Building : i)Residential apartment with G+10. ii) Proposed Hospital with G+6
- Location : Chennai (zone 3).
- Zone factor : 0.16
- Basic wind Speed : 50 m/s.
- Ground condition : Resting on Hard strata.(Pile Foundation)
- Importance factor : 1.2 for Residential ; 1.5 for Hospital as per IS1893-2016
- Type of Structure: RCC moment resisting Framed building.
- Response reduction factor : 5
- Damping Ratio : 5
- Typical storey height : i) 3.00 m for Residential building, ii)3.60 m for Hospital building

4.1 Plan of the Building

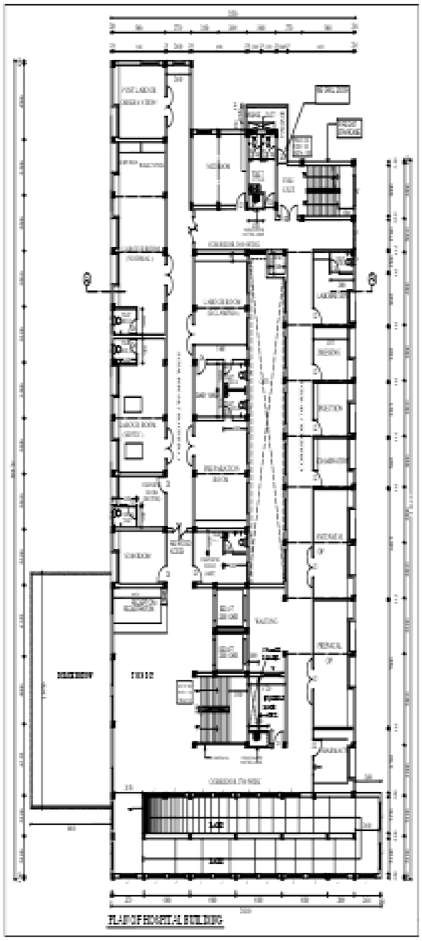

Figure 1. Plan of Hospital Building

Figure 2. Plan of Residential Building

material Properties: The materials and grade of Concrete and Steel adopted for this study has been discussed below

- Concrete : Grade M25 Design Mix
- Density : 25KN/m3,
- Young's Modulus (E) : 5000 x *fck* $^{1/2}$
- Steel : Fe415
- Bricks : unit weight of 20 KN/M^2

4.2 Loads and Load Cases For Analysis

The Loads acting on the structure and the various Load cases considered for analysis of the structure have been listed below

Loads on Building:

(a) Dead Loads: as per IS: 875 (part-1) 1987
Self wt. of slab considered based on the thickness of slab
Floor Finish load = 1 kN/m2
Water Proofing Load on Roof = 2.5 kN/m2
(b) Live Loads: as per IS: 875 (part-2) 1987
Live Load on toilet floors = 2 kN/m2
Live Load on Roof = 1.5 kN/m2
Stair case & Corridor = 4 kN/m2
(c) Wind Loads: as per IS: 875 (part-3) 1987
(d) Earth Quake Loads: Earthquake load: Along X & Z Directions as per IS: 1893 -2016

Load Combinations on Building:

The following load combinations considered as listed as per IS: 1893 -2016
LOAD COMB 9 DL+LL
3 1.5 4 1.5
LOAD COMB 10 DL+SLX
3 1.5 1 1.5
LOAD COMB 11 DL-SLX
3 1.5 1 -1.5
LOAD COMB 12 LL+SLX
4 1.5 1 1.5
LOAD COMB 13 LL-SLX
4 1.5 1 -1.5
LOAD COMB 14 DL+SLZ

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3 1.5 2 1.5
LOAD COMB 15 DL-SLZ
3 1.5 2 -1.5
LOAD COMB 16 LL+SLZ
4 1.5 2 1.5
LOAD COMB 17 LL-SLZ
4 1.5 2 -1.5
LOAD COMB 18 DL+LL+SLX
3 1.2 4 1.2 1 1.2
LOAD COMB 19 DL+LL-SLX
3 1.2 4 1.2 1 -1.2
LOAD COMB 20 DL+LL+SLZ
3 1.2 4 1.2 2 1.2
LOAD COMB 21 DL+LL-SLZ
3 1.2 4 1.2 2 -1.2
LOAD COMB 22 DL+LL+WLX
3 1.2 4 1.2 5 1.2
LOAD COMB 23 DL+WLX
3 1.5 5 1.5
LOAD COMB 24 DL+LL-WLX
3 1.2 4 1.2 6 1.2
LOAD COMB 25 DL-WLX
3 1.5 6 1.5
LOAD COMB 26 DL+LL+WLZ
3 1.2 4 1.2 7 1.2
LOAD COMB 27 DL+WLZ
3 1.5 7 1.5
LOAD COMB 28 DL+LL-WLZ
3 1.2 4 1.2 8 1.2
LOAD COMB 29 DL-WLZ
3 1.5 8 1.5
```

Selection of diaphragm:

a. With diaphragm
b. Without diaphragm

Soft-wares Model for Analysis and Design: STAAD.Pro is used in modeling of building frames. STAAD.Pro is Structural Analysis and Design Program is a general purpose program for performing the analysis and design of a wide variety of structures. The basic three activities carried out to achieve this goal are -

a. Model generation
b. Calculations to obtain the analytical results with the following two cases.
    CASE-01: Bare frame without diaphragm (Flexible diaphragm)
    CASE-02: Building frame with rigid diaphragm (Rigid diaphragm)
c. Result verification- These are all facilitated by tools contained in the program's graphical environment.

These results will enable us to make a comparative study of the effect of two diaphragms on the vertical elements in terms of maximum moments in columns and beams, base shear, story displacement, peak story displacement and thereby arriving the conclusion to choose the better diaphragms for analysis and design

5. Analysis & Design

This chapter enumerate the analysis and design part of this project. As discussed in the methodology two structures having different utility in nature have been considered without and with diaphragm effects for analysis and design by using STAADPRO.

5.1 Anaysis & Design Of The Structure

The analysis &design part starts from the model generation, assigning loads etc as discussed briefly below.

- STAAD model generation without with diaphragm
- STAAD model generation with diaphragm
- Assigning loads
- Performing the analysis & Design

5.2 STAAD model Generation

This model generation involves creating the structural members such as beams, columns, virtually in the STAAD as per the required dimension STAAD model has been generated for the Hospital building of G+6 without diaphragm & with diapragm as shown

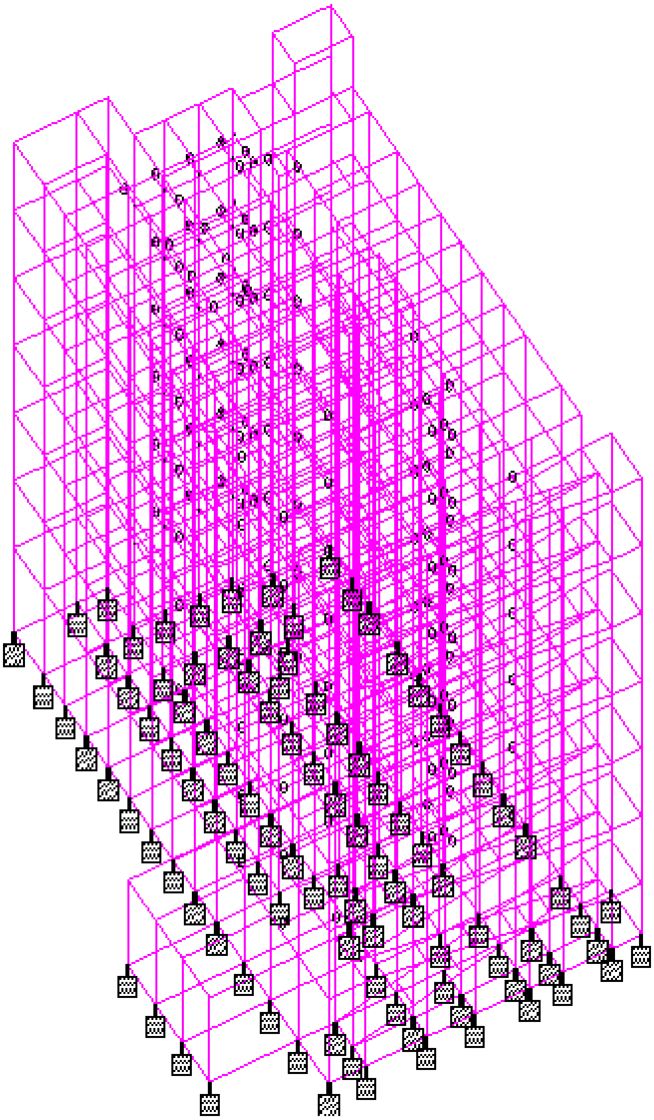

Figure 4.2.1. STAAD Model of Hospital Building(without diaphragm) in isometric view

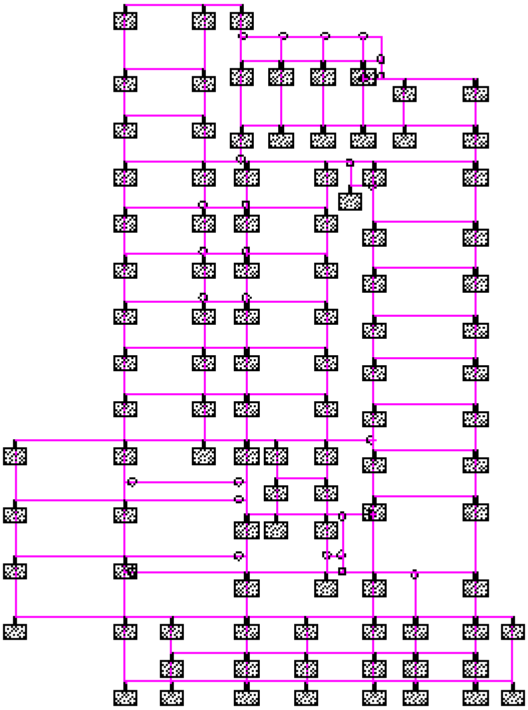

Figure 4.2.2. STAAD Model of Hospital Building (without diaphragm) in Plan view

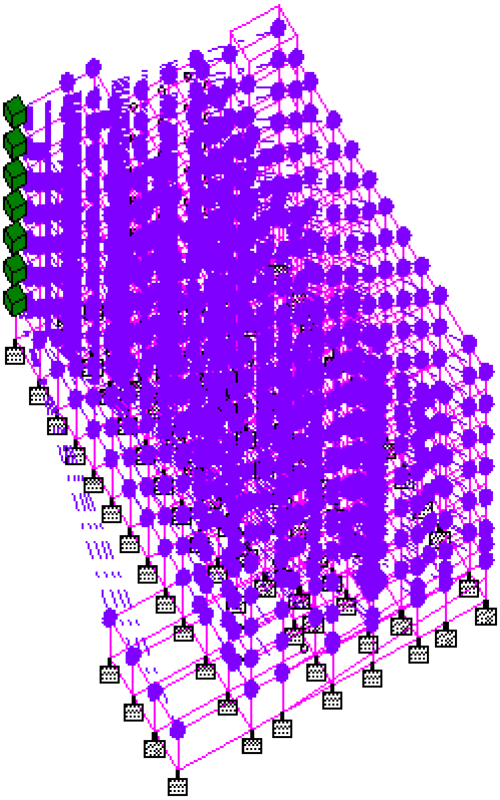

Figure 4.2.3. STAAD Model of Hospital Building(with diaphragm) in isometric view

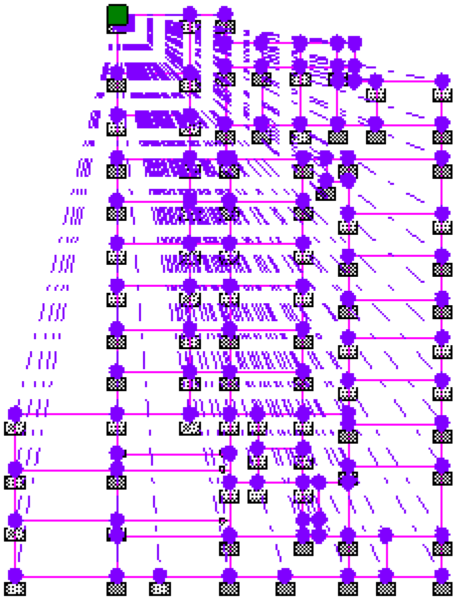

Figure 4.2.4. STAAD Model of Hospital Building(with diaphragm) in plan view

STAAD model has been generated for the Residential building of G+10 without diaphragm & with diapragm as shown below

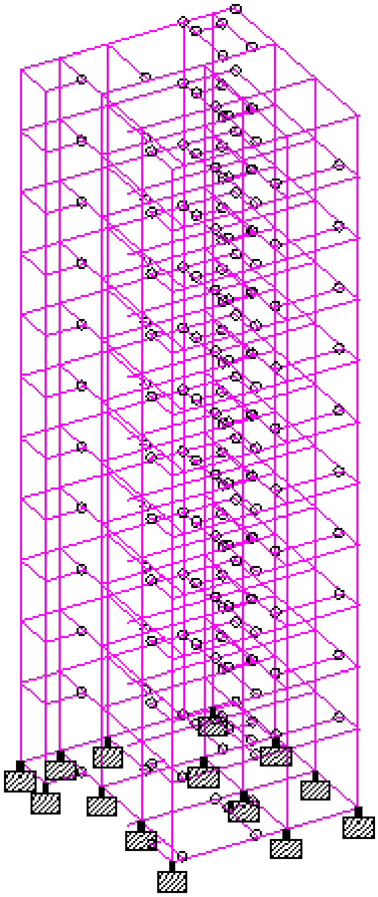

Figure 4.2.5. STAAD Model of Residential Building(without diaphragm) in isometric view

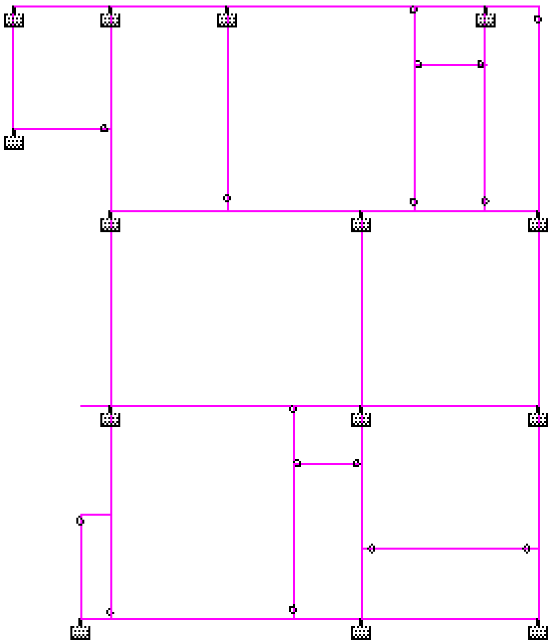

Figure 4.2.6. STAAD Model of Residential Building(without diaphragm) in plan view

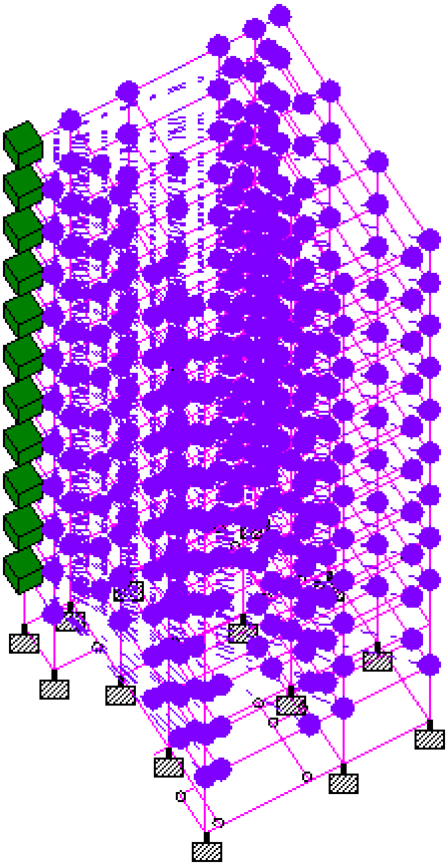

Figure 4.2.7. STAAD Model of Residential Building(with diaphragm) in isometric view

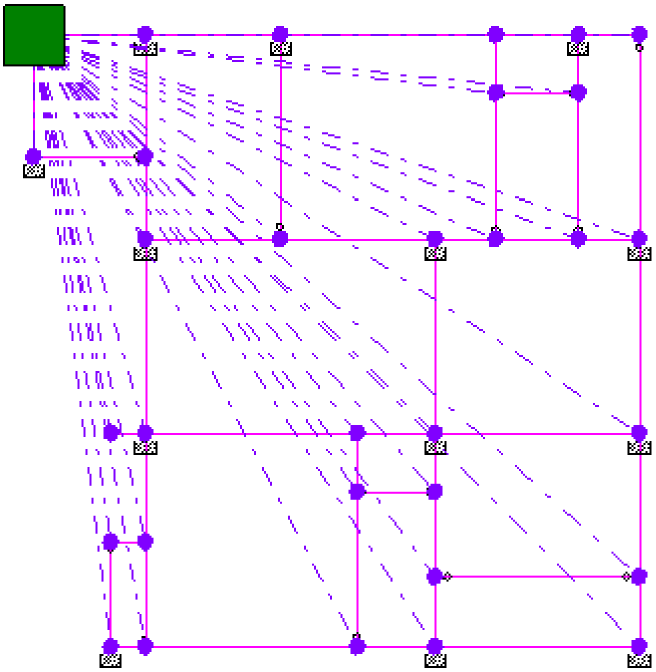

Figure 4.2.8. STAAD Model of Residential Building(with diaphragm) in Plan view

Assigning load

The Dead load, Live load , wind load & seismic load have been assigned properly for the above said two buildings as shown below

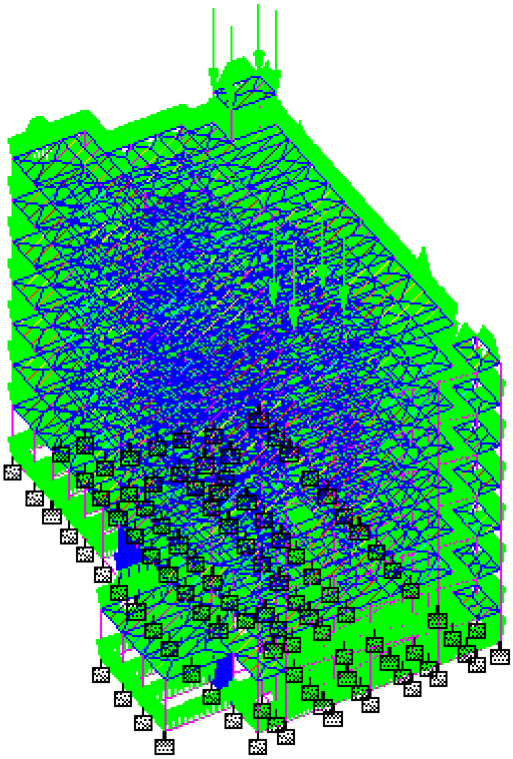

Figure 4.2.3. Assigning of Loads for Hospital Building

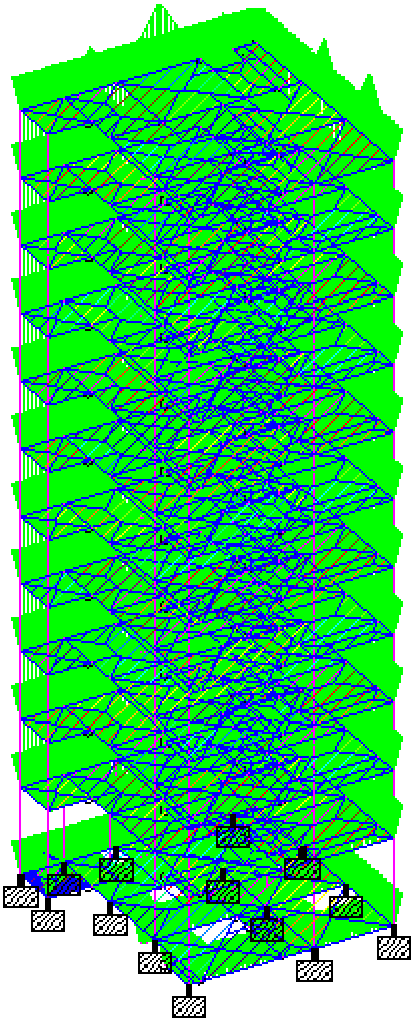

Figure 4.2.4. Assigning of Loads for Residential Building

Analysis & Design

After the model generation and assigning loads analysis & design have been carried out for both the Hospital and residential building with and without the diaphragm effect. The interpretation of results have been described in the next chapter.

6. Results

This chapter discuss the results obtained from the analysis and design part of this project. The comparison has also been made between the diaphragm & non diaphragm structures with the parameters such as, bending moments, shear, required Ast for Columns and Beams.
The sectional view of LHS first row of beams & columns from the G+7 Hospital building has been considered for interpreting the results for both without and with diaphragms.
For residential building RHS corner column has been considered.

FINDINGS

The results are interpreted and compared for both the without diaphragm and with diaphragm effects. The chart is prepared for the various items such as SF,BM and Deflection of structural members.
The following chart shows that diaphragm model has the lesser shear values while comparing the without diaphragm model.

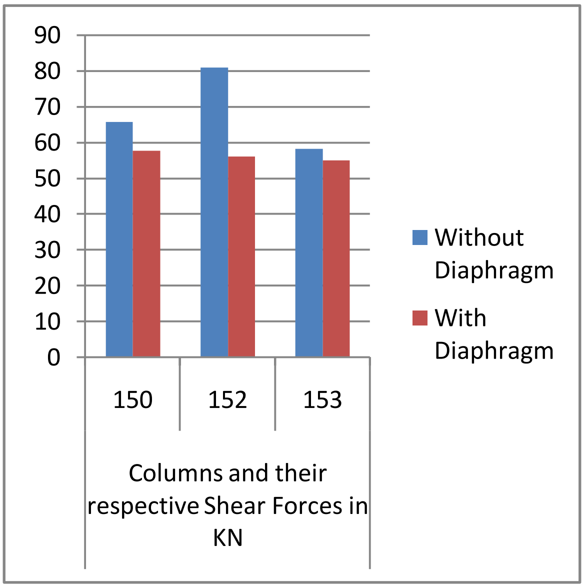

Figure 5.2.41. Comparison chart for Shear Forces in Columns.

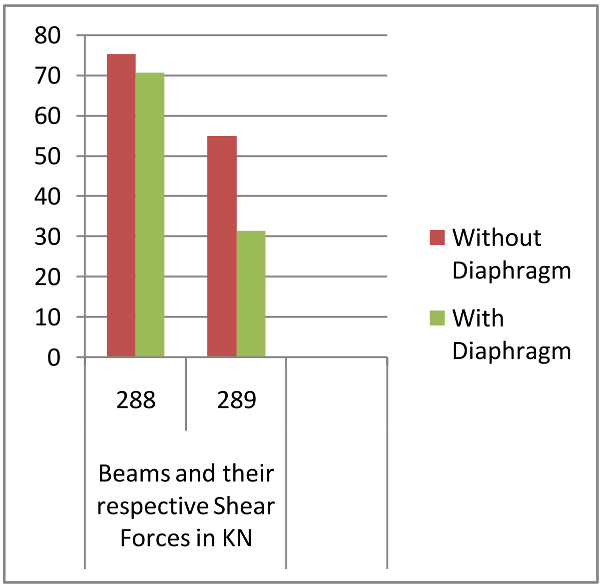

Figure 5.2.42. Comparison chart for Shear Forces in Beams.

The following chart shows that diaphragm model has the lesser Bending moment while comparing the without diaphragm model

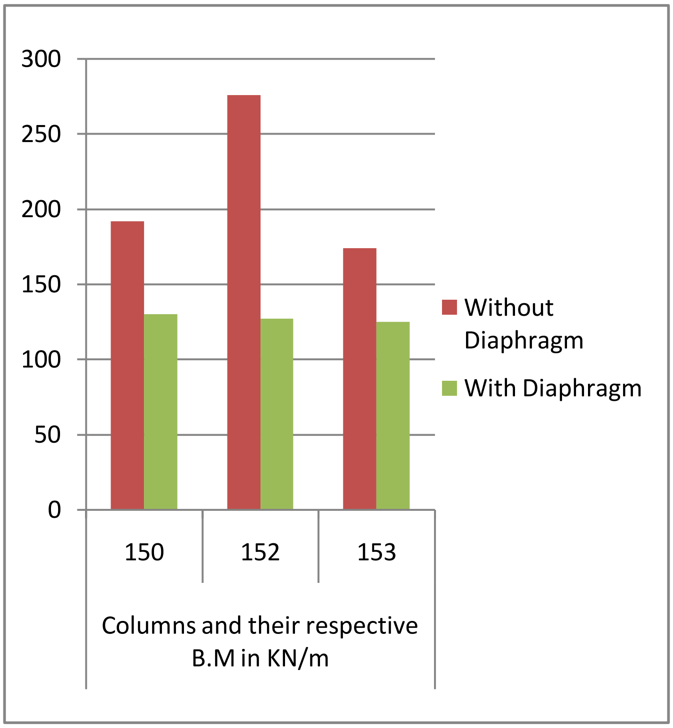

Figure 5.2.43. Comparison chart for Bending Moments in Columns.

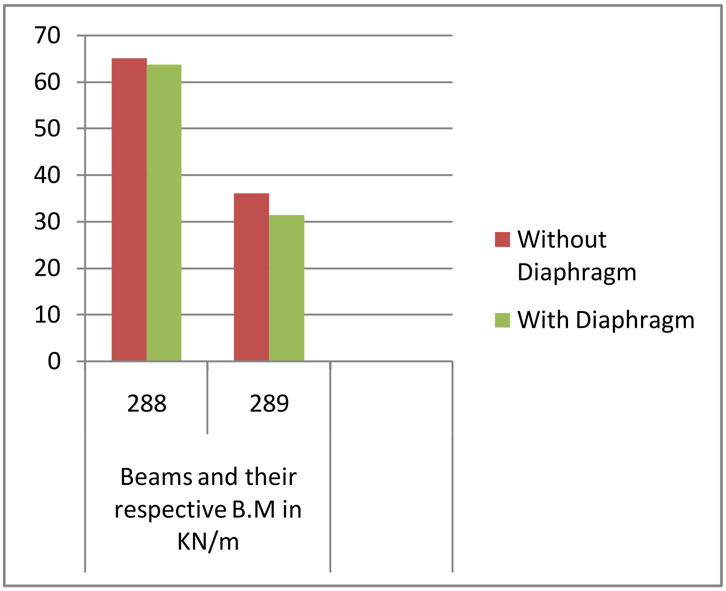

Figure 5.2.44. Comparison chart for Bending Moments in Beams.

The following chart shows that diaphragm model has the lesser Deflection while comparing the without diaphragm model

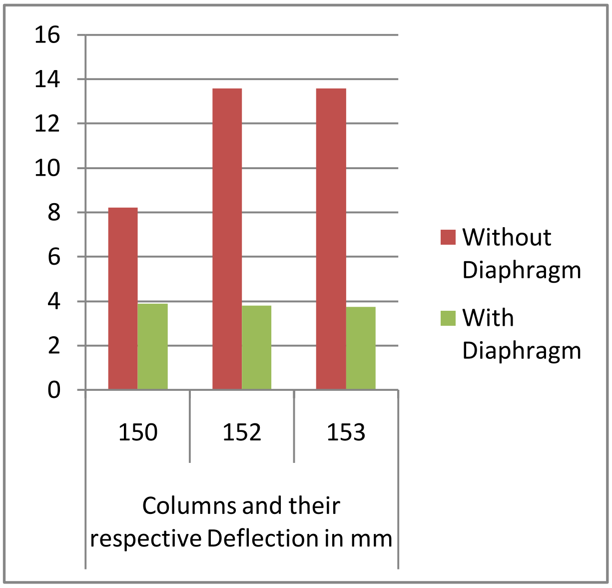

Figure 5.2.45. Comparison chart for Deflection in Columns.

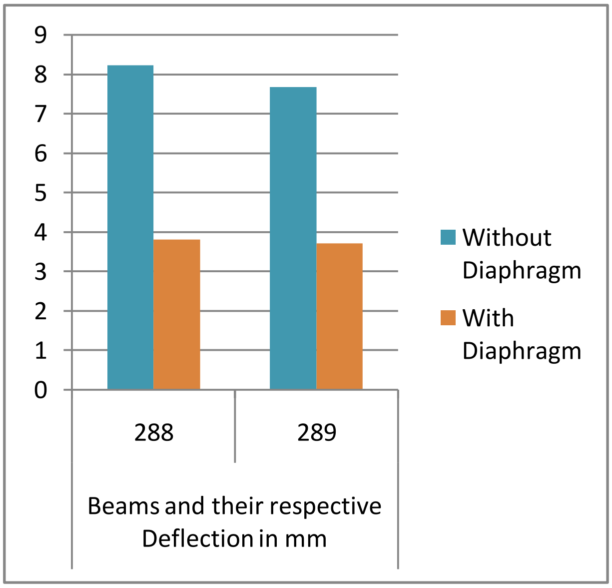

Figure 5.2.46. Comparison chart for Deflection in Beams.

The results are summarized in the tabular format for easy interpretation. From The following table one can understand that diaphragm effect has considerable impact in analysis and design of the structures

For Hospital Building						
Column No	WithOut Diaphragm			With Diaphragm		
	SF KN	BM KN/m	Deflect mm	SF KN	BM KN/m	Deflect mm
150	65.8	191.68	8.2	57.65	130	3.87
152	80.9	275.7	13.58	56	127	3.78
153	58.2	173.9	13.58	55	125	3.72
Beam No						
288	75.2	65	8.22	70.7	63.7	3.8
289	55	36	7.66	54	31.4	3.7
For Residential Building						
Column no.						
53	70.95	189	8.36	70.9	185.4	7.7
Beam no.						
69	118	183.4	8.37	98.4	146	7.8

7. Conclusion

From the present study it is seen that diaphragm effects (rigid) plays a vital roles in the designing aspects.

It has been clearly observed that rigid diaphragm is much lesser bending moment, shear force and displacements in compared to flexible diaphragms system. . It will leads to the provision of lesser section in structural members thereby the consumption of concrete and steel can be reduced in larger extent especially in multi storey buildings.

The advantages of the diaphragm action has been established well in this project. Nowadays more and more researches are being carried out to decrease the construction cost of projects. Various measures are being followed in the construction stage in order to decrease the cost. It will be a boon to the construction industry when the cost saving methods adopted in the designing of the structures itself. The study will be imprative especially for cost saving measures in the designing stage itself.

The final outcome of the project deliberately ensures the importance of diaphragm effects in designing the structural members and it is the edge over the conventional methods.

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