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SEISMIC RESPONSE OF REINFORCED CONCRETE TALL BUILDINGS

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ABSTRACT

Earthquakes present one of the most devastating hazards on the planet. They threaten the safety of civilians in seismically active regions, and are of extreme concern in applications that demand a high level of safety, i. e. the nuclear industry. However, in nearly all cases, the fatalities that occur are as a result of the collapse of man-made structures. Hence the problems facing Civil Engineers who are concerned with seismic mitigation is evident. Seismic engineering research and application has progressed rapidly over the last few decades, not least in part due to the evolution of computer technology, and our ability to produce computer models which aid us in the design and analysis processes. Hence the research presented focuses on the global behaviour of a typical statically designed tall reinforced concrete building. A literature review has been performed to investigate current mathematical and experimental work which has been carried out with regard to reinforced concrete structures under seismic/cyclic loading. In this paper, the seismic behavior of reinforced concrete tall building **is** presented. The 5,7,9 and ,11 storey concrete buildings with six frames in each direction has been analyzed for static, modal and time-history analyses under a typical (synthetic) earthquake by popular structural design software "STAAD Pro 2007". The buildings are analyzed firstly with Slab-beam-column structure, and secondly for without beam i.e. as flat slab construction and thirdly flat slab construction with shear wall. This has resulted in to analyzing 12-models. The results are compared with each other for natural time period, Sa/g, Story drift, base shear & column forces. The test results suggest that buildings with beam-column system have better seismic performance than buildings without beam i.e. as flat slab system.

Keywords: Earthquakes**,** seismic response, tall buildings, natural time period, Story drift, base shear.

INTRODUCTION

Tallness is a relative matter and tall buildings cannot be defined in specific terms related just to high to the number of floors. The tallness of a building is a matter of persons or community's circumstances and their consequent perception. Therefore, a measurable definition of a tall building cannot be universally applied. From the structural engineer's point of view, however, a tall building may be defined as one that, because of its height, is affected by lateral forces due to wind or earthquake action to an extent that they play an important role in the structural design.

Earthquake load acting on a structure depends on epicenter distance and depth of hypocenter below earth surface and the energy released during an earthquake. For easier understanding, it can be said that the line of action joining hypocenter to the center of mass of structure indicates direction of load vector. The most determinant effect on a structure is generally caused by lateral component of earth quick load. As compared to gravity load effect, earthquake load effects on buildings are quite variable and increase rapidly as the height of building increases. For gravity loads, structure is designed by considering area supported by a column, and spans of beam; whereas for earthquake loads, design is a function of total mass, height. It is likely that low and mid rise structures, having good structural form can carry most of earthquake loads. The strength requirement is a dominant factor in the design of structure. As height increases the rigidity (i.e. the resistant to lateral deflection) and stability (i.e. resistant to overturning moments) of structure gets affected, and it becomes necessary to design the structure preferably for lateral forces, moments, story drift and total horizontal deflection at topmost story level. Pure rigid frame system or frame action obtained by the interaction of slabs, beam and column is not adequate. The frame alone fails to provide the required lateral stiffness for buildings taller than 15 to 20 (50 to 60m) stories. It is because of the shear taking component of deflection produced by the bending of columns and slab causes the building to deflect excessively. There are two ways to satisfy these requirements. First is to increase the size of members beyond and above the strength requirements and second is to change the form of structure into more rigid and stable to confine deformation. First approach has its own limits, whereas second one is more elegant which increases rigidity and stability of the structure and also confine the deformation requirement. In earthquake engineering, the structure is designed for critical force condition among the load combination. Shear walls can most economically provide when coupled with sufficient ductility or energy absorption capacity [1]. Reinforced concrete can be used for all standard buildings both single storey and multistory and for containment / retaining structures and bridges. Concrete has low tensile strength and a high compressive strength. The Steel reinforcement is provided to effectively overcome the deficiencies in the tensile strength of the concrete. So the reinforcing steel must have adequate tensile properties and form a strong bond with the concrete since the concrete transmits load to the steel by longitudinal shearing stresses, in structures such as beams & columns [2]. The degree of ductility of reinforced concrete material is related to the physical properties of each constituent material as well as the relative percentages of steel and concrete that are present. Park also mentioned that the ductility of reinforced concrete structures required for earthquake resistance is best achieved by ensuring in design that it occurs by flexural yielding of plastic hinges [3]. Pauley and Priestly mentioned that one of the most common causes of failure in earthquakes, the "soft story mechanism". Where one level, typically the lowest, is weaker than upper levels, a column sway mechanism can develop with high local ductility demand [4]. Chandler and Lam presented an effective approach to mitigate the destructive effects of earthquakes is the proper enforcement of the knowledge that is currently available for designing, constructing, and maintaining new earthquake-resistant structures and upgrading existing seismically hazardous structures [5]. The dynamic response of the structures is dependent on its modal characteristics. Modal analysis method is one of the dynamic analysis techniques used to calculate the dynamic response of the structures in absence of the applied external force and this analysis is carried out prior the actual seismic analysis of the structures as a preliminary analysis [6]. Lateral vibration of buildings braced by frame works is characterized by three types of deformation: the full-height 'local' bending of the individual columns/wall sections the full-height' global' bending of the frame works, which is associated with the axial deformations of the columns/wall sections, and the shear deformation of the frameworks [7]. Manfredi and Verderame, [8], mentioned that the RC frames designed without seismic provisions have in many cases a structural behaviour characterised by low available ductility and lack of strength hierarchy inducing undesirable failure mechanisms. The lack of horizontal and vertical regularity and the high torsion deformation are also problems resulting in an unsatisfactory global behavior. The strength as well as ductility of a structure can be enhanced using ferromesh jacketing [12,13,14].

ANALYTICAL ANALYSIS

The main objective of the analysis is to study the different forces acting on a building. The analysis is carried out in STAAD Pro2007 software. Various tables presented in this shows the results obtained from STAAD Pro2007 software. Results of conventional R.C.C structure i.e slab, beam and column and flat slab R.C.C structure for different heights are discussed below.

In this, conventional R.C.C structure and flat slab R.C.C for different height are modeled and analyzed for the different combinations of static loading. The comparison is made between the conventional R.C.C structure and flat slab R.C.C. Buildings are situated in seismic zone II other details of the buildings are as below.

The heights of the buildings are kept as 17.5 m, 25 m, 32.5 m, 39.5 m from ground these buildings are of 5 storey, 7 storey, 9 storey, 11 storey respectively. The height of one floor is of 3.6m each. In this way the number of total modal which were analyzed are 12 model. Following are the different name of models

Model 1 : A 5 storey conventional R.C.C structure
Model 2 : A 5 storey Flat slab R.C.C structure
Model 3 : A 5 storey Flat slab R.C.C structure with shear wall
Model 4 : A 7 storey conventional R.C.C structure
Model 5 : A 7 storey Flat slab R.C.C structure
Model 6 : A 7 storey Flat slab R.C.C structure with shear wall
Model 7 : A 9 storey conventional R.C.C structure
Model 8 : A 9 storey Flat slab R.C.C structure
Model 9 : A 9 storey Flat slab R.C.C structure with shear wall
Model 10 : A 11 storey conventional R.C.C structure
Model 11 : A 11 storey Flat slab R.C.C structure
Model 12 : A 11 storey Flat slab R.C.C structure with shear wall

Description For Loading

The loading on the buildings is considered as per following calculations

Dead Loads

Wall load with 150mm thickness = 19 x 3.6 x 0.15 = 10.26kN
Wall load with 230mm thickness = 19 x 3.6 x 0.23 = 15.73kN
Weight of the slab having thickness 0.150mm = 25 x 0.150 = 3.75kN/m
Weight of the slab having thickness 0.162mm = 25 x 0.162 = 4.05kN/m

Self weight of building is automatically considered by the STAAD Pro2007 soft ware .

Live Loads

The live load of 4 kN/m2 is considered on the buildings.

Earthquake Forces Data

Earthquake load for the building has been calculated as per IS-1893-2002

Zone (Z)	= II
Response Reduction Factor (RF)	= 3
Importance Factor (I)	= 1.5
Rock and soil site factor (SS)	= 2
Type of Structures	= 1
Damping Ratio (DM)	= 0.05

Loading Combinations

The different loading combinations for the analysis of the building and tower considered are shown in Table1

Table 1: Different Loading Combinations for Analysis of Building

Sr. No.	Load Combinations
1	1.5 (DL + LL)
2	1.2 (DL + LL + WLX)
3	1.2 (DL + LL + WLZ)
4	1.2 (DL + LL – WLX)
5	1.2 (DL + LL - WLZ)
6	1.5 (DL + WLX)
7	1.5 (DL + WLZ)
8	1.5 (DL – WLX)
9	1.5 (DL – WLZ)
10	0.9 DL + 1.5 WLX
11	0.9 DL + 1.5 WLZ
12	0.9 DL - 1.5 WLX
13	0.9 DL - 1.5 WLZ

Natural Time Period

The time required for the undamped system to complete one cycle of free vibration is the natural period of vibration of the system in units of seconds. Table 2, mentioned the result values of natural time period for different model. Similarly, the graph based on this table a graph of variation of natural time period of different model Vs no. of storey is as shown in fig.1 below

Table 2: Result Values of Natural Time Period for Different Model.

Height of building (m)	No of storey	Time Period (sec)		
		Conventional Structures	Flat Slab Structures	Flat Slab With Shear Wall
17.5	5	0.6417	0.315	0.315
25	7	0.829	0.441	0.441
32	9	0.997	0.567	0.567
39	11	1.159	0.693	0.693

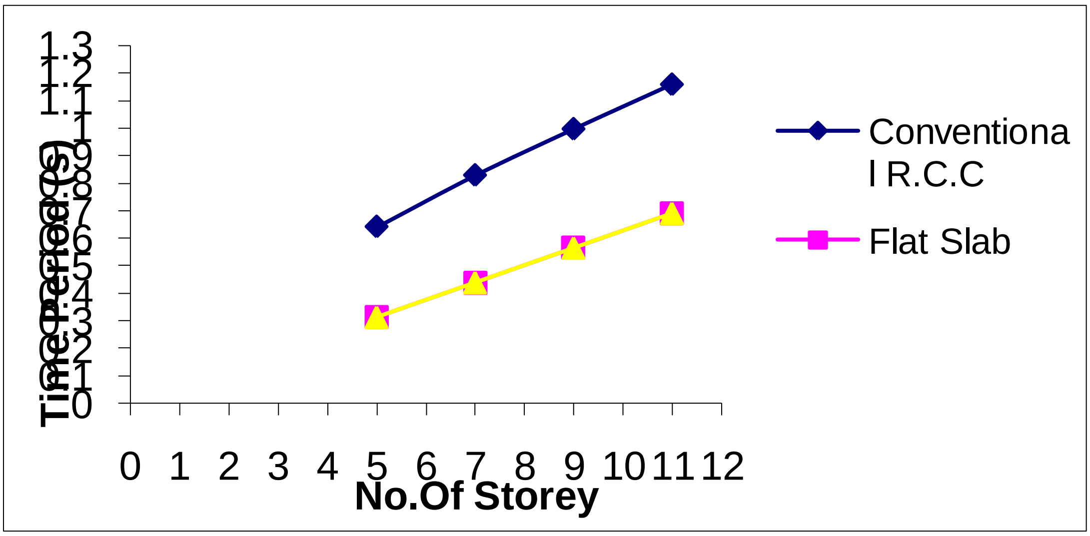

Figure.1: Variations of No. Of Storey’s V/s Natural Time Period

Average Response Acceleration Coefficient

It is a factor denoting the acceleration response spectrum of the structure subjected to earthquake ground vibrations, and depends on natural period of vibration and damping of the structure. Table 3 below shows the result values of Sa/g for the different models. Similarly based on this a graph shows the variations of Sa/g with no. of storey's are drawn as shown in fig.2.

Table 3: Result Values of Average Response Acceleration Coefficient for Different Model

Height of building (m)	No of storey	Average Response Acceleration		
		Conventional Structures	Flat Slab Structures	Flat Slab With Shear Wall
17.5	5	2.119	2.50	2.50
25	7	1.647	2.50	2.50
32	9	1.364	2.39	2.39
39	11	1.173	1.96	1.96

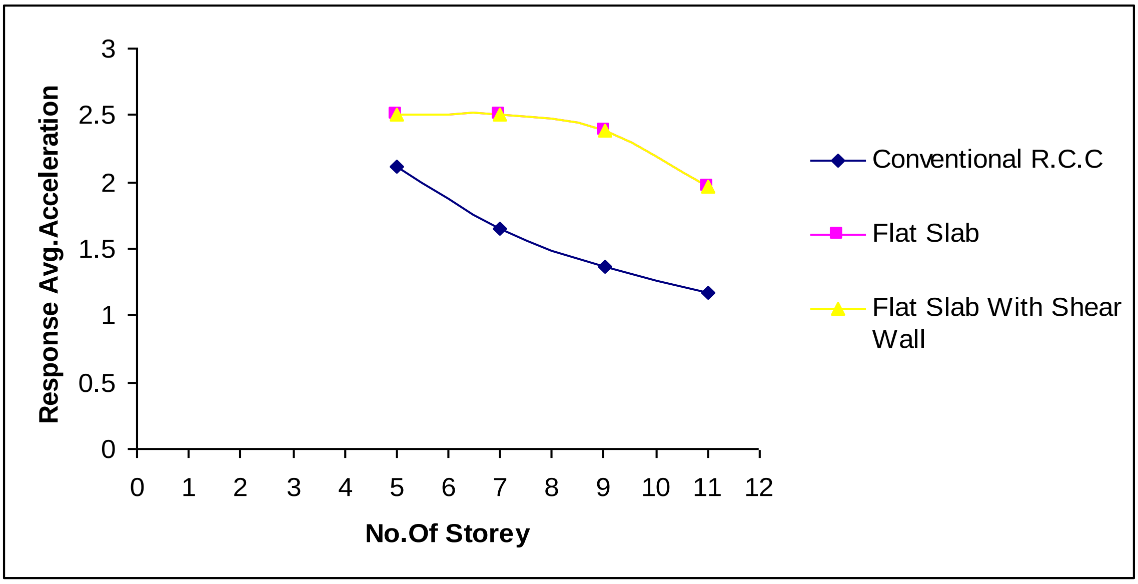

Figure 2: Variation of No.of Storeys V/s Sa/g

Base Shear

The total design lateral forces or design seismic base shear (V_b) along any principal direction shall be determined by the following expression.

$$V_b = A_h W$$

Table 4 below shows the result values of base shear for the different models. Similarly based on this a graph shows the variations of base shear with no. of storeys are drawn as shown in fig 3.

Table 4: Result Values of Base Shear for Different Models.

Height of building (m)	No of storey	Base Shear (kN)		
		Conventional Structures	Flat Slab Structures	Flat Slab With Shear Wall
17.5	5	3087	3633	3721
25	7	3334	5079	5225
32	9	3535	6121	6265
39	11	7897	8252	6477

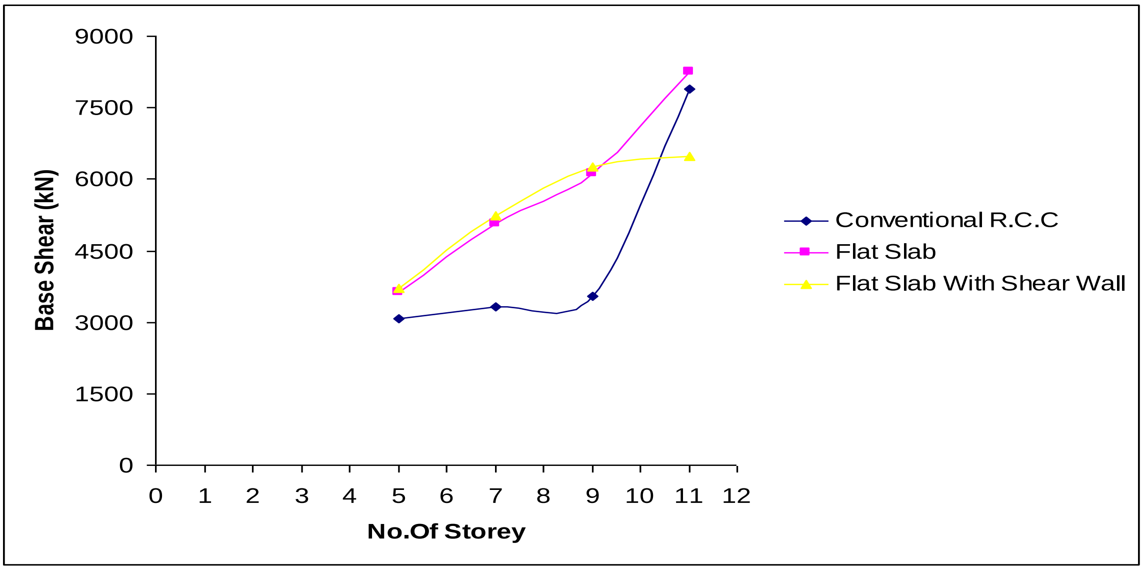

Figure 3: Variation of No of storey V/s base shear

Sway

Storey is defined as the space between two adjacent floor. And sway is defined as the displacement of one level relative to the other level above or below.

Table 5 below shows the result values of sway for the different models. Similarly based on this graph shows the variations of sway with no. of storey are drawn as shown in fig 4.

Table 5: Result Values of Sway for Different Models

Height of building (m)	No of storey	Sway (mm)		
		Conventional Structures	Flat Slab Structures	Flat Slab With Shear Wall
17.5	5	0.414	1.2	0.148
25	7	0.452	1.818	0.2717
32	9	0.467	2.22	0.467
39	11	1.08	2.27	0.59

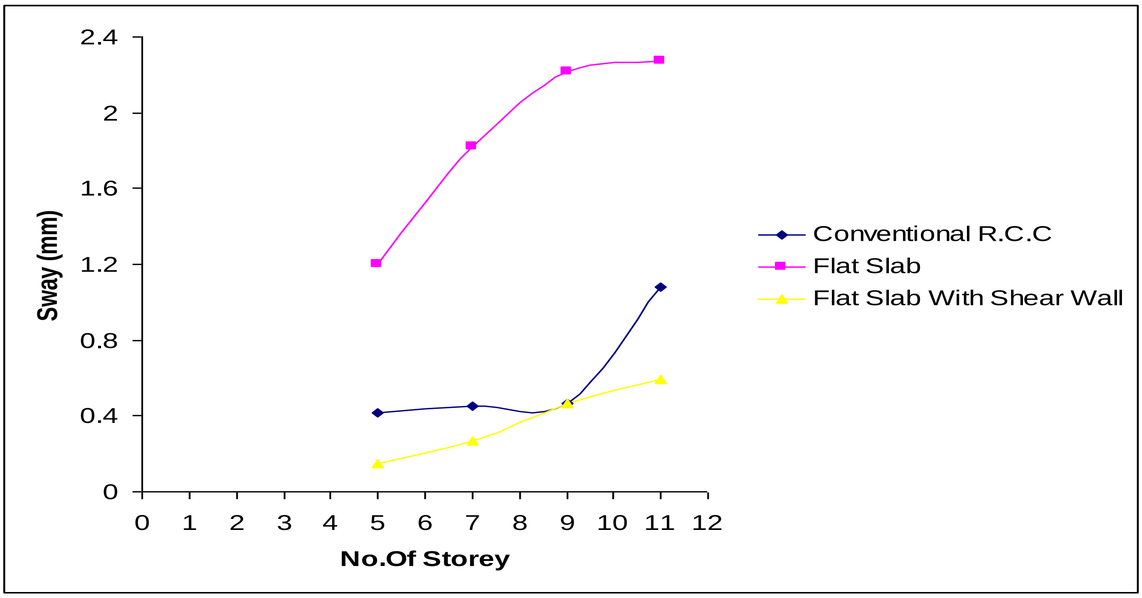

Figure 5: Variation of No. of Storey V/s Sway

Column Force

Axial force, Shear forces and Moments

For this model the result values of column forces like axial force, shear force and moment are mentioned below. Based on these values different graphs are prepared. For the same the table 6, 7 and 8 shows the result value of different models for axial force, shear force and moments respectively. Similarly based on this graph are prepared which shows the variations as shown in fig.6,7 and 8 for axial force, shear force and moments.

Table 6: Result Values of Axial Force for Different Model

Height of building (m)	No of Storey	Axial Force (kN)		
		Conventional Structures	Flat Slab Structures	Flat Slab With Shear Wall
17.5	5	3623	3679	3679
25	7	5038	5169	5169
32	9	6426	6505	6505
39	11	7776	8252	8252

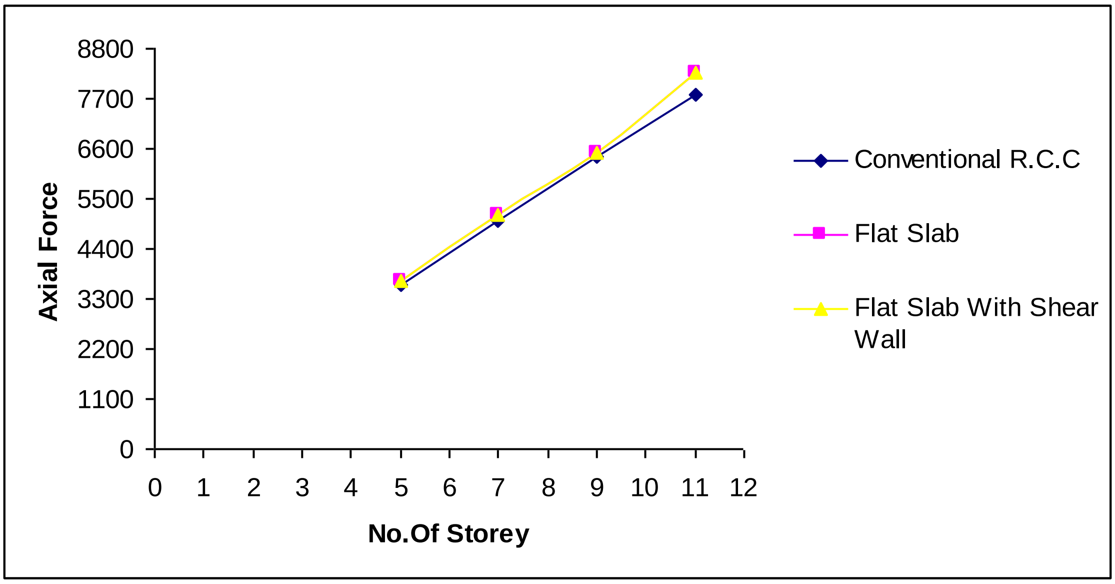

Figure 6: Variation of No. of Story V/s Axial Forces

Table 7: Result Values of Shear Force for Different Model

Height of building (m)	No of Storey	Shear Force (kN)		
		Conventional Structures	Flat Slab Structures	Flat Slab With Shear Wall
17.5	5	154	217	66
25	7	174	318	111
32	9	323	387	178
39	11	412	476	476

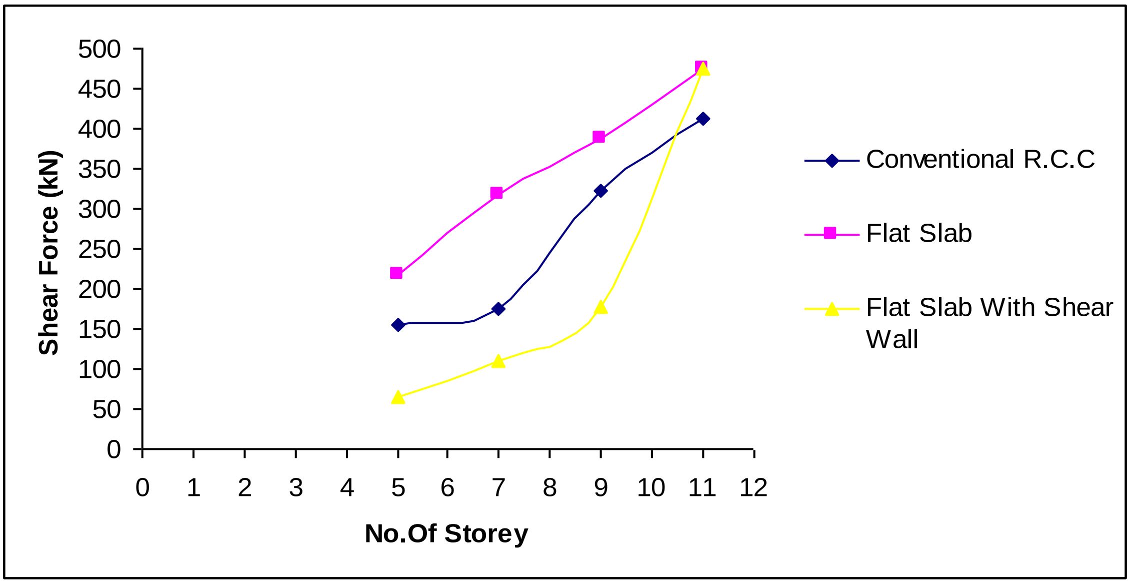

Figure 7: Variations of No. of Storey V/s Shear Force

Table 8: Result Values of Moment for Different Model

Height of building (m)	No of storey	Moment (kN-m)		
		Conventional Structures	Flat Slab Structures	Flat Slab With Shear Wall
17.5	5	275	577	125
25	7	305	806	221
32	9	567	967	348
39	11	722	1007	435

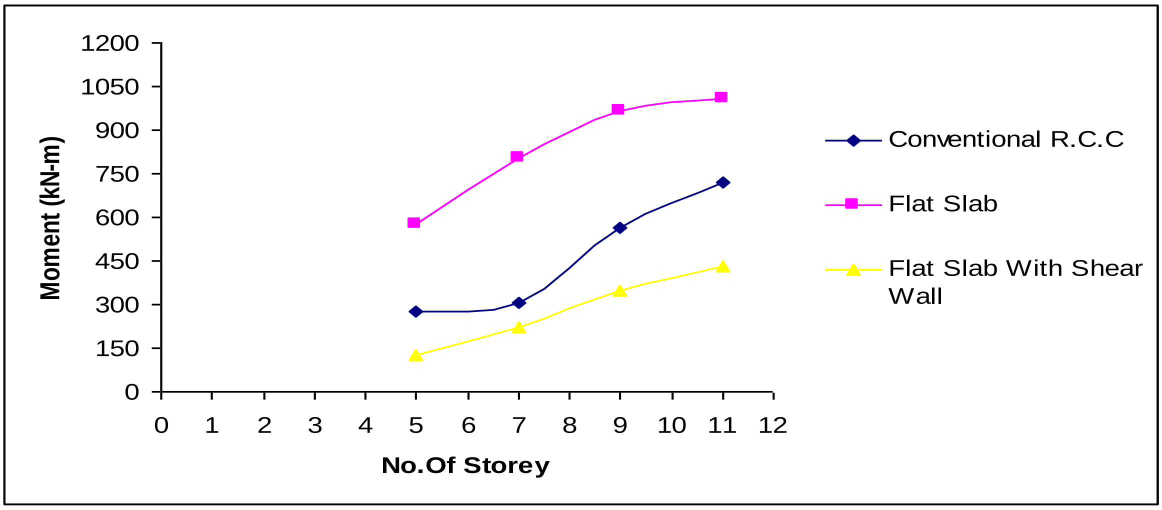

Figure 8: Variations of No. of Storey V/s Moments

CONCLUSIONS

This presents a summary of the study, for conventional R.C.C building and flat slab building for different floor height. The effect of seismic load has been studied for the two types of building with different height. On the basis of the results and discussions obtained in this investigation, the following conclusions have been drawn:

1. The natural time period increases as the height of building (No. of stories) increases, irrespective of type of building viz. conventional structure, flat slab structure and flat slab with shear wall. However, the time period is same for flat slab structure and flat slab with shear wall.
2. In comparison with the conventional R.C.C building to flat slab building, the time period is more for conventional building than flat slab building.
3. For conventional building, average response acceleration coefficient decreases with increase in the height of building, however, for, flat slab structure and flat slab with shear wall., this change is not significant.
4. For all the structure, base shear increases as the height increases. This increase in base shear is gradual unto 9^{th} -storey, thereafter, it increases significantly.
5. Base shear of conventional R.C.C building is less than the flat slab building.
6. Story drift in buildings with flat slab construction is significantly more as compared to conventional R.C.C building. As a result of this, additional moments are developed. Therefore, the column of such building should be designed by considering additional moment caused by the drift.
7. The moments in the columns of conventional R.C.C building are less than the flat slab R.C.C building.
8. A structure with a large degree of indeterminacy is superior to one with less indeterminacy, this is primarily because of more members are monolithically connected to each other and if yielding takes place in any one of them, then a redistribution of forces takes place. As a result, the structure can sustain to take additional load. Additionally, redistribution reduces as the number of member reduces in a selected lateral load resisting system.

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