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Behavior of Buildings having Flat Slabs under Seismic Loading

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***Abstract*—Experience in past earthquakes has demonstrated that many common buildings and typical methods of construction lack basic resistance to earthquake forces due to which life threatening collapses have occurred. This vast devastation of engineered systems created a new awareness about the earthquake resistant design of structures (EQRD) among the professionals. It made these professionals to carryout research works for various cost-effective design solutions so as to make structures less vulnerable to earthquakes. The objectives of the present study is to analysis of multistoried beam-slab buildings & flat slab buildings under DL, LL & EQ loads and to study of the effect of shear walls on the above four types of buildings in terms of storey drift, lateral displacement and column forces.**

***Index Terms*— Flat slab, seismic loading, storey drift and lateral displacement.**

I. INTRODUCTION

A very general practice of design and construction of buildings is that the slabs are supported by beams and beams are supported by columns. This type of construction may be called as beam slab construction. A major drawback of using beams is they reduce the net available ceiling height. Hence in public halls, offices and warehouses sometimes beams are avoided and slabs are directly supported by columns. This type of construction is aesthetically appealing also. These slabs which are directly supported by columns are called Flat Slabs.

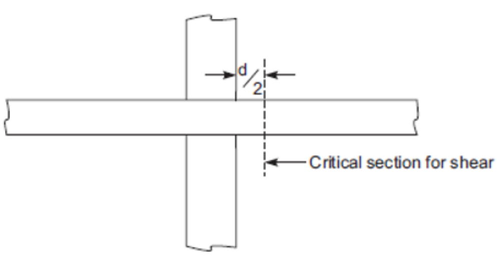

Fig. 1. A typical flat slab (without drop and column head)

The column head is sometimes widened so as to reduce the punching shear in the slab. The widened portions are called column heads. The column heads may be provided with any angle from the consideration of architecture but for the design, concrete in the portion at 45º on either side of vertical only is considered as effective for the design. Moments in the slabs are more near the column. Hence the slab is thickened near the columns by providing the drops. Sometimes the drops are called as capital of the column.

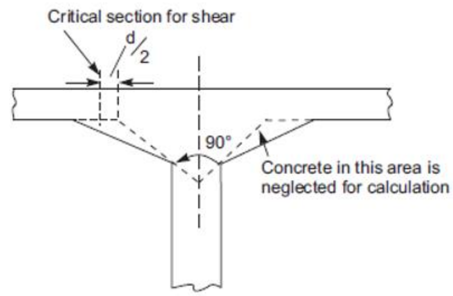

Fig. 2. Slab without drop and column with column head

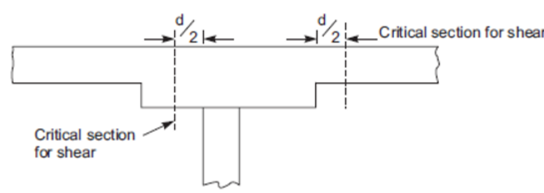

Fig. 3. Slab with drop and column without drop

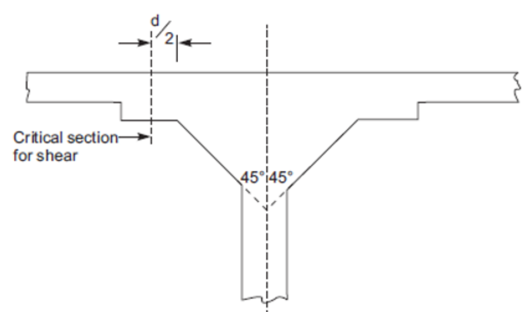

Fig. 4. Slab with drop and column with column head

II. SEISMIC BEHAVIOR OF FLAT SLAB

The construction of reinforced concrete buildings with flat slab has become common for commercial and residential buildings in some high seismic European countries. The behavior of this type of structural systems with flat slabs shows important drawbacks. One of the major drawbacks is the non-dissipative feature towards the seismic response. The other one is that the flat slab building structures are significantly more flexible than the traditional beam-slab frame structures, and so are more vulnerable to second order P-Δ effects under seismic excitations. Therefore, the characteristics of the seismic behavior of flat slab buildings suggest that additional measures for guiding the concept and design of these structures in seismic regions are needed.

III. Literature Review

Alpa Sheth (2008). "Effect of Perimeter Frames in Seismic Performance of Tall Concrete Buildings with Shear Wall Core and Flat Slab System." the 14th World Conference on Earthquake Engineering, Beijing, China:

The paper studies the effect of perimeter frames for structural systems with flat slabs and shear wall core for different locations of the shear wall core and for different heights and spans of three concrete towers. Tall buildings are being increasingly designed with structural system comprising of flat slab or flat plate system and shear wall core with or without perimeter beams. The behavior of this system under lateral loads is dependent on numerous parameters such as the height of the building, floor plate size, size and location of the shear wall core, flat slab spans, amongst others. Importantly, it is also dependent on the provision of a perimeter frame. In a structure with a central shear core, the effective depth of structure resisting lateral loading is practically equal to the depth of the shear wall core. Providing outriggers to such a system greatly helps in improving its behavior by engaging the perimeter columns with the shear wall core and thus increasing the effective depth of structure participating in lateral load resistance.

R. P. Apostolska, G. S. Necevska - Cvetanovska, J. P. Cvetanovska and N. Mircic (2008). "Seismic Performance of Flat-Slab Building Structural Systems."

This paper focuses the results of the analysis of six types of structural systems for a prototype of a residential building to define the seismic behavior and resistance of flat-slab structural systems. The analysis has been performed by using finite element method & SAP 2000. It concluded that purely flat-slab RC structural system is considerably more flexible for horizontal loads than the traditional RC frame structures. In order to increase the bearing capacity of the flat-slab structures under horizontal loads, modification of these structures by adding structural elements is necessary.

George E. Lelekakis, Athina T. Birda, Stergios A. Mitoulis, Theodoros A. Chrysanidis and Ioannis A. Tegos. "Applications of Flat-Slab R/C Structures in Seismic Regions"

In the present study an extended parametric investigation was carried out in order to identify the seismic response of structural systems consisting of α) slabs-columns b) columns-parametric beams c) columns shear walls-slabs d) columns-shear walls-slabs and parametric beams. The aforementioned systems were studied for all possible storey heights in Greece by means of F.E.M. Code SAP2000 ver.9. The compliance criteria provided by the Greek Code for earthquake resistance are related to second order effects, torsional flexibility, capacity design and the sensitivity of masonry infill. Conclusions were extracted concerning the number of storeys which can be applied to each case.

IV. Design Philosophies

The principle of earthquake resistance design is to evolve safe and economical design of structures to withstand possible future earthquake. This can be achieved by provisions of adequate strength, stiffness and ductility in the structure. Besides this, earthquake resistance of structure can also be increased by careful planning, design and constructions.

IS code 456:2000 permits only 2 methods for the analysis of flat slabs:

1. The Direct Design Method: This method has the limitation that it can be used only if the following conditions are fulfilled:
    1. There shall be a minimum of three continuous spans in each direction.
    2. The panels shall be rectangular and the ratio of the longer span to the shorter span within a panel shall not be greater than 2.
    3. The successive span length in each direction shall not differ by more than one-third of longer span.
    4. The design live load shall not exceed three times the design dead load.
    5. The end span must be shorter but not greater than the interior span.
2. The Equivalent Frame Method: IS: 456-2000 recommends the analysis of flat slab and column structure as a rigid frame to get design moment and shear forces with the following assumptions:
    1. Beam portion of frame is taken as equivalent to the moment of inertia of flat slab bounded laterally by center line of the panel on each side of the center line of the column. In frames adjacent and parallel to an edge beam portion shall be equal to flat slab bounded by the edge and the center line of the adjacent panel.
    2. Moment of inertia of the members of the frame may be taken as that of the gross section of the concrete alone.
    3. Variation of moment of inertia along the axis of the slab on account of provision of drops shall be taken into account. In the case of recessed or coffered slab which is made solid in the region of the columns, the stiffening effect may be ignored provided the solid of the slab does not extend more than 0.15 lef into the span measured from the center line of the columns. The stiffening effect of flared columns heads may be ignored.
    4. Analysis of frame may be carried out with substitute

frame method or any other accepted method like moment distribution or matrix method.

V. Problem Formulation and Methodology

The objective of the present work is to compare the behavior of multistoried buildings having flat slabs with that of having two way slabs with beams and to study the effect of shear walls on the performance of these two types of buildings under seismic forces. In order to reduce lateral displacement and storey drift, shear walls have been provided throughout the height of the buildings at 4 corners in adjacent panels. For this purpose a 9 storied building is considered.

A. Loadings Considered

1. Dead Load- It is taken by software itself.
2. Live Load- 4 KN/m^2 on all the floors.
3. Earthquake Load- As per IS 1893 (Part-I):2002.

B. Load Combinations

1. 1.5(DL + LL)
2. 1.2(DL + LL + EQL)

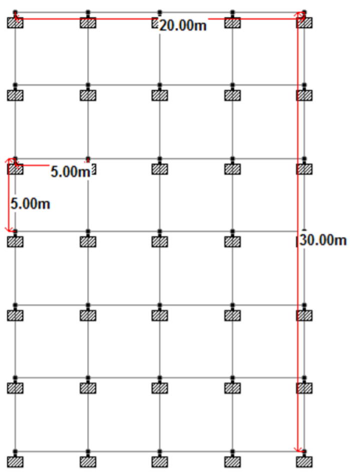

Fig. 5. Plan without shear walls

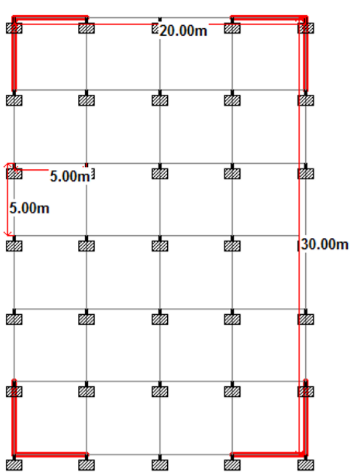

Fig. 6. Plan with shear walls

C. Details of the Cases

The building is of (G + 8) configuration, having storey height of 3m. The columns are provided in 5m x 5m grid form. Shear walls are placed at the corners of plan. The sizes of beams are taken as 200mm x 400mm throughout the height of building. The thickness of slab is taken as 120mm. The thickness of shear walls is taken as 150mm. The thickness of flat slabs is 250mm. The sizes of columns are provided same in buildings with shear walls and without shear walls according to the table.

TABLE I
SIZES OF COLUMNS

Storeys	Size of Column (in mm)
Bottom storey	450 × 450
Next 4 storeys	400 × 400
Top 4 storeys	300 × 300

VI. Result

The performance of shear walls is assessed for different building heights through three cases each having four models for three earthquake zones. The results obtained from analysis are discussed below:

A. Results of Lateral Displacement and Storey Drift for zone III

TABLE II
LATERAL DISPLACEMENT AND STOREY DRIFT FOR ZONE III

Height (m)	Lateral Displacement (mm)				Storey Drift (mm)			
	B – S	F - S	B - S (W)	F- S (W)	B – S	F - S	B - S (W)	F- S (W)
3	0.31	0.39	3.39	3.89	0.31	0.39	3.39	3.89
6	0.87	1.06	10.3	11.7	0.56	0.67	6.93	7.81
9	1.65	2.00	17.9	20.1	0.79	0.94	7.58	8.45
12	2.59	3.11	25.3	28.4	0.94	1.12	7.45	8.27
15	3.63	4.35	32.4	36.2	1.04	1.24	7.45	8.27
18	4.73	5.66	39.7	44.6	1.11	1.31	7.37	8.41
21	5.87	7.00	45.9	51.7	1.13	1.34	6.14	7.07
24	7.00	8.32	50.3	56.9	1.13	1.32	4.43	5.15
27	8.11	9.62	52.8	59.8	1.11	1.31	2.50	2.92

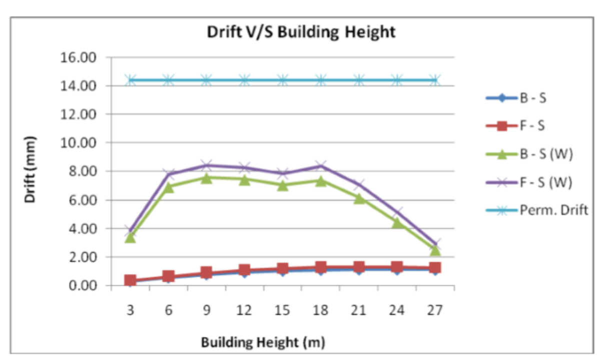

Fig. 7. Drift vs. building height

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B. Results for Maximum Column Forces at various storey levels of buildings having Shear Wall

TABLE III
MAXIMUM COLUMN FORCES AT VARIOUS STOREY LEVELS OF BUILDINGS HAVING SHEAR WALL

Storey Levels	Axial force (P) (kN)		Moment (kNm)	
	B-S	F-S	B-S	F-S
Lower 4 Storeys	1757.4	1587.0	8.8	0
	568.4	575.7	2.4	27.1
	547.1	558.7	43.2	0
Next 3 Storeys	928.5	943.8	9.4	0
	462.7	485.4	3.8	29.9
	443.7	469.5	50.8	0
Next 2 Storeys	301.5	449.8	7.9	0
	149.1	222.4	4.2	27.1
	140.5	215.0	44.7	0

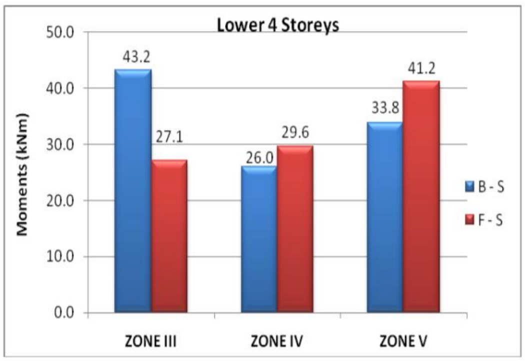

Fig. 8. Zones vs. Moments (Lower 4 storeys)

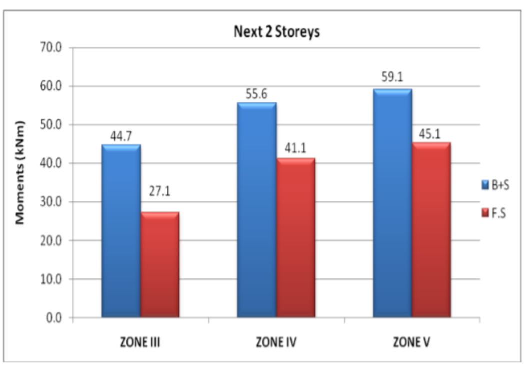

Fig. 9. Zones vs. Moments (Next 2 storeys)

C. Results for Maximum Column Forces at various storey levels of buildings without Shear Wall

TABLE IV
MAXIMUM COLUMN FORCES AT VARIOUS STOREY LEVELS OF BUILDINGS WITHOUT SHEAR WALL

Storey Levels	Axial force (P) (kN)		Moment (kNm)	
	B-S	F-S	B-S	F-S
Lower 4 Storeys	1754.14	1736.23	0	0
	1019.70	958.09	86.13	145.04
	1013.29	956.14	0.32	0.54
Next 3 Storeys	925.93	915.61	0	0
	527.69	485.08	72.83	54.87
	526.33	483.33	0	0
Next 2 Storeys	300.38	296.00	0	0
	163.66	152.41	58.08	53.74
	163.83	152.01	0	0

D. Results for the Effect of EQ forces on corner columns for zone III and 9 storied building

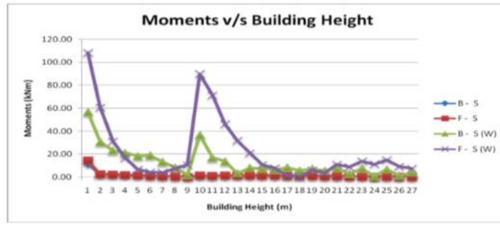

Fig. 10. Building height vs. Moments

VII. CONCLUSION

Effect of shear walls on drift values

1) In buildings without shear walls:
   a) The variation in drift values with height is parabolic having maximum ordinate at about one-third of the building height. b. The drift values in zone III is within permissible limits.
2) In buildings having shear walls:
   a) The variation in drift values with height is almost linear.
   b) The drift values get reduced by 6 to 7 times.

Effect of Earthquake forces on columns carrying maximum forces

1) In buildings having shear walls:

In 9 storied buildings, the axial forces in flat slab buildings are 14 to 20% more than in beam slab buildings. However, moments in flat slab buildings are lesser than those in beam slab buildings by 20 to 40 %.

2) In buildings without shear walls:

In 9 storied buildings, the axial forces in flat slab buildings are almost equal to those in beam slab buildings but moments in lower four storeys of flat slab buildings are almost doubled while these get almost equaled in the upper remaining storeys.

Effect of shear walls on lateral displacement

In zone III, lateral displacements of both the types of buildings are within permissible limits.

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