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RELIABILITY ASSESSMENT OF FLAT SLAB BUILDING USING PUSHOVER ANALYSIS

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Abstract. Concrete is said to be workable, durable but it is never mentioned as reliable only because of the uncertainties that are present in it. These uncertainties can be measured by performing reliability analysis. American Concrete Institute (ACI) code classifies the state of structure based on reliability index value which is not specified in Indian codes. This study was to compare the seismic response and reliability index by taking base shear values of flat slab and conventional beam slab buildings using non-linear static analysis. It is a method to calculate seismic performance point along with the failure pattern. Both the buildings – flat slab and conventional beam slab – were analysed by considering the uncertainties in material properties, geometric properties and loads applied. Pushover analysis was carried out for different random values that were created by using Monte Carlo Simulation method to get the reliability index. The non-linear static analysis was carried out in SAP 2000 and the results were plotted. The study reveals that the flat slab system has increased failure rate compared to the beam slab system with higher hinge formations because of randomness and hence reliability analysis can be mandated as an industrial practice. The current study not only reveals the comparative advantage but also fills the gaps in failure pattern study, which is existing in this research fraternity.

Key words:- Reliability Analysis, Vulnerability Analysis, Failure pattern study, Pushover analysis, Flat Slab System

Introduction

With the tremendous growth instructural design aspects there is a desperate need in knowing the type of slab system that is to be adopted based on the consideration of seismic loads. From past few years, Performance Based Seismic Design came into existence where in, it fills the gap between linear analysis methods and the dynamic Non-Linear behaviour of structures.Seismic vulnerability can be stated as the tendency of structure to damage during the ground motion. It is a relationship between the ground motion and intensity of structural damage state.In this paper, a comparative study on Seismic performance of Flat slab system over a conventional Beam slab system was carried out for all the seismic zones by using Non-linear Static Pushover analysis as a tool which gives progressive collapse of the structure along with the plastic deformation of hinges. Concrete structures possess various number of uncertainties which are not considered in our design concepts and hence to understand the effect of these uncertainties in seismic performance, Reliability Analysis was carried out. This paper observed that there is a dearth of literature on the seismic behaviour of flat slab system and the objective of the study is to overcome this gap.

Da Gang Lu [2008], made a study on global reliability along with the combination of random pushover analysis, point estimation method and MCS over a RC frame structure to get the seismic performance and found out a new semi-analytical approach, which comprises pointestimation method, pushover analysis and FORM. By applying the proposed methodology in reinforcedconcrete frame buildings, some changing rules of global seismic reliability of the structure with COV of totalseismic action and correlation coefficient of storey-level seismic forces were obtained.

Hardik[2015],carried out a study on pushover analysis of RC frame with floating column and soft story in different seismic zones by varying the stories respectively using SAP 2000. As it concluded that the base shear and displacement values increased as the number of stories and zone increased. The displacement value increases when floating columns were placed.

The study on literatures has shown that there is a very less of information about the seismic behaviour of flat slab system over a beam slab system in different seismic zones and also the effect of randomness that is present in concrete when analysed by pushover analysis.

System Development

The simulation study was performed in 3 phases,

1. Modelling of slab systems using SAP 2000:

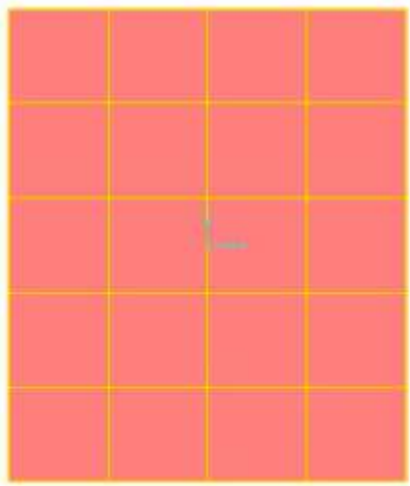
The actual behaviour of the structure cannot be prototyped and analyzed due to the time and economic factors, and hencea tool based classical approach is implemented using SAP 2000. Conventional beam slab and flat slab with drop structures were modelled in SAP 2000 by keeping the same geometry (Table 1 & 2) and support data for all the seismic zones. Apart from the preliminary (Gravity) loads, static earthquake analysis along with response spectrum analysis was carried out. The beam slab system and flat slab system modelled using SAP 2000 is as shown in Fig 1and Fig 2.

Table.1. Specifications of the buildings

Parameters	**Beam slab system**	**Flat slab system**
Grade of concrete	M 30N/mm^2	
Grade of steel	Fe 500 and Fe 415 N/mm^2	
Number of stories	G+5	
Beam size	300x600mm	
Beam cover	50mm	
Column size	300x600mm	
Column cover	40mm	
Slabs	150mm	In. Panels-150mm
		Drops- 250mm
Live load and finishes	3 kN/m^2 and 3kN/m^2	

Table.2. Seismic definitions

Zones considered	I, II, III and IV
Damping Ratio	5%
Importance factor	1
Type of Soil	II (Medium Soil)
Response Reduction Factor	5
Time Period	0.075xh$^{0.75}$



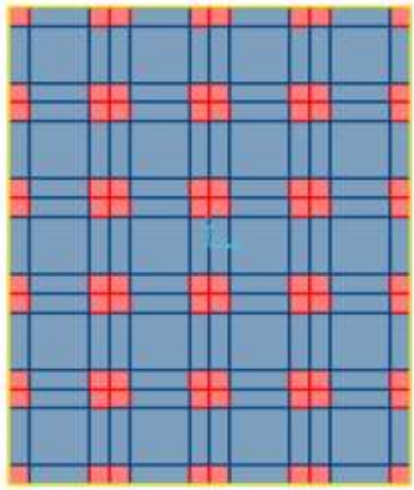
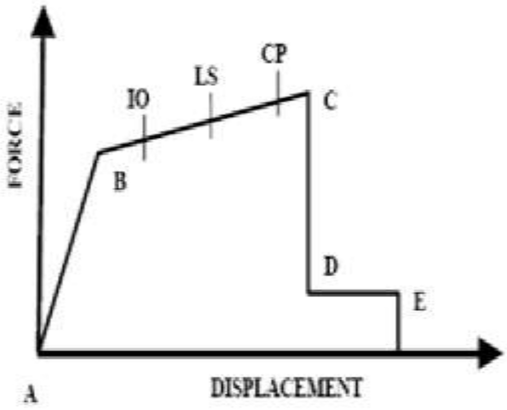


Fig.1. Beam slab modelFig.2. Flat slab model

2. Pushover Analysis

Pushover analysis was performed by subjecting lateral loads monotonically over the entire structure once after the gravity loads were assigned. The stiffness thus obtained from the gravity loads was considered as the initial load for lateral loads. Auto hinges of M3 for beams(Bending members) and PM2M3 for columns (Axial members) were assigned on either ends of the members along with P-Delta effect. Demand spectrum was developed by using response spectrum method and is super-imposed over the Displacement vs Base shear graph generated by the pushover analysis to get the performance point (Fig.4).Displacement controlled type of pushover analysis was performed.In this paper, pushover analysis was considered as a vital tool since it gives more précised seismic behaviour of the structure.



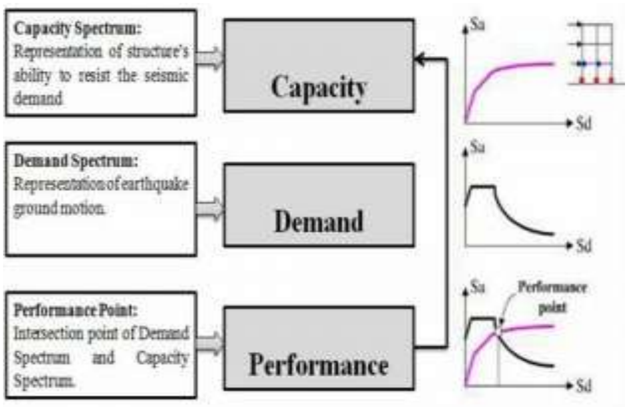


Fig.3 Force-Deformation curve **Fig.4 Spectrum Curve**

(Source: http://www.engineeringcivil.com/evaluation-of-response-reduction-factor-for-rc-elevated-water-tanks.html)

Where,

A to B – Elastic state,
B to IO- below immediate occupancy,

IO to LS – between immediate occupancy and life safety,

LS to CP- between life safety to collapse prevention,

CP to C – between collapse prevention and ultimate capacity,

C to D- between C and residual strength,

D to E- between D and collapse

>E – collapse

3. Reliability Analysis

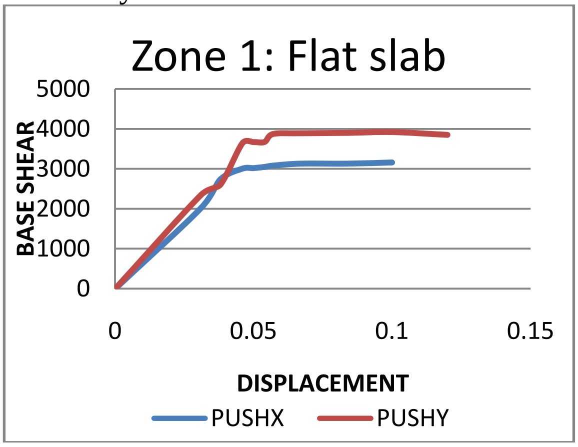
Uncertainties like Geometric-breadth, depth and cover of beams and columns, Materialistic- f_{ck} , and as well as loads on the slabs are calculated by Monte Carlo simulation technique using Excelconsidering the standard deviation values(Table 3). Random pushover analysis was carried out by considering all these values to get the randomized results of performance point, safety index and as well as differential hinge patterns.Basically Monte Carlo Simulation was used to carry out risk analysis by giving predefined probability distribution of an uncertainty. In this technique random values were obtained from the probability distribution for any number of values that are needed.

Table.3. Reliability analysis definitions (Source: Ranganathan&Ellingwood)

Specifications	Standard deviation
Beams	Breadth- 9.47
	Depth- 9.38
	Cover- 8.41
Columns	Breadth- 5.69
	Depth- 7.89
	Cover- 12.13
f_{ck}	3.04
Loads	1.6

Results and discussions

The following are the Displacement vs Base shear graphs for both beam slab and flat slab system for all the seismic zones.



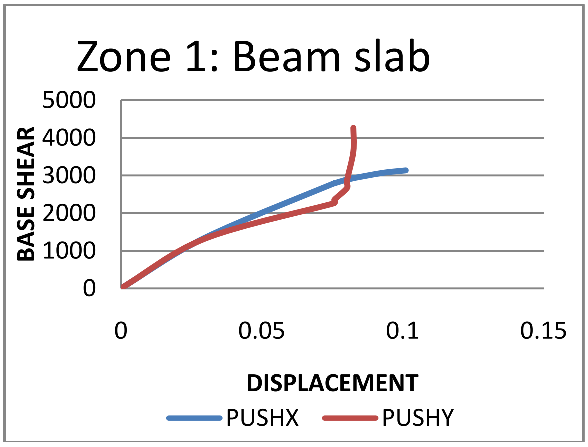
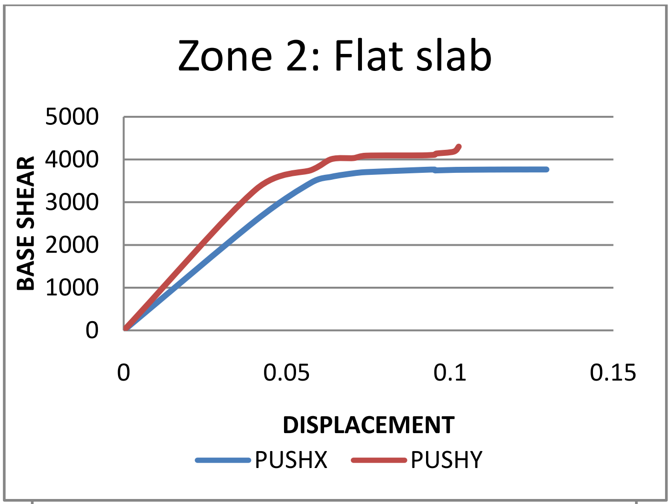


Fig.5 Pushover curve Z1 FSFig.6 Pushover curve Z1 BS



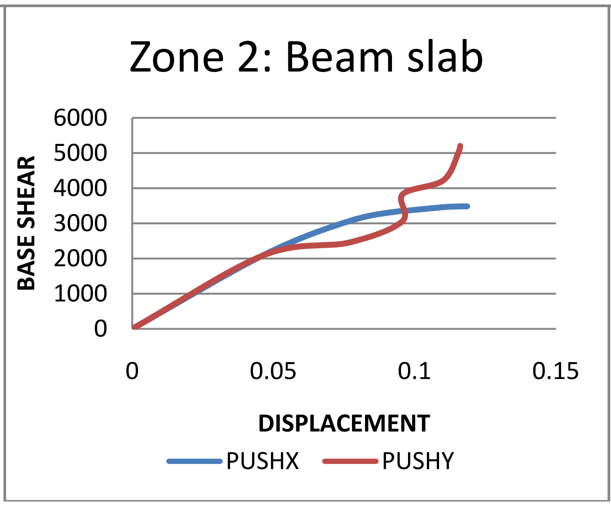
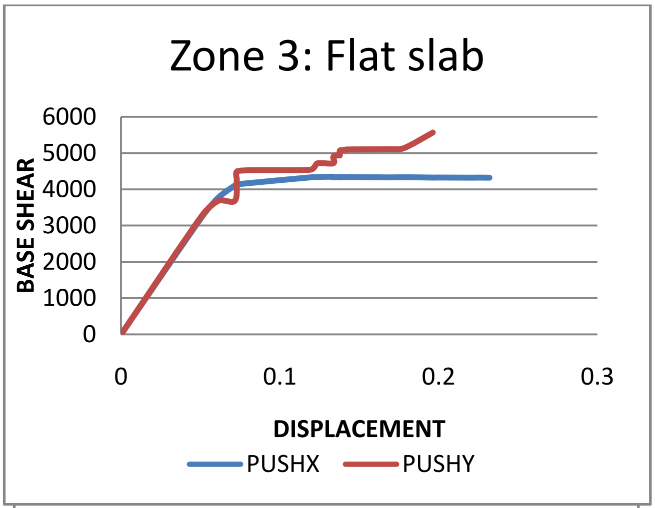


Fig.7 Pushover curve Z2 FS **Fig.8 Pushover curve Z2 BS**



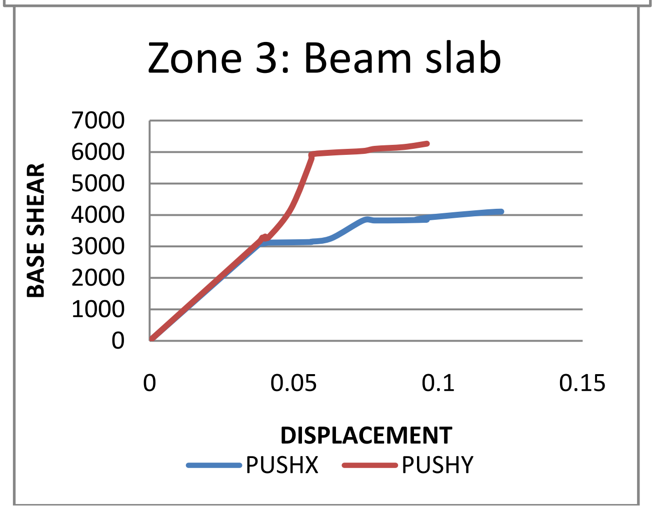
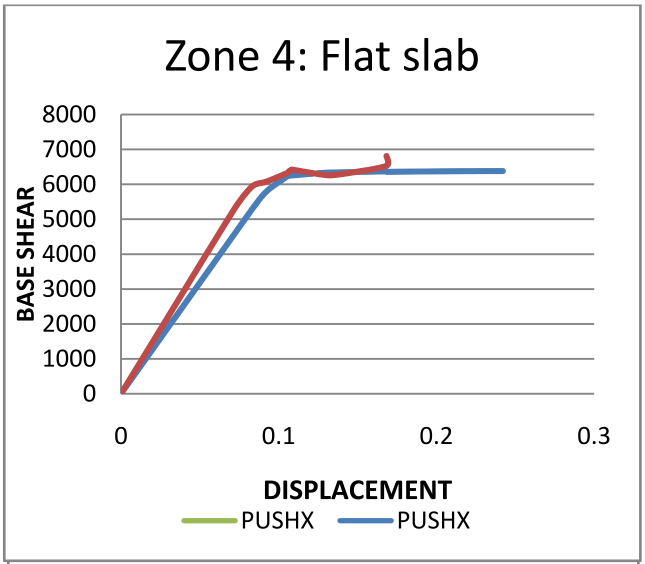


Fig.9 Pushover curve Z3 FS **Fig.10 Pushover curve Z3 BS**



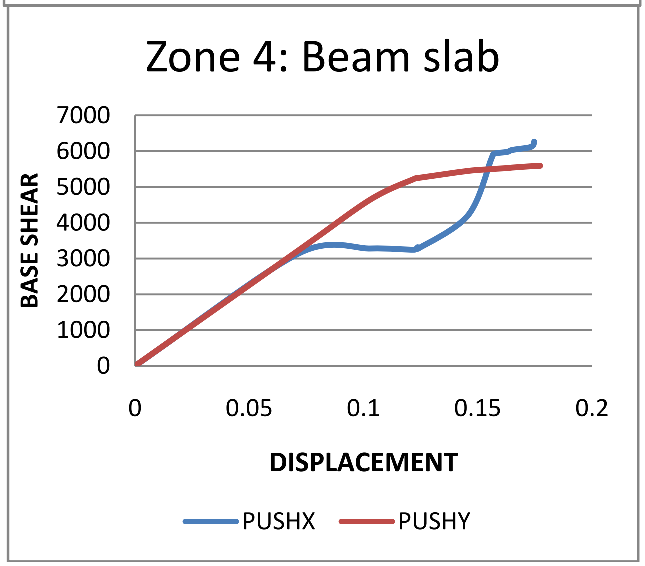


Fig.11 Pushover curve Z4 FS **Fig.12 Pushover curve Z4 BS**

From the above graphs we can see that the base shear value increased as the seismic zone value increased, and also that the base shear value for flat slab is higher than that of the beam slab structure.

Table.4. Plastic hinge formations

SYSTEM	ZONES	CASE	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
BS	Z1	PX	680	250	18	0	0	0	0	0	948
		PY	780	168	0	0	0	0	0	0	948
FS	Z1	PX	306	270	0	0	0	0	0	0	576
		PY	401	175	0	0	0	0	0	0	576
BS	Z2	PX	656	270	22	0	0	0	0	0	948
		PY	760	188	0	0	0	0	0	0	948
FS	Z2	PX	251	303	26	0	0	0	0	0	576
		PY	356	220	0	0	0	0	0	0	576
BS	Z3	PX	580	326	40	2	0	0	0	0	948
		PY	572	376	0	0	0	0	0	0	948
FS	Z3	PX	238	296	38	4	0	0	0	0	576

		PY	332	244	0	0	0	0	0	0	576
BS	Z4	PX	600	269	70	9	0	0	0	0	948
		PY	646	302	0	0	0	0	0	0	948
FS	Z4	PX	309	166	88	13	0	0	0	0	576
		PY	295	281	0	0	0	0	0	0	576

Table.5. Performance point

Zone	System	Load case	Performance point (kN)	Displacement (m)
Zone 1	Beam slab	PUSHX	1352.32	0.027
		PUSHY	1737.1	0.002114
	Flat slab	PUSHX	2920.57	0.03
		PUSHY	3894.88	0.00246
Zone 2	Beam slab	PUSHX	2145.9	0.047
		PUSHY	2672.47	0.00233
	Flat slab	PUSHX	2890.8	0.048
		PUSHY	3873.9	0.00335
Zone 3	Beam slab	PUSHX	3190.2	0.067
		PUSHY	3921.51	0.00273
	Flat slab	PUSHX	3956.63	0.072
		PUSHY	4310.83	0.00464
Zone 4	Beam slab	PUSHX	4766.68	0.101
		PUSHY	5769.46	0.00385
	Flat slab	PUSHX	6094.45	0.107
		PUSHY	6328.6	0.00618

Conclusions

- Results shows that the plastic hinge formations are more in flat slab system when compared to beam slab system.
- Flat slab system has higher values of performance point and target displacement than that of Beam slab system.
- Beam slab building has 8% increase in the hinge formations when reliability analysis is carried out and whereas Flat slab building shows 19% of increase.
- Beam slab building has safety index of 5.41 and Flat slab has 4.95 with respect to base shear values.

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