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# Seismic Fragility Analysis of Flat Slab Structures

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**ABSTRACT:** A new methodology is essential to understand the response of structure when subjected to nonlinear dynamic loadings like earthquake, tsunami, hurricanes etc. Incremental dynamic analysis (IDA) is the powerful tool which will be able to simulate the connection between ground motion and structural response assessment. IDA is a computational method developed to provide the results of conditional probability seismic hazard analysis in order to define the seismic capacities of structure under the seismic loading. IDA is carried out by performing non-linear dynamic analysis by considering the suite of earthquake ground motions and scaling each ground motion to several levels of its intensity. Postprocessing the results of each analysis will give the graph of Intensity measure versus Engineering Demand parameter which is known as Incremental Dynamic Analysis Curve. In addition to this, an evaluation of seismic fragility that recite the probability of exceeding a performance level to the earthquake excitation was carried out. The behaviour of the structure was anticipated using nonlinear static and dynamic analyses with earthquake excitation records. Flat slab RC structures are being preferred over the conventional RC structures. Flat slab RC building provide various advantages over the conventional Beam Column RC frame like higher floor to floor height, ease in installation of mechanical & electrical services etc. A ten-story flat slab with perimeter beam structure is modelled using the analytical software ETABS 19. In this project report, IDA & Fragility curves are developed duly analysing the flat slab structure.

**KEYWORDS:** Incremental Dynamic Analysis, Flat Slab, Seismic Hazard Analysis, Intensity Measure, Engineering Demand Parameter

## I. INTRODUCTION

A number of structures across susceptible regions to earthquakes have been substantially damaged, resulting in economic and human losses. To make wise decisions for enhanced earthquake mitigations, it is required that seismic losses of structures with regional characteristics data (e.g., structural dimensions) be appropriately predicted. It is well known that the most efficient methodology to estimate seismic losses of structures accounting for uncertainty in seismic loadings and structural capacities is the seismic fragility analysis.

### PROBLEM STATEMENT

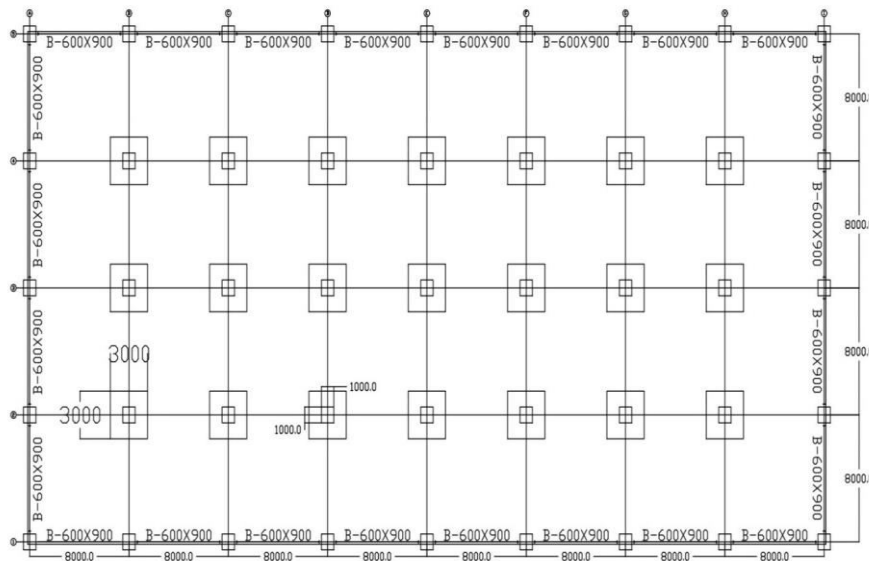
To carry out the Incremental Dynamic Analysis & Seismic Fragility Analysis, a structure is to be modelled in Analytical Software. The suite of minimum 7 earthquake ground motion has to be applied on the structure by scaling, incrementing till the structure reaches to its collapse state. After analysing the structure, the graph of Intensity measure versus Engineering demand Parameter as IDA curve is to be developed. Similarly graph of probability of exceedance versus spectral acceleration is to be plotted for various limit states as per codes known as Fragility Curve.

### PROBLEM SOLUTION

To achieve the above objective a G+10 Flat slab structure is modelled and analysed using the Extended Three-Dimensional Analysis of Building System (ETABS) version of 2019 (ETABS). The suite of 11 earthquake ground motions is applied on the structure to understand the response of the structure for each & every ground motion. Then graph of Spectral acceleration for first mode time period at 5% damping versus Maximum Inter story Drift ratio (%) as single record IDA for a particular ground motion is plotted. Thereafter the graphs of all ground motions are plotted in a one graph due to scaling, is known as Multi Record IDA Curve. Similarly, the fragility curves are plotted for three limit states viz. Immediate occupancy, Life Safety, Collapse prevention.

## II. STRUCTURAL MODELLING

The structure is so chosen that each bay is 8m in both ways such that symmetry should be maintained in X as well Y direction. The flat slabs are provided with drop panels at column slab connection as same thickness of slab to restrict punching shear at that junction. The beams are provided at perimeter to reduce the transverse shear at periphery.



Structural Configuration Dimensions of building	64mX32m	
Height of Structure	35.5m	
Location	Mumbai	
Bay spacing	8m	
No. of Bays X Direction	8	
No. of Bays Y Direction	4	
Story Height	3m	
No. of Stories	11 (G+10)	
Column Dimensions	1000mmX1000mm	
Beam Dimensions	600mmX900mm	
Thickness of slab & Drop Panel	200mm each	
Grade of Concrete	M40	
Grade of Steel	Fe500 (Longitudinal r/f)	Fe415 (Shear r/f)

### Loading on Structure

#### Gravity Loading (Indian Standards, 1987)

The loads which are acting in the direction of gravity on the structure are considered under the gravity loading.

Gravity Loading Data Dead load of Structural Members	Thickness*unit length*Density of concrete
Live Load	5 kN/m <sup>2</sup>
Floor Finish	1.5 kN/m <sup>2</sup>
Partition Wall Load	1 kN/m <sup>2</sup>

### Wind Load (Wind Loads)

Wind load on the structure is applied as per the Indian Standard code viz. IS 875 part3: 2015 (Design Loads (Other Than E Seismic Load (IndianStandards, Earthquake loading, 2016)

Wind Load Data	44 m/sec
Wind speed for Mumbai	
Terrain Category	4
Structure Class	B
Risk Coefficient (K1)	1
Topography Factor (K3)	1

Earthquake loading on the structure is applied as per Indian Standard viz. IS 1893: 2016 (Criteria for Earthquake resistant of d Load Combinations (IndianStandards, Earthquake loading, 2016)

Seismic Load Data	Zone III	0.16
Seismic zone & Factor for Mumbai		
Site Type	2	
Importance Factor	1.2	
Response Reduction Factor	5 (SMRF)	
Time Period X Direction	0.39 sec	
Time Period Y Direction	0.56 sec	

### Design of

Structures Part 1 General Provisions & Buildings). Earthquake) For Buildings and Structures).

Structure is analysed for various load combinations of service as well as ultimate. These load combinations are as per Indian standard codes. These Combinations are listed below; 1.5(DL + LL)

1.2(DL ± LL	&	1.2(DL ± LL ±
±EQx)		EQy)
1.5(DL ± EQx)	&	1.5(DL ± EQy)
0.9DL ± 1.5Qx	&	0.9DL ± 1.5EQy

### Software Used- Analysis in ETABS 2019

Extended Three-Dimensional Analysis of Building System (ETABS) 2019 is the latest version developed by Computers and Structures Incorporation. In this software, structure can be analysed

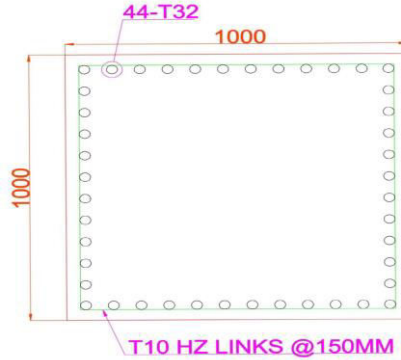
### Types of Analysis used

Main objective of structure is to carry out IDA & SFA on the structure. But before these analysis for a reinforced concrete structure, it is necessary to carry out linear as well as non-linear static and dynamic analysis on structure to understand stability of structure for regular loading. Therefore, in this research 4 types analysis are considered. They are as follows;

#### -Types of Analysis Linear

Static	Equivalent Static Analysis
Non-Linear Static	Push Over Analysis
Linear Dynamic	Response Spectrum Analysis
Non-Linear Dynamic	Time History Analysis





Column Reinforcement Layout

**Criteria for selection**

Criteria	Values or Types
Magnitude	6.5-8.0
Site Class	D
Source Type	Strike Slip
PGA	More than 0.2g

Ground Motion Data

Sr no.	Earthquake Name	Year	Recording Station Name	Magnitude	Site class	Fault Type	PGA (g)	PGV (cm/s.)
1	Northridge	1994	Canyon Country	6.7	D	Thrust	0.48	45
2	Loma Prieta	1989	Capitola	6.9	D	Strike-slip	0.53	35
3	Superstition Hills	1987	El Centro Imp.	6.5	D	Strike-slip	0.36	46
4	Duzce Turkey	1999	Bolu	7.1	D	Strike-slip	0.82	62
5	Imperial Valley	1979	Delta	6.5	D	Strike-slip	0.35	33
6	Imperial Valley	1979	El Centro Array	6.5	D	Strike-slip	0.38	42
7	Kobe, Japan	1995	Shin-Osaka	6.9	D	Strike-slip	0.24	38
8	San Fernando	1971	LA – Hollywood	6.6	D	Thrust	0.21	19

9	Kocaeli, Turkey	1999	Duzce	7.5	D	Strike-slip	0.36	59
10	Landers	1992	Coolwater	7.3	D	Strike-slip	0.42	42
11	Denali	2002	Carlo	7.9	D	Strike-slip	0.69	67

Incremental Dynamic Analysis

Northridge Earthquake  
Scaling

Table Scaling of Northridge Earthquake

Scaling of Earthquake				
Northridge				
First Mode (X direction) Time period= 1.958				
pSa Value for 1.958 second= 0.361613				
Scale Factor= 2.7653				

Response spectrum matched-

From figure 3.3 it is observed that the response spectrum curve gives maximum spectral acceleration as 177.13 mm/s<sup>2</sup> at 1.95second which is fundamental mode time period. This shows that the structures response spectrum is matched with the earthquake’s response spectra.

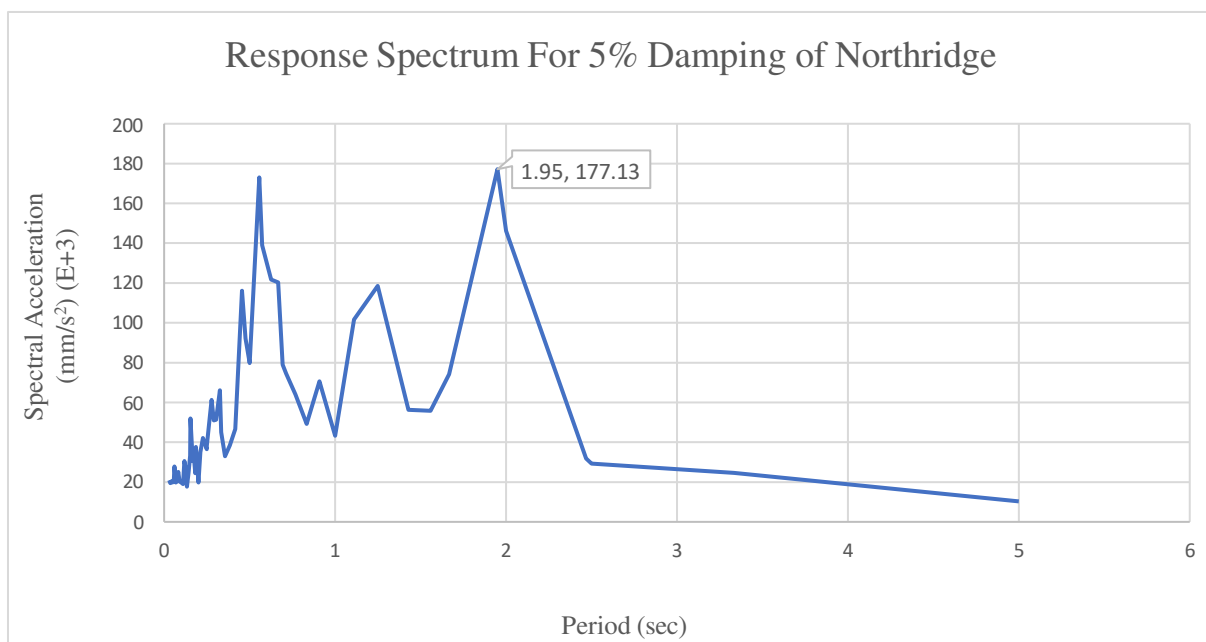


Figure 1- Matched RSP for 5% Damping of Northridge

Increment

From figure 3.4 & 3.5, it can be observed that increment in acceleration is similar to the increment in scale factor in table 3.10 at the particular time step.

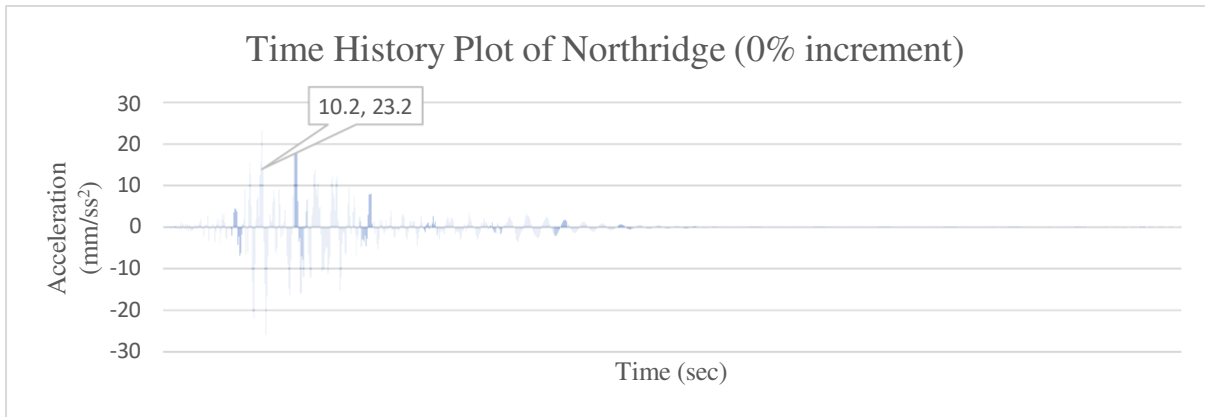


Figure - 2 Time History Plot of Northridge (0% increment)

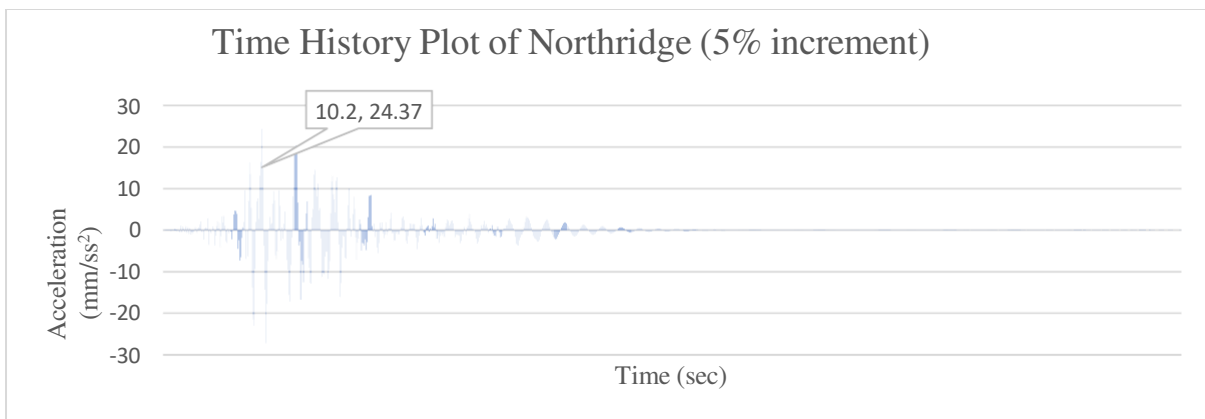


Figure - 3 Time History Plot of Northridge (5% increment)

Drift values

Drift values for Northridge

Increment	% Increment	Scale Factor	g	SF ETABS	X(Drift)	Y (Sa, T1)
0	1	2.7653	9.81	27.127593	0.0057	1
5	1.05	2.7653	9.81	28.48397265	0.006	1.05
10	1.1	2.7653	9.81	29.8403523	0.0063	1.1
15	1.15	2.7653	9.81	31.19673195	0.0065	1.15
20	1.2	2.7653	9.81	32.5531116	0.0069	1.2

25	1.25	2.7653	9.81	33.90949125	0.0072	1.25
30	1.3	2.7653	9.81	35.2658709	0.0076	1.3
35	1.35	2.7653	9.81	36.62225055	0.0078	1.35
40	1.4	2.7653	9.81	37.9786302	0.0081	1.4
45	1.45	2.7653	9.81	39.33500985	0.0084	1.45
50	1.5	2.7653	9.81	40.6913895	0.0087	1.5
55	1.55	2.7653	9.81	42.04776915	0.0091	1.55
60	1.6	2.7653	9.81	43.4041488	0.0093	1.6
65	1.65	2.7653	9.81	44.76052845	0.0096	1.65
70	1.7	2.7653	9.81	46.1169081	0.0099	1.7
75	1.75	2.7653	9.81	47.47328775	0.012	1.75
80	1.8	2.7653	9.81	48.8296674	0.0203	1.8
83	1.83	2.7653	9.81	49.64349519	0.0278	1.83
86	1.86	2.7653	9.81	50.45732298	0.0384	1.86

### III. ANALYTICAL RESULTS & DISCUSSIONS

#### Equivalent Static Analysis

##### Modal Mass Participation

Case	Mode	Time period	Ux	Uy	Rz
Modal	1	2.521	0	0.7549	0
Modal	2	1.958	0.7772	0	0
Modal	3	1.584	0	0	0.79

For equivalent static analysis according to IS1893:2016 (IndianStandards, Earthquake loading, 2016) the modal mass participation should be more than 60% for first three modes & pure translation as well as pure torsion will be in first three modes. From table no.4.1 it is proven that structure is achieving its modal mass participation in first three modes.

#### Response Spectrum Analysis

##### Base Shear Reactions

Output Case	Case Type	FX kN	FY kN
EQ X	LinStatic	-14672.5997	0
EQ X	LinStatic	-14672.5997	0



EQ X	LinStatic	-14672.5997	0
EQY	LinStatic	0	-14253.3826
EQY	LinStatic	0	-14253.3826
EQY	LinStatic	0	-14253.3826
RSP X	LinRespSpec	14671.56	0
RSP Y	LinRespSpec	0	14252.2477

For response spectrum analysis it is important that base shear for earthquake loading in X & Y direction should be matched to base shear of response spectrum loading for X as well as Y direction.

In table it is found that the base shear is nearly matched by applying suitable scale factor in ETABS analytical

#### IV. CONCLUSION AND RECOMMENDATIONS

##### Incremental Dynamic Analysis

IDA curves demonstrate the inter story drift ratio changes with respect to earthquake excitations. For the various earthquake intensities observed in the past are applied onto the G+10 story flat slab structures and curves plotted. In all the above graphs, the drift is increasing in multiples for a slight change in increase of intensity measure after a certain point i.e., increment in spectral acceleration by 1% or 2%. This shows that structure is going into the collapse state.

##### Fragility Curves

The different damage states corresponding to earthquakes excitations are classified as immediate occupancy (IO), life safety (LS), collapse prevention (CP). Fragility curves demonstrates the damage states of a building pushed to failure to the corresponding excitations of earthquake.

The curve is plotted for three performance limit states as immediate occupancy, life safety & collapse prevention from FEMA 356 design code. The maximum limits for each limit state are taken as follows;

Limits for Performance states

Immediate Occupancy (IO)	1% of Height	0.355
Life Safety (LS)	2% of Height	0.700
Collapse Prevention (CP)	4% of Height	1.420

From figure the immediate occupancy curve, it is observed that the structure is crossing its limit with a probability of 80%.

From figure the life safety curve, it is observed that the structure is crossing its limit with a probability of 60%.

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