INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

IJARIIT

ISSN: 2454-132X
Impact factor: 4.295
(Volume 4, Issue 2)
Available online at: www.ijariit.com

Incremental dynamic analysis and static pushover analysis of existing RC framed buildings using the seismostruct software

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ABSTRACT

Civil Engineering structures are designed to withstand environmental forces like earthquake, along with gravity loads. These forces are random and dynamic in nature. Therefore the response of the structure is also dynamic and that is what causes the unsafe and uncomfortable conditions.

So, performance based analysis of the structure is required which can be achieved by Incremental Dynamic Analysis (IDA) as well as static pushover analysis (SPA). But, incremental dynamic analysis is quite accurate and actual response of the structure of the structure from the particular considered earthquake can be obtained by this method. It involves performing a series of nonlinear dynamic analyses in which the intensity of the ground motion selected for the collapse investigation is incrementally increased until the global collapse capacity of the structure is reached.

In the present work, incremental dynamic analysis of reinforced concrete G+6 and G+11 building is carried out. IDA curves are developed with respect to peak ground acceleration. Performance stages of the buildings such as yielding and collapse are defined with respect to peak ground acceleration of the considered earthquake from the IDA curve.

Building susceptibility that is whether the building can sustain the particular considered earthquake or not is found out using IDA.

Also, serviceability criterion for inter-storey drift ratio from IS 1893:2002 is checked from the IDA.

Static push over analysis of both the G+6 and G+11 building is also carried out. From the static push over analysis, graph of base shear to top displacement is plotted. From the graph, base shear capacity of the building is found out. Base shear capacity of both the buildings is also found out using IDA and capacity curve of base shear to top displacement from IDA is compared with that of SPA.

Keywords: *Seismic analysis, Incremental dynamic analysis, Static Pushover analysis.*

1. INTRODUCTION

1.1 Relevance

Numerous reinforced concrete frame buildings have partially or totally collapsed during the 2001 Bhuj earthquake. The world Housing Encyclopedia Report presented by EERI mentions that RC building with brick masonry infill walls design for gravity loads performed very poorly during the Bhuj earthquake of January 2001 in which several thousand such a buildings collapsed. The collapse was not limited to the epicentral region. About 75 RC frame buildings collapsed and several thousand others were damaged in and around Ahmadabad, which is over 250 km from the epicenter, clearly demonstrating the seismic vulnerability of these constructions. Past earthquakes occurring in Europe (Campania, Italy 1980; Umbria/Marche, Italy 1987; Kocaeli, Turkey 1999; Athens, Greece 1999; Molise, Italy 2002) have Shown that existing RC buildings constructed are seismically deficient due to lack of seismic design provisions in the codes aimed to provide structural ductility behavior.

Recent earthquakes have shown that research in earthquake engineering has to be focused on the assessment of vulnerability of existing constructions lacking appropriate seismic resisting characteristics. In fact, older buildings design and constructed until the late 1980's, without considering the earthquake provisions, constitute a significant hazard in many cities. Most of the older buildings had been design and constructed before the adoption of recent seismic codes. In addition, many new buildings in developing countries are not designed and/or constructed according to the provisions of these seismic codes due to several socio economical reasons. Current Indian codes do not address the evaluation of seismic resistance of existing building stock, which may not have designed for earthquake forces. An appropriate level of safety needs to be ensured for occupants of these buildings through strengthening measures, if found deficient. Existing buildings not design in accordance with the philosophies of current seismic codes need to be assessed for their expected seismic performance in future earthquakes. In earthquake resistant design of R.C. structures, it is generally necessary to permit some degree of dampness; otherwise the design would be too costly. In order to implement this philosophy properly, models for assessing structural damage within the context of a random earthquake environment are required. Thus existing R.C. buildings which has seismic deficiency must assessed properly and strengthen by retrofitting techniques so that it will ensure safety to the occupants.

1.2 General

Incremental dynamic analysis (IDA) is recently emerged as a powerful mean to study the overall behaviour of structures, from their elastic response through yielding and nonlinear response and all the way to global dynamic instability. An incremental dynamic analysis involves performing a series of nonlinear dynamic analyses in which the intensity of the ground motion selected for the collapse investigation is incrementally increased until the global collapse capacity of the structure is reached. It also involves plotting a measure of the ground motion intensity (peak ground acceleration) against a response parameter such as peak inter-story drift ratio. When the slope of the IDA curve changes from linear to nonlinear, yield stage is considered to be reached. Collapse capacity of the structure is considered to be reached when the IDA curve becomes significantly flat or nonlinear slope is less than 20% of elastic slope (Vamvatsikos D and Cornell A, 2002). As different ground motions (i.e., ground motions with different frequency content and different durations) lead to different intensity versus response plots, the analysis is repeated under different ground motions to obtain meaningful statistical averages. IDA is used as a basis for a comparative Performance-Based Earthquake Engineering (PBEE) assessment. The initial step is to model RC Frame using nonlinear dynamic analysis subjected to few selected earthquake records. Responses in terms of displacements, inter-story drift, base shear are examined statistically and IDA curves are plotted.

IDA can be performed when the model and ground motions records are selected. To begin with the IDA, the selected earthquake records are required to be scaled gradually from a low intensity measure (IM) to a high intensity measure, giving an earthquake large enough to cause collapse of the Structure. For each increment of IM, a nonlinear dynamic time history analysis is performed. Analyses are continued until structural collapse occurs at a very high IM.

1.3 Motivation

1. The response of structures deforming into their inelastic range during intense ground shaking is of central importance in earthquake engineering. This performance based study of the structure can be efficiently done by Incremental Dynamic Analysis.

2. From the IDA curve, performance stages such as yielding and collapse can be defined.

3. We can find out whether the building is susceptible to the particular considered earthquake or not.

4. We can take decisions regarding the dimensions of structural elements so as to achieve more strength if required in case of stronger earthquake in that region.

1.4 Objectives

1. To carry out the incremental dynamic analysis of existing RC building.

2. To calculate probability of yielding and probability of collapse with respect to peak ground acceleration.

3. To decide whether the building can withstand the particular considered earthquake or not.

4. To study the building serviceability to the considered earthquake.

5. To compare the response of the structure from incremental dynamic analysis with that of static pushover analysis.

1.5 Scope of Work

This work includes the performance based evaluation of the RC buildings by using incremental dynamic analysis. Building susceptibility to the particular considered earthquake is found out. Building serviceability to that earthquake is also studied. From the Incremental Dynamic Analysis, graph of base shear to top displacement and capacity curve is plotted. Behaviour of structure using the Incremental Dynamic Analysis is obtained using Seismostruct Software.

1.6 Methodology

a. Methods of research

To achieve the objective of the current study Three Seismostruct models are planned. The models will obtained under several selected earthquake ground motions using Seismostruct software. Seismic analysis is a subset of structural analysis and is a calculation of the response of a structure to earthquakes. It is a part of process of structural design, structural assessment and retrofit in regions where earthquakes are prevalent.

b. Sampling design and assumption

Based on earthquake intensities and magnitude, in India, there are four seismic zones. This type of study is essentially needed in the critical zones and therefore above stated problem is focused on these zones.

To achieve specific objectives three categories of multistoried buildings will be selected viz: Buildings up to five stories, buildings up to Ten stories and building above Ten stories.

As research based on existing reinforced concrete building with the help of structural drawings Steel and concrete properties such as yield strength of steel and compressive strength of concrete is selected then beam, column, slab thickness, depth of foundation is taken from the drawing and model is prepared with this available data in STADD-Pro Software and design is checked for Dead load, Live load, Seismic load & various combinations. Dead load and live load is applied as per IS 875.

Load combinations given in IS 1893-2000 are considered for the earthquake resistant design of building. If design is obtained safe then models are prepared in Seismostruct Software version 7.0.3, Then Incremental dynamic analysis & Static Pushover analysis is carried out in SeismoStruct software for the designed reinforcement.

c. Methods of data collection:

The necessary data is collected by

1. Primary data is collected from reviewing Literature.

2. Earthquake data for dynamic analysis is collected from Earthquake Research Centres, like National Geophysical Research Centre (Council of Scientific and Industrial Researches.), Hyderabad.

3. Data from I.S. Codes, Seismic handbooks

4. Data regarding architectural and structural plans of existing multi-storeyed building is collected from site situated in Wagholi Pune.

2. LITERATURE REVIEW

2.1 Introduction

Incremental dynamic analysis is a new emerging technique to study the behaviour of structure. This chapter presents a literature review confining to the areas of incremental dynamic analysis and static pushover analysis.

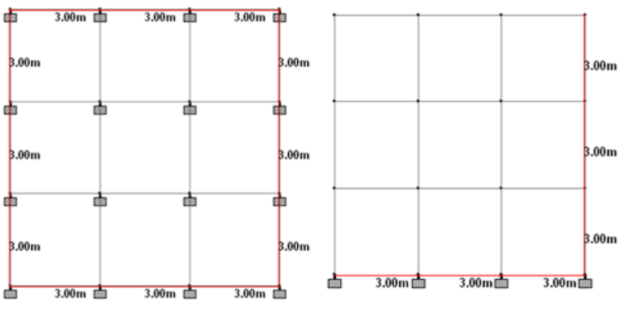
2.2 Research Review

Research works on seismic performance of RC building with shear wall and diagrid has been done many investigators in research area as;

Maniyar M., (2009) [1] performed the Incremental Dynamic Analysis of 2 storey RCC frame using 14 different time history data by using IDARC-2D program and IDA curves are plotted and probabilistic analysis of the building is carried out. The author has performed the IDA of the 2 storey RCC building with varying steel percentage in column and beam elements as shown in Table 2.1.

The performance based study is useful to the designer as following –

- Seismic hazard analysis of the building
- Response of building
- Nonlinear analysis of the structure to evaluate the performance of the structure.
- Financial risk assessment



(a) Plan **(b) Elevation**

Figure 2.1 (a) Plan and (b) Elevation of the building

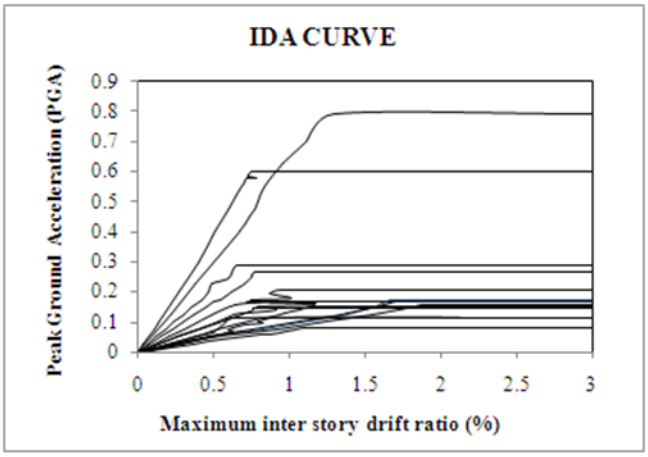


Figure 2.2 IDA curve for Type1 structure

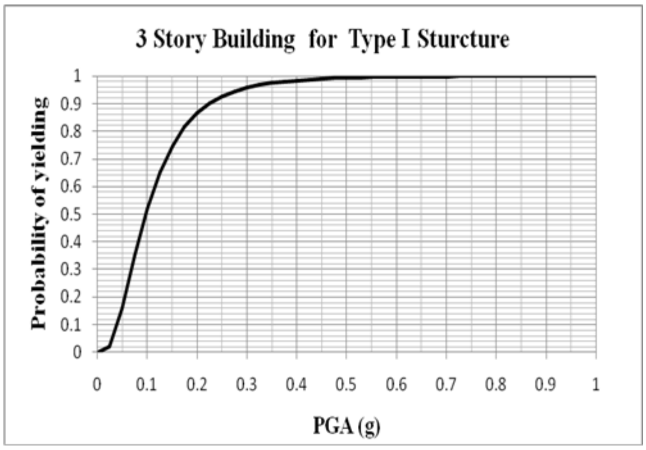


Figure 2.3 Fragility Curve for Type1 structure

Vamvatsikos D. and Cornell C., (2002) [2] performed the incremental dynamic analysis of 9 storey steel moment resisting frame. Twenty different time histories are applied to the structure to carry out IDA. Application of Incremental Dynamic Analysis to Performance-Based Earthquake Engineering (PBEE) is studied and limit states such as immediate occupancy, collapse prevention are defined.

Asgarian B., Sadrinezhad A., (2010) [3] performed IDA to obtain Seismic Performance Evaluation of steel moment resisting frame. Three types of moment resisting frames namely Special, Intermediate and Ordinary Moment Frames, each of which has certain level of ductility are considered for the analysis. Comparative studies on seismic performance of these three different structures are performed in this study.

Mwafy A., Elnashai A., (2001) [4] compared the results of nonlinear static analysis to nonlinear dynamic analysis of 12 reinforced concrete buildings of different characteristics. IDA is used to prepare dynamic push over envelopes and compare these with static pushover results.

Seismic Performance Assessment of Buildings (FEMA P-58-1, Volume 1 – Methodology, 2012) [5] - This code describe the resulting methodology as well as the development of basic building information, response quantities, fragilities, and consequence data used as inputs to the methodology.

Mander J., Dhakal R., Mashiko N. and Solberg K., (2007) [6] Incremental dynamic analysis applied to seismic financial risk assessment of bridges

Giordano A., Guadagnuolo M. and G.Faella (2008), [7] investigates the seismic response of plan irregular masonry building structures in order to evaluate the magnitude of torsional coupling and the applicability of 3D Push analysis for assessing the behavior under earthquakes. A two storey masonry building having un symmetric plan is selected for analysis. Nonlinear static and dynamic analysis is carried out using refined Finite Element approach. The Pushover analysis is carried out using a lateral load distribution proportional to the masses distribution within walls and floors.

Dhimen Basu and Sudhir K. Jain (2004) [8] studied seismic analysis of asymmetric buildings with flexible floor diaphragm.

Dorde Ladinovic (2008) [9] presented nonlinear seismic analysis of asymmetric plan buildings. The inelastic seismic behavior of asymmetric-plan buildings is considered using the histories of base shear and torque.The procedure to construct the base shear and torque (BST) surface of system with an arbitrary number of resisting elements in the direction of asymmetry and of ground motion is proposed.

Peter Fajfar,M.EERI (2000) [10] presented a relatively simple nonlinear method for the seismic analysis of structures. It combines the push over analysis of multi-degree of freedom (MDOF) model with response analysis of an equivalent single-degree-of freedom (SDOF) system. The method is formulated in the acceleration-displacement format, which unable the visual interpretation of the procedure and of the relations between the basic quantities controlling the seismic response.

Mao Jianmeng, zhai changhai and xie Lili (2008) [11] presented an improved model push over (MPA) procedure to estimate the seismic demands of structures, considering the redistribution of inertia forces after the yields. This procedures is verified with numerical examples of five, nine and twenty two story buildings. It is concluded that the improved MPA procedure is more accurate than either push over analysis or MPA procedure.

2.3 Summary

Incremental dynamic analysis is a powerful tool to study the performance based study of the structure. Yielding and collapse stages can be defined on the IDA curve. Numbers of time histories are applied to study the behavior of structure. Response of the structure getting from incremental dynamic analysis is actual response of building subjected to considered earthquake. Structural response, financial losses, damage outcomes can be calculated from incremental dynamic analysis.

3. SYSTEM DEVELOPMENT

3.1 Steps involved in Incremental Dynamic Analysis

1) Appropriate modeling of the building
2) Selection of intensity measure of earthquake like peak ground acceleration
3) Selection of response measure like interstorey drift ratio, base shear
4) Selection ground motions according to zone the building is situated in.
5) Generation of IDA curves by interpolation
6) Plotting of Fragility Curves

3.2 Incremental Dynamic Analysis of G+1 story building

A RCC frame of three story with three bays of 3.00m each in both the directions and 3m floor height is considered for validation of results with Maniyar [7]. Building is assumed to be situated in earthquake zone IV in India. Column frames are assumed as fixed on ground. All columns are 300 x 300 mm in size and 3.00 m high with steel reinforcement of 8 bars of diameter 12mm. All beams are 200 x 300 mm with steel reinforcement of 4 bars of diameter 12mm. The concrete considered is having compressive strength 25 N/mm2 and the reinforcement is of grade Fe415. Finite element program used for the analysis is SeismoStruct version 7.0.3. Incremental dynamic analysis is carried out and peak ground acceleration (PGA) values are noted down at which IDA curve is becoming flat i.e. for small amount of increase in the ground motion; there is a large amount of increase in the building response. These PGA values are considered as collapse points. Values of PGA in Table 3.1 are that of collapse stage.

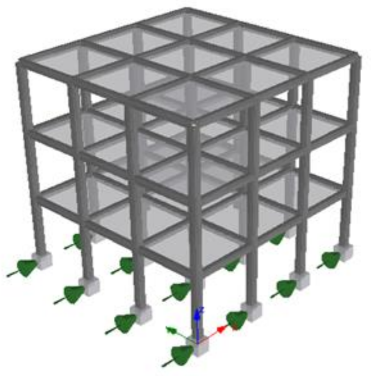


Figure 3.4 Model of the building

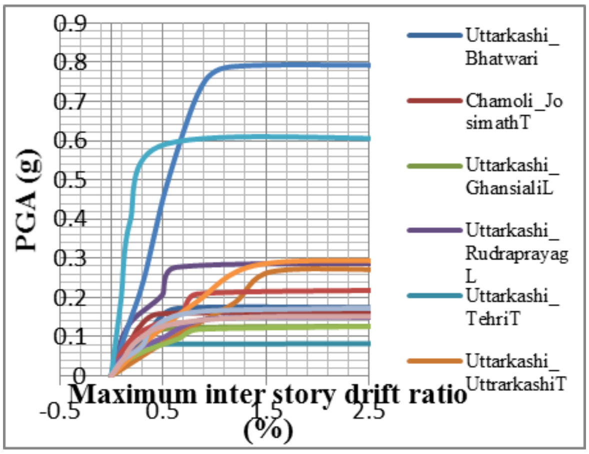


Figure 3.5 IDA curves (present study)

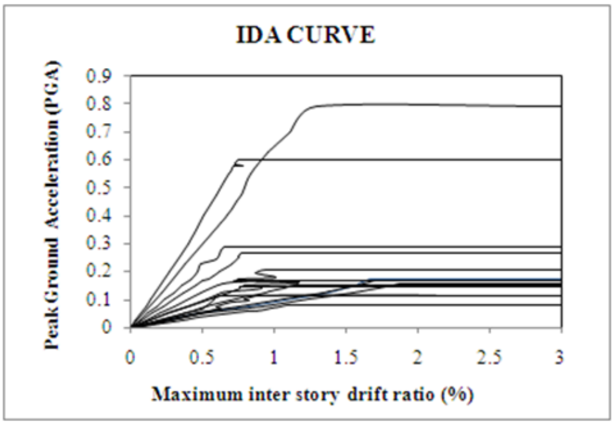


Figure 3.6 IDA curves plotted by Maniyar (2009)

Table 3.1 Collapse peak ground acceleration

Earthquake	Station	Maniyar (2009)		Present Work	
		PGA (g)	Maximum inter story drift ratio (%)	PGA (g)	Maximum inter story drift ratio (%)
1991 Uttarkashi	Bhatwari T	0.17	1.66	0.17	1.61
1999 Chamoli	Joshimath T	0.16	1.87	0.16	1.72
1992 Uttarkashi	Ghansiali L	0.12	0.62	0.12	0.79
1992 Uttarkashi	Rudraprayag L	0.29	0.65	0.29	0.73
2001 Uttarkashi	Tehri T	0.08	1.09	0.08	0.95
2003 Uttarkashi	Uttarkashi T	0.27	0.77	0.27	0.81
1986 Dharmshala	Bandlakhas L	0.79	1.29	0.79	1.16
1997 India-burma border	Doloo T	0.21	0.93	0.21	0.83
1997 India-burma border	Katakhal L	0.12	0.91	0.12	0.84
1997 India-burma border	Katakhal T	0.15	1.14	0.15	1.05
1997 India-burma border	Pynursla L	0.60	0.75	0.59	0.65
1997 India-burma border	Silchar L	0.17	0.76	0.28	0.71
1997 India-burma border	Silchar T	0.17	1.69	0.17	1.65
1995 Dharmshala	Sihunta T	0.15	0.76	0.15	0.72
Median		0.17	0.92	0.17	0.84

3.3 Incremental Dynamic Analysis of G+6 story building

3.3.1 Building Description

Floor Height = 3.5m

Column Dimension = (230 x 650) mm

Beam Dimension = (230 x 500) mm

Slab thickness = 150 mm

Building Location = Zone IV

Boundary Condition = fixed on ground

Material properties = M25, Fe415

Depth of Foundation = 3m

Size of Column 230X650 steel 8#16

Size of Beam 230X500 steel 3#16 at top, 3#16 at bottom

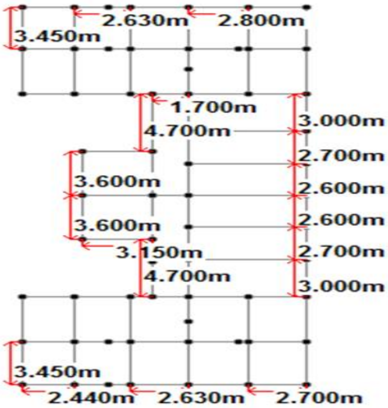
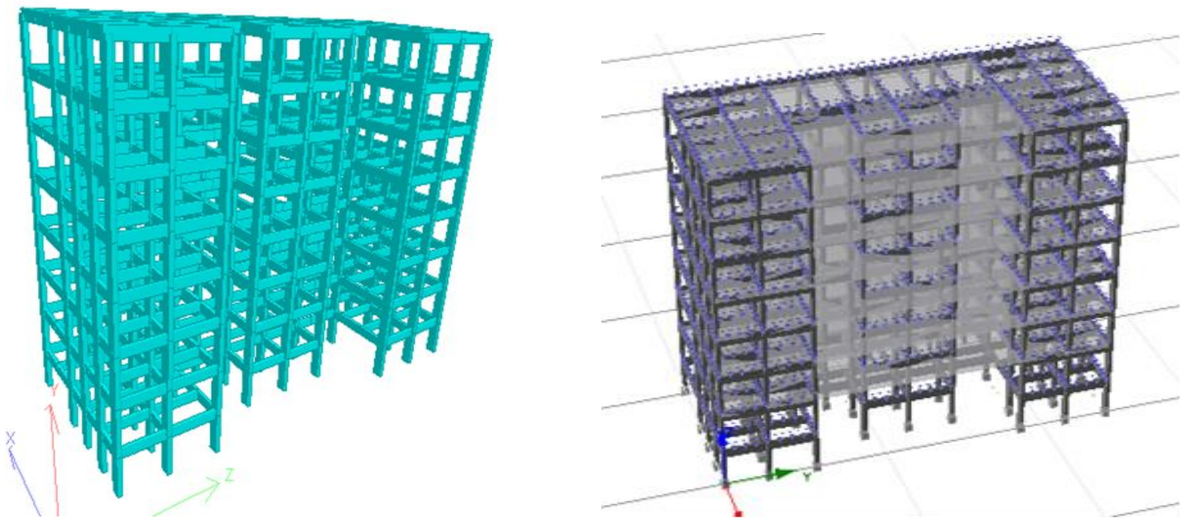


Figure 3.9 plan of G+6 building (With Dimensions)



(a) **(b)**

Figure 3.10 (a) STADD-PRO model (b) SeismoStruct model of G+6 Building

3.4 Incremental Dynamic Analysis of G+11 story building

3.4.1 Building Description

The procedure for analyzing G+6 building is followed to carry out the incremental dynamic analysis of G+11 building.

Building information is given below

Floor Height = 3.5 m

Column Dimension = (300 x 750) mm steel 14#20

Beam Dimension = (230 x 750) mm steel 3#25 straight extra, 2#25 Curtail @450, 4#16 midspan extra, 4#16 at end support

Slab thickness = 180 mm

Building Location = Zone IV

Boundary Condition = fixed on ground

Material properties = M25, Fe500

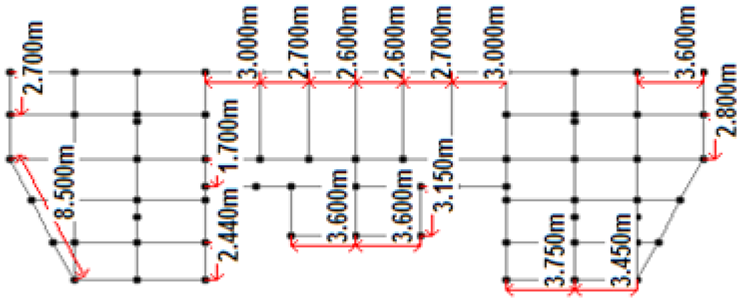
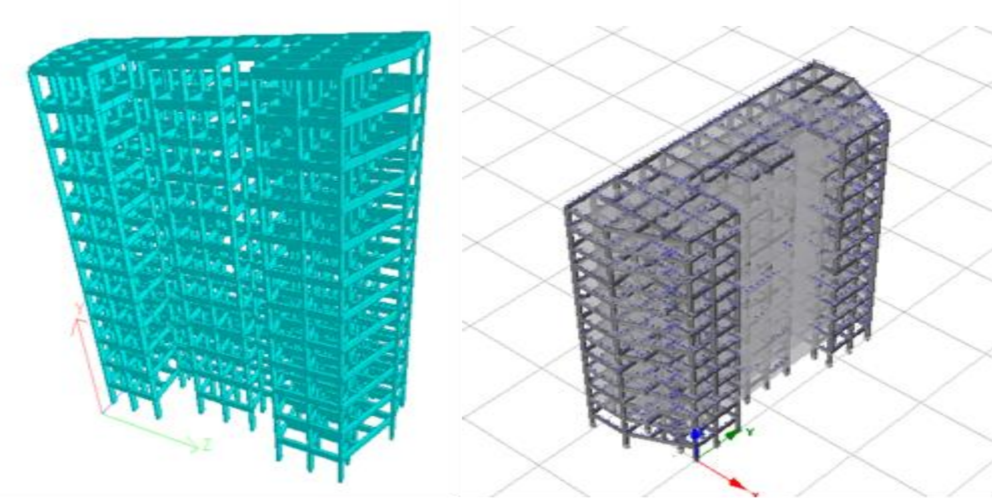


Figure 3.14 Plan of G+11 building (With Dimensions)



(a) **(b)**

Figure 3.15 Model of the building (a) STADD-PRO model (b) SeismoStruct model

3.5 Summary

First IDA of G+1 building is carried out in SeismoStruct software and results are validated with Maniyar [7]. Then, IDA of G+6 and G+11 building is also carried out in SeismoStruct. IDA curves are plotted for applied time histories. Generalized graph of both the buildings is also plotted. Yielding stage and collapse stage with respect to peak ground acceleration are determined for both the buildings.

Lastly, fragility curves denoting the extent of yielding and collapse with respect to peak ground acceleration is also plotted.

4. BUILDING SUSCEPTIBILITY PREDICTION

4.1 General

Incremental dynamic analysis is a powerful tool to study the performance based earthquake study. Various stages such as yielding and collapse can be defined with respect to peak ground acceleration by using IDA curve as stated in previous chapter. A generalized IDA curve is also plotted considering the effect of number of time histories. From the IDA curve, we can determine whether the given structure can sustain a particular earthquake or not. If the scaled PGA at yield and collapse is more than the original un-scaled PGA of the considered earthquake, we can say that the given structure can sustain a particular considered earthquake.

4.2 Building susceptibility of G+6 building

Table 4.1 Yield and collapse peak ground acceleration of G+6 building

Time History	Station	PGA (g)	Yield PGA(g) X direction	Collapse PGA(g) X direction	Yield PGA(g) Y direction	Collapse PGA(g) Y direction
2001 Bhuj	Bhuj L	0.11	0.33	0.41	0.30	0.37
1991 Uttarkashi	Uttarkashi T	0.26	0.30	0.36	0.31	0.39
1967 Koyna	Koyna L	0.34	**0.19**	**0.25**	**0.20**	**0.27**
1991 Uttarkashi	Bhatwari T	0.25	0.30	0.39	0.29	0.41
1967 Koyna	Koyna T	0.40	**0.21**	**0.29**	**0.22**	**0.35**
1986 Dharmshala	Dharmshal L	0.17	0.39	0.43	0.41	0.44
1986 Dharmshala	Dharmshala T	0.18	0.29	0.38	0.26	0.37
1995 Chamba	Chamba L	0.14	0.28	0.35	0.30	0.38
1995 Chamba	Chamba T	0.12	0.28	0.41	0.28	0.37
Median			0.29	0.37	0.29	0.38

4.3 Building susceptibility of G+11 building

Table 4.2 Yield and collapse peak ground acceleration of G+11 building

Time History	Station	PGA (g)	Yield PGA(g) X direction	Collapse PGA(g) X direction	Yield PGA(g) Y direction	Collapse PGA(g) Y direction
1995 Chamba	Chamba L	0.14	0.67	0.75	0.57	0.71
1995 Chamba	Chamba T	0.12	0.66	0.74	0.53	0.72
1986 Dharmshala	Dharmshala L	0.17	0.62	0.77	0.51	0.75
1986 Dharmshala	Dharmshala T	0.18	0.60	0.76	0.54	0.70
1995 India-Burma border	Katakhal L	0.14	0.60	0.72	0.57	0.67
1995 India-Burma border	Katakhal T	0.16	0.63	0.76	0.58	0.71
1991 Uttarkashi	Bhatwari T	0.25	0.58	0.63	0.50	0.65
1967 Koyna	Koyna L	0.34	0.56	0.74	0.53	0.72
1967 Koyna	Koyna T	0.40	0.53	0.67	0.52	0.58
Median			0.61	0.73	0.53	0.69

5. INCREMENTAL DYNAMIC ANALYSIS

5.1 General

In this chapter, building capacity is found out by using incremental dynamic analysis. Graph of base shear to top displacement from incremental dynamic analysis is plotted. Capacity base shear from Incremental dynamic analysis method for G+6 and G+11 building is calculated.

5.1.1 Incremental Dynamic Analysis of G+6 building

Above procedure is followed to find out the collapse base shear of G+6 building by using incremental dynamic analysis. Table 6.1 shows the yield and collapse base shear of G+6 building from incremental dynamic analysis.

Table 6.1 Yield and collapse base shear

Time History	Station	Yield Base Shear) X direction	Collapse Base Shear (kN) X direction	Yield Base Shear (kN) Y direction	Collapse Base Shear (kN) Y direction
2001 Bhuj	Bhuj L	1400	1990	1450	2100
1991 Uttarkashi	UttarkashiT	1370	1920	1410	2080
1967 Koyna	Koyna L	1500	2190	1575	2210
1991 Uttarkashi	BhatwariT	1450	1880	1480	1930
1967 Koyna	KoynaT	1380	1890	1400	1930
1986 Dharmshala	DharmshalL	1510	1920	1575	1980
1986 Dharmshala	DharmshalaT	1280	1820	1350	1870
1995 Chamba	ChambaL	1345	1830	1360	1900
1995 Chamba	ChambaT	1330	1850	1390	1880
Median		1375	1885	1405	1950
Base Shear (IS:1893)		850		880	

5.1.2 Incremental Dynamic Analysis of G+11 building

Table 6.2 Yield and collapse base shear of G+11 building

Time History	Station	Yield Base Shear (kN) X direction	Collapse Base Shear (kN) X direction	Yield Base Shear (kN) Y direction	Collapse Base Shear (kN) Y direction
1995 Chamba	ChambaL	4178	4750	3744	4492
1995 Chamba	ChambaT	3868	4870	3600	4450
1986 Dharmshala	DharmshalaL	3992	4912	3234	4059
1986 Dharmshala	DharmshalaT	4125	5031	3310	4300
1995 India-Burma border	KatakhalL	4150	4600	3656	4100
1995 India-Burma border	KatakhalT	4010	4950	3510	4145
1991 Uttarkashi	BhatwariT	4135	4987	3467	4400
1967 Koyna	KoynaL	3956	5056	3765	4612
1967 Koyna	KoynaT	4100	5145	3489	4687
Median		4100	4950	3510	4400
Base Shear (IS:1893)		2100		1770	

5.1.3 Static Pushover Analysis in SEISMOSTRUCT

SEISMOSTRUCT, the finite element program works with complex geometry and monitors deformation at all hinges to determine ultimate deformation.The analysis in SEISMOSTRUCT involves following steps:

1) Creating the basic computer model in SEISMOSTRUCT Software

2) Define properties and acceptance criteria for the pushover hinges.

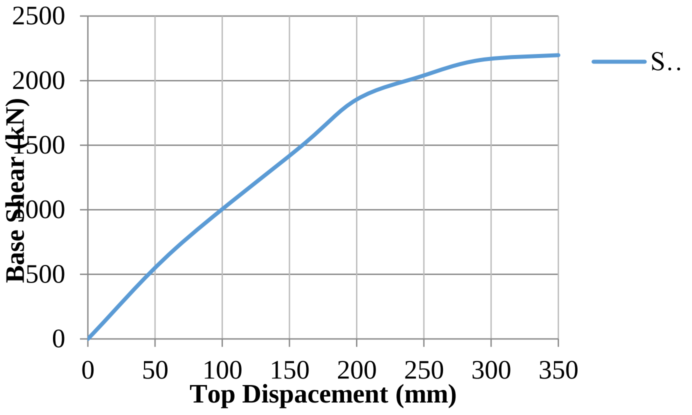
3) Locate the pushover hinges on the model.

4) Define the pushover load cases. Typically a gravity load pushover is force controlled and lateral pushovers are displacement controlled.

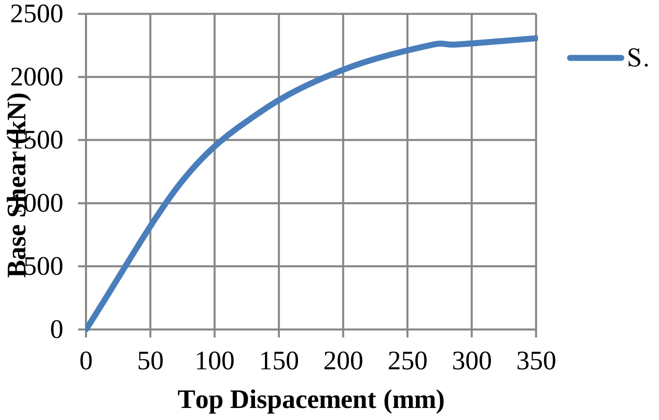
5) Run the basic static pushover analysis.

6) Display the pushover curve and the table.

5.1.4 Static Pushover Analysis of G+6 Building



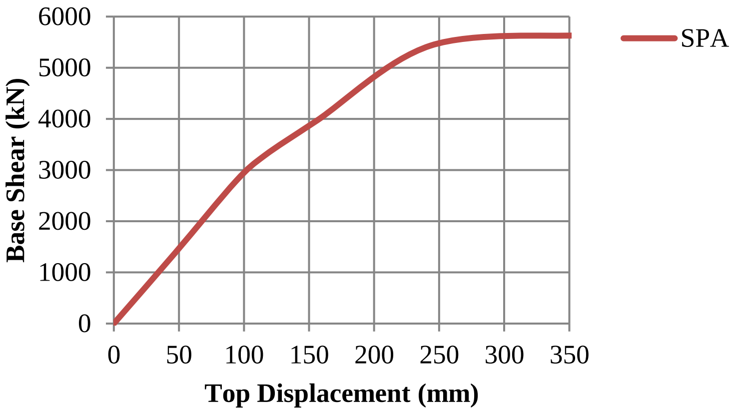
(a)



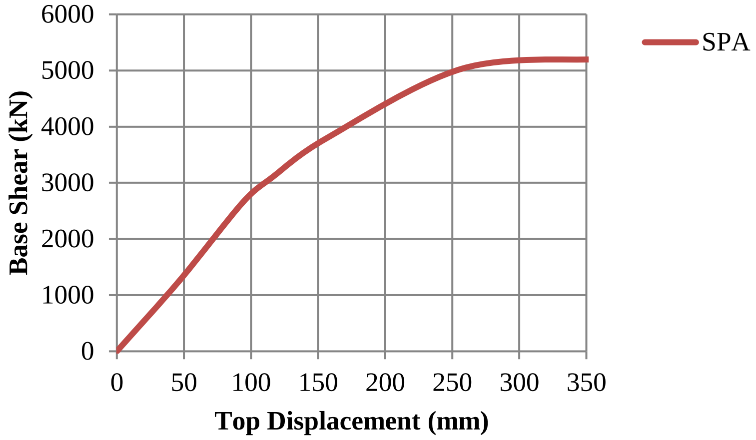
(b)

Figure 6.6 Graph of Base shear to top displacement of G+6 building by Static Pushover Analysis for lateral force in (a) X direction (b) Y direction

5.1.5 Static Pushover Analysis of G+11 Building



(a)



(b)

Figure 6.7 Graph of Base shear to top displacement of G+11 building by Static Pushover Analysis for lateral force in (a) X direction (b) Y direction

5.2 Comparison between Incremental Dynamic Analysis (IDA) and Static Pushover Analysis (SPA).

Table 6.3 shows the collapse base shear of both G+6 and G+11 building by static pushover analysis and incremental dynamic analysis.

Table 6.3 Collapse base shear capacity (kN)

Building	Collapse base shear (kN) X direction			Collapse base shear (kN) Y direction		
	IDA	SPA	Base Shear (IS: 1893)	IDA	SPA	Base Shear (IS: 1893)
G+6	1885	2200	850	1950	2300	880
G+11	4950	5640	2100	4400	5200	1770

Building base shear capacity by both the methods is more than base shear for which the building was actually designed as per the load combinations given in IS 1893: 2000.

Base shear capacity by IDA method is observed to be lesser than that of SPA method.

6. SUMMARY AND CONCLUSION

6.1 Summary

In this study, incremental dynamic analysis is used to study the performance based analysis of the structure. First, the buildings are designed in SEISMOSTRUCT. For the building frame, seismic coefficient and response spectrum analysis is carried out along with dead load and live load combinations. Dead load and live load is applied as per IS 875. Load combinations given in IS 1893-2000 are considered for the earthquake resistant design of building. Incremental dynamic analysis is carried out in SeismoStruct for the designed reinforcement.

While carrying out incremental dynamic analysis, number of time histories are applied. Response of the structure like interstorey drift ratio, base shear is found out for the scaled time histories. IDA graph of peak ground acceleration to interstorey drift ratio (%) is plotted for every time history applied. Yielding and collapse stages are defined with respect to peak ground acceleration.

Fragility curves denoting the extent of yielding and collapse with respect to peak ground acceleration are also plotted.

Building susceptibility i.e. whether the building can sustain the considered earthquake or nor is found out using IDA. Building serviceability under working loads is also studied.

Building capacity is found out using incremental dynamic analysis and static pushover analysis. Base shear capacity from IDA is compared with that of SPA.

Following are the observations and conclusions that can be drawn from the study-

6.2 Observations

1. From the IDA curve, we can study the behaviour of building under a particular earthquake and define the performance stages of the structure such as yield and collapse.

2. If the yield and collapse acceleration of the structure for the considered earthquake is more than the original un-scaled acceleration, we can say that building sustains the considered earthquake. In this study; G+6 building sustains all the earthquakes except Koyna L and Koyna T. So, stiffness of the structure needs to be increased i.e. column dimensions need to be increased. For the G+11 building considered in this study, building is safe from all the earthquakes.

3. Next, serviceability criteria given in IS 1893:2000 is also taken into consideration in the analysis. G+6 building fails to satisfy the serviceability criteria while G+11 building satisfies the serviceability criteria.

4. Fragility curves denoting percentage of yielding and collapse for the G+6 and G+11 building are also plotted. These curves denote the percentage of yielding and collapse with respect to peak ground acceleration of the considered earthquakes.

5. Lastly, base shear to top displacement graph from incremental dynamic analysis is compared with that of static pushover analysis. Static pushover analysis gives higher values of base shear than from incremental dynamic analysis.

6.3 CONCLUSIONS

Building susceptibility can be easily studied using incremental dynamic analysis. We can find out whether the building can fail to the considered earthquake or not. Building serviceability to the considered earthquake can also be easily studied using this method. If building is failing to the considered earthquake or failing to satisfy the criteria of serviceability, stiffness of the structure needs to be increased by increasing column dimensions.

Pushover analysis is a static nonlinear procedure in which the magnitude of the structural loading along the lateral direction of the structure is incrementally increased in accordance with a certain pre-defined pattern and response of the building is studied. Incremental dynamic analysis is accurate than static pushover analysis because response of the structure is plotted by applying actual available earthquake data. So, response of the building from incremental dynamic analysis is actual response generated from the considered earthquake. Incremental dynamic analysis is tedious and very much time consuming, if the structure is of much importance and high accuracy is needed, then only incremental dynamic analysis is preferred.

6.4 FUTURE SCOPE

In this work, different earthquakes are applied to building, earthquake data is incremented and response of building is plotted at each time. Yielding and collapse stages of the building are plotted with respect to peak ground acceleration of the considered earthquake.

For the building location considering zone of earthquake, time histories should be selected and response spectrum curve should be plotted for each time history. Now, this curve can be incremented and response can be studied. Yielding and collapse stages to be plotted will be with respect to spectral acceleration.

Demand curve and capacity curve can be plotted and performance point can be identified for various time histories by incremental dynamic analysis. Same curve can be plotted by static pushover analysis and compared with that of IDA. In this way, building capacity can be found out using both the methods.

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