Incremental Dynamic Analysis of RC Framed Buildings

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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.Static push over analysis of both the G+7 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- Incremental Analysis Of RC Framed Structure, Incremental Analysis Of G+7 And G+11 Storied Building , Building Susceptibility Prediction , Static Pushover Analysis of G+7 and G+11 building, summary, conclusion, Future Scope.

I. INTRODUCTION

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.

1. Nonlinear Dynamic Analysis

Nonlinear dynamic analysis utilizes the combination of ground motion records with a detailed structural model, therefore is capable of producing results with relatively low uncertainty. In nonlinear dynamic analyses, the detailed structural model subjected to a ground-motion record produces estimates of component deformations for each degree of freedom in the model and the modal responses are combined.

2. Static Pushover Analysis

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. It is generally assumed that the behaviour of the structure is controlled by its fundamental mode and the predefined pattern is expressed either in terms of story shear or in terms of fundamental mode shape.

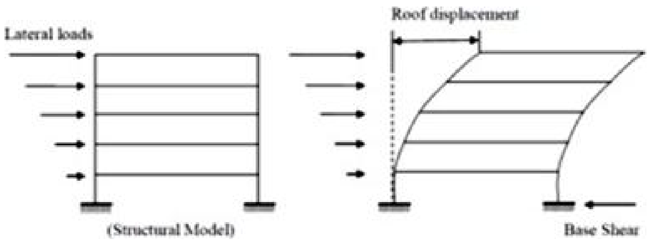


Figure1:-Static approximations in Pushover analysis

3. Motivation

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.

II. OBJECTIVES

- To carry out the incremental dynamic analysis of existing RC building.
- To calculate probability of yielding and probability of collapse with respect to peak ground acceleration.
- To decide whether the building can withstand the particular considered earthquake or not.
- To study the building serviceability to the considered earthquake.
- To compare the response of the structure from incremental dynamic analysis with that of static pushover analysis.

III. 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.

IV. INCREMENTAL DYNAMIC ANALYSIS

General

Incremental dynamic analysis is a powerful tool to study the performance based analysis of the structure. Actual response of the building to the considered earthquake can be plotted by using this method. In this chapter, IDA of G+2 building is carried out to validate the results from the SeismoStruct software. Also, IDA of G+7 and G+11 building is carried out.

For plotting fragility curves, following equation is used (FEMA P-58-1, 2012)

$$P = \Phi\left[\frac{\ln(X) - \zeta}{\beta}\right] \quad (3.1)$$

Where,
Φ = Standard Normal Distribution
X = Lognormal distributed ground motion index
ζ = Mean of ln(X)
β = Standard Deviation of ln(X)

(a) Newmark-β method

Newmark-β method is the most popular method for earthquake response analysis because of its superior accuracy.Differential equation of motion is given by

$$m\ddot{u}_i + c\dot{u}_i + ku_i = P_i \quad (3.2)$$

The numerical procedures like average acceleration method and linear acceleration method will enable us to determine quantities such u_{i+1}, $\dot{u}_{i+1}$ and $\ddot{u}_{i+1}$ at the time i+1

$$m\ddot{u}_{i+1} + c\dot{u}_{i+1} + k\,u_{i+1} = P_{i+1} \quad (3.3)$$

Newmark (1959) developed a family of time stepping methods based on following equations:-

$$\dot{u}_{i+1} = \dot{u}_i + [(1-\gamma)\Delta t]\ddot{u} + (\gamma\Delta t)\ddot{u}_{i+1} \quad (3.4a)$$

$$u_{i+1} = u_i + (\Delta t)\dot{u}_i + [(0.5-\beta)(\Delta t)^2]\,\ddot{u}_i + [\beta(\Delta t)^2]\,\ddot{u}_{i+1} \quad (3.4b)$$

The parameters ϒ and β define the variation of acceleration over a time step and determine the stability and accuracy characteristic of the method. Typical selection for ϒ is 1⁄2 and $1/6 \leq \beta \leq 1/4$ is satisfactory for the accuracy. Equations (3.4a) and (3.4b) combined with the equilibrium equation (3.3) at the end of time step, provide the basis for computing u_{i+1}, $\dot{u}_{i+1}$, $\ddot{u}_{i+1}$ at time i+1 from the known u_i, $\dot{u}_i$ and $\ddot{u}_i$ at time i.

(b) Material Model

A bilinear steel model is used for reinforcement. Bilinear steel model consists of kinematic strain hardening. The elastic range remains constant throughout the various loading stages, and the kinematic hardening rule for the yield surface is assumed as a linear function of the increment of plastic strain.

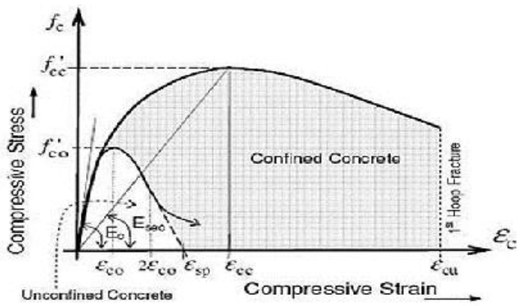


Figure2:-Confined Concrete Model by Mander, Priestley and Park (1988)

$$\varepsilon_{cc} = \varepsilon_{co}\{1 + 5[(f' / f_{co}') - 1]\}$$

$$fc = \frac{fcc'xr}{(r - 1 + xr)}$$

fcc’ = Compressive Strength of Confined Concrete
fco’ = Unconfined Concrete Strength(Corresponding strain **ε**co)

(b) Frame Elements

Inelastic Force Based Frame Element (infrmFB) is used for the columns and beams for the analysis. infrmFB is capable of modelling members of space frames with geometric and material nonlinearities. Stress-strain state of beam-column elements is obtained through the integration of the nonlinear uniaxial material response of the individual fibres in which the section has been subdivided, fully accounting for the spread of inelasticity along the member length and across the section depth.

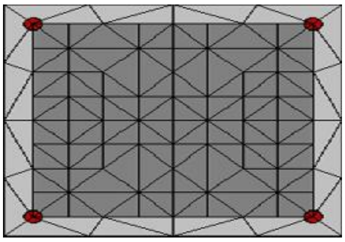


Figure3:- Section Discretization Pattern

Incremental Analysis of G+2 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/mm^2 and the reinforcement is of grade Fe415. Finite element program used for the analysis is SeismoStruct version 7.0.3.

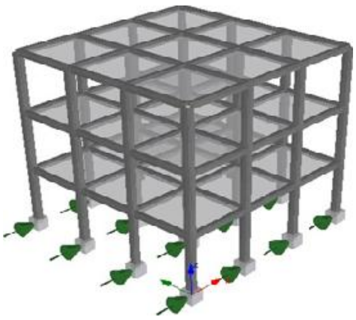


Figure4 :-Model of the building

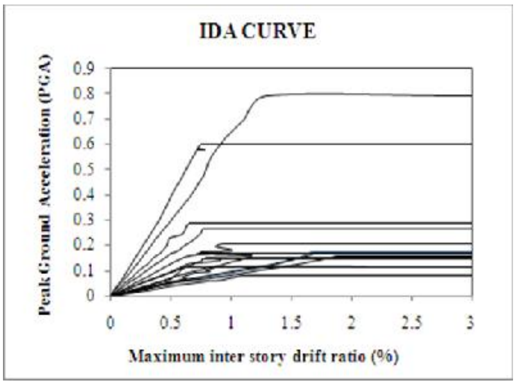


Figure5:- IDA curves plotted by Maniyar (2009)

Incremental Dynamic Analysis of G+7 storybuilding

- **Building Description**

Floor Height = 3mColumn Dimension = (230 x 650) mm Beam Dimension= (230 x 500)mm Building Location = Zone IV Boundary Condition = fixed on ground Material properties = M25, Fe415

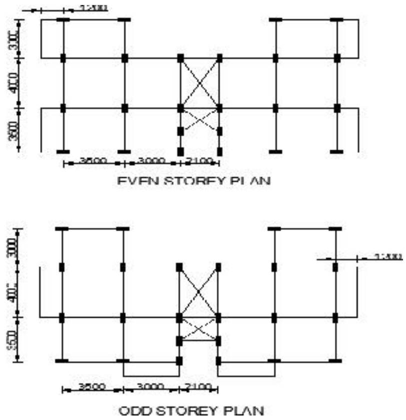


Figure6 :-Plan of G+7 building

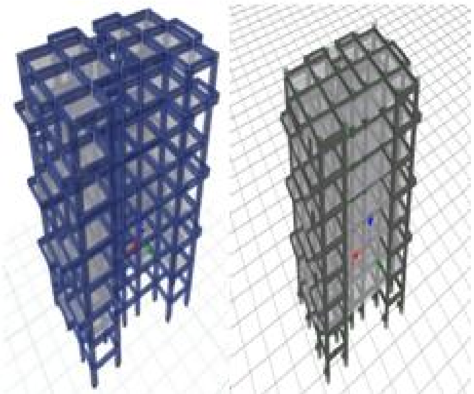
G+7 building is designed in ETABS and parameters such as interstorey drift ratio, floor acceleration, and base shear are found out. For the building frame, seismic coefficient and response spectrum analysis is carried out along with dead load and live load combinations.

Table1:-Column and beam dimensions and reinforcement

	Size (mm)	Steel
Column	230 x 650	8#16
Beam	230 x 500	3#16 at top 3#16 at bottom

Table2:-Column and beam dimensions andreinforcement

Mode	Time Period (sec)	Frequency (Hz)
1	0.72	1.38
2	0.60	1.67
3	0.58	1.72



a **b**

Figure7:(a)ETABS model (b) SeismoStruct model of G+7 Building

Incremental Dynamic Analysis:-

- Time Histories applied areNow these time histories are applied one by one to the structure and for each scale of time history data, response (maximum interstorey drift ratio (%)) is plotted to get IDA curve.IDA curve for one of the time history is plotted as shown in Figure.

Incremental Dynamic Analysis of G+11 story building

Building Description

The procedure for analyzing G+7 building is followed to carry out the incremental dynamic analysis of G+11 building.Building information is given below Floor Height = 3.2 mColumn Dimension = (300 x 750) mm Beam Dimension = (300 x 600) mm Slab thickness = 180 mmBuilding Location = Zone IV Boundary Condition = fixed on ground Material properties = M25, Fe500

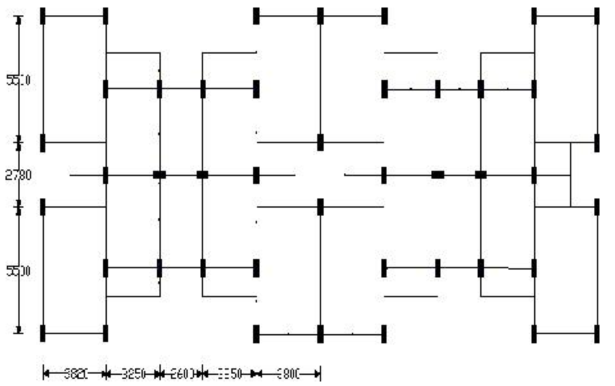


Figure8 :-Plan of G+11 building

The plan of G+11 building is as shown in Figure 3.14. Building is first designed in ETABS software and incremental dynamic analysis is carried out for the designed reinforcement in SeismoStruct. IDA graph for earthquake in X and Y direction is plotted. Yielding and collapse stages are defined by using IDA curve. Fragility curves are also plotted to determine percentage of yielding and collapse of the structure. Then building susceptibility i. e building can sustain the particular earthquake or not is studied. Building serviceability criteria given in IS 1893 for limiting interstorey drift ratio is alsoconsidered.

Table 3.5 shows the column and beam dimensions and designed reinforcement from ETABS software.

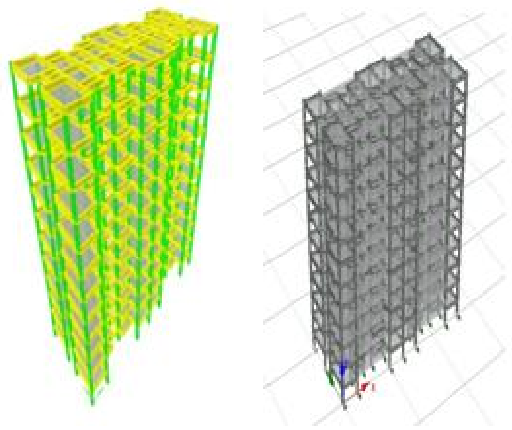
Table 3:- Column and beam dimensions and reinforcement

	Size (mm)	Steel
Column (base to storey6)	300 x 750	10#25
Column(storey7 to storel2)	300 x 750	6#25
Beam	300 x 600	4#16 at top 4#16 at bottom

Incremental dynamic analysis

Now the same procedure as for G+7 building is followed for G+11 building for plotting of IDA curve and for determining the yielding and collapse stages.

IDA curve for G+11 building for Chamba_Chamba T applied in Y direction is as shown in Figure 3.16. From the IDA curve, building yields at PGA of 0.60g and collapse occurs at 0.72g for Chamba_Chamba T applied in Y direction.



a) b)

Figure9:-Model of the building (a) ETABS model (b) SeismoStruct model

V. BUILDING SUSCEPTIBILITY PREDICTION

- **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.

- **Building susceptibility of G+7 building**

IDA curves are plotted for the G+7 building in previous chapter. Figure 4.1 shows the generalized IDA curve of a G+7 building plotted by combining the response from all the time histories in X and Y direction. Table 4.1 shows the yielding and collapse peak ground acceleration of G+7 building in X and Y direction. Scaled yield and collapse PGA of all the earthquakes are more than the original un-scaled PGA except for the Koyna L and Koyna T earthquake. Therefore, we can say that building can sustain all the considered earthquakes except Koyna earthquake.

- **Building susceptibility of G+11 building**

Similar approach to study the building susceptibility is used for G+11 building. G+11 building has large column dimensions; hence stiffness of the structure is also considerably high. Also, building weight is large because of more number of stories.The yield and collapse peak ground acceleration of G+11 building for the considered number of time histories for the analysis.

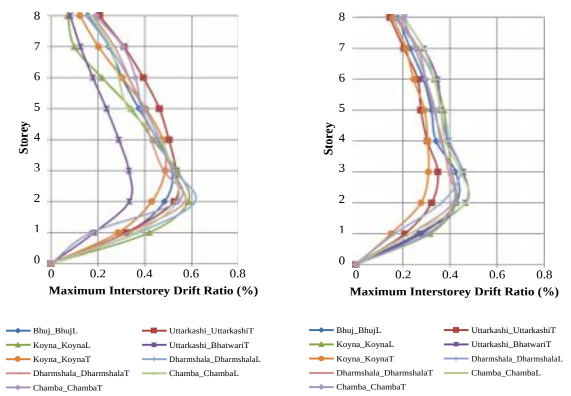
BUILDING SERVICEABILITY ANALYSIS

- **General**

In the method of design based on limit state concept, the structure shall be designed to withstand safely all loads liable to act on it throughout its life; it shall also satisfy the serviceability requirements, such as limitations on deflection. The acceptable limit for the safety and serviceability requirements before failure occurs is called a 'limit state'.

- **Serviceability of G+7 building**

For the G+7 building, ten number of time histories are applied and incremental dynamic analysis is carried out. To study the serviceability, time histories with scaling factor as 1 are applied along with dead and live loads



a **b**

Figure10:-Graph of Maximum Interstorey drift ratio (%) with respect to storey height at yield in (a) X direction (b) Y direction

Combined graph of interstorey drift ratio for all the earthquakes is as shown in Figure 5.2. It can be clearly seen from the graph that interstorey drift ratio exceeds the acceptable limit by IS 1893: 2000 in both X and Y direction.

- **Serviceability of G+11building**

For G+11 building, nine number of time histories are applied and response of the structure is plotted for every time history. For studying the serviceability, time histories with scaling factor as one is applied along with dead loads and live loads.

- **Summary**

Building serviceability is studied in this chapter and interstorey drift ratio should be less than 0.4% of storey height criteria given in IS 1893 (Part 1):2002, clause 7.11.1, is considered. From the analysis, median graph of G+7 building exceeds the 0.4% limit. So, G+7 building fails to satisfy the serviceability criteria. So, building stiffness needs to be increased. While G+11 building satisfies the serviceability criteria. So, there is no need of revising the design of G+11building.

VI. STATIC PUSHOVER ANALYSIS

- **General**

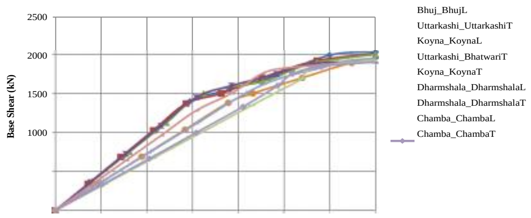
In this chapter, building capacity is found out by using both incremental dynamic analysis and static pushover analysis. Graph of base shear to top displacement from incremental dynamic analysis is compared with that of static pushover analysis. Capacity base shear from both the methods are compared for G+7 and G+11building.

- **Methodology of Incremental Dynamic Analysis**

We have applied number of time histories to the structure and their acceleration data points are scaled from zero up to up to collapse of the structure. For every scaling factor of every time history data, base shear and top displacement are found out and graph of base shear to top displacement is plotted for earthquake in X and Y direction.

- **Incremental Dynamic Analysis of G+7building**

Above procedure is followed to find out the collapse base shear of G+7 building by using incremental dynamic analysis. Table 6.1 shows the yield and collapse base shear of G+7 building from incremental dynamic analysis.



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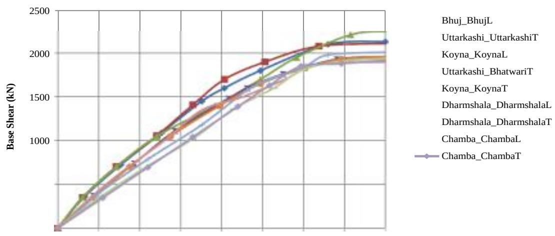
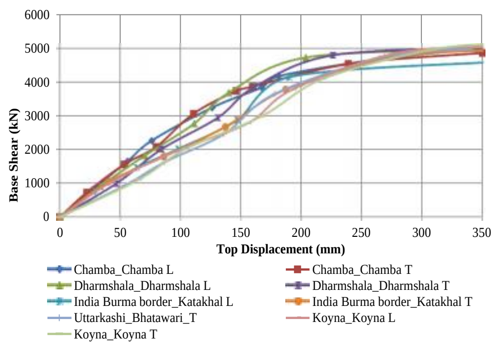


b

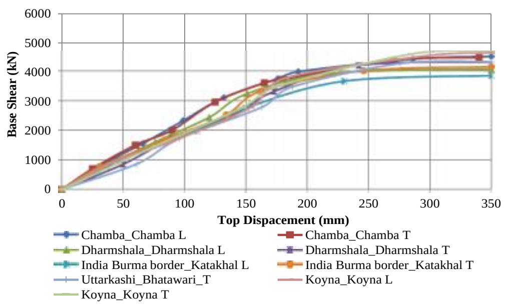
Figure 11:-Graph of base shear to top displacement from IDA for earthquake in (a) X direction (b) Y direction

Incremental Dynamic Analysis of G+11building

To calculate the base shear capacity of G+11 building, same procedure is followed as that for G+7 building. Table 6.2 shows the yield and collapse base shear while Figure 6.3 shows the response of G+11 building to various time histories.



a)



b)

Figure12:- Graph of base shear to top displacement from IDA for earthquake in (a) X direction (b)Y direction

Median graph of G+11 building is as shown in Figure 6.4. Collapse base shear is 4950 kN and 4400 kN for earthquake in X and Y direction which is more than the base shear for whichbuilding was designed which indicates building capacity is more than for which it is designed.

- **Static PushoverMethodology**

ATC 40, FEMA 273, FEMA 356 and FEMA 440 have described the pushover analysis procedure, modeling of different components and acceptable limits. Two methods, namely CapacitySpectrummethodandDisplacementCoefficientmethod areintroducedinFEMA440.

- **Capacity:** The overall capacity of a structure depends on the strength and deformation capacity of the individual components of the structure. In order to determine the capacities beyond elastic limits, some form of nonlinear analysis, such as the pushover procedure, is required.

- **Demand:** Ground motion during an earthquake produces complex horizontal displacement patterns in the structures. It is impractical to trace this lateral displacement at each time-step to determine the structural design parameters.

- **Static Pushover Analysis in ETABS**

In ETABS nonlinear version 9.6.0, a frame element is modeled as a line element having nonlinear force displacement characteristics of individual frame elements are modeled as hinges represented by a series of straight line segments.

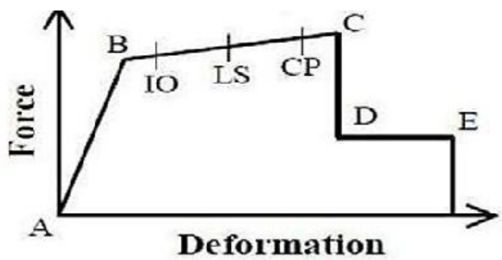


Figure13:-Force-Deformation relationship of Pushover curve

- **Static Pushover Analysis of G+7 Building**

Above procedure is followed to carry out the static pushover analysis of G+7 building in ETABS software. Modal pushover analysis is carried out to find the capacity of the structure. It is observed that base shear at collapse is 2200kN and 2300kN for lateral force in X and Y direction respectively.

- **Static Pushover Analysis of G+11Building**

Static pushover analysis of the G+11 building is carried out in ETABS software and base shear to top displacement graph is plotted.

It is observed that based shear capacity of the G+11 building is 5640 kN and 5200 kN for lateral force in X and Y direction respectively.

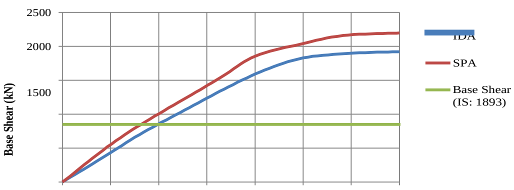
Comparison between Incremental Dynamic

- **Analysis (IDA) and Static Pushover Analysis(SPA).**

Base shear capacity from incremental dynamic analysis is compared with that of static pushover analysis of both the G+7 and G+11 building.

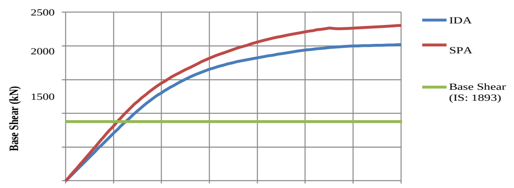
- **Analysis of G+7Building**

Median graph of base shear to top displacement from incremental dynamic analysis is compared with the corresponding graph from static pushover analysis as shown in Figure.



Top Dispacement (mm)

a)



Top Dispacement (mm)

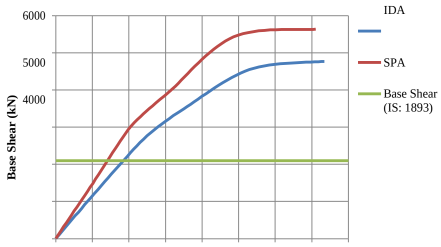
b)

Figure 14:-Graph of base shear to top displacement for IDA and SPA for lateral force in (a) X direction (b) Y direction

It is observed that capacity of the building by static pushover analysis is more than incremental dynamic analysis.

- **Analysis of G+11 Building**

Figure 6.9 shows the base shear capacity of G+11 by IDA and SPA methods.



Top Displacement (mm)

a)

Figure15:-Graph of base shear to top displacement for IDA and SPA for lateral force in (a) X direction

VIII. SUMMARY AND CONCLUSION

- **SUMMARY:-**

In this study, incremental dynamic analysis is used to study the performance based analysis of the structure. First, the buildings are designed in ETABS. 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.

- **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.

- **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.

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