

**SEISMIC EVALUATION OF EXISTING COMMERCIAL COMPLEX WITH
SOFT STOREY BY PUSHOVER METHOD**Ashish Vijay Sojrani¹, Wankhade Lavkesh R.²¹M. Tech (Structural Engineering) Scholar, Dept. of Applied Mechanics,
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Abstract— Damages caused by recent earthquakes have exposed the vulnerability of R.C buildings in India. Many of existing buildings will be found to lack compliance with the current codes of practice, especially in terms of seismic resilience. The risk of failure of structure can be ascertained only after proper structural evaluation. The present study aims to evaluate the seismic vulnerability of one of the existing commercial complex with Soft Storey situated in Amravati, Maharashtra. The non-linear static analysis is done in SAP2000 (v20) to obtain capacity curve of the building and also to track the formation of hinges in structural members. The study highlights the complete process of seismic evaluation of existing R.C building starting from Rapid Visual Screening of building to detailed vulnerability assessment.

Keywords— Seismic vulnerability, pushover, capacity curve, SAP2000, performance point, soft storey

I. INTRODUCTION

Seismic risk is a function of the vulnerability of existing building stock. Existing buildings may not comply with requirements of the prevailing seismic standards due to various reasons. The condition of the buildings may also have deteriorated (cracking, corrosion, etc.) over the years, in the absence of repair and maintenance. The buildings may not have been designed specifically to resist earthquake loads. Even if designed, the seismic resistance provided may not measure up to the current code requirements (which are periodically upgraded). It is important to note that a wide range of building stock in this region are designed for gravity loads only and some are constructed even without consulting the design engineer. So, these buildings pose enormous threat to human life and will also cause tremendous economic losses. Hence, it is necessary to establish mandatory guidelines for seismic evaluation of existing building at major urban centres. This will form an essential component of a comprehensive earthquake disaster risk management policy.

The aim of this evaluation is to find the deficiencies in structure before taking any necessary measures to upgrade the seismic performance of building. Several methodologies have been developed to estimate the vulnerability of existing buildings, and time by time these methodologies have improved considerably. Here, seismic performance and damage evaluation of a low rise (3 storied) existing RC building with a soft storey, designed under gravity load as per Indian code IS 456-2000 is considered and nonlinear static analysis is carried out using computer program SAP2000 (v20).

II. LITERATURE REVIEW

The literature review focuses on several methods for assessing vulnerability of building stock in Indian scenario that has been done so far for major cities, any particular method is chosen based on the objective of the seismic evaluation, data availability and resources available at hand.

Tanaya Sarmaha, Sutapa Das [5] tried to develop ward level hazard map of Guwahati City by Rapid Visual Screening for reinforced cement concrete buildings with variable roofing options. Here they gave scores and ranks to existing buildings on the basis of seismic vulnerability. Piyoosh Rautela, Girish Chandra Joshi, et. al [6] attempted to assess the seismic vulnerability of two Himalayan tourist destination, i.e. Nainital and Mussoorie using Rapid Visual Screening. They also tried to evaluate the economic losses based on the damage grades of EMS-98. Pankaj Agrawal, G. Navya [7] have done detailed seismic evaluation and retrofitting for two building each being G+6 Storey located in Zone IV one which is designed by IS 456: 2000 and other by IS 1893 (Part 1) 2002. The building was retrofitted with steel bracings and fragility analysis was done to understand the probability of damage.

P. Singh [12] have graded the vulnerability of building and population during earthquakes in city of Dehradun using GIS considering both day time and night time population, Agrawal and Chaurasia used both demand-capacity computation (quantitative approach) and rapid screening procedure (qualitative approach). The seismic score (S) inversely proportional to the seismic vulnerability was calculated based on visual inspection of a building and noting the structural configuration i.e. lateral load resisting structural system and the construction materials [13].

R. Sinha, M Goyal, et. al [14] have tried to elaborate the importance earthquake risk mitigation for Mumbai in seismic zone IV. The earthquake risk assessment presented in the paper can be used for developing the Disaster Risk Management Master Plan (DRMMP). The Amount of research done for assessing the seismic vulnerability assessment of existing buildings is very limited in Indian Context. If done, it is done by Rapid Visual Screening Method (RVS).

III. RAPID VISUAL SCREENING

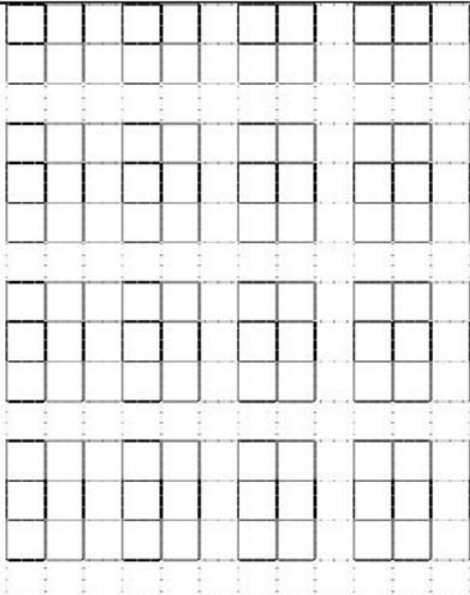
A procedure for rapid visual screening even though originally developed for typical constructions in the US has been widely used in many other countries after suitable modifications. The most important feature of this procedure is that it permits vulnerability assessment based on walk-around of the building by a trained evaluator. The rapid visual screening method is designed to be implemented without performing any structural calculations. The procedure utilizes a scoring system that requires following observation:

1. Identify the primary structural lateral load-resisting system, and
2. Identify building attributes that modify the seismic performance expected for this lateral load resisting system.

The screening is based on numerical seismic hazard and vulnerability score. The inspection, data collection and decision-making process typically occurs at the building site. It helps to identify if the building required further detailed investigation for seismic vulnerability.

Rapid Visual Screening of Buildings for Potential Seismic Vulnerability
(Seismic Zone II)

FEMA-154/ATC-21 Based Data Collection Form

 Plan and Elevation Scale:	Address: _____ Pin _____ Other Identifiers _____ GPS Coordinates (if available) _____ No. Stories _____ Year Built _____ Surveyor _____ Date _____ Total Floor Area (sq. ft./sq. m) _____ Building Name _____ Use _____ Current Visual Condition: Excellent ☐ / Good ☐ / Damaged ☐ / Distressed ☐ Building on Stilts / Open Ground Floor: Yes ☐ / No ☐ Construction Drawings Available: Yes ☐ / No ☐ PHOTOGRAPH (OR SPECIFY PHOTOGRAPH NUMBERS)
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OCCUPANCY			SOIL TYPE (IS 1893:2002)			FALLING HAZARDS						
Assembly	Govt. Historic	Office Residential School	Max. Number of Persons	0 – 10	11 – 100	Type I Hard Soil	Type II Medium Soil	Type III Soft Soil	☐ Chimneys	☐ Parapets	☐ Cladding	☐ Other:
Commercial	Industrial		101 – 1000	1000+								

BASIC SCORE, MODIFIERS, AND FINAL SCORE, S										
BUILDING TYPE	Wood	S1 (FRAME)	S2 (LM)	C1 (MRF)	C2 (SW)	C3 (INF)	URM1 (BAND-RD)	URM2 (BAND-FD)	URM3	URM4
Basic Score	6.0	4.6	4.6	4.4	4.8	4.4	4.6	4.8	4.6	3.6
Mid Rise (4 to 7 stories)	N/A	+0.2	N/A	+0.4	-0.2	-0.4	-0.2	-0.4	-0.6	-0.6
High Rise (>7 stories)	N/A	+1.0	N/A	+1.0	0.0	-0.4	N/A	N/A	N/A	N/A
Vertical Irregularity	-3.0	-2.0	N/A	-1.5	-2.0	-2.0	-1.5	-2.0	-1.5	-1.5
Plan Irregularity	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
Code Detailing	N/A	+0.4	N/A	+0.6	+0.4	N/A	N/A	N/A	N/A	N/A
Soil Type II	-0.4	-0.8	-0.4	-0.6	-0.4	-0.4	-0.2	-0.4	-0.4	-0.4
Soil Type III	-0.8	-1.4	-1.0	-1.4	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8
Liquefiable Soil	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-1.6	-1.4	-1.4	-1.4

FINAL SCORE, S										
Result Interpretation (Likely building performance) S < 0.3 High probability of Grade 5 damage; Very high probability of Grade 4 damage 0.3 < S < 0.7 High probability of Grade 4 damage; Very high probability of Grade 3 damage 0.7 < S < 2.0 High probability of Grade 3 damage; Very high probability of Grade 2 damage 2.0 < S < 3.0 High probability of Grade 2 damage; Very high probability of Grade 1 damage S > 3.0 Probability of Grade 1 damage										Further Evaluation Recommended YES NO

* = Estimated, subjective, or unreliable data
 DNK = Do Not Know
 FRAME = Steel Frame
 INF = Burnt Brick Masonry Infill Wall
 MRF = Moment-Resisting Frame
 FD = Flexible Diaphragm
 SW = Shear Wall
 LM = Light Metal
 BAND = Seismic Band
 URM4 = Unreinforced masonry (lime mortar)

Fig. 1 Sample Format for Rapid Visual Screening of Buildings for Seismic Vulnerability [14]

IV. DETAILED VULNERABILITY ASSESSMENT

The Detailed Vulnerability Assessment or Tier 3 systematic procedure involves an analysis of the entire building by nonlinear procedure, either in its current condition or with proposed retrofit measures, using the provisions in Chapters 7 through 12 for the structural systems and Chapter 13 for non-structural components of ASCE 41-13, 2014 [10]. The detailed vulnerability assessment procedure is highly specialized and the procedure also requires extensive as-built information regarding a building components, site, adjacent buildings, which may not be readily available in the Indian context. The detailed vulnerability assessment procedure is most suitable for critical structures. The standard [10] also specifies the data collection requirement to account for the uncertainty associated with building analysis. There is an urgent need to continue implementation of vulnerability assessment procedures with the other tasks of fine-tuning the technical aspects of based on benchmarking with past earthquake field data of India, since the applicability of American seismic standard in Indian Scenario is doubtful.

V. DETAILS AND MODELLING OF EXISTING R.C BUILDINGS

In this present study, G+2 storey reinforced concrete existing commercial building with a soft storey is considered for seismic evaluation purpose. All the features are collected by walk around the building by RVS procedure. The building is assumed to be designed as per Indian Standard IS 456 2000 [3] for gravity load only and the plan and elevation of the building are as shown in the Fig. 2. Approximate age of building is 15 years as per conversation with shop owners in complex. Typical floor area of commercial complex is 200 sq.m and height for ordinary storey is 3.0 m and for soft storey with wooden mezzanine is 6.0 m. the grade of concrete for complex is assumed to be M20 and grade of steel is Fe415D for longitudinal steel as well as transverse steel. The minimum and maximum reinforcement criterion of Indian Standard IS 456: 2000 [3] is assumed to be present for beams and columns of building.

The thickness of Infill wall as observed at site is 0.15 m. The load of the infill wall is uniformly distributed on the beams. The slab thickness is assumed to 0.15 m at all storey levels. The dead loads conforming to IS 875 Part-I and Live Load conforming to IS 875 Part-II [9] have been taken in the analysis of building. Since no record (structural design record) is available for reinforcement detailing of the structure. The same is assumed on the basis of Gravity load design of the structure and is mentioned in the Table 1 and Table 2 below. The sizes of beams and columns have been obtained from site. Time dependent property such as deterioration of the material is taken into account as per IS 15988: 2013 [8]. Knowledge factor is taken as 0.5 as per the above standard. Further Useable Life factor is taken for reducing lateral load as per available life as 0.67. In this study beam and column plastic hinges are modelled to take the material nonlinearity into account.

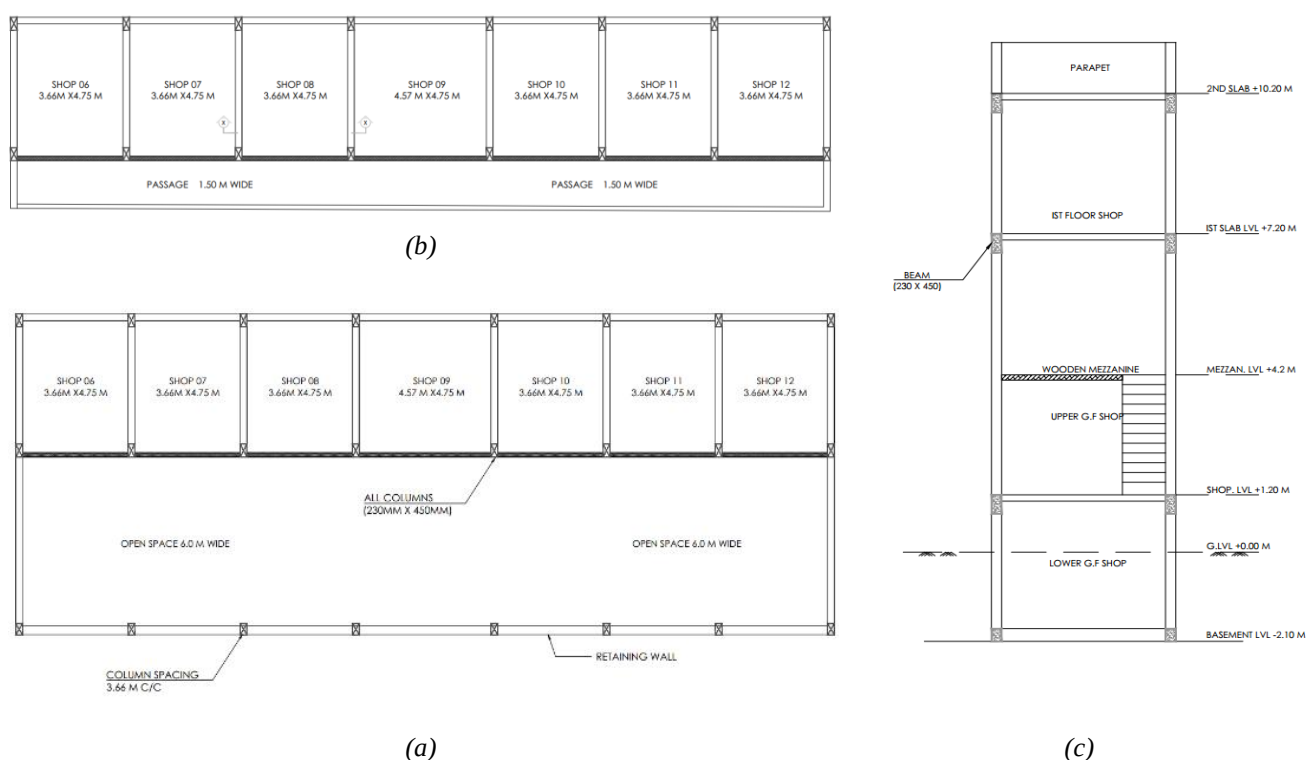


Fig. 2 (a) Lower Ground Storey Plan, (b) Typical Upper Floor Plan (c) Section of single Shop

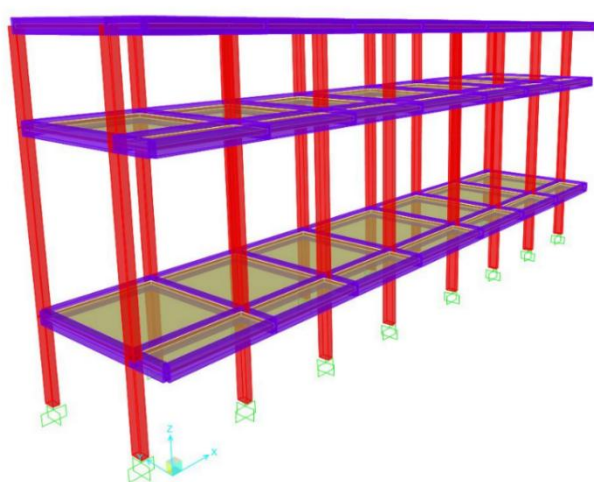
Table I Column Main and Shear Reinforcement

Storey	Beam Notation	Reinforcement in Sq.mm	
		Longitudinal	Transverse
Top Storey	Rear Columns	904	8mm @150 c/c
	Front Columns	904	8mm @150 c/c
Second Storey	Rear Columns	1608	8mm @150 c/c
	Front Columns	1608	8mm @150 c/c
Ground Storey	Rear Columns	1608	8mm @150 c/c
	Front Columns	1608	8mm @150 c/c

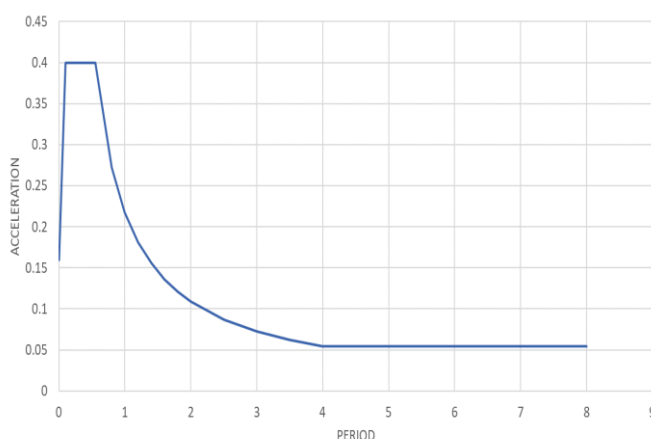
Table II Beam Reinforcement

Slab Level	Beam Notation	Top Reinforcement		Bottom Reinforcement	
		Left	Right	Left	Right
Third Slab	Long Beams	275	275	275	275
	Short Beams	700	175	350	175
	Canti. Beam	275	850	275	450
Second Slab	Long Beams	275	275	275	275
	Short Beams	1000	175	500	175
	Canti. Beam	275	1000	275	500
First Slab	Long Beams	500	500	275	275
	Short Beams	1200	275	600	275
	Canti. Beam	275	1000	275	500

To study the seismic response of the structure hazard level have been chosen design basis earthquake for Zone III. Fig 3 shows the smoothed acceleration response spectrum for DBE for 5% damping with importance factor 1.2 for the commercial complex. Response reduction factor is taken as 3 assuming it to be OMRF [2]. For RC frame buildings subjected to lateral loads such as seismic action, flexural deformations occur near the element joints. Moment or flexural M3 hinges are used for beams and Coupled P-M2-M3 hinge which considers the interaction of axial force and biaxial bending are used for columns. Auto-Hinges Properties are used for reinforced concrete components subjected to lateral load. The hinge properties according to ASCE-41-13 [10] are dependent on the cross sectional properties such as percentage area of steel in tension (A_{st}) and confining reinforcement and overall flexural strength of the member.



(a)



(b)

Fig. 3 (a) Building Model Developed in SAP 2000 (v20) (b) Smoothed Acceleration Response Spectrum for Zone III DBE.

VI. RESULTS AND DISCUSSIONS

The push over is plotted as ratio of base shear vs. roof displacement. The base shear is dependent on the seismic weight of the structure and plotted as function of roof displacement and is shown in Figure 4 (a) along with its bilinear representation as per coefficient method [11]. This curve is useful in obtaining the yield displacement and ultimate displacement of the structure. Also the capacity curve is shown for hazard level of Zone III DBE is shown in Figure 4 (b), here we get performance point for response spectrum. Also SAP2000 helps to track the hinge formation in the frame elements and the hinges formed in the columns at step 6 and 8 for lateral pushover cases "PUSH X" and "PUSH Y" is shown in Figure 5 (a) and (b) respectively.

Since the roof displacement is approximately equal to 0.5% of height of the structure before formation of prominent hinges, the structure can be expected to show good performance in low to moderate earthquake. But the formation of plastic hinges in columns prior to that of beams is not acceptable as per codal provisions. Also it should be noted from Fig. 5 (a) and (b) that hinges first form in soft storey and achieve overall performance objective of collapse prevention is achieved.

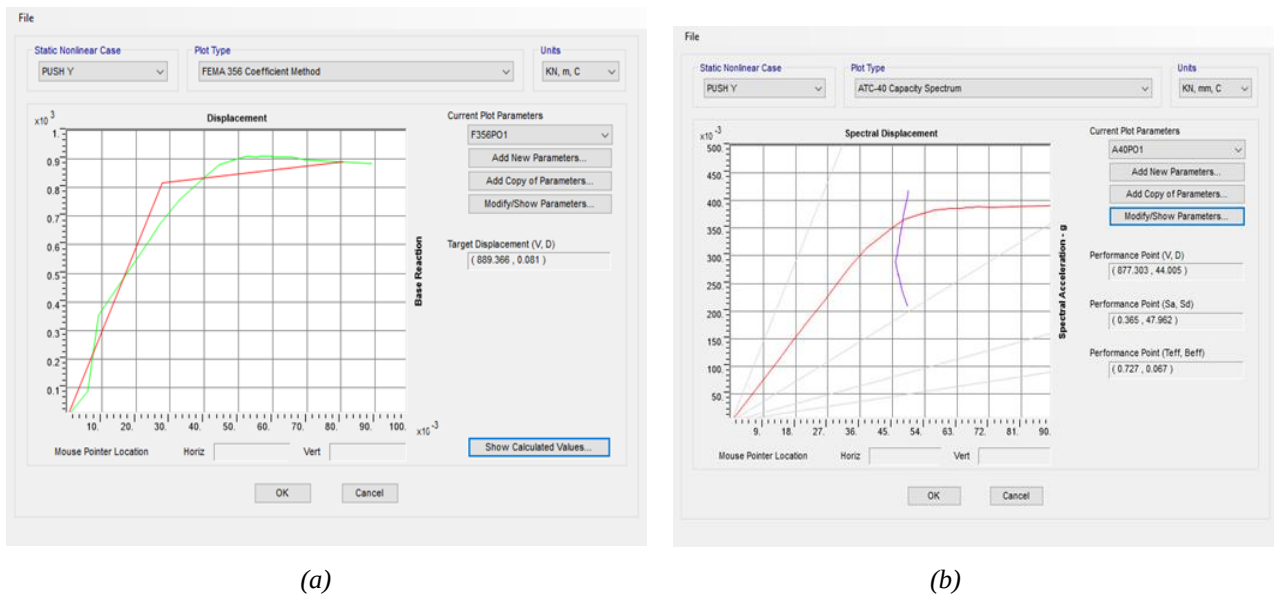


Fig. 4 (a) Pushover Curve with Bilinear representation as per FEMA 356 Coefficient Method (b) Capacity curves as per ATC-40 along with demand curve for Zone III DBE

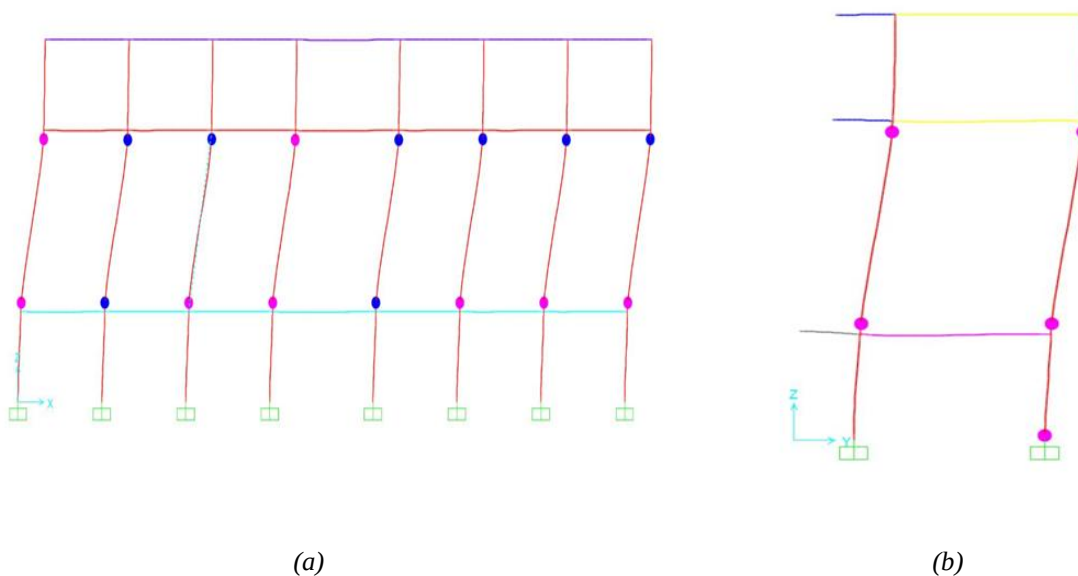


Fig. 5 (a) Pushover Curve with Bilinear representation as per FEMA 356 Coefficient Method (b) Capacity curves as per ATC-40 along with demand curve for Zone III DBE

VII. CONCLUSIONS

In this study seismic performance of the existing G+2 commercial complex is evaluated by non-linear static pushover analysis for lateral loads. The following conclusions can be drawn from the analysis:

1. For a building drift ratio of 0.5% prominent hinges do not form the structure can be expected to show good performance in Zone III DBE moderate Earthquake.
2. The structure achieved performance objective of collapse prevention level for Zone III DBE. In case there is need to improve by this objective a global retrofitting strategy can be formulated.
3. It is observed the hinges first form in the columns of soft storey; hence such an irregularity should be paid attention while designing the complex.
4. Stiffness of soft storey can be improved by providing bracing or tie beams and structure can be further revaluated for seismic performance.
5. Suitable column strengthening techniques can be adopted for retrofitting the existing structure for efficient performance in an event of earthquake.

This study can form a reference for complete seismic vulnerability assessment for existing building. The farther goal of this study is to develop an economic and efficient retrofit scheme for existing building as per importance of the structure and it is recommended to carry out such detailed vulnerability assessment for all the important and lifeline buildings of prominent urban centers which are found to be vulnerable by RVS method.

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