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Capacity Based Earthquake Resistant Design of Multi-Storied R.C. Building: A Review

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Abstract—*Presented in this paper is an updated literature review of the Capacity-based Seismic design (CBSD) method. Concept of CBSD is the spreading of inelastic deformation demands in a structure in such a way so that the formation of plastic hinges takes place at predetermined positions and sequences. It is an art of avoiding failure of structure in brittle mode.Shear failure is brittle mode of failure, hence shear capacity of all components capacity based design are made higher than their flexural capacities so as to avoid shear failure. Therefore, it is better to make beams to be the ductile weak links than columns.In the capacity design of structures for earthquake resistance, distinct elements of the primary lateral force resisting system are chosen and suitably designed and detailed for energy dissipation under severe imposed deformations. The critical regions of these members, often termed as plastic hinges, are detailed for inelastic flexural action.*

Keywords-*Capacity Based Seismic Design, Performance Levels, Performance Objectives, Plastic Hinges, Response reduction factor*

I. INTRODUCTION

In the recent major earthquakes, it is noticed that the seismic risk in urban areas is increasing and the infrastructure facility is far from socio-economically acceptable levels. The potential of capacity-based seismic engineering is to produce structures with probable seismic performance. This approach is not new using this approach/ model turbines, airplanes & automobiles are made. In these applications one or more pattern are built and subjected to broad testing. To include the lessons learned from the experimental calculations the design and manufacturing process is then revised, once the cycle of design, pattern manufacturing, testing and redesign is successfully completed, the product is manufactured in a considerable scale. In the automotive industry, for example, millions of automobiles which are effectively identical in their mechanical characteristics are produced following each capacity-based design exercise. Capacity Based earthquake engineering/design is not that popular because the scale of output is not large in comparison to the automobile industry and others[1].

Each building designed by this process is effectively unique and the experience obtained is not directly exchangeable to buildings of other types, sizes, and performance objectives. Therefore, up to now Capacity Base Seismic Engineering has not been an economically feasible alternative to conventional prescriptive code design practices. In coming few years we can say that Capacity Based Design will become the standard method of providing Earthquake resistant designs[8].

The facts are clear – We cannot avoid big, destructive earthquakes from arising. These pose a continuing hazard to lives and property in more than 55% of the area of this country. However, it is possible to avoid the terrible consequences of an earthquake and that accurately is the objective of every seismic design code practice. The seismic codes are surrounded primarily with the objective of prevention of loss of life. In order to meet this objective it is important that the structures/constructed facilities respond to the projected earthquake ground motions at the site in a selected manner, which in turn depends on the nature of ground motion stimulating the structure[1].

Thus the consistency of achieving the life safety performance objective of any constructed facility is governed by the most uncertain element in the chain- expected ground motion.

Seismic exposure and Damage state are the two crucial parts of a Performance Objective. Seismic performance is defined by designating the maximum allowable damage state (performance level) for an identified seismic exposure (earthquake ground motion). The target Performance level is divided into two levels Non-structural damage and Structural damage, the grouping of the two gives the building a combined performance level.Performance levels shown here are Operational, Immediate Occupancy, Life Safety and Last one is Collapse Prevention[7].

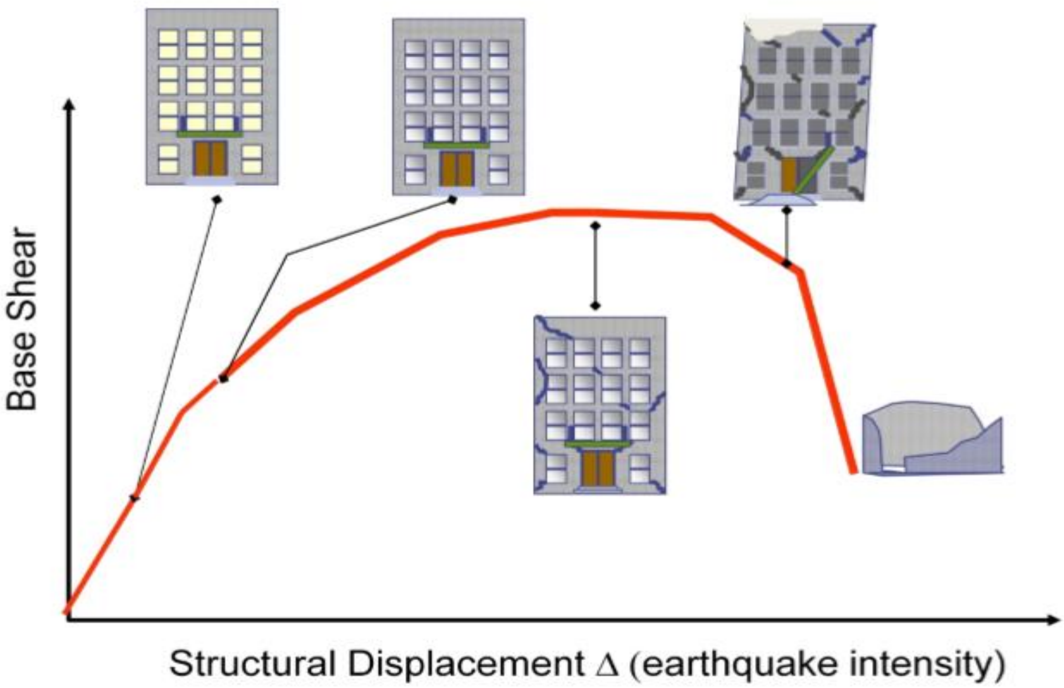

Figure 1. Building Performance Levels [7]

The Various Performance levels are tabulated below with their affects on both Structural and Non-structural elements.

Table 1. Performance Levels [7]

Performance Level	Structural Performance	Non-Structural Performance
Operational (O)	Very light damage No permanent drift	Negligible damage. Power & other utilities are available
Immediate Occupancy (IO)	Light damage No permanent drift Substantially original strength & stiffness Minor cracking Elevators can be restarted Fire protection operable	Negligible damage. Power & other utilities are available
Life Safety (LS)	Moderate damage Some permanent drift Residual strength & stiffness in all stories Gravity elements function Building may be beyond economical repair	Falling hazard mitigated but extensive system damage
Collapse Prevention(LS)	Severe damage Large permanent drifts Little residual strength & stiffness Gravity elements function Some exits blocked Building near collapse	Extensive damage

II. LITERATURE REVIEW

A. Evaluation of Response Reduction Factor of a reinforced cement concrete building by performance based plastic design method and limit state design method; Sciencedirect: 1854 – 1861, 2016. [8]

Kunal P Shukla, Sejal P Dalal; In this Paper, A fifteen storey Reinforced Cement Concrete frame was designed using the displacement based Performance Based Plastic Design (PBPD) method and currently used force based Limit State Design (LSD) method. They Selected fifteen storied L-shaped school building located in Vadodara City.

Here, an L-shaped plan has been broken into three square Plans in shapes using a separation joints at the junctions. Dead load and live Load as been taken as per IS: 875:1987 (parts 1 and 2).

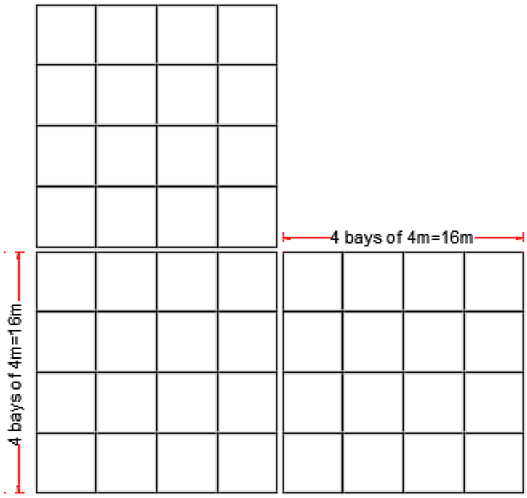

Figure 2. Plan Layout of Study Frame

Table 2. Design Parameters

Parameter	Value
Initial Time Period (sec)	1.35 sec
Total Weight of Structure W	59040 kN
Zone Factor “Z”	0.16
Importance Factor “I”	1.5
Design Spectral Acceleration Sa (g)	1.1
Response Reduction Factor “R”	5
Ductility Factor	5
$Sa_{inelastic (g)}$	0.23
Span of the bay “L”	4 m
$W_{tributary}$	65.5 kN/m
V_b/W	0.006
V_b	379.75 kN

Design was done using IS code method and PBPD Method in SAP2000.

It could be seen from fig.3 that the storey shear for PBPD method was much less than those obtained from IS code method.The beam moments in PBPD method were evenly distributed unlike IS code method where there was uneven distribution near base.

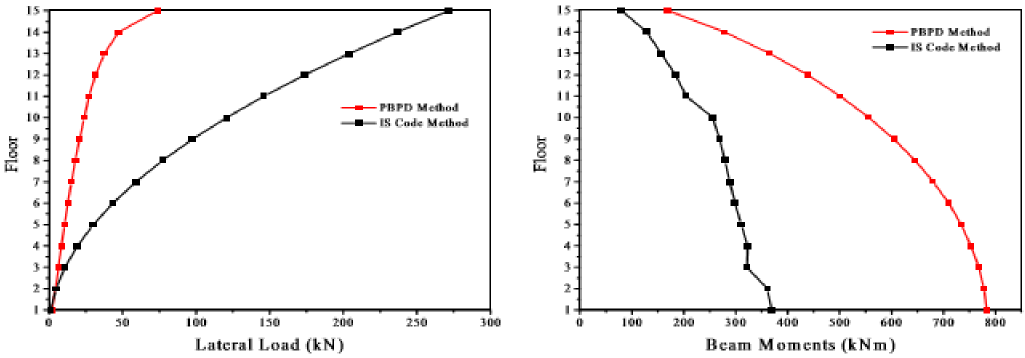

Figure3.Lateral Load and Beam moments Comparison between PBPD and IS code Method

It could be seen from fig.4 that column moments obtained from PBPD method were significantly larger than beam moments in PBPD method which ensures that strong column-weak beam principle was satisfied.

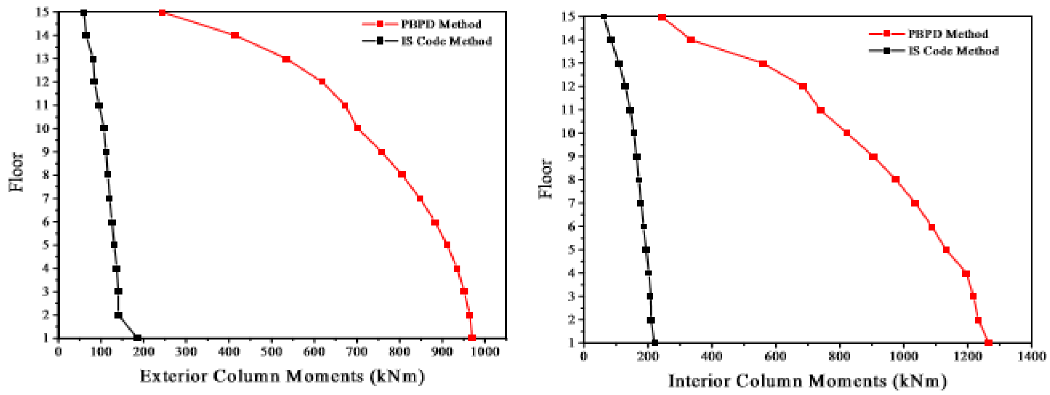

Figure 4. Exterior and Interior Column moments Comparison between PBPD and IS code Method

Nonlinear Static Pushover Curves for the Study frame were created as shown in fig.3-8. Response reduction factor "R" had been calculated

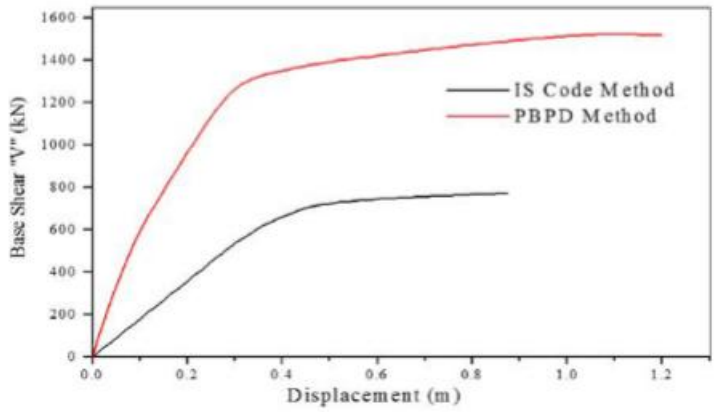

Figure 5.Pushover curves for PBPD and IS Code Method

As shown in Fig. 6 in IS code Method Plastic Hinges are developed in both beams and columns whereas in PBPD method Plastic hinges are developed only in predetermined locations i.e. in beams.

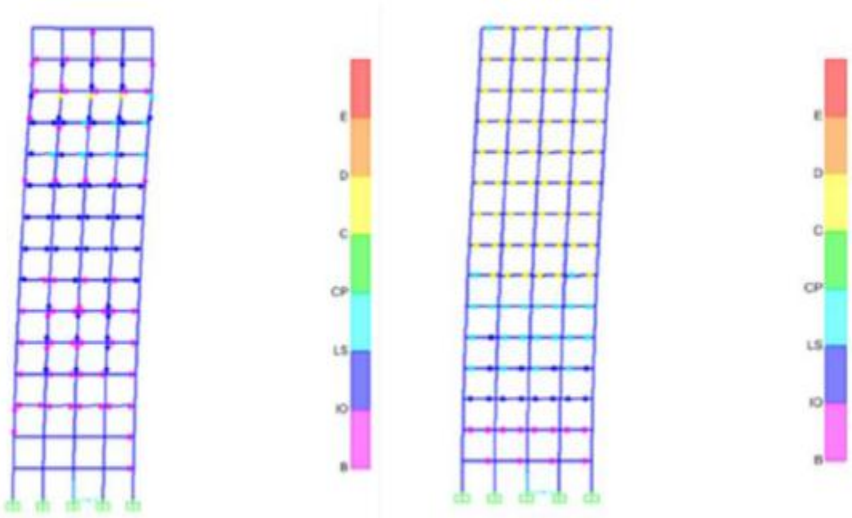

Figure 6. Failure Pattern and hinge formation for IS Code and PBPD Method

At the end authors concluded that, Columns were designed for higher moments compared to beam which fulfill the strong column-weak beam principle. Lateral Load obtained by PBPD Method are lower than that of IS Code due to higher ductility factor.

Here, R for IS Code method is almost same as mentioned in IS Code, still hinges were developed in column, which suggests that Strong Column-weak Beam does not hold true.

B. Improved Design of five storey building frame using Capacity based design; European Journal of Advances in Engineering and Technology,ISSN 2394 – 658X, P-ISSN 7-20 ,Volume-1, No-3, 2017. [9]

Naresh Choubisa, Digvijay Singh Chouhan, Trilok Gupta and Ravi K Sharma; In this Paper, Concept of capacity based design of structures is the spreading of inelastic deformation demands in a structure in such a way so that the formation of plastic hinges takes place at predetermined positions and sequences. Capacity based design is an art of avoiding failure of structure in brittle mode. Shear failure is brittlemode of failure, hence shear capacity of all components capacity based design are made higher than their flexural capacities so as to avoid shear failure. Therefore, it is better to make beams to be the ductile weak links than columns.In this study, systematic study was carried out for a building frame of five storeys. Analysis of these frame have been carried out using structural software (STAAD Pro.). In this analysis, building frame was assumed in zone II (IS 1893-2002).

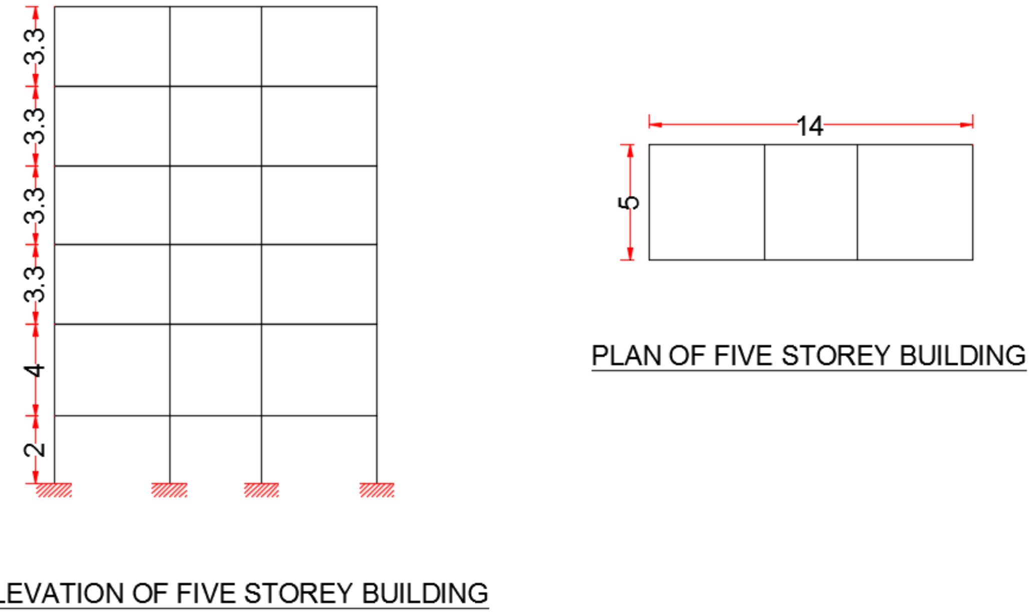

Figure 7. Plan and Elevation of Five storey building

Table 3 . General Data

Type of Structure	Ordinary RC moment resisting frame
Seismic zone (IS 1893: 2002)	II
Type of soil	Medium
Imposed Load	3.0 kN/m²
Dead Load	3.75 kN/m²
Floor finishes	1.0 kN/m²
Thickness of slab	150 mm
Material	M30 concrete & Fe415 steel
Unit weight of RCC	25 kN/m³
Unit weight of Masonary	19.20 kN/m³
Width of building	5 m
Beams Size	300 X 500 mm
Columns Size	300 X 600 mm
Height of building Clear cover for beam	19.2 m 25 mm
Clear cover for column	40 mm

Different Load Combinations for Analysis

1. 1.5(DL + IL)
2. 1.2(DL + IL +EL)
3. 1.2(DL + IL - EL)
4. 1.5(DL + EL)
5. 1.5(DL - EL)
6. 0.9DL + 1.5EL

Where,
DL = Dead Load,
IL = Imposed Load and
EL = Earthquake Load

The model was analyzedfor different combination of loads in Staad-Pro. Maximum moments, axial force and shear forces were noted from the analysis results. They Compared Column moments, Shear in Columns and Shear in Beams using Capacity based Design and Conventional Design.
They found that, Column moments and Column shear obtained by capacity based design method were more than those obtained from conventional design method. Increase in moments were insignificant for exterior columns and increase in shear is significant for both exterior and interior columns.
Beam shear obtained by capacity based design method was more than those obtained from conventional design method and also insignificant for exterior beams.

C. Performance-based evaluation of the response reduction factor for ductile RC frames; Engineering Structures, Sciencedirect: pp. 1808-1817, 2013. [2]

A Mondal , S Ghosh, G. R. Reddy; "This research focuses on estimating the actual values of this factor for realistic RC moment frame buildings designed and detailed following the Indian standards for seismic and RC designs and for ductile detailing, and comparing these values with the value suggested in the design code. The primary emphases are in a component-wise computation ofR, the consideration of performance-based limits at both member and structure levels, a detailed modelling of the RC section behaviour, and the effects of various analysis and design considerations on R. Values of R were obtained for four realistic designs at two performance levels. The results shows that the Indian standard recommends a higher than actual value of R, which is potentially dangerous. This paper also provided other significant conclusions and the limitations of this study.

In this research Pushover Analysis done by considering with P-Δ effect and without P-Δ effect for different story frames for computing value of R.The actual value of R in real life designs is expected to be even lower than what was computed from pushover Analysis for different storey, because of irregularity in dimentions leading to lack of quality control and poor workmanship during construction.R comes to be close to the IS-1893Recommended value if P-Δ effects are not considered.So, R=5.0 may be safe for a design where P-Δ effects are negligible.

D. Performance based seismic design of structure –A Review;IJMTER, ISSN: 2349-9745, pp. 393-399, 2015. [12]

Saba Bano, T. Naqvi, M, Anwar;In this Paper, An overview of the current state of knowledge of Performance based design method was presented. Performance-based earthquake engineering (PBEE) includes the design, evaluation, and construction of structures performing during design earthquakes and extreme earthquakes to the desires / needs of owners, user, society and environment. The general promise of performance based design is to produce engineered structures with expected performance during future earthquakes.
The main of performance based design to achieve multiple performance objectives when the structure is subjected to stated levels of earthquake ground motion. The general promise of performance based design is to produce engineered structures with predictable performance during future earthquakes. Due to advancement in research and test facilities, rapid development of structural analysis and design software, PBD is becoming more popular and efficient tool of design over the usual code methods.

E. Performance Based Seismic design of reinforced concrete building ; Open Journal of civil engineering, pp. 188-194, 2016. [7]

D. J. Chaudhari, G. O. Dhoot; In this Paper, The performance based seismic design (PBSD), evaluated how the buildings were likely to perform under a design earthquake. As compared to force-based approach, PBSD provides a methodology for assessing the seismic performance of a building, ensuring life safety and minimum economic losses. The non-linear static procedures also known as pushover analysis were used to analyze the performance of structure under lateral loads. Pushover analysis gives pattern of the plastic hinge formations in structural members along with other structural parameters which directly show the performance of member after an earthquake event.

In the present work, a four storey RC frame building situated in zone IV was taken for the purpose of study. It consists of 2 bays of 5 m each in X-direction and 2 bays of 4 m each in Y-direction. The total height of the building was 14 m. The building was modelled and designed as per IS 456:2000 in SAP 2000 v17.

The seismic performance of a building was evaluated in terms of pushover curve, performance point and plastic hinge formation. Capacity demand spectrum was the representation of structures ability to resist the seismic demand. The point of intersection of capacity spectrum and demand spectrum was required performance point.The limiting value of inter storey drift is 0.4% as per IS 1893:2002. For building under consideration inter storey drift was within permissible limit satisfying the displacement requirements. Hence, the building performance should be satisfactory. The sequence of plastic hinge formation and state of hinge at various levels of building performance was obtained from SAP output. All the hinges were within required performance levels. Building was safe for design basis earthquake and life safety performance level was achieved.

The target roof displacement ratios at various performance levels where the targetroof displacements were provided in terms of lateral drift ratio. For Immediate Occupancy, 98 mm Target roof displacement achieved. Similarly for Life Safety, 350 mm Target roof displacement should be achieved. By analysis, roof displacement achieved was 149.298 mm. Thus, by this design building lies in between immediate occupancy and life safety range. So, the required performance objective of design was achieved.

They found that, Performance based seismic design provides reliable methodology for seismic up-gradation or for retrofitting of the existing building to achieve required performance objectives. Pushover analysis is a consistent method in determination of the sequence of yielding of the components of a building, possible mode of failure, and final state of the building after a organized level of lateral load sustained by the structure.

III. CONCLUSION

From the above literature we conclude that

1) Performance based seismic design provides proper methodology for seismic up-gradation or for retrofitting of the existing building to achieve required performance purposes.
2) Columns are designed for higher moments compared to beam moments to achieve strong column weak beam principle.
3) Pushover analysis method is useful for finding displacements, Column moments, Beam moments, Lateral loads, formation of plastic hinges at different storey level.
4) Structure is design for both IS code method and Performance based design method. Comparison between both the method should be done and they found Response reduction factor "R" for both the cases.
5) Performance based design gives greater value of "R" than IS code method, which proves that, Structure should not be resist against higher value of seismic loads. For that performance based design is best way for designing the structure

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