Performance Based Seismic Design of Multistorey RCC Buildings with Re-entrant Corner Combine Diaphragm Discontinuity

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ABSTRACT

A Performance Based Seismic Design is aimed at controlling the structural damage under the action of earthquake forces, based on precise estimation of proper response parameters using Nonlinear Pushover Analysis. It is a highly iterative process needed to meet designer specified and code requirements. The most important cause of damage of RC buildings during earthquake is the irregular building configuration. An RC building which are unsymmetrical and has lack of continuity in geometry, mass or load resisting elements is considered for pushover analysis as there are many studies carried out irregular buildings in seismic zones, but still more research is needed in this field. Therefore, this study is about the seismic response of reinforced concrete structures having combination of two plan irregularities, re-entrant corner and diaphragm discontinuity buildings. This thesis presents a Performance Based Seismic Design of Re-entrant corner RCC Buildings with different shapes of opening in Diaphragm under the Zone III and Zone V by choosing performance criteria in terms of Inter-storey Drift (IDR) and Inelastic Displacement Demand Ratio (IDDR). The Capacity Spectrum Method of Pushover Analysis is performed in SAP 2000, based on FEMA 365[4] and ATC 40 [3] guidelines, to study the performance of RC buildings designed as per IS 1893:2016 [1], with Re-entrant Corner combine diaphragm discontinuity.

Keyword: - *Performance Based Seismic Design, Pushover analysis, Re-Entrant Corner, Diaphragm Discontinuity*

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1. INTRODUCTION

For a structure to perform well during earthquake, the structure ought to have four fundamental traits, in particular basic and general design, sufficient lateral strength, stiffness and ductility. Structures with straightforward normal geometry and consistently distributed mass and stiffness in plan and in addition in rise are considered to endure much lesser harm than structures with irregular designs. However, these days, with the progression in fast development of urbanization and for aesthetic reason structures with irregular arrangements are broadly built. These setups in structures prompt non-uniform appropriations in their masses, stiffness and strength accordingly they are inclined to damage amid tremors. Henceforth in present study an attempt has been made to think about the conduct of such structures situated in serious seismic zone.[6] The maximum drift of the structure without total collapse under seismic loads is called the target displacement or Performance Point [3,4]. Pushover analysis is an estimated analysis method where the structure is subjected to different monolithically increasing lateral forces, with a distribution which is height wise invariant. Until the target displacement is touched.

The nonlinear static analysis procedure requires determination of three elements like capacity, demand and performance point. The capacity spectrum can be obtained through the pushover analysis, which is generally produced based on first mode response of structure assuming that the fundamental mode of vibration is predominant response of structure. The demand spectrum curve is normally estimated by reducing the standard elastic 5% damped design spectrum by spectral reduction method. The intersection of pushover capacity and demand spectrum curve defines the 'Performance point' of structure and should be checked using certain acceptability criteria. Pushover analysis comprises of a series of successive elastic analysis, superimposed to estimate a force-displacement curve of overall structure. Pushover analysis can be performed as force controlled and displacement controlled [3].

In force controlled, full load combination is applied as specified and this procedure should be used when the load is known. Also such procedure having some numerical problems that affect the accuracy of results occur since target displacement may be associated with a very small positive or negative lateral stiffness because of development of mechanisms and p-delta effects. Pushover analysis allows tracing the sequence of yielding and failure on member and structural level as well as progress of overall capacity of the structure.

Performance-based design begins with the selection of design criteria stated in the form of one or more performance objectives. Each performance objective is a statement of the acceptable risk of incurring specific levels of damage, and the consequential losses that occur as a result of this damage, at a specified level of seismic hazard. Losses can be associated with structural damage, non-structural damage, or both. They can be expressed in the form of casualties, direct economic costs, and downtime (time out of service), resulting from damage. Methods for estimating losses and communicating these losses to stakeholders are at the heart of the evolution of performance-based design [5]. Once the performance objectives are set, a series of simulations (analyses of building response to loading) are performed to estimate the probable performance of the building under various design scenario events. If the simulated performance meets or exceeds the performance objectives, the design is complete. If not, the design is revised in an iterative process until the performance objectives are met.

2. OBJECTIVE OF THE STUDY

To study the impact of discontinuity diaphragm and re-entrant corners in tall structures under serious seismic zone considering parameters like displacement, drift, base shear and time period.

3. METHODOLOGY

- Select the buildings with discontinuity diaphragm and re-entrant corners.
- All building plan areas, beam area, column area should be the same.
- Design the building as per prevailing Indian standards for dead load, live load and earth quake load in SAP2000 V20.
- Analyze the irregular building using Pushover analysis methods.
- Analyze the results and arrive at conclusions.

4. PERFORMANCE-BASED SEISMIC DESIGN DIAGRAM

Now a day Performance based engineering is not new concept. Automobiles, turbines, and airplanes have been designed and manufactured by using this approach from many decades. Generally one or more full-scale prototypes of the structure are built and subjected to extensive testing for effective implementation of prototype to actual scale. The design and manufacturing process of structure is revised to incorporate the lessons learned from the experimental evaluated results. Once the cycle of design, prototype manufacturing, testing and redesign is successfully completed, the product is manufactured in a large scale. For example, in the automotive industry millions of automobile products, which are identical in their mechanical characteristics are produced following each performance-based design exercise. Performance-based seismic design precisely evaluates a building performance under the given earthquake hazard it is likely to exposed.

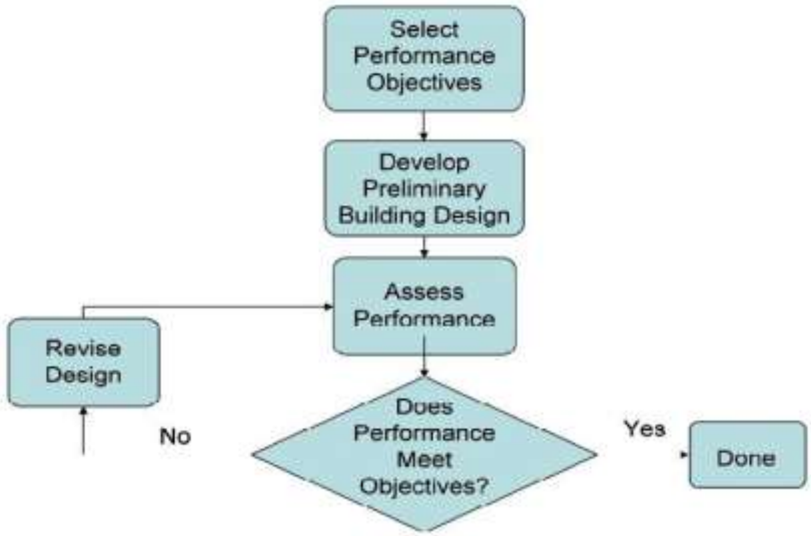

Fig-1: Performance-based seismic design flowchart for new buildings [7]

2.1 Performance Level

Table -1: Performance Level of Building [3, 4]

Level	Description
Operational	Very light damage, no permanent drift, structure retains original strength and stiffness, all systems are normal
Immediate Occupancy	Light damage, no permanent drift, structure retains original strength and stiffness, elevator can be restarted, Fire protection operable
Life Safety	Moderate damage, some permanent drift, some residual strength and stiffness left in all stories, damage to partition, building may be beyond economical repair
Collapse Prevention	Severe damage, large displacement, little residual stiffness and strength but loading bearing column and wall function, building is near collapse

Regarding ductility, the concept of inelastic displacement demand ratio (IDDR) [7] is employed. IDDR represents the ratio of inelastic displacement demand over the ultimate inelastic displacement capacity. Acceptable values IDDR associated with structural system performance levels OP, IO, DC, LS, and CP are 0, 0.2, 0.4, 0.6 and 0.8, respectively. Subscript a stands for the allowable value

Table -2: Allowable Inter-Storey Drift Ratio (IDR)

Structural System	OP	IO	DC	LS	CP
Masonry shear wall system	0.005	0.007	0.007	0.007	0.009
Others	0.005	0.01	0.015	0.02	0.025

Regarding stiffness, the maximum inter-story drift ratio (IDR) is considered to limit building lateral displacement. In this research, based on references such as the ATC 40 [3], FEMA 356 [4] other literature studies, the IDR limits in Table III are preliminarily suggested. Structural systems are mainly classified into four types, namely, the load-bearing walls, the frame systems, the moment resisting frames and the dual systems.

Table -3: Allowable Inelastic Displacement Demand Ratio (IDDR)

Performance level	OP	IO	DC	LS	CP
IDDRa	0	0.2	0.4	0.6	0.8

5. STRUCTURAL MODELING

RCC buildings (G+10), one without and three with complex shapes are chosen to compare the effect of plan shape on elastic behaviour of buildings. These buildings have approximately the same plan area of about 776m2 in each floor. The combination of two plan irregularities (G+10 floors) is modelled using SAP2000. Dead and live loads of the sections were applied to slab and beam elements. Initially, static linear analysis is performed using only dead load of the member and live load with reduction factor of 0.25 with Lateral load or other regular load applied to frame as per IS 1893:2016 [1].

Multiple numbers of pushover load cases are define in irregular structures or irregular geometry. The first pushover load case was used to apply gravity load case (which is force controlled) and then subsequent lateral pushover load cases (which is displacement controlled) were specified. In Pushover analysis the iteration is done using Newton-Raphson method.

5.1 Non-Linear Plastic Hinge (Pushover Analysis)

In irregular structures plastic hinges usually formed at the ends of beams and columns under earthquake action. For beam elements, plastic hinges are mostly caused by uniaxial bending moments, whereas for column elements, plastic hinges are mostly caused by axial loads and biaxial bending moments. Therefore, in push-over analysis different types of plastic hinges should be applied for the beam elements and the column elements separately.

In SAP2000 v20, hinge properties can be assigned to members using options of default hinge properties (Beam& Column) and user-defined hinge properties. The built-in default hinge properties are typically based on FEMA-356 and ATC-40 criteria.

Five points behaviour A (unloaded condition), B (effective yield), C (ultimate strength), D (residual strength), and E (failure) are used to define the force deformation 237ehaviour of the plastic hinge. These points are specified to determine hinge rotation 237ehaviour of RC members. The points between B and C represent acceptance criteria for the hinge, which may be any of the 3 conditions of Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) [4].

6. PROBLEM DEFINITION

There are 5 types irregularities of buildings selected to study the effect of diaphragm discontinuity on non-linear response parameters and based on that, performance based seismic design is carried out meet predefined performance criteria in terms of IDR and IDDR. Model I is taken as building without opening as shown in figure I. Model II, III, IV and V are building with different shapes of opening as shown in figure 3, 4, 5 and 6 respectively. The prototype buildings are G+10-storied reinforced concrete buildings & the story height is taken as 3m. Primary Beam size is 230mm x 450mm and columns are 425mm x 425mm (For Model I) & 400mm X 400mm (For Model II, III) and other two model beam size is 230mm x 370 mm and columns are 411mm x 411mm (For Model IV)

Now other beam size is 230mm x 393 mm and columns are 376mm x 376 mm (For Model V) with fixed support at base. To achieve the performance objective size of beam and column are increased until required performance is not met. Slab thickness is 150mm.

6.1 Design Data:

Table -4: Design data

Live load	3.0 Kn/m^2 at typical floor
	1.5 Kn/m^2 on terrace
Floor finish	1.0 kN/m^2
Water proofing	2.0 kN/m^2
Terrace finish	1.0 kN/m^2
Wall Load	230 mm thick brick masonry walls only at periphery (4.9 kN/m^2)
Earthquake load	As per IS-1893 (Part 1) – 2002
Zone factor, Z	0.16,0.36
Importance factor	1
Response reduction factor	5
Type of soil	Type II, Medium as per IS:1893
Grade of concrete	M30
Grade of steel	fe 500 (HYSD)

6.1 Plan and Elevation of the Building models:

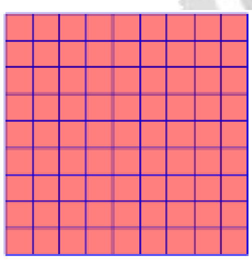

Fig-2: model I

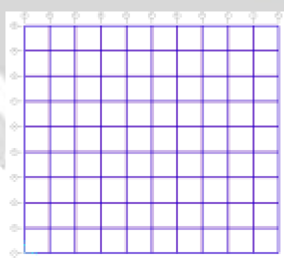

Fig-3: model I

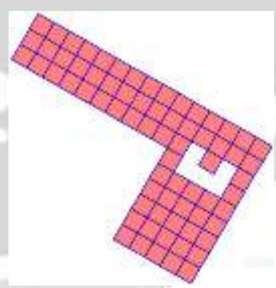

Fig-4: model II

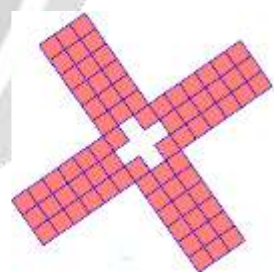

Fig-5: model III

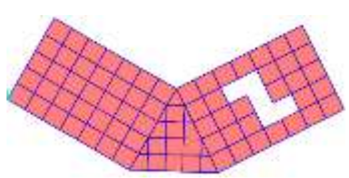

Fig-6: model IV

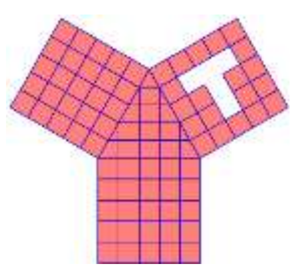

Fig-7: model V

- Model I: Building without opening
- Model II: Building with C shape opening
- Model III: Building with + shape opening
- Model IV: Building with Z shape opening
- Model V: Building with T shape opening

7. ANALYSIS AND RESULTS

The performance point of the irregular structure that responds to the considered hazard level is evaluated through the capacity-spectrum method [3]. The structure is pushed again to the target displacement associated with the performance point to access the behaviour of both the structural system and the elements if such a hazard level occurs.

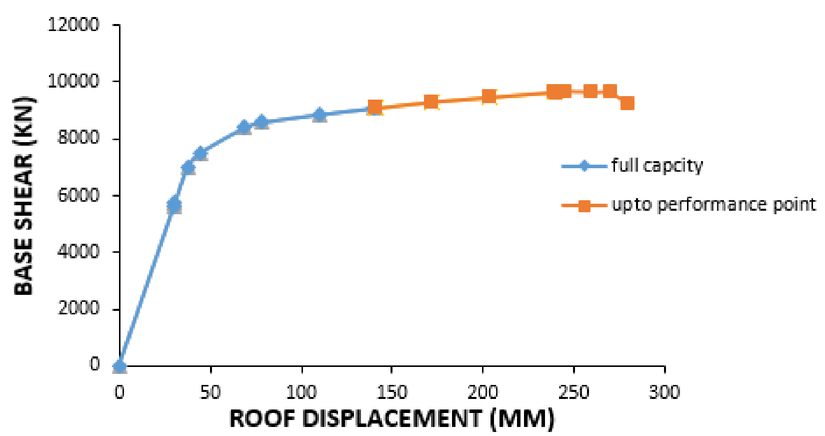

Fig-8: Overlap of pushover curve for full capacity and up to performance point (Model II)

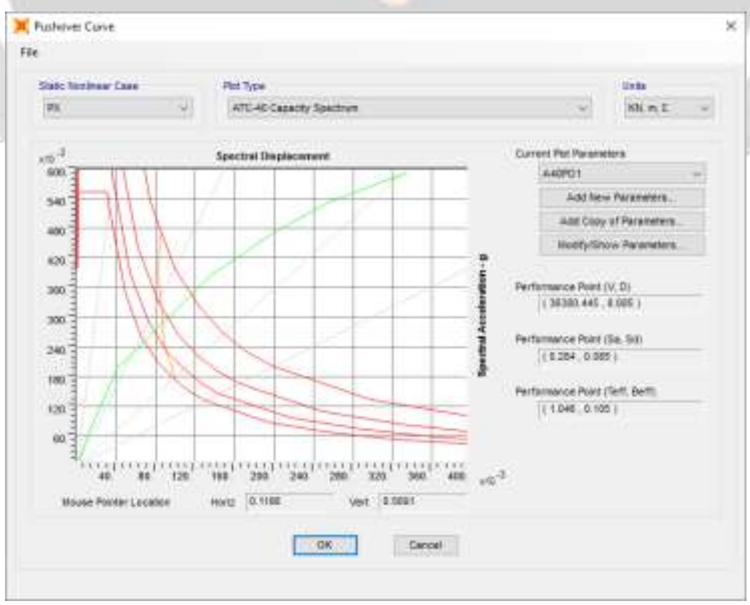

Fig-9: pushover curve at performance point

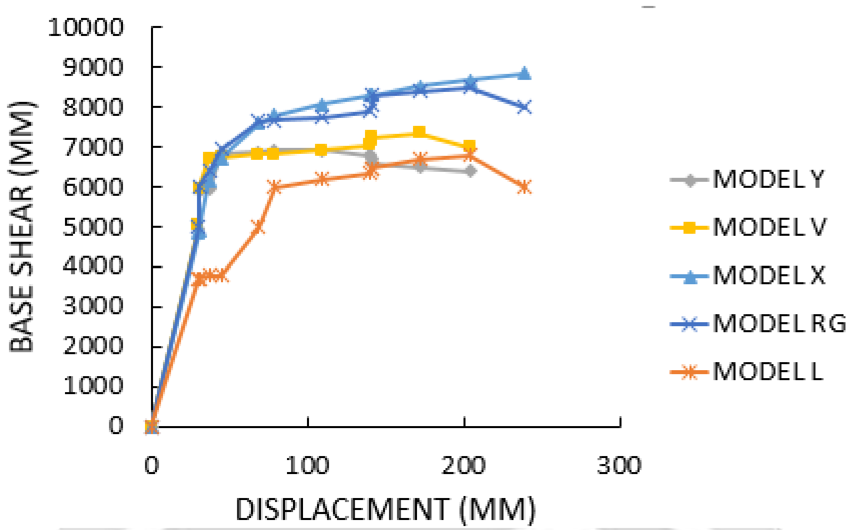

Fig-10: pushover curve in x direction

The result shows that, whenever there is re-entrant corner & opening present in diaphragm is considerably lower down the capacity of building. Also, to achieve the performance objectives, the model with opening required higher section (Beam, Column) size compared to model without opening in diaphragm. Also performance points shows that for same section size of members, base shear observed is lesser and displacement is higher in case of buildings with opening in diaphragm compared to model I.

Table -5: System Performance Evaluation Regarding IDR and IDDR for Model I

Zone	III	V	III	V
Selected section	C-400X400, B-230X450		C-500X500, B-230X600	
IDRa	1.2	1.9	0.7	2.0
IDR (%)$_{X-Direction}$	0.7	1.86	0.675	1.71
IDR (%)$_{Y-Direction}$	0.61	0.98	0.8	0.99
Check if IDR ≤ IDRa	Yes	Yes	Yes	Yes
IDDRa	0.4	0.8	0.2	0.6
IDDR (%)$_{X-Direction}$	0.18	0.73	0.13	0.54
IDDR (%)$_{Y-Direction}$	0.15	0.56	0.14	0.55
Check if IDDR ≤ IDDRa	Yes	Yes	Yes	Yes

Table -6: System Performance Evaluation Regarding IDR and IDDR for Model II

Zone	III	V	III	V
Selected section	C-400X400, B-230X450		C-500X500, B-230X600	
IDRa	1.2	2.9	1.2	2.2
IDR (%)$_{X-Direction}$	0.81	2.24	0.83	1.62

IDR (%)$_{\text{Y-Direction}}$	0.81	2.5	0.9	1.32
Check if IDR ≤ IDRa	Yes	Yes	Yes	Yes
IDDRa	0.4	0.8	0.6	0.8
IDDR (%)$_{\text{X-Direction}}$	0.34	0.78	0.51	0.67
IDDR (%)$_{\text{Y-Direction}}$	0.3	0.67	0.53	0.56
Check if IDDR ≤ IDDRa	Yes	Yes	Yes	Yes

Table -7: System Performance Evaluation Regarding IDR and IDDR for Model III

Zone	III	V	III	V
Selected section	C-400X400, B-230X450		C-500X500, B-230X600	
IDRa	1.2	2.1	1	2.3
IDR (%)$_{\text{X-Direction}}$	0.8	2.3	0.99	1.36
IDR (%)$_{\text{Y-Direction}}$	0.73	2.55	0.82	1.85
Check if IDR ≤ IDRa	Yes	Yes	Yes	Yes
IDDRa	0.6	0.8	0.6	0.8
IDDR (%)$_{\text{X-Direction}}$	0.59	0.64	0.45	0.63
IDDR (%)$_{\text{Y-Direction}}$	0.55	0.49	0.38	0.66
Check if IDDR ≤ IDDRa	Yes	Yes	Yes	Yes

Table -8: System Performance Evaluation Regarding IDR and IDDR for Model IV

Zone	III	V	III	V
Selected section	C-356X356, B-230X370		C-456X456, B-230X493.40	
IDRa	1.3	2.8	1	2.2
IDR (%)$_{\text{X-Direction}}$	0.76	2.10	0.54	1.56
IDR (%)$_{\text{Y-Direction}}$	0.79	2.12	0.57	1.9
Check if IDR ≤ IDRa	Yes	Yes	Yes	Yes
IDDRa	0.4	0.8	0.4	0.6
IDDR (%)$_{\text{X-Direction}}$	0.12	0.76	0.12	0.52
IDDR (%)$_{\text{Y-Direction}}$	0.11	0.77	0.10	0.52
Check if IDDR ≤ IDDRa	Yes	Yes	Yes	Yes

Table -9: System Performance Evaluation Regarding IDR and IDDR for Model V

Zone	III	V	III	V
Selected section	C-376X376, B-230X393.9		C-470X470, B-230X526.55	

IDRa	1.8	2.2	1.5	2.3
IDR (%)$_{X\text{-Direction}}$	0.74	2.12	0.63	1.55
IDR (%)$_{Y\text{-Direction}}$	0.73	2.13	0.52	1.52
Check if IDR ≤ IDRa	Yes	Yes	Yes	Yes
IDDRa	0.8	0.8	0.6	0.8
IDDR (%)$_{X\text{-Direction}}$	0.64	0.78	0.51	0.62
IDDR (%)$_{Y\text{-Direction}}$	0.59	0.77	0.50	0.64
Check if IDDR ≤ IDDRa	Yes	Yes	Yes	Yes

8. CONCLUSION

In this work, Performance based seismic design of a G+10 storey buildings re-entrant corner with and without opening in diaphragm has been done by evaluating their performance using pushover analysis. By varying member (Beam, Column) size in different combinations and their effect on the performance of the structure was studied.

1) Performance of building increase with increasing member size, by using these we can easily achieved pre-established performance objectives for PBSD of Buildings.
2) Results shows that, to achieve the same performance objective in terms of IDR and IDDR parameters, higher member size is required whenever there is opening present in building.
3) Pushover curve shows opening in Diaphragm decrease base shear capacity significantly.
4) At performance point reduction of base shear is almost 22.05%, 37.46%, 9.85%, and 37.47% in both directions for all the Models compared to model I (For Initial Section Size).
5) The L-shape of the building will base shear reduced but the building will base shear increase.

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