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# Performance Seismic Design of Reinforced Concrete Buildings with Soft Storey

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***Abstract: Performance based seismic design studies are carried out before an earthquake occurrence for assessing the desideratum to vigour essential facilities and structures against future earthquakes. For providing ample parking spaces, now a day's soft storey of the building is utilized. The buildings having no infilled walls in ground storey, but which are in-filled in all upper storey, are called soft storey buildings. Soft ground storey framed buildings are generally analyzed as linear bare frame analysis. Design codes give multiplication factors on the design forces in the columns of ground storey. The present study endeavours to estimate and compare performance of soft storey building designed with multiplication factors given by IS codes. A typical Low Rise (G+2), Mid-Rise(G+4) and High Rise (G+6) building framed is considered and the design forces for the ground storey columns are evaluated predicated from code and ground storey columns are designed. The performance of each building is studied utilizing the Performance Based Seismic Design Analysis method. Models of buildings designed with different multiplication factors are developed in SAP2000 Software for nonlinear dynamics analysis on which a set of seven time histories is applied. In the present study, P.B.S.D are engendered for each building, by developing a performance level checks. The relative performances of different storeys of each building are compared utilizing performance objective for different performance levels. Results show that performance of upper storeys while applying multiplication factor only to the ground storey needs to be checked. Performances of Soft Storey frames, (ground storey drift) increases in the incrementing order of multiplication factors.***
***Keywords: Soft storey, multiplication factors, , performance levels, ****, non-linear procedures, seismic performance, PBSD*

## I. INTRODUCTION

The susceptibility of an element is defined as the probability that the verbally expressed element will sustain a designated degree of structural damage given a certain level of ground kineticism rigor. An astronomically immense number of subsisting buildings in India need seismic evaluation due to sundry reasons such as, nonconformity with the codal requisites, revision of codes and design practice and transmute in the utilization of building. Hence P.B.S.D estimation of the RC buildings in India is a growing concern. P.B.S.D of building

### *A. Soft Storey*

Soft Storey buildings are commonly constructed in India and all over world since they provide much needed parking space in an urban environment. Collapses of buildings in Bhuj earthquake are mostly due to the formation of soft-storey mechanism in the ground storey columns. Figure 1 represents an example of typical open ground storey provided for parking spaces. The sudden reduction in lateral stiffness and mass in the ground storey tends to increase stresses in the ground storey columns under

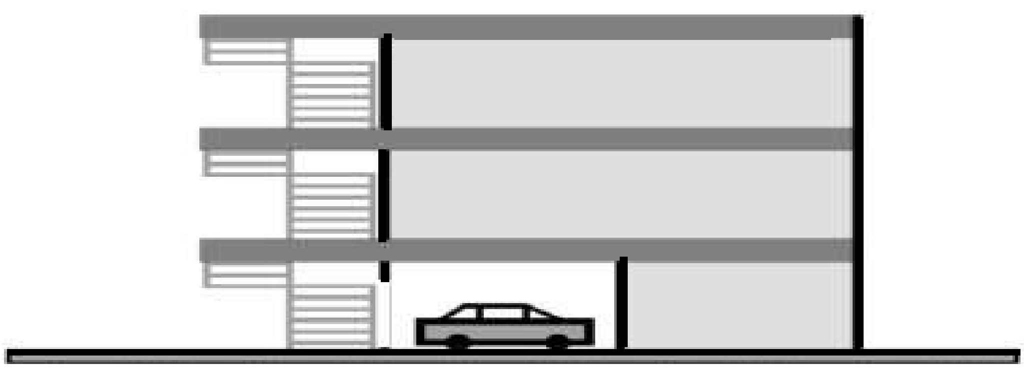

Figure.1.: Soft storey for parking space

Seismic loading. Design based on bare frame analysis results in underestimation of the bending moments and shear forces in the ground storey columns, which is responsible for the damages observed. Therefore it is necessary that the ground storey columns must have sufficient strength, stiffness and adequate ductility.

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TABLE 1: Multiplication Factor (MF) As Per IS Codes

| Code | Criteria | Expression for MF | MF considered |
|---|---|---|---|
| Indian | $\frac{K_i}{K_{i+1}} < 0.7$ | 2.5 | 2.5 |

Where, Ki- Lateral stiffness of i[th] storey considered, Ki+1- Lateral stiffness of (i+1)[th] storey considered,

In the aftermath of the Bhuj earthquake, the IS 1893 code was revised in 2002, giving new design recommendations to address soft story buildings. Clause 7.10.3(a) of IS 1893:2002 states: The columns and beams of the soft storey are to be designed for 2.5 times the storey shears and moments calculated under seismic loads of bare frames. The factor 2.5 can be said as a multiplication factor (MF) or Magnification factor. This multiplication factor (MF) is supposed to be the compensation for the stiffness discontinuity. IS code recommend multiplication factors for this type of buildings which are given in Table 1. The main objective of this work is to study and compare the seismic performance of typical soft storey buildings designed as per applicable provisions in Indian code in a PBSD framework.

## II. SOFT STOREY CASES

The soft storey irregularity is one of the main reasons for heavy damage and collapse of multistorey buildings after seismic events. During earthquakes, ground floors with different storey heights usually behave differently compared to other storeys. There are many structures with soft storeys in the first floor. These buildings are mostly located on the main streets where they are used for commercial purposes, e.g. department stores, restaurants, banks and showrooms. These places are usually enclosed with glass windows. Brick walls are placed just above the soft storey.

In such situations, serious problems occur in the soft storey during an earthquake. Significant damage and sudden collapses can be observed due to big deformations and energy dissipation at the soft storey columns. Behaviour of a structural system having soft storey irregularity under lateral loads is presented in Figure 2.

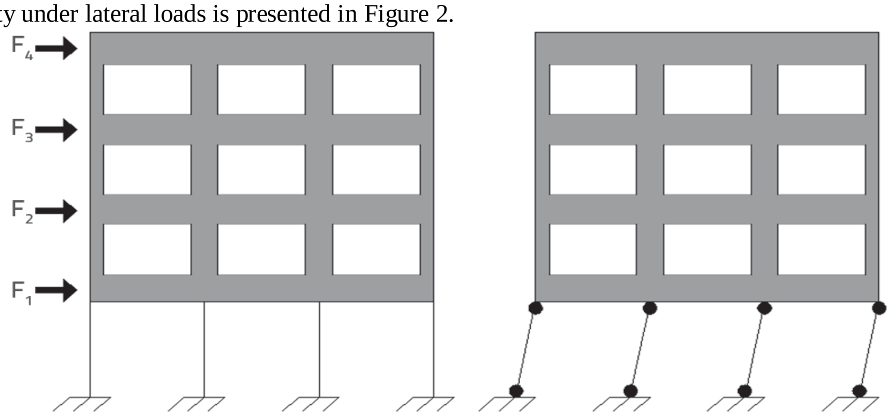


Figure2. Behaviour of soft storey

The soft storey irregularity is usually seen in multistorey apartment buildings with large openings. Since deformations are concentrated in the first storeys, these storeys have been mostly affected by earthquakes registered in recent years . These types of buildings usually have a poor load carrying capacity, especially when subjected to lateral loads. While massive damage is usually observed in the ground storeys, the damage to upper storeys is limited. Some examples of buildings with soft storey after earthquakes are presented in Figure 3.

Figure 3. Damage to soft storeys

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## III. PERFORMANCE BASED SEISMIC DESIGN

Performance based design is gaining a new dimension in the seismic design philosophy wherein the near field ground motion (usually acceleration) is to be considered. Earthquake loads are to be carefully modelled so as to assess the real behaviour of structure with a clear understanding that damage is expected but it should be regulated. The promise of performance-based seismic engineering (PBSE) is to produce structures with predictable seismic performance. To turn this promise into a reality, a comprehensive and well-coordinated effort by professionals from several disciplines is required.

Basic concept of Performance Based Seismic Design is to provide engineers with the capability to design buildings that have a predictable and reliable performance in earthquakes. Performance based Seismic design is an elastic design methodology done on the probable performance of the building under input ground motions.

The performance-based seismic design process explicitly evaluates how a building is likely to perform; given the potential hazard it is likely to experience, considering uncertainties inherent in the quantification of potential hazard and uncertainties in assessment of the actual building response.

In performance-based design, identifying and assessing the performance capability of a building is an integral part of the design process, and guides the many design decisions that must be made. Figure 4 shows a flowchart that presents the key steps in the performance-based design process. It is an iterative process that begins with the selection of performance objectives, followed by the development of a preliminary design, an assessment as to whether or not the design meets the performance objectives, and finally redesign and reassessment, if required, until the desired performance level is achieved.

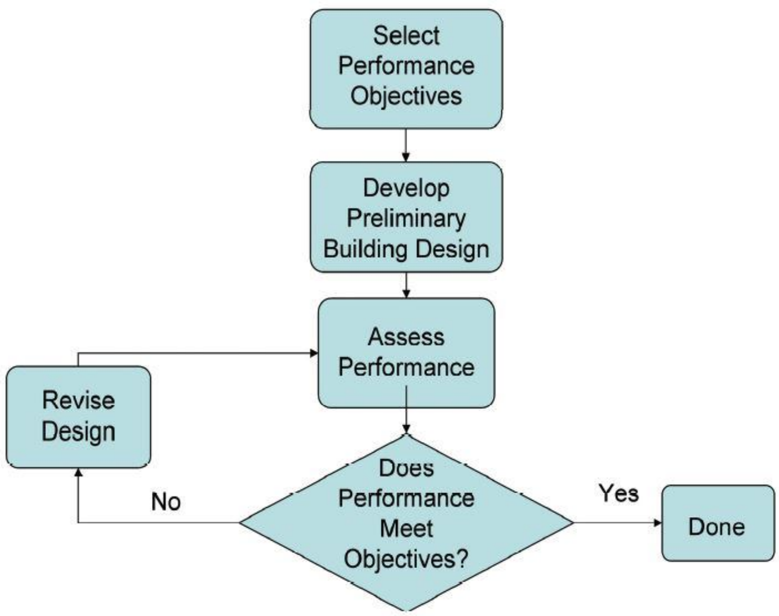


Figure 4.: Flowchart of Performance Based Seismic

## IV. DESCRIPTION OF BUILDINGS

The sample buildings have 3, 5, and 7 storeys, respectively. These structures are intended to represent typical residential low-rise, medium-rise and high-rise reinforced concrete buildings in urban areas. The frame buildings have typical column-beam sections without any shear walls. Since storey height is an important parameter in the soft storey irregularity, it should be noted that the storey height is 3 m at all levels except for the ground floor which is 5 m in height. Outer axes of ground storeys are covered by glass windows. Walls are 200 mm in thickness in outer axes and 100 mm in thickness in the remaining storeys of the buildings under study. The soil type is II for zone III according to IS1893 (Part1) - 2016 The buildings are assumed to be located in an earthquake-prone area. Three-dimensional finite element models are shown in Figure 5.

The buildings are 13.5 m by 13.5 m in plan. Material properties are assumed to be 25 MPa for the concrete compressive strength and 500 MPa for the yield strength of both longitudinal and transverse reinforcement. The height of the slabs is taken to be 120 mm. The plan view and elevation of the buildings are presented in Figure 4. Sections of corner ground-floor columns are bigger compared to sections of other columns. Beam sections are constant on all storeys. Sections of structural members are shown in Table 2 with M.F = 1and Table 3 with M.F = 2.5 Details of ground- floor column and beam sections are also shown in Figure 6.

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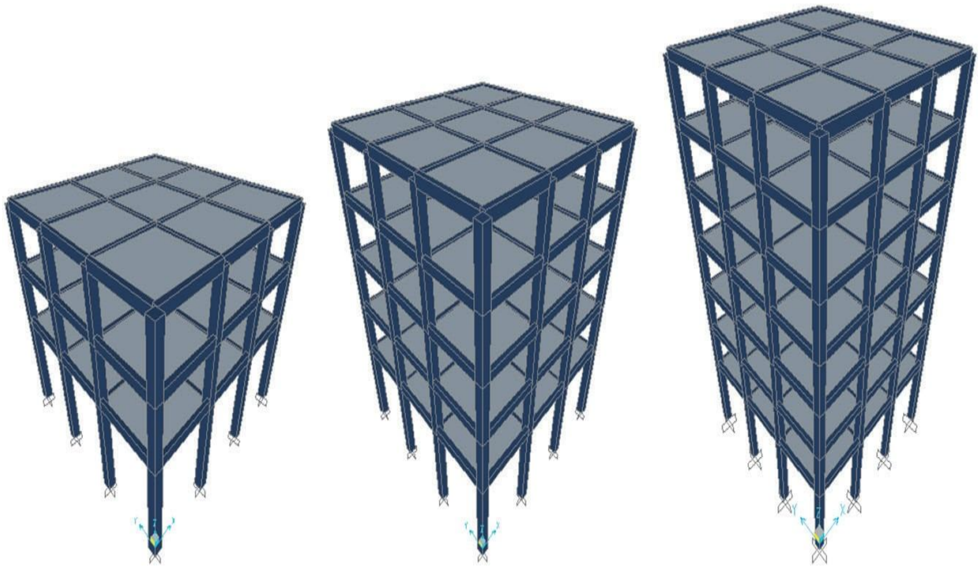

Figure 5. Three dimensional views of structures

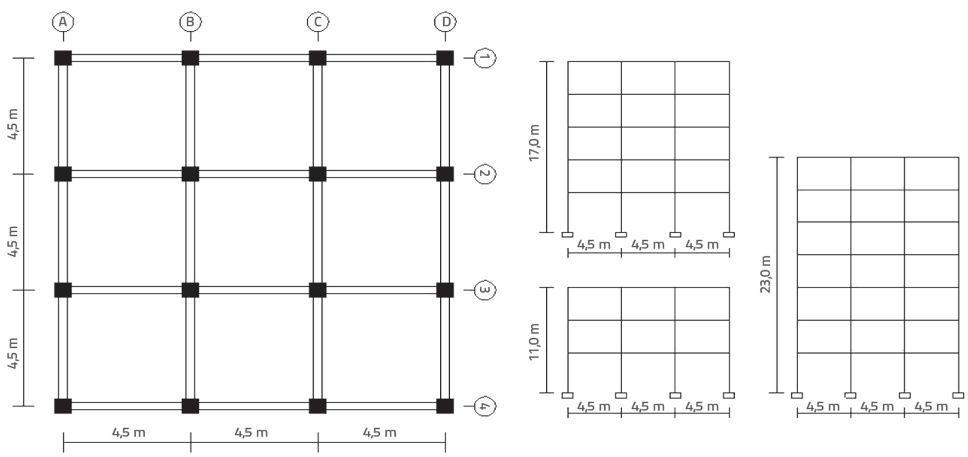


Figure6. Geometry of buildings

Table3. Section sizes of members

| Structure type | Beam sections [mm] | Corner ground-floor column sections [mm] | Other column sections [mm] |
|---|---|---|---|
| 3 storey | 250 x 500 | 400 x 400 | 300 x 400 |
| 5 storey | | 450 x 450 | 350 x 450 |
| 7 storey | | 500 x 500 | 400 x 500 |

Table 4. Section sizes of members

| Structure type | Beam sections [mm] | Corner ground-floor column sections [mm] | Other column sections [mm] |
|---|---|---|---|
| 3 storey | 300 x 350 | 650 x 650 | 450 x 550 |
| 5 storey | | 750 x 750 | 550 x 650 |
| 7 storey | | 800 x 800 | 520 x 670 |

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After determining the weight and modal properties, plastic hinges are assigned at two ends of columns and beams to perform non-linear analyses. The moment-rotation relationship of members is defined using the SAP2000 finite-elements analysis program. Moment-curvature analyses for structural members are utilized for this purpose according to the Semap analysis program , as shown in Figure 7. The modified Kent- Park Model for confined concrete is used in the moment- curvature analyses of members.

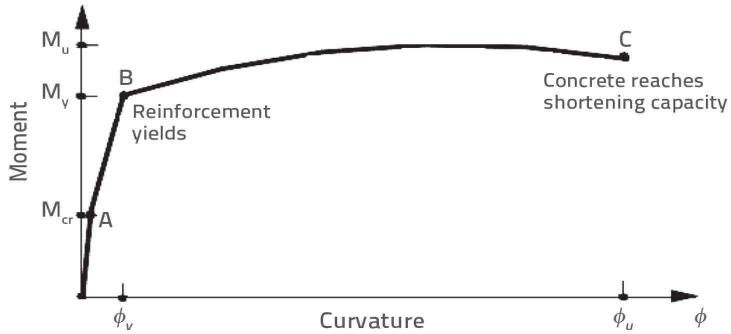


Figure 7. Moment-curvature relationship

The idealized force-deformation relationship of a plastic hinge, shown in Figure 8, is defined using the SAP2000 analysis program. By this curve, the relationship is determined by plastic hinges on structural members. Eight points are required to define the curve. However, four points are sufficient for symmetrically reinforced members.

The unloaded situation of hinge deformation is represented by point A. The yield of a structural member occurs when the Fy strength value in a hinge is reached. After the point B, the force on hinge changes according to deformation. When the displacement value reaches the point C, the plastic hinge reaches the collapsing situation. Finally, the plastic hinge completely loses its strength, and the building failure situation is defined, when points D and E are reached.

Locations of plastic hinges at structural ground-floor members are presented as an example in Figure 9. In this figure, Lp is the length of the plastic hinge.

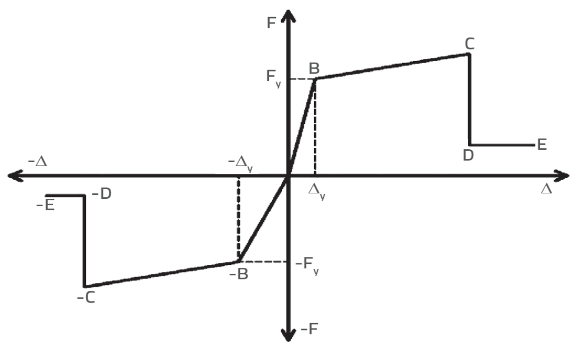


Figure 8. Idealized force-deformation relationship

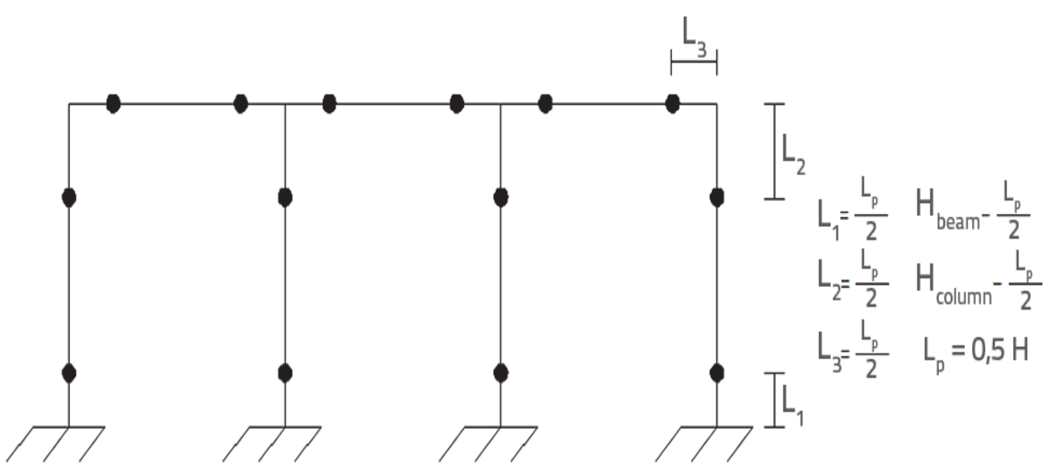


Figure 9. Locations of plastic hinges

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The damage situations of the members, and the performance levels of all buildings, are then determined by comparing the plastic-rotation values with limit values defined in FEMA-356 (DCM), FEMA-440 (DCM) and IS -1893(Part-I)-2016.

## V. NON-LINEAR ANALYSIS

### *A. Nonlinear Dynamic Analysis*

As per FEMA356 there are different criteria for selection of time histories such as Magnitude, source to site distance, rupture mechanism and soil conditions. This study have restricted criteria for selecting time histories only for magnitude. Time histories are taken from PEER ground motion data. Total seven time histories are selected for analysis having magnitude greater than 6.5 for design based earthquake hazard level.

Earthquake Names,

*1)* "Imperial Valley-02"
*2)* "Northwest Calif-02"
*3)* "Borrego"
*4)* "Kern County"
*5)* "El Alamo"
*6)* "Borrego Mtn"
*7)* "San Fernando"

Each Building frames are modeled in the SAP2000 Software (Version 19.1.0).

### *B. Criteria for Performance Level*

In this section we will discuss various performance level criterias as per FEMA273, FEMA P58, Volume 1 & 2 from which we will determine whether given model is in desired performance level or not. The various case criterias obtained from referred literature as described below.

### *C. Storey Drift*

FFMA 273 describes performance level criteria for storey drift. Storey drift of given model should be in following limit.

Table 5:- Storey Drift Criteria

| Performance Level | Operational | Immediate Occupancy | Life Safety | Collapse Prevention |
|---|---|---|---|---|
| Storey Drift | < 0.2% | < 0.5% | < 1.5% | < 2.5% |

### *D. Plastic Rotation*

Following table gives the allowable Plastic Rotation as per FEMA 273/356. After each trial plastic rotation of each member is checked with following table. If plastic rotation of member is going beyond the permissible rotation design is revised or vice versa. Plastic rotation limit for various performance levels is given as per following table,

| Structural Elements | Immediate Occupancy | Life Safety | Collapse Prevention |
|---|---|---|---|
| Beam | 0.01 | 0.02 | 0.025 |
| Column | 0.005 | 0.015 | 0.02 |

Table 6: Plastic rotation criteria

## VI. RESULTS AND DISCUSSIONS

After initially analysing and design models by IS code method the structures are analyse with non-linear dynamic analysis method in which storey drift as main parameter to decide the performance of the building will be consider. Storey drift is calculated as shown in figure 9, 10 and 11 and finalise the design for longitudinal reinforcement sections area are find out for the I.O, L.S and C.P performance level as a performance objective for the low, mid and high rise building models in table 7, 8 and 9.

Table 7 :- Final Design of Models for I.O as Performance Level

| Section | Storey Level | Section Size | Area of Steel | |
|---|---|---|---|---|
| Beam | 5,6,7 | 380 x 600 | 1350 | Top |
| | | | 1200 | Bottom |
| | 1,2,3,4 | 380 X680 | 1600 | Top |
| | | | | Bottom |

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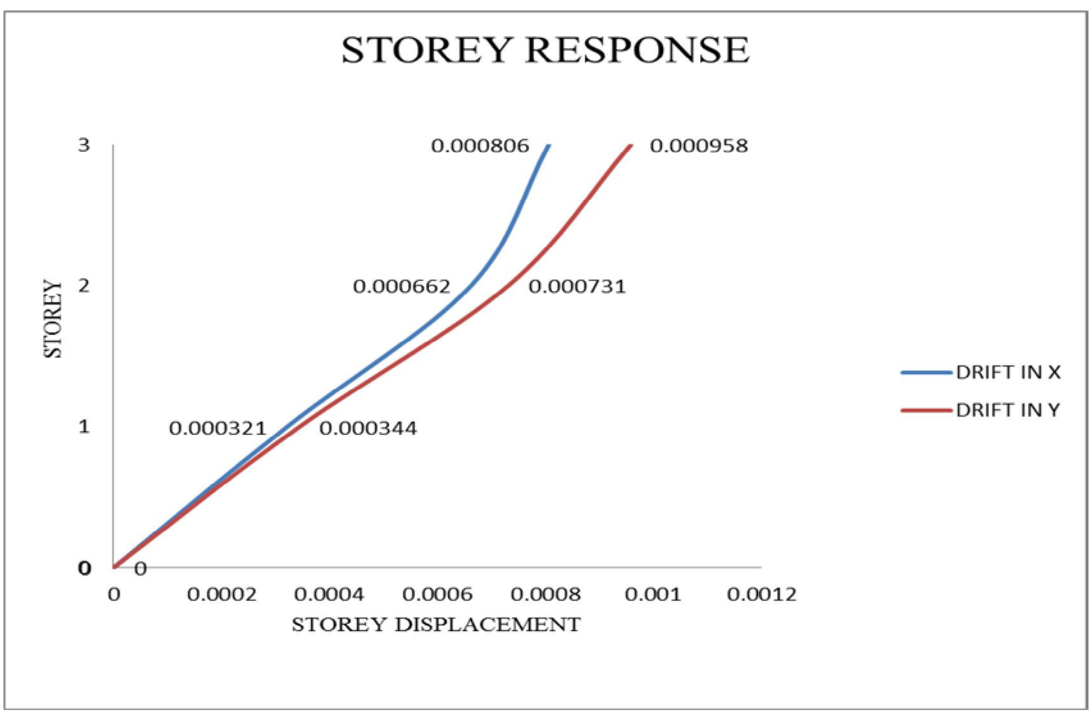
| | | | |
|---|---|---|---|
| Column | 5,6,7 | 600 X 600 | 2500 |
| | 2,3,4 | 830 X 830 | 3500 |
| | 1 C.C | 980 X 980 | 6100 |
| | 1 O.C | 980 X 980 | 8000 |

Table 8 :- Final Design of Models for L.S as Performance Level

| Section | Storey Level | Section Size | Area of Steel | |
|---|---|---|---|---|
| Beam | 4,5,6,7 | 230 x 380 | 1300 | Top |
| | | | 900 | Bottom |
| | 1,2,3 | 380 X680 | 1400 | Top |
| | | | | Bottom |
| Column | 5,6,7 | 500 X 500 | 4000 | |
| | 2,3,4 | 550 X 550 | 5500 | |
| | 1 C.C | 680 X 680 | 6500 | |
| | 1 O.C | | 7000 | |

Table 7 :- Final Design of Models for C.P as Performance Level

| Section | Storey Level | Section Size | Area of Steel | |
|---|---|---|---|---|
| Beam | 4,5,6,7 | 230 X 300 | 900 | Top |
| | | | 700 | Bottom |
| | 1,2,3 | 300 X 420 | 1200 | Top |
| | | | 900 | Bottom |
| Column | 5,6,7 | 450 X 450 | 2500 | |
| | 2,3,4 | 530 X 530 | 3000 | |
| | 1 C.C | 600 X 600 | 4000 | |
| | 1 O.C | 650 X 650 | 4500 | |

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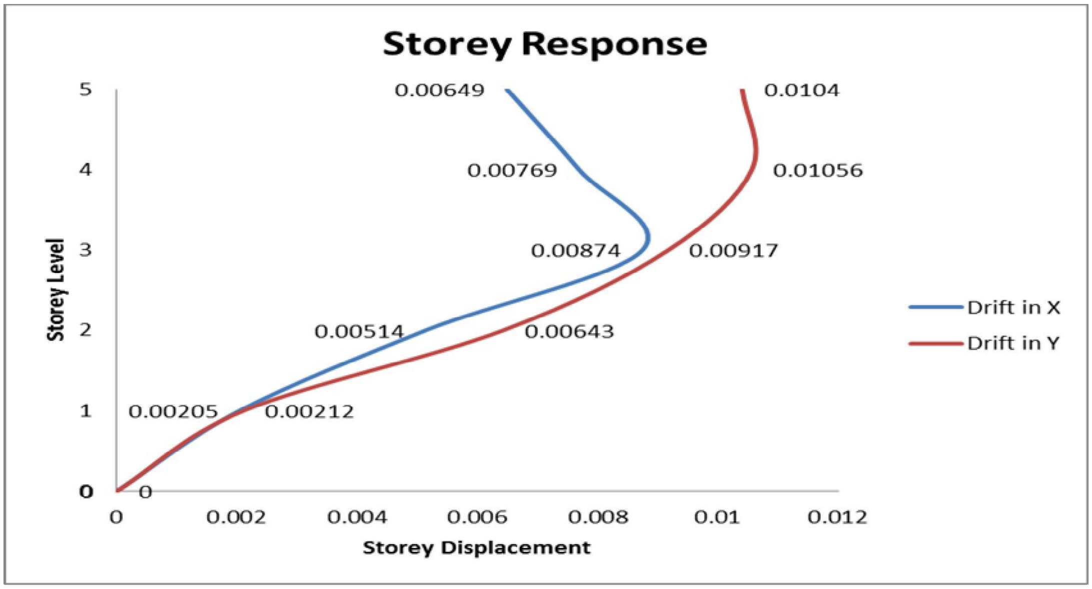


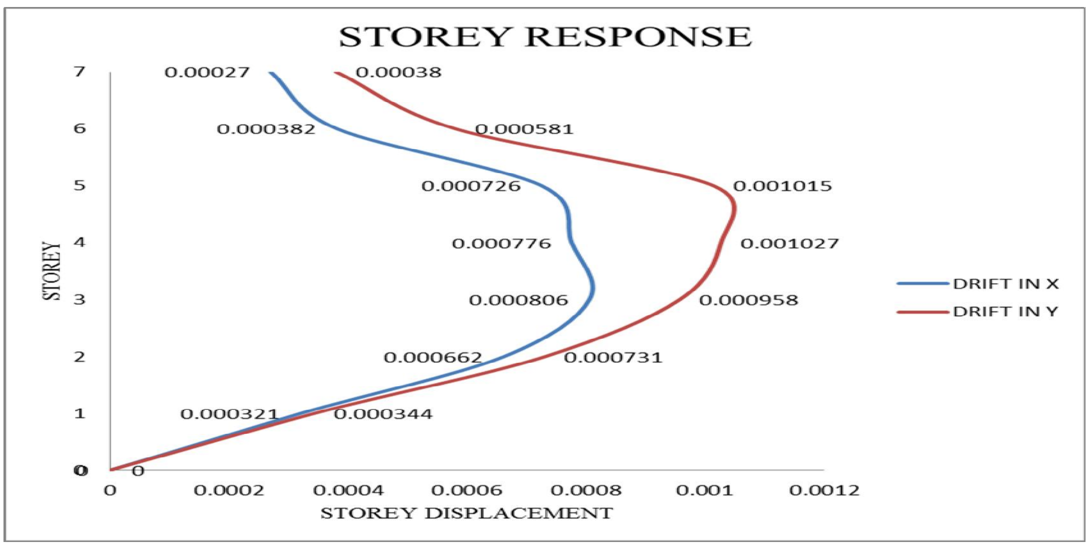


Figure 9. Storey Drift for I.O as performance level low, mid and high rise model


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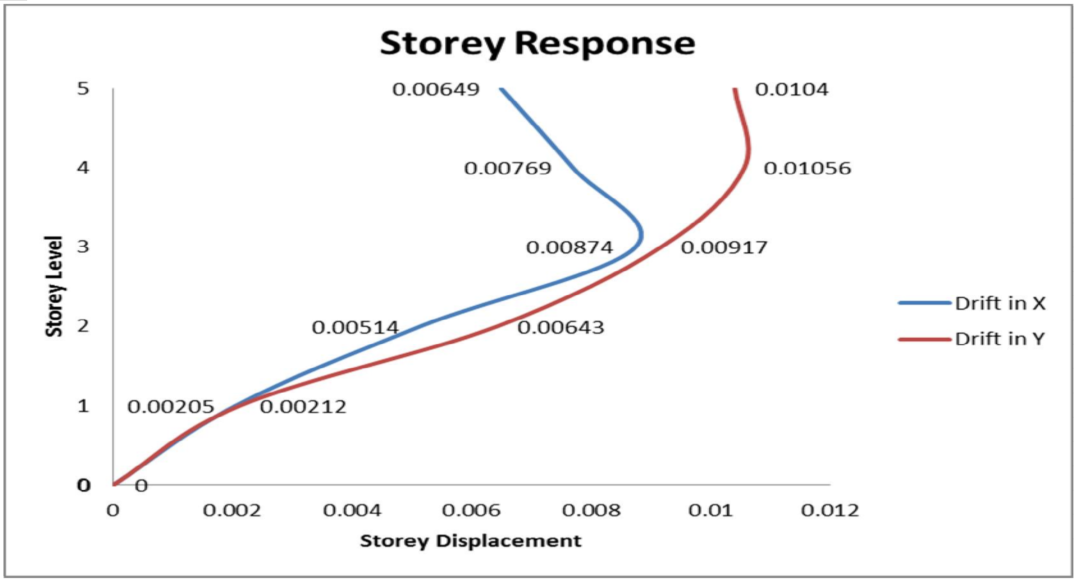


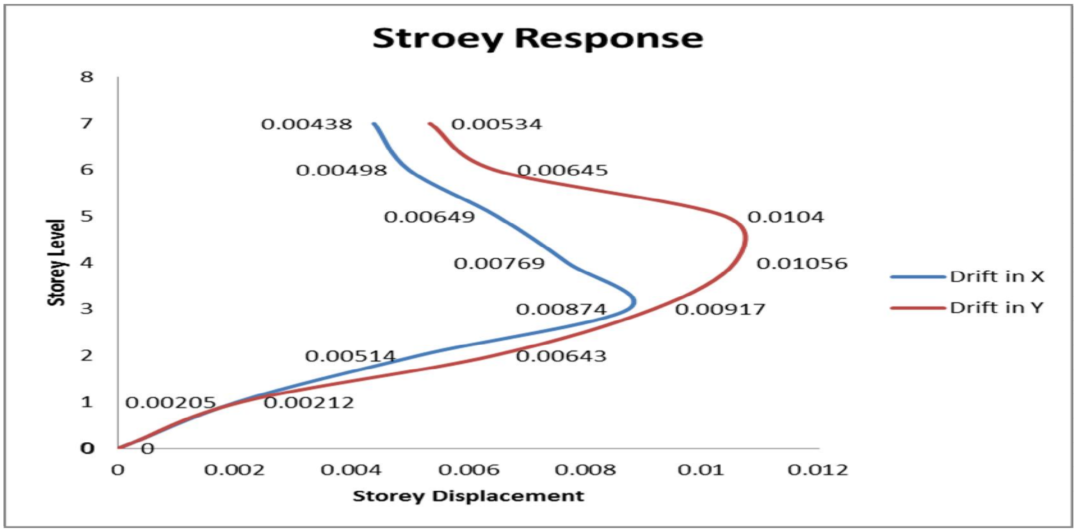
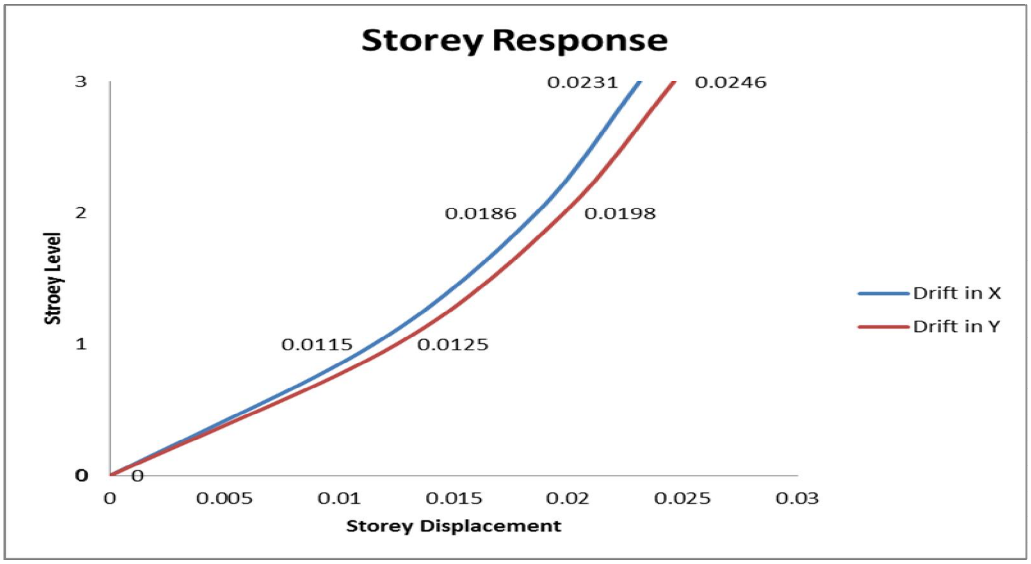
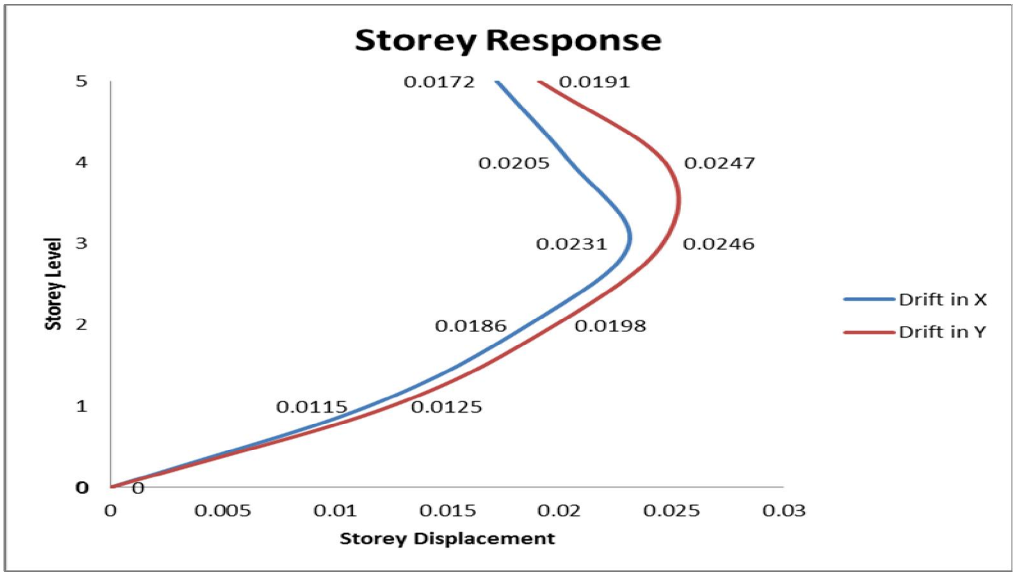




Figure 10. Storey Drift for L.S as performance level low, mid and high rise model





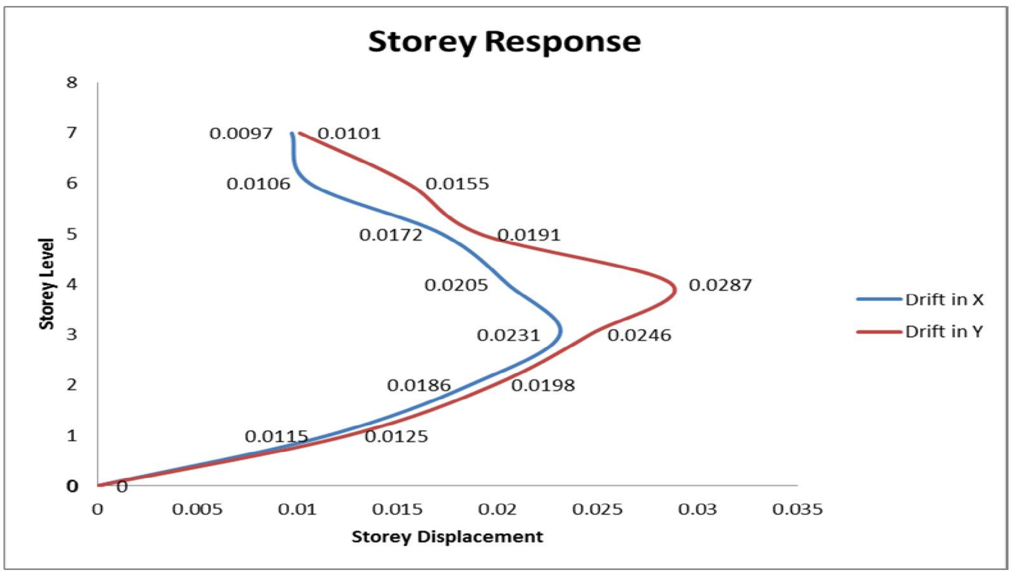




Figure11. Storey Drift for C.P as performance level low, mid and high rise model

## VII. CONCLUSIONS AND SUGGESTIONS

Structural damage and collapse events are known to cause important losses. For this reason, performance based design and evaluation procedures have been developed in response to recent large scale earthquakes. In this respect, many researchers focus their studies on seismic performance of existing buildings, and on the strengthening of buildings exhibiting poor seismic performance. Recent codes place a primary emphasis on the definition of linear and non-linear performance evaluation techniques.

Non-linear analysis of structural performance can nowadays be performed by both dynamic and static procedures. These procedures are considered to be more reliable since more data about properties of material structural systems are required.

The seismic performance of structures can be determined more realistically using displacement-based methods. Displacement-based methods rely on the relationship between the displacement demand and the lateral force carrying capacity of structures for a specific ground motion. In these methods, the displacement demand is calculated numerically. The time history analysis is a complicated non-linear dynamic method in which ground motion seismic loads are applied until the plastic collapse mechanism is reached. The lumped plasticity approach is adopted and an inelastic behavior is determined by plastic hinges at two ends of structural members.

A soft storey is one of important irregularities causing structural damage and losses. Main reasons for this irregularity are the stores designed for commercial purposes, which have higher storey heights and are devoid of brick walls. As behavior of soft

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storey's is different from that exhibited by other storeys, and as bigger displacements are observed in soft storey columns, these buildings are highly susceptible to sudden collapse during an earthquake. Researchers have invested significant efforts to understand the behavior of soft storey's under seismic action, which causes disproportionate lateral stresses and severe damage.

Non linear dynamic analysis of the existing 3, 5, and 7 storey reinforced concrete buildings having soft storey irregularities are performed in this paper according to FEMA-356 (DCM), FEMA-440 (DCM), and IS 1893(Part-1)2016. Material properties, storey plans, and section sizes, are assumed to be constant for these structures. The structures are assumed to represent typical residential low-rise, mid-rise, and high-rise buildings. Modal properties with damage ratios of structural members and storey drifts are determined for the buildings.

After evaluation of structural performance results for the three codes, it was established that more conservative results are obtained by IS 1893(PART-1)2016 compared to FEMA-356 and FEMA-440. Light damage levels are observed in the upper floors of the structures. Damage situations of structural members increase in severity in direct proportion to the total height of the buildings. More pronounced damage and bigger storey drift ratios are registered at the 7-storey structure. While all soft storey columns reach collapse prevention level according to IS 1893(PART-1)2016, 75 % and 63 % of them get this damage level according to FEMA-356 and FEMA-440, respectively, for the 7-storey structure. The maximum beam damage is also observed according to IS 1893(PART-1)2016. 19.0 %, 14.3% and 9.5 % of the beams remain at the collapse prevention level according to IS 1893(PART-1)2016, FEMA-356 and FEMA-440 for the 7-storey structure.

Based on the results obtained for the three buildings, it can be stated that soft storey irregularities may cause heavy damage, especially in case of taller buildings. Soft storey columns can ensure the life safety level for the 3-storey structure only. On the other hand, the collapse damage situation is observed at more than one floor, especially for the beams of the 7-storey structure, according to each code. Finally, this study can be improved by further analysis of different types of structures, with strengthening techniques based on non-linear methods according to various codes.

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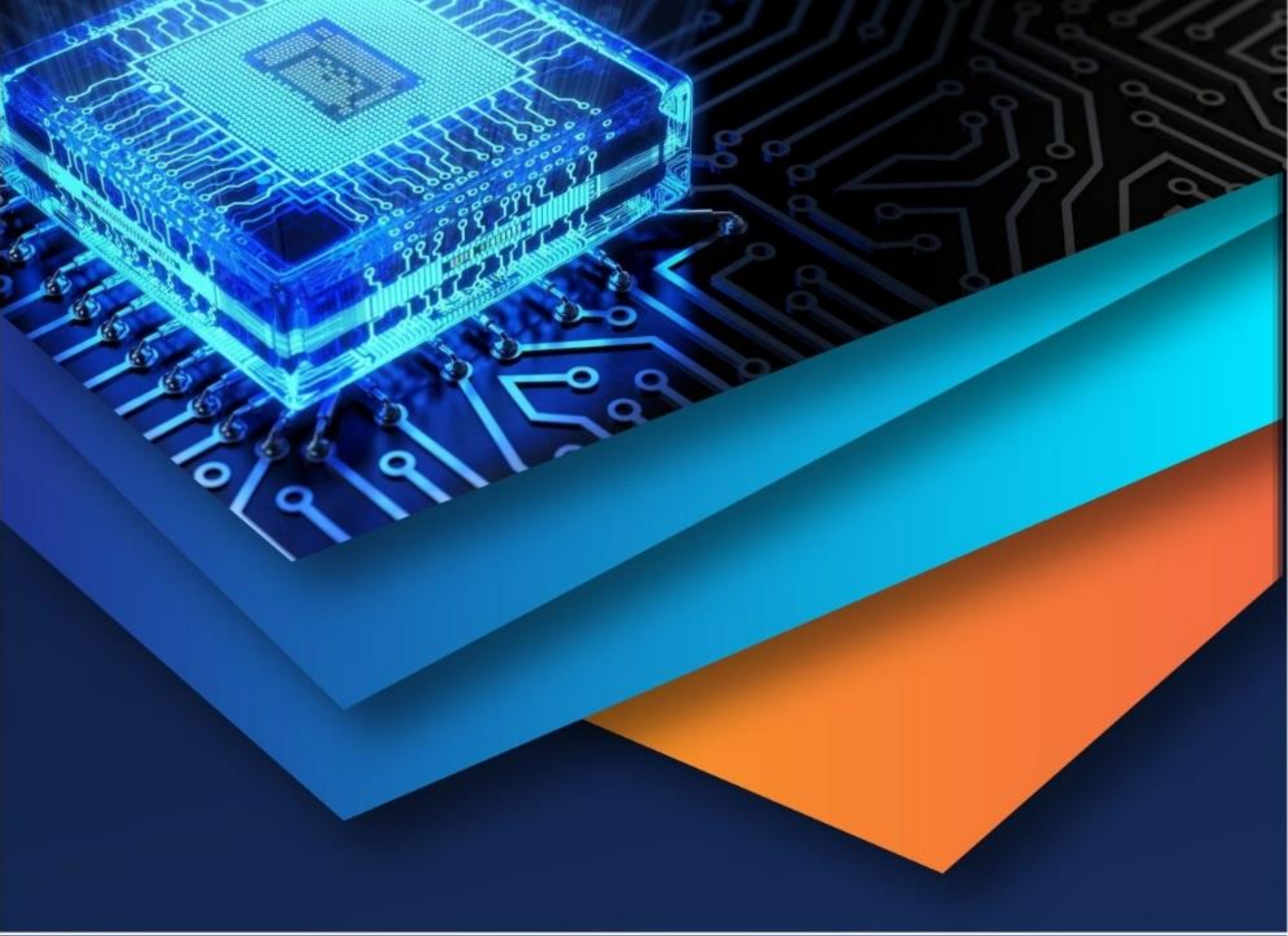


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