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Seismic Analysis of Multi Storey Building Using Strong Column Weak Beam Ratio (SCWB) in Different Zones of India

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Abstract: An earthquake structures are mandatory to avoid significant damages (i.e., collapse) and aims that structure withstand a major earthquake without collapse. The design approach adopted is to ensure that the columns of the structure more capable to resist moments than beam; to avoid progressive collapse of structure due to failure of columns in lower level; it is necessary the columns have stronger than beams (strong column weak beam). The concept of SCWB is to ensure that plastic hinge formed in the beam not in the column; this help in dissipating the more energy along with providing ductility to the structure. If the plastic hinge is formed on the both ends of column then, the column is not able to spread the plasticity and collapse which are leads to global failure. The failure modes in all past earthquake is exactly opposite i.e, strong beam weak column; and comes to sway mechanism and fails to collapse. For this it is foreseen that the values of ratio of Mc/Mb (ratio of sum of ultimate moment of resistance of columns to sum of ultimate moment of resistance of beam) in the beam-column joint are stated by many design codes and the values are different ranging from 1.2,1.3,1.4,1.5 to 2, etc. Another effect of ratio Ic/Ib (ratio of moment of inertia of column to moment of inertia of beam) have been studied but the exact meeting of SCWB behaviour in the structures at the time of collapse not stated clearly. The Mc/Mb and Ic/Ib ratio are very important to prevent damage in the structure under seismic action. In the present work, attempts are made to achieve exact ratio of exact strong column weak beam. In this study, the combined effect of two ratio (Mc/Mb, Ic/Ib) simultaneously investigated in different zones of India to find out exact SCWB ratio's value for to meet the SCWB behaviour. Different numerical examples are presented of combine ratios (Mc/Mb,Ic/Ib) and pushover analysis is performed on each ratio's. The result of the investigation highlighted on the objective that is to find exact SCWB ratio value considering the parameter like target displacement, ductility ratio, hinge response etc.

Keyword: Strong column – Weak beam, SCWB (Mc/Mb, Ic/Ib) , plastic hinge, hinge response, ductility ratio, target displacement, pushover analysis

I. INTRODUCTION

The fundamental design concept of earthquake resistance design of building is for make strong column and weak beam but building that collapse during past earthquake exhibited exactly opposite i.e. strong beam and weak column behavior means column failed before the beam yields mainly. The intent of the SCWB strength concept in building code is to reduce the likelihood of the formation of plastic hinge in beams helps to build the most desired and suitable energy dissipating mechanism of structure in seismic conditions. If the plastic hinges formed on both ends of the column then the column is not able to spread the plasticity and collapses which are lead to global failure. The failure modes in all the past earthquakes are almost similar and strong beam weak column comes to sway or sway mechanism and the structure also have lack of ductile detailing in beam and column joint. To avoid progressive collapse of a structure due to cascade effect created by column failure in the lower levels, the columns and beams are to be designed as per strong column weak beam design. This helps the structure to dissipate seismic energy better, without total collapse that is this plastic hinge formed in the beams, increases the ductility of the structure and hence the structure would be able to undergo large lateral displacement. An earthquake resisting building is one of that has been deliberately to remain safe and suffer no appreciate damage during destructive earthquakes.

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However, during past earthquakes many buildings have collapsed due to failure of vertical members. Hence columns in building should be strong and stiff so as to sustain the design earthquake without Catastrophic failure. Capacity designing aims towards providing stronger vertical member compared to horizontal structural element. A structure designed with capacity design concept does not develop any failure mechanism or modes of inelastic deformation that causes the failure of the structure. Hence, the concept of strong column and weak beam is introduced in the design of structures resisting the lateral loads.

II. OBJECTIVE OF STUDY

A. To check the effect of changing Ic/Ib ratio of beam and column on pushover analysis result.
B. To check the parameter used to quantify the performance of multi-story building (parameter like status of performance points. Ductility ratio, base shear v/s roof displacement, etc.) for different Ic/Ib ratio and Mc/Mb ratio.
C. To check the ductility performance of building for different Ic/Ib ratio and Mc/Mb ratio in different seismic zones.
D. At the end of the study, check behavior of SCWB and lay down the guideline for preliminary design of building before analysis to be performed

III. MODELLING AND ANALYSIS:

In this work, a six-story single bay RC frame (fig.1) is modeled by using ETABS. And at the end, a six-story multi bay RC building is designed by using SCWB ratio calculate based on the analysis on single bay RC frame modeled by using ETABS as stated above. To understand the effect, the similar six-story building (i.e. already design by IIT) is used for comparison with RC frame modeled by SCWB ratio. In this paper, the whole work is divided into two

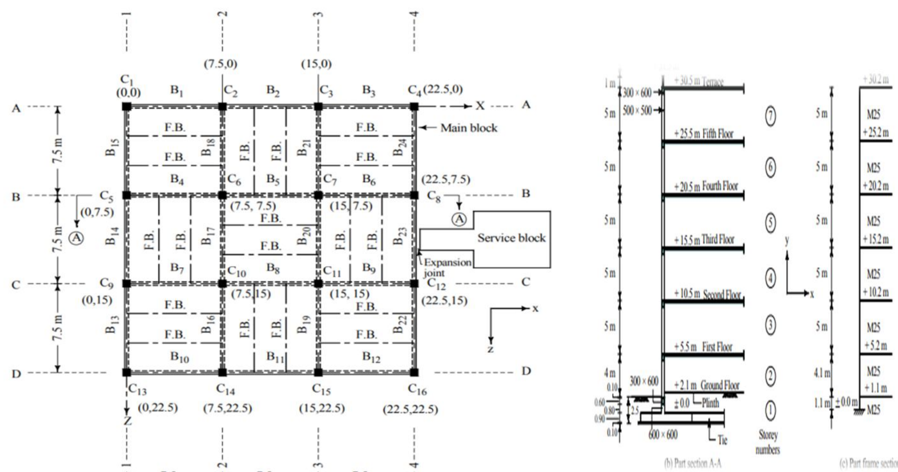

Fig.1 Typical floor plan and sectional elevation

Phase respectively. Phase(I): a) Performance comparison of six-story single bay RC frame with different Ic/Ib (ratio moment of inertia of column to moment inertia of beam). b) Assessment of SCWB ratio i.e. Mc/Mb (ratio of ultimate moment of resistance of column to ultimate moment of resistance of beam) Ic/Ib (ratio moment of inertia of column to moment inertia of beam) effect of different zones of India.

Phase (2) Performance base design of a six-story building using SCWB ratio. In phase one, to understand the performance of Ic/Ib ratio the various model of Ic/Ib ratio value modeled in ETABS in same zone (III) of India. At the end from the result, select value of Ic/Ib having good ductility and performance in pushover analysis. And in part b) the various model of Mc/Mb – Ic/Ib are modeled in ETABS and analysis (both static and pushover) performed in each zone of India. and at last from the result the comparative statement along with comparative graphs of all the Mc/Mb – Ic/Ib value and one value of ratio is selected which show the behavior of SCWB, after perform pushover analysis on the frame and compare the results with IIT design building and present a comparative statement along with result discussion. And input data shown in tables are shown below:

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1) *Phase 1:* Data Details

Table: Performance comparison of six-story single bay RC frame with different Ic/Ib

VALUE IF Ic/Ib	Column size in mm (M25) grade	Beam size in mm (M25) grade
1.3	535 x 535	300 x 600
1.4	550 x 550	300 x 600
1.5	560 x 560	300 x 600
IIT model	500 x 500	300 x 600

NOTE: Column 600 x 600 (M30) provide in IIT model up to plinth level only and column 500 x 500 at all typical floor. Same rebar fe415 steel and reinforcement in all model.

2) Tables for Assessment of SCWB ratio i.e. Mc/Mb- Ic/Ib effect of different zones of India

Model 1 : C – 1, Ic/Ib = 1.3 , M = 1.4, MuB = 371 kN/m, MuC = 1.4 x 371 = 519.4 kN/m

Storey	*Pu(kN)*	*Muc*	$\frac{Pu}{fckxbxd}$	$\frac{Mu}{fck\ xbxd^2}$	$\frac{d'}{d}$	$\frac{Pt}{fck}$	*pt%*	*Ast*
1	3055	519.4	0.42	0.135	0.1	0.13	3.25	18 - #25
2	2532	519.4	0.35	0.135	0.1	0.10	2.5	14 - #25
3	1992	519.4	0.28	0.135	0.1	0.09	2.25	12 - #25
4	1447	519.4	0.2	0.135	0.1	0.08	2	12 - #25
5	898	519.4	0.12	0.135	0.1	0.08	2	12 - #25
6	342	519.4	0.04	0.135	0.1	0.08	2	12 - #25

Similar calculation shown in above table have to carried out for remaining ratios.
Main Beam = 230x 560 mm $Ast_{pro.}$ = Top = 1884 mm²

$Ast_{pro.}$ = Bottom = 402 mm², Secondary Beam = 200 x 560 mm,Column = 500x 500 mm M25 & Fe 415

IV. PARAMETRIC STUDY

From the hinge formation result and above parametric study the ratio Ic/Ib = 1.5 show good ductility and strength. Hence we adopt the ratio Ic/Ib = 1.5 for the performance based design of a six story building in next chapter.

MODEL NO.	TARGET DISPLACEMENT mm	DUCTILITY RATIO	BASE SHEAR kN
IIT MODEL	187.791	2.41	5650.4281
Ic/IB=1.3	240.77	3.1	6613.85
Ic/IB=1.4	241.364	3.522	5277.9988
Ic/IB=1.5	237.822	4.40	6387.5931

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V. RESULTS AND DISCUSSION (PHASE 1)

All the model of different Ic/Ib ratio are analyzed by linear static method in ETABS and the comparative results are shown below:

A. Performance Comparison of six-story single bay RC frame with different Ic/Ib

Static method results

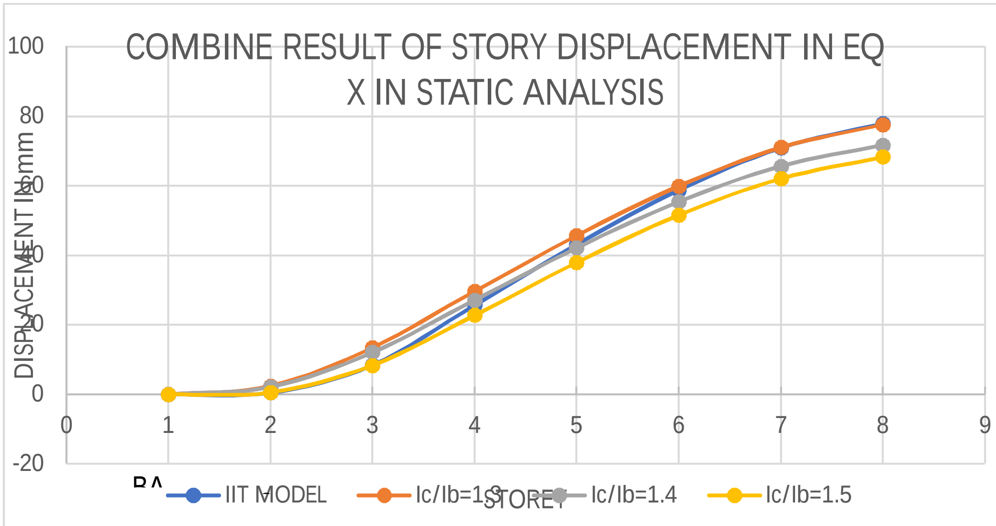

Fig.2 Combine results of story displacement in X-Direction

Note: All above models of building with different Ic/Ib ratios are analyzed in ETABS 2017. Here the above graph showing roof top displacement at respective stories with Ic/Ib ratios. In all these graphs the roof top displacement is less for Ic/Ib 1.5 in Zone III. This indicate that the performance of building having ratio 1.5 is acceptable and good for this condition.

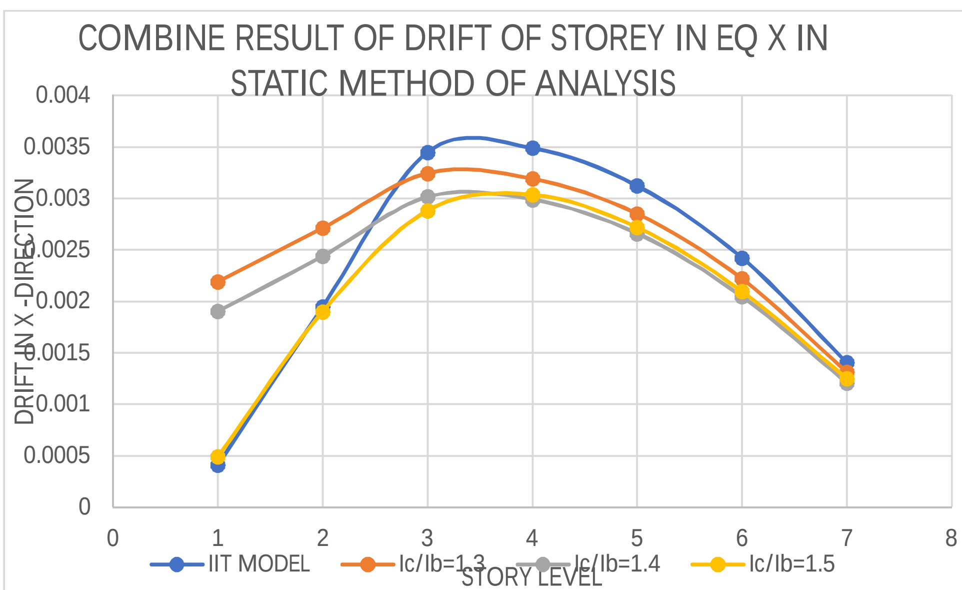

Fig.3 Combine results of story drift in X-Direction

Note: All above models of building with different Ic/Ib ratio' are analyzed in ETABS 2017. Here the above graph represent drift in X-direction at respective stories with Ic/Ib ratios. In all these graphs the drift in X-direction is (less than 0.004) for Ic/Ib 1.5 in Zone III. This indicate that the performance of building having ratio 1.5 is acceptable and good for this condition only

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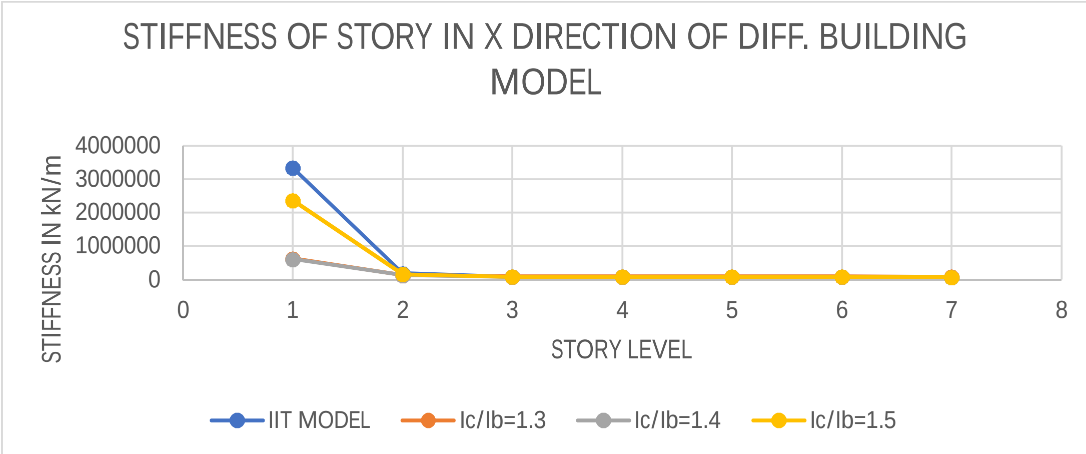

Fig.4 Combine results of story stiffness in X-Direction

Note: All above models of building with different Ic/Ib ratios are analyzed in ETABS 2017. Here the above graph showing Stiffness in kN/m at respective stories with Ic/Ib ratios. In all these graphs the drift in X-direction is more for model 1 in Zone III.

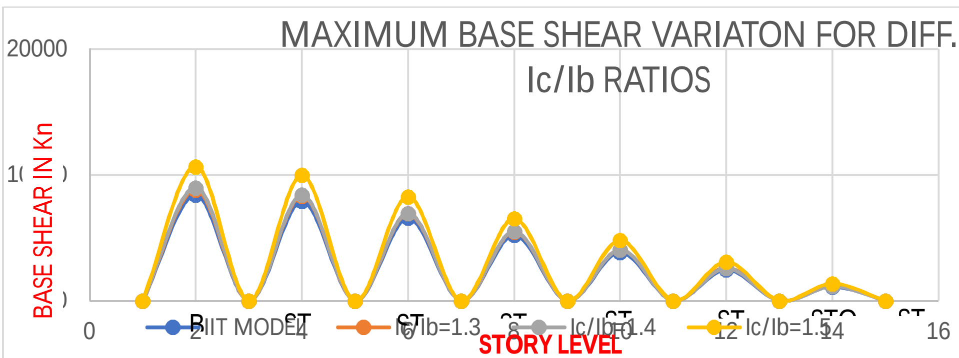

Fig.5 Combine results of story shear in X-Direction

Note: All above models of building with different Ic/Ib ratio are analyzed in ETABS 2017. Here the above graph showing Base Shear at respective stories with Ic/Ib ratios. In all these graphs Base Shear of model Ic/Ib 1.5 is more than all model for Zone III. This indicate that this experience large base shear (force) but, the resulting roof displacement is less in between all the models. Hence, for the ratio 1.5 has more potential along with the stiffness.

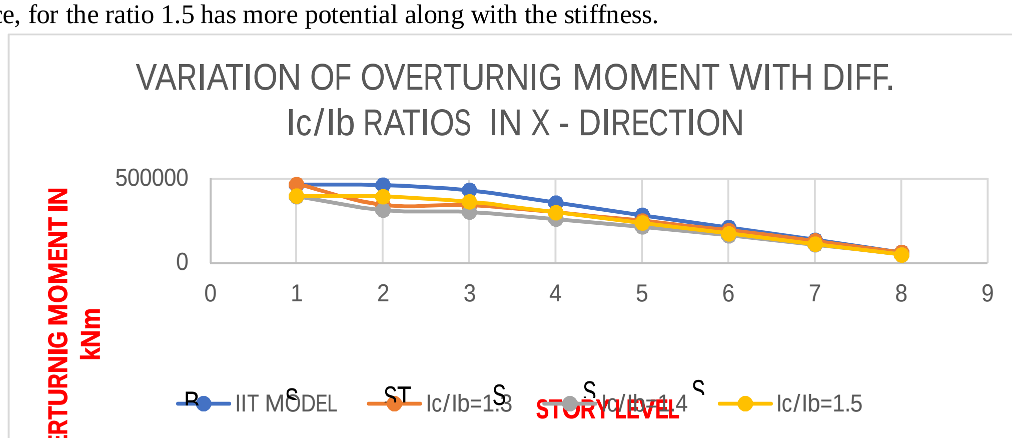

Fig.6 Combine results of story overturning moment in X-Direction

Note: All above models of building with different Ic/Ib ratio are analyzed in ETABS 2017. Here the above graph showing Overturning moment at respective stories with Ic/Ib ratios. In all these graphs the Overturning moment is (more than 0.004) for Ic/Ib 1.5 in Zone III. This indicate that the performance of building having ratio 1.5 is acceptable and good for this condition only

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B. Pushover Results

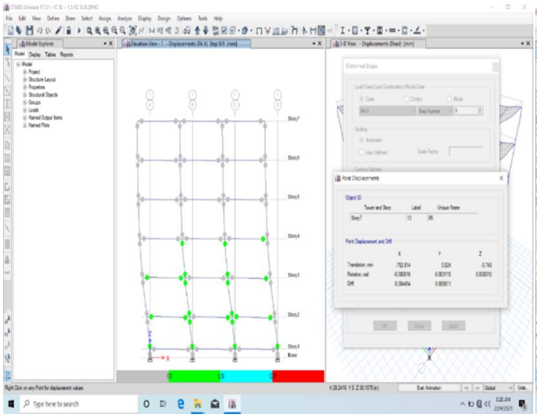

Fig.7 Ic/Ib=1.5 ratio model

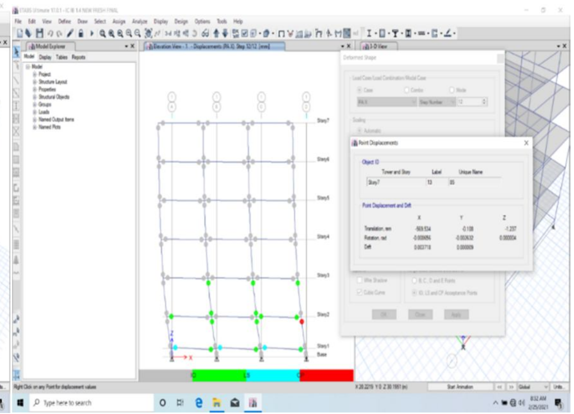

Fig.7 Ic/Ib=1.4 ratio model

Hinges are formed simultaneously in beams and column at roof top 752.814mm displacement. But no hinge reaches it ultimate capacity i.e. collapse hinge for the model having Ic/Ib=1.5.

Collapse hinge first formed in corner column of story 2 at roof top displacement 569.534 mm . this indicate that the column fails first than beam. here one thing must be note that no hinge is formed at columns of story 1 and beams at story one reached upto its capacity before reaching in column. Hence it conclude, that the story one indicate strong column weak beam behavior

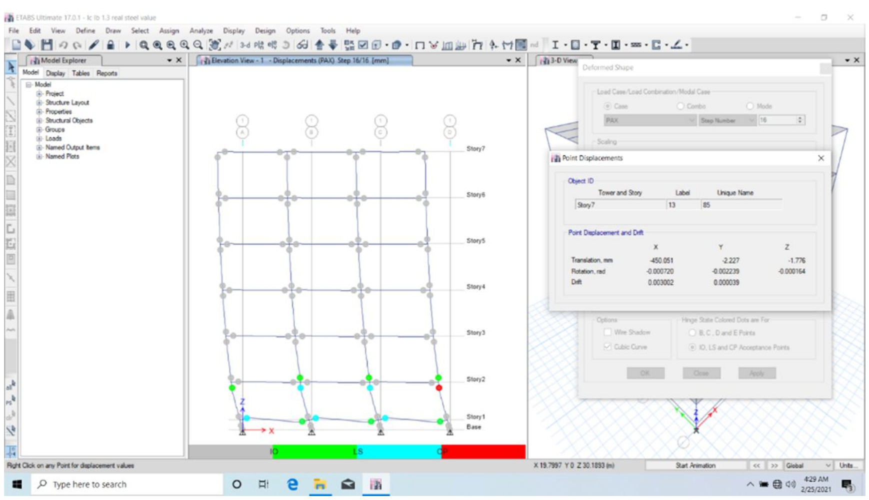

Fig.7 Ic/Ib=1.5 ratio model

Final step showing that the collapse hinge formed in corner column of story 2 joint at 450.051 mm top roof displacement. here one thing must be note that no hinge is formed at columns of story 1 and beams at story one reached upto its capacity before reaching in column. Hence it conclude, that the story one indicate strong column weak beam behavior.

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C. Assessment of SCWB ratio i.e. Mc/Mb- Ic/Ib effect of different zones of India

The results of zone 5 are shown here only because the ratio I=1.5 M=1.5 and I=1.3 M=1.5 showing good performance in all zones similar passion only the magnitude of parameter change in respective zones .

COMPARATIVE RASULT OF ZONE 5 (0.36)

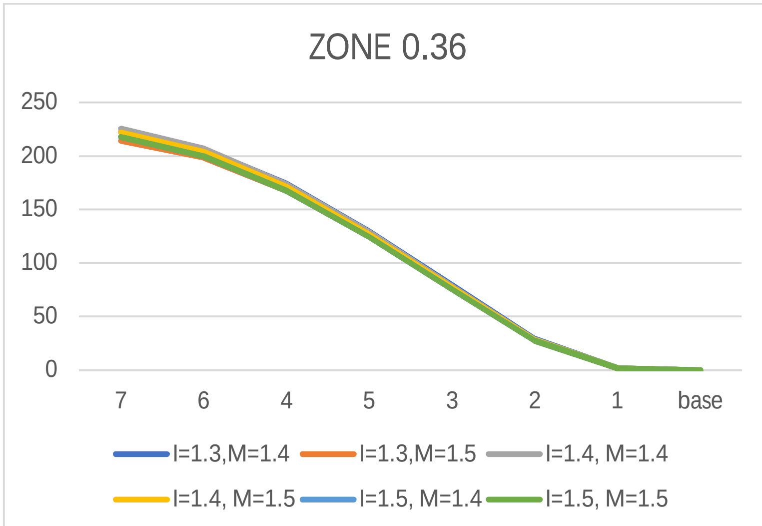

Fig.8 Combine results of story displacement in X-Direction

Note: All above models of building with different Ic/Ib & Mc/Mb ratios are analyzed in ETABS 2017. Here the above graph showing roof top displacement at respective stories with Ic/Ib & Mc/Mb ratios. In all these graphs the roof top displacement is less for Ic/Ib = Mc/Mb =1.5 and Ic/Ib=1.3, Mc/Mb=1.5 in Zone 5. This indicate that the performance of building having ratios is acceptable but it is necessary to compare pushover result of both the ratio stated above.

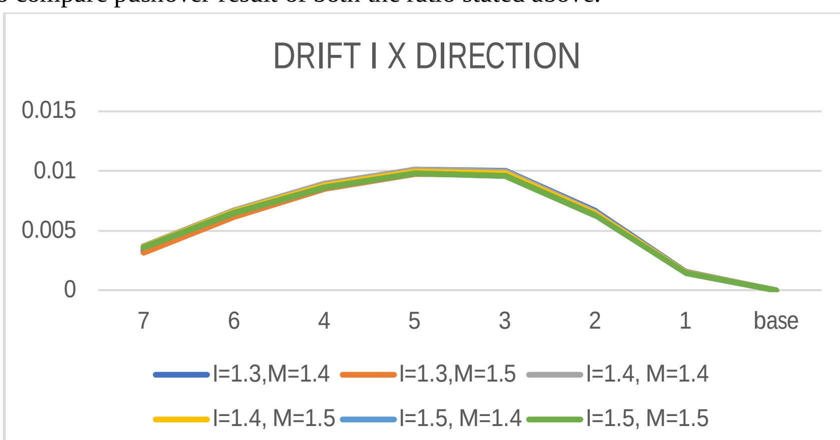

Fig.9 Combine results of story drift in X-Direction

Note : All above models of building with different Ic/Ib ratios are analyzed in ETABS 2017. Here the above graph represent drift in X-direction at respective stories with Ic/Ib ratios. In all these graphs the drift in X-direction is (less than 0.004) for Ic/Ib = Mc/Mb =1.5 and Ic/Ib=1.3, Mc/Mb=1.5 in Zone 5. This indicate that the performance of building having above ratio is acceptable and it is necessary to compare pushover result of both the ratio stated above.

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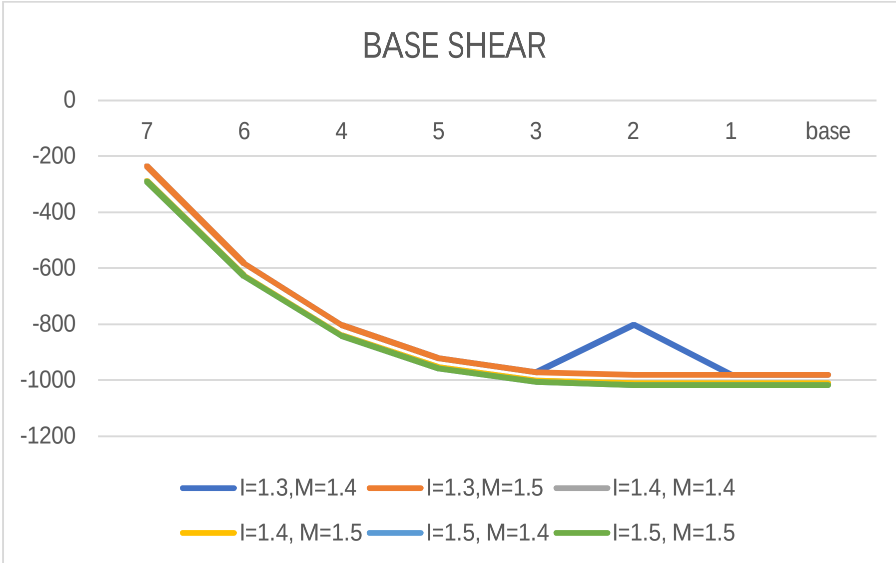

Fig.10 Combine results of story shear in X-Direction

Note: All above models of building with different Ic/Ib ratio are analyzed in ETABS 2017. Here the above graph showing Base Shear at respective stories with Ic/Ib ratios. In all these graphs Base Shear of model Ic/Ib = Mc/Mb =1.5 and Ic/Ib=1.3, Mc/Mb=1.5 is more than all model for Zone 5. This indicate that this experience large base shear (force) but, the resulting roof displacement is less in between all the models. Hence, for the ratio 1.5 has more potential along with the stiffness.

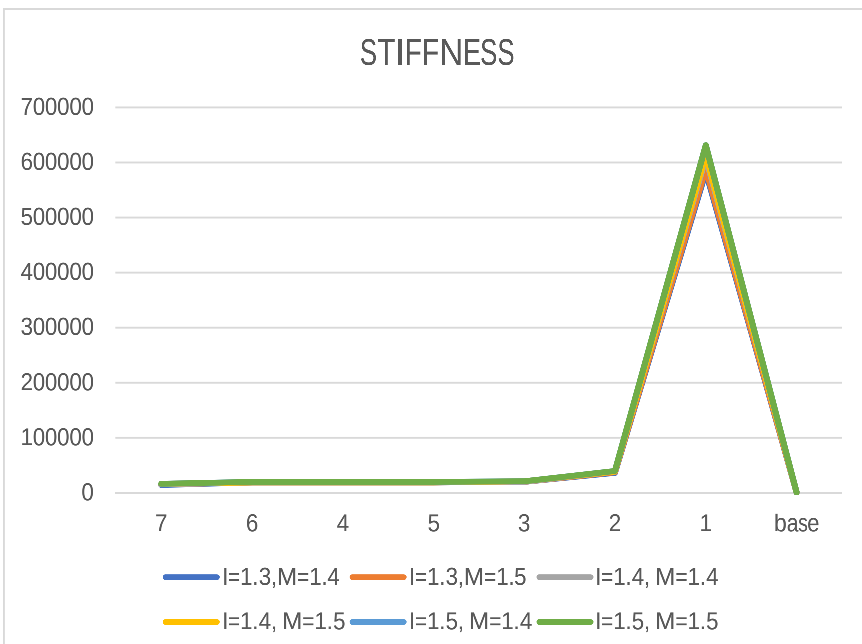

Fig.11 Combine results of story stiffness in X-Direction

Note: All above models of building with different Ic/Ib ratios are analyzed in ETABS 2017. Here the above graph showing Stiffness in Kn/m at respective stories with Ic/Ib ratios. In all these graphs the stiffness in X-direction is more for model Ic/Ib=1.5 in Zone 5.

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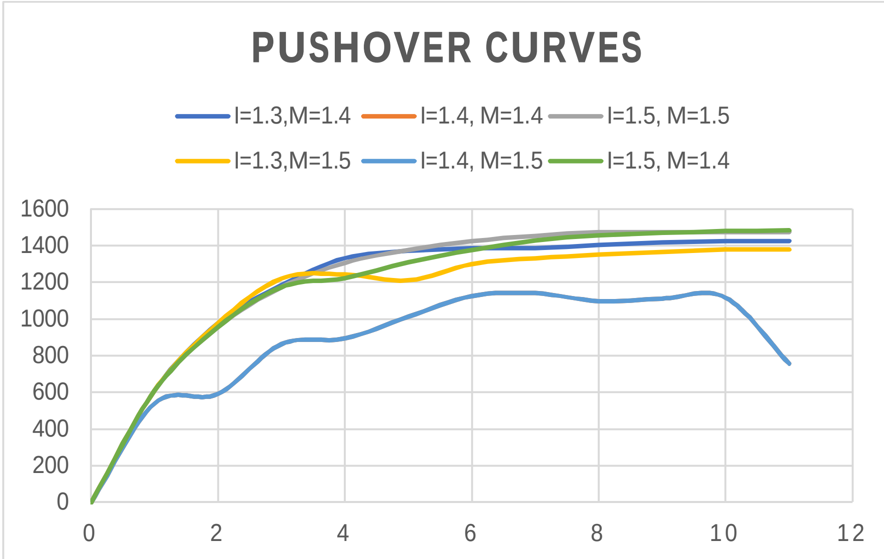

Fig. 24 Combine results of pushover curve base shear vs steps

All above models of building with different Ic/Ib ratios are analyzed in ETABS 2017. Here the above graph showing pushover/capacity curve with Ic/Ib & Mc/Mb ratios. In all these graphs the capacity curve in X-direction is more uniform for model Ic/Ib=1.5, Mc/Mb=1.5. This uniformity of the curve indicate that the energy dissipation is follow step by step formation of hinges in beams. 2. Here one thing must be notice that in static linear analysis the result of Ic/Ic=1.3, Mc/Mb=1.5 are similar to Ic/Ic=1.5, Mc/Mb=1.5 but in pushover curve Ic/Ic=1.3, Mc/Mb=1.4 is more uniform than Ic/Ic=1.3, Mc/Mb=1.5 . hence due to ambiguity in between **(**Ic/Ic=1.3, Mc/Mb=1.5 and Ic/Ic=1.3, Mc/Mb=1.4 **)** ; it can be conclude that the ratio **Ic/Ic=1.5, Mc/Mb=1.5** give better results. It is more, clear that when we compare pushover result.

DEFORMRED SHAPE OF MODEL AT DIFFERENT STEPS OF PUSHOVER ANALYSIS ALONG WITH FORMATION OF HINGES IN BEMS & COLUMN:MODEL : Ic/Ib =1.3 , Mc/Mb=1.5 zone : 3 MODEL : Ic/Ib =1.5 , Mc/Mb=1.5 Zone 3

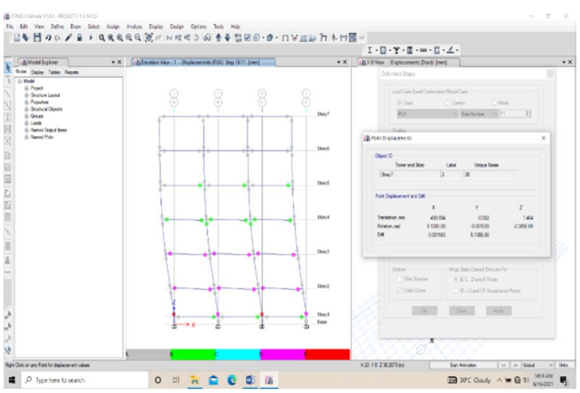

Fig.25 hinge formation

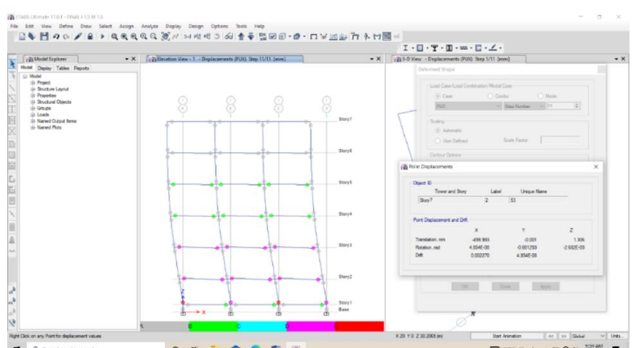

Fig.26 hinge formation

The above fig. show the formation of hinges at final step (i.e. 499.954 mm push). Here the clearly show that all the collapse hinges are formed in beams only at story4 the IO hinges are formed in columns before formation of hinge in beams. Here all the story represent the SCWB behavior except at story 4 .

The above fig. show the formation of hinges at final step (i.e. 499.993 mm push). Here the clearly show that all the collapse hinges are formed in beams only not in columns. Here all the story represent the SCWB behavior. Finally the building behave as strong column

weak beam.

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Parametric Study

MODEL NO.	TARGET DISPLACEMENT mm	DUCTILITY RATIO	BASE SHEAR Kn
Ic/IB=1.3	149.173	2.85	865.2765
Ic/IB=1.5	140.081	3.29	934.1413

From the hinge formation result and above parametric study the ratio Ic/Ib = 1.5 Mc/Mb = 1.5 give the SCWB behavior along with ductility and strength. Hence we adopt the ratio Ic/Ib = 1.5, Mb/Mc=1.5 for the performance based design of a six story building in next chapter.

VI. RESULTS AND DISCUSSION (PHASE 2)

From the analysis in the case columns are stronger than beams (SCWB) the following results are made;

1) Location of Hinge formation : The formation of hinge (in case of SCWB) in the beam not in column hence, it helps in decapitating energy in the structure and prevent the structure from global collapse of the structure.

Hinge formation result for application target displacement to model:

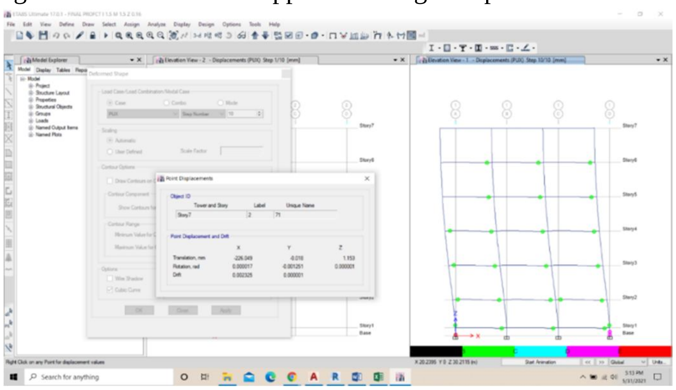

Fig.27 Hinge formation at target displacement

Above fig show that all the hinge formed in beams not in column; this indicate the SCWB ratio . as this building is commercial building it is expected that to formed an IO hinge (immediate occupancy) in beams not in column. And above fig. show only formation of IO hinge in beams. Hence the above result valid.

2) *Ductility Ratio Criteria:* The ductility ratio of SCWB model is more than the IIT model i.e., the ductility of the building to large deformation are possible in tn SCWB model without significant damages to column of structure.

3) *Reinforcement Details in Beams:* As show in the study that at support the reinforcement provided in IIT model is (Top = 7-25# 3430 sq.mm and Bottom = 6-20# 1884sq.mm) i.e., 2.95% of c/s steel provided; but in case of SCWB model the steel provide at top 6-20# (1884 sq.mm) and at bottom 3-20# (942 sq. mm) i.e. 2.19%. Hence with comparison of two steel it concluded than, 25 to 26% of saving of saving a steel in the beam reinforcement at support. The steel provided at center of IIT Model is bottom 5-20# and top 2-25# and the steel provided in SCWB ratio is at bottom 3-20#. Top 2-20# the percentage saving if steel is at centers is 38% in the SCWB model than IIT model. .Reinforcement details in columns: As shown in the study that the percentage of reinforcement at bottom i.e, (above base and story 1) is 3% SCWB and in IIT model this percentage is 3.14% at same location hence, near about same reinforcement is provided at this location. And all other story above story 1 the percentage of steel in column is 2.78% in IIT model but in case of SCWB it vary from bottom to top story i.e., 2.35% to 1.5% hence saving of steel in column is ranging from 10% to 40%.

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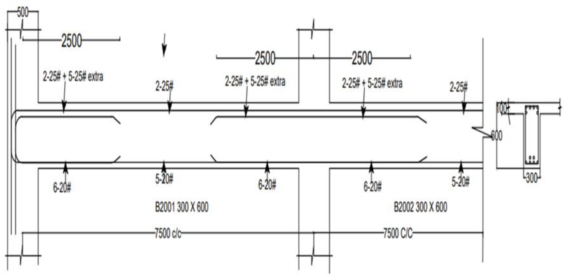
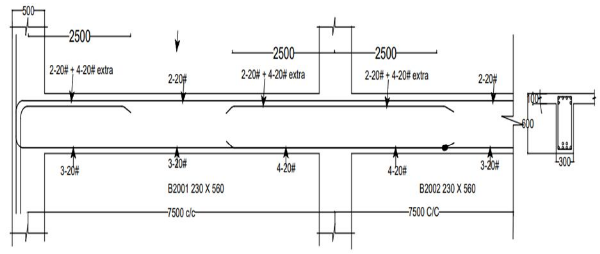


DETAILS OF BEAMS B2001 , B2002, B2003 IIT MODEL



DETAILS OF BEAMS B2001 , B2002, B2003 BASED ON SCWB MODEL

Column =500 x500 Beam = 300 x 600

Column =500 x500 Beam = 230 x 560

4) Bending moment variation: In case SCWB model a beam is designed for moment 191.85knm for combination 1.5(DL+LL) and the plastic hinge reaches collapse in beam is at 480 Kn; likewise column which is designed for capacity 287.77 kNm for combination 1.5(DL+LL) and the plastic hinge reaches collapse is at 693.221knm. Hence the coefficient of Re column to indicate ratio of collapse moment to design moment is 2.20 in column and the coefficient Rb of beam is 2.50. Hence we conclude that design moment in beam should be such that beam will not become overstrength which involve unnecessary investment but we also not complete rely on the software result; for this we find out the design moment in such a way that the collapse moment is 1.5 times the maximum values of combination 1.5 (DL+EQX) linear static method. For ex. In a beam the ultimate moment for combination 1.5 (DL+EQX) is 464knm then multiplied (1.5 x 464 = 692knm) and then divided by Rb 2.5 therefore the design moment is 278.2knm.This study can continued in the case where the building having structural walls that is shear wall.

VII. CONCLUSION

A. The ductility ratio of SCWB model is more than the IIT model i.e., the ductility of the building to large deformation are possible in tn SCWB model without significant damages to column of structure.
B. With comparison of two steel in two model; it concluded than, 25 to 26% of saving of saving a steel in the beam reinforcement at support. And the percentage saving if steel is at centers is 38% in the SCWB model than IIT model.
C. Saving of steel in column is ranging from 10% to 40%.
D. The strong column weak beam is achieve in SCWB MODEL and not in IIT model.
E. The ductility ratio increases with increasing Ic/Ib , Mc/Mb ratio .
F. In all the seismic zone Ic/Ib=1.5 Mc/Mb=1.5, effective and help in achieving SCWB behavior.

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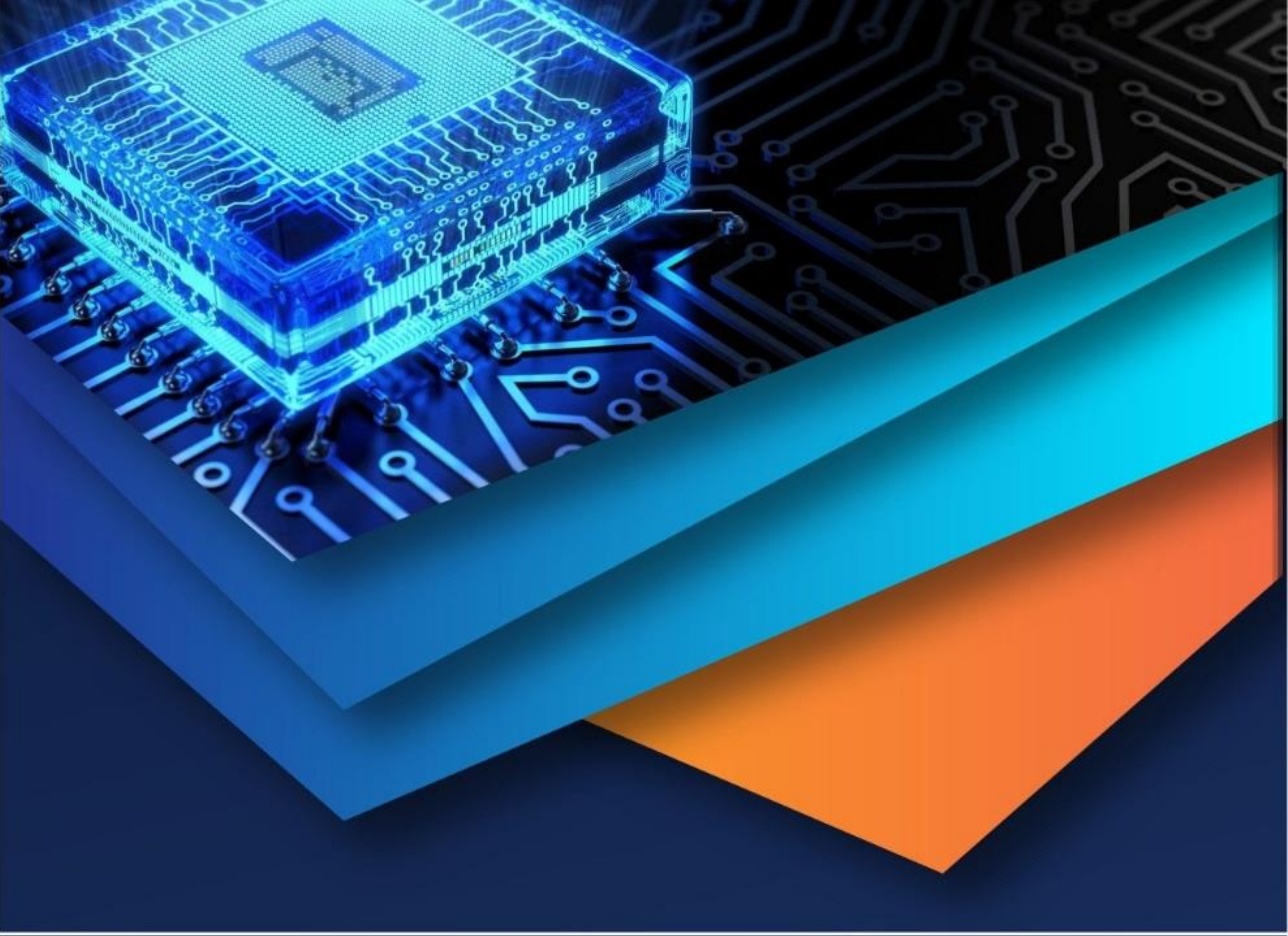

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