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PERFORMANCE BASED STRUCTURAL DESIGN OF MULTISTOREY BUILDING

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ABSTRACT
The primary goal of major building codes is to protect life safety by designing buildings that have sufficient integrity and strength to resist collapse in severe earthquakes. The secondary objective of these codes is to control property damage and maintain function in more moderate but frequent events.
Performance is about going through a process and explicitly looking at the outcome, which is well defined, without overly focusing on or conforming to implicit standards and predefined procedures. Of course, there are going to be standards and guidelines and ways to do performance-based design (PBD) itself, but the end focus is on performance and not literal or generic conformance and that is the basic difference between conventional and performance-based design. When we do conventional design, our objective is to satisfy the design code. We may lose the sense of what the structure's performance would be if we do satisfy or do not satisfy the code.
Performance-based design method is a direct design method starting from the pre-quantified performance objectives, in which plastic design is performed to detail the frame members and connections in order to achieve the intended yield mechanism and behavior.
In this study we performed the nonlinear static pushover analysis to find the performance of the three building configurations (i.e. Bare Frame, Bare frame with Peripheral middle walls and Bare frame with corner shear walls) structures using ETAB 21, taking ASCE 41-17 and FEMA guidelines to find and compare the performance of the structures. Firstly, the details design of all three buildings has been performed as per IS-456, 2000 and IS-1893 2016 using ETAB 21 software and later their performance is calculated using nonlinear static push over analysis taking deflection control criteria using ETABs. The building performance is compared in terms of Push over curve, Base shear, Deflection, Performance point, Stage and number of Plastic hinges formed together with the storey drifts.

Keywords:
Performance-based design, conventional design, performance objectives, yield mechanism, nonlinear static pushover analysis, Base shear, Deflection, Plastic hinges story drifts

1. INTRODUCTION

In the traditional method of designing a building structure for earthquake forces (force-based design), an equivalent seismic base shear is calculated based on the estimated fundamental period of the structure and an elastic response spectrum that is representative of the seismicity of the site. The design base shear value depends on the height (period), type, location and importance of the structure as well as on the nature of foundation soil. The shear is adjusted to take into account the ductility capacity of the structure and its expected over-strength. It is then distributed along the height using an empirical relationship to determine the story level forces. An elastic analysis is carried out next to find the element forces and the elements are designed for such forces.
Finally, the inelastic inter-story drifts produced by the design forces are obtained from the calculated elastic drifts and are checked against prescribed displacement limits. If necessary, the structure is stiffened to ensure that displacements do not exceed the specified limits. This method is widely used by seismic design codes all over the world, including the National Building Code of India (IS-456 2016). It is now recognized that the performance of a structure during an earthquake is a function of the ductility demand placed on it, and/or on the displacements and inter-story drifts induced in it. The force-based design method, which controls the strengths, and only indirectly the displacements, is not capable of producing a uniform level of performance, and concerns have been expressed regarding the reliability and economy of the current design method. Displacement-based design (DBD) methods are better able to ensure a uniform level of performance and have therefore attracted considerable attention during recent years. They are being considered as the recommended methods of seismic design in the future design codes.
In this study a displacement-based design method (i.e. **Non-Linear Static Push Over analysis**) will be presented that could be used in the design of any structural system. The method is used to evaluate the performance of a given structure. It may be noted that by using a displacement-based design at various hazard levels, the desired performance at each hazard level can be achieved. For this reason, displacement-based design could be considered as the main component of performance-based design.

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2. PUSH OVER ANALYSIS

Pushover analysis has been developed over the past twenty years and has become the preferred analysis procedure for design and seismic performance evaluation purposes as the procedures are relatively simple and consider post elastic behavior. The nonlinear static analysis where the lateral loads are increased keeping vertical loads constant, to maintaining a predefined distribution pattern along the height of the building, until a collapse mechanism develops. The performance-based approach requires a lateral load versus deformation analysis. The pushover analysis is a static method of nonlinear analysis. The pushover analysis is a method to observe the successive damage states of a building. However, the procedure involves certain approximations and simplifications that some amount of variation is always expected to exist in seismic demand prediction of pushover analysis. Pushover analysis of finite element was performed by ETAB 21 where the deficiency of an elastic analysis displays the following features.

1. The analysis considers the inelastic deformation and ductility of the members.
2. The sequence of yielding of sections in members and redistribution of loads in the building are observed.

2.1 Description of the nonlinear analysis

Pushover analysis provides a wide range of application options in the seismic evaluation and retrofit of structures. Mainly two guidelines are available for this analysis- FEMA, ASCE 41-17. This thesis mainly follows the procedures of ASCE 41-17 in evaluating the seismic performance of residential building consisting explained above. Here the pushover analysis of the structure represents a static nonlinear analysis under constant vertical loads and push the building till failure mechanism is developed and various performance limits are crossed as per ASCE 41-17 using maximum deflection as a criterion. Analysis is carried out till to failure of the structures. This analysis identifies weakness in the structure so that appropriate retrofitting could be provided in governing element. Basically, demand and capacity are the two components of the performance-based analysis and design where demand is a representation of the seismic ground motion and capacity is a representation of the structure ability to resist seismic demand. The performance is dependent in a manner that the capacity is able to handle the seismic demand. Once the capacity curve and demand displacement are defined, a performance check can be done.
In our study, nonlinear static pushover analysis was used to evaluate the seismic performance of the structures. The numerical analysis was done by ETAB 21 and guidelines of ASCE 41-13 and FEMA 356 were followed. Overall evaluation was done using base shear, deflection, story drift, stages of number of hinges form. Plastic hypotheses were used to mark the nonlinear behavior according to which plastic deformations are lumped on plastic hinges and rest of the system shows linear elastic behavior. The discrete structural performance levels are- Immediate Occupancy (S-1), Life Safety (S-3), Collapse Prevention (S-5) and Not Considered (S-6) whereas intermediate structural performance ranges are the Damage Control Range (S-2) and the Limited Safety Range(S-4) Figure 1. This definition of performance ranges is served by ASCE 41-17. The model frame used in the static nonlinear pushover analysis is based on the procedures of the material, defining force – deformation criteria for the hinges used in the pushover analysis. Figure 1 describes the typical force-deformation relation proposed by those documents. Fig 1:

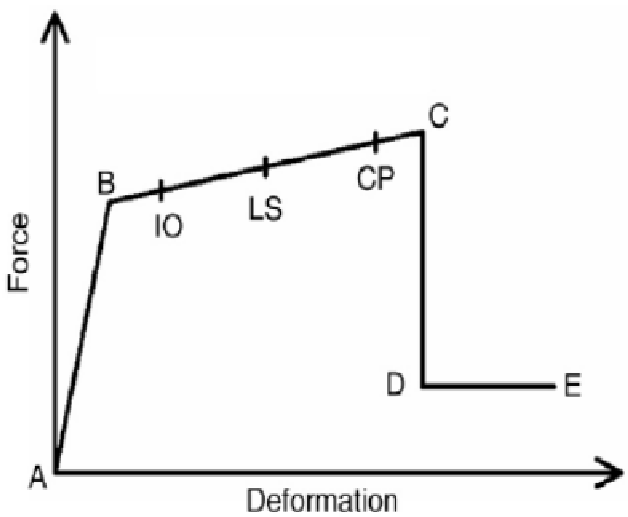

Fig 1 Force-Deformation Curve

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Force-Deformation for pushover analysis Five points labeled A, B, C, D and E are used to define the force deflection behavior of the hinge and these points labeled A to B – Elastic state, B to IO- below immediate occupancy, IO to LS – between immediate occupancy and life safety, LS to CP between life safety to collapse prevention, CP to C – between collapse prevention and ultimate capacity, C to D- between C and residual strength, D to E- between D and collapse >E – collapse.

3. METHODOLOGY

Pushover analysis is a static, nonlinear procedure in which the magnitude of the lateral force is incrementally increased, maintaining the predefined distribution pattern along the height of the building. With the increase in the magnitude of the loads, weak links and failure modes of the building are found. Pushover analysis can determine the behavior of a building, including the ultimate load and the maximum inelastic deflection. Local Nonlinear effects are modelled and the structure is pushed until a collapse mechanism gets developed. The base shear and the roof displacement can be plotted to generate the pushover curve. It gives an idea of the maximum base shear that the structure was capable of resisting at the time of the earthquake. For regular buildings, it can also give a rough idea about the global stiffness of the building.
Ten storied frame structures are modelled and designed with the help of finite element software ETABS 21 to perform the pushover analysis to meet the objectives of this study. Depth of column from Ground floor is taken as 1.5 meters. Seismic effect is computed using IS1893-2016. Static and dynamic earthquake load is calculated according to National Building Code. Dead load and live load are taken according to standard practice among the professional designers and engineers as per relevant National building codes. Standard load combinations are taken according to latest IS-456-2000. To perform the non-linear analysis ASCE 41-17 is reviewed all through the study. Plastic and Fiber hinges required for performing pushover analysis of RCC structure are chosen from the experimental data and ASCE 41-17 for column, beam and shear walls. Allowable hinge deformation at different performance level for beams and columns is computed and established. All types of hinges are assigned to each element according to required type. Structures are then subjected to push over analysis which include progressive damage of elements with plastic deformation of the hinge assigned on the element of the structure as the structure is laterally pushed through. Later to present the objectives performance point, base shear and number of hinges form taken into account under proper jurisdiction.

4. BUILDING GEOMETRY AND LOADING

In this present work, G+10 storied concrete buildings with and without share walls for different configurations are considered as explain in this section. The frame consists of 8 m x 8 m span with total 5 spans in each direction having total length of 40 x 40 meter in plan. The number of bays and size is shown in Fig 4.1 to Fig 4.10. The total height of the building is 36.5 meters with typical storey height is 3.5 meters and three configurations as

- Bare Frame
- Bare Frame with middle peripheral shear walls
- Bare frame with corner shear walls

Slab thickness for all floors is considered as 150 mm and Beam and column dimensions are 500 mm x 750 mm and 900 mm x 900 mm respectively.
The buildings are analysesd using non-linear push over method using ETABS version 21. The building is considered as Special RC moment-resisting frame (SMRF) with response reduction factor as 5.0. This building is considered as a residential building with Importance factor is considered as 1.
Load combinations are taken as per IS 456: 2000 and IS 1893(part 1): 2016. Super impose Dead load on slab is taken as 1.5 KN/m^2 and Live load on slab is taken as 2 KN/m^2 with 1.5 KN/m^2 is considered on roof. Brick works dead load of 9" wall is applied on the all beams is 13.75 KN/m and parapet wall are 6.75 KN/m. Capacity spectrum method is carried out as per guidelines mentioned in ATC 40 and ASCE 41-17 definitions are used.

5. PUSHOVER ANALYSIS USING ETABS

1. Create the basic computer model. Assign sectional properties, material properties and place columns, beams and supports to the structure, apply gravity load i.e. dead load and live load on the structure. Run analysis and find shear force and bending moments for the applied load and check whether structure is safe or not according to IS 456:2000.
2. Add lateral forces and allocate load combination as per IS 1893 (Part 1): 2002 and check whether structure is safe or not.

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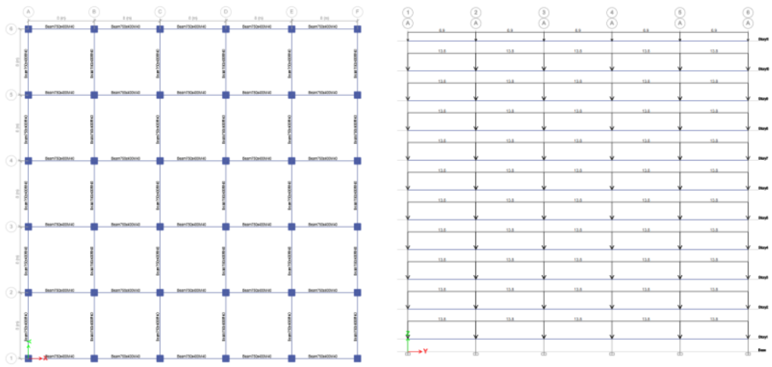
3. Add Response Spectrum function and assign Response spectrum load cases, and find out max storey displacement, max storey drift from Response spectrum method.
4. Define and modify Pushover load cases. In ETABS more than one pushover load case can be run in the same analysis. Pushover load cases can be force controlled i.e. pushed to a certain defined force level, or they can be displacement controlled, i.e. pushed to a specified displacement controlled. ETABS contains several built-in hinges that are based on average values from ASCE 14-17 for concrete members. M3 hinges have been defined at both the ends of all the beams and PMM Fiber hinges have been defined at both the column ends.
5. Assign pushover hinge properties to beams and columns by selecting all the frame members at particular hinge location, run pushover analysis.

The capacity curve and capacity spectrum curve are obtained. The performance point for a given set of values is defined by intersection of the capacity curve and the single demand spectrum curve. Observe plastic hinge formation sequence.



6. RESULTS AND DISCUSSION

After analysis, outcomes are organized to meet the study objectives. For that the performances of structures are evaluated with the help of

1. Push Over Curve
2. Base Share
3. Deflection
4. Stage of number of hinges form (i.e. A-IO, IO-LS, LS-CP, > C.P.)
5. Performance Points
6. Storey Drift

base shear, deflection, storey drift, push over curve, Performance points and stages of number of hinges form (fig 6.1-fig 6.11) for different cases were evaluated under systematic review process which reveals that using a Shear wall in a medium height RC structure increases the performance point and base shear significantly and provides extra safety by delaying number of plastic hinges form in early stage. Comparing three cases it reveals that bare frame has lowest performance point as per FEMA 440 but by analysis results it can be concluded that bare frame with middle shear walls reaches earliest hinge formation in push over step 8. The reason is due to weak Wall-beam junction and walls are not connected directly to columns. the corner shear wall structure acts significantly strong has highest performance point and delayed hinges formation in all cases because corner column is bounded by shear wall in both directions.

6.1 **Push Over Curve**

Push over analysis is performed using ETAB 21 and push over curves result are presented in tabular form. The push over curve is plotted for all three structures and results are compared. After analyzing the curve, we can conclude that the maximum base shear is resisted by bara frame corner shear wall structure before reaching to IO, LS and CP limits on the other hand, the early hinges are formed in bare frame middle shear wall structure among all three structures. The Minimum base shear is resisted by bare frame with middle shear wall structure. It is observed that the early hinges in bare frame middle shear wall structure is due to discontinuity of shear walls before the columns so that it is the good practice to continue the shear wall up to columns to utilize full potential and benefits of shear walls to have optimum design.

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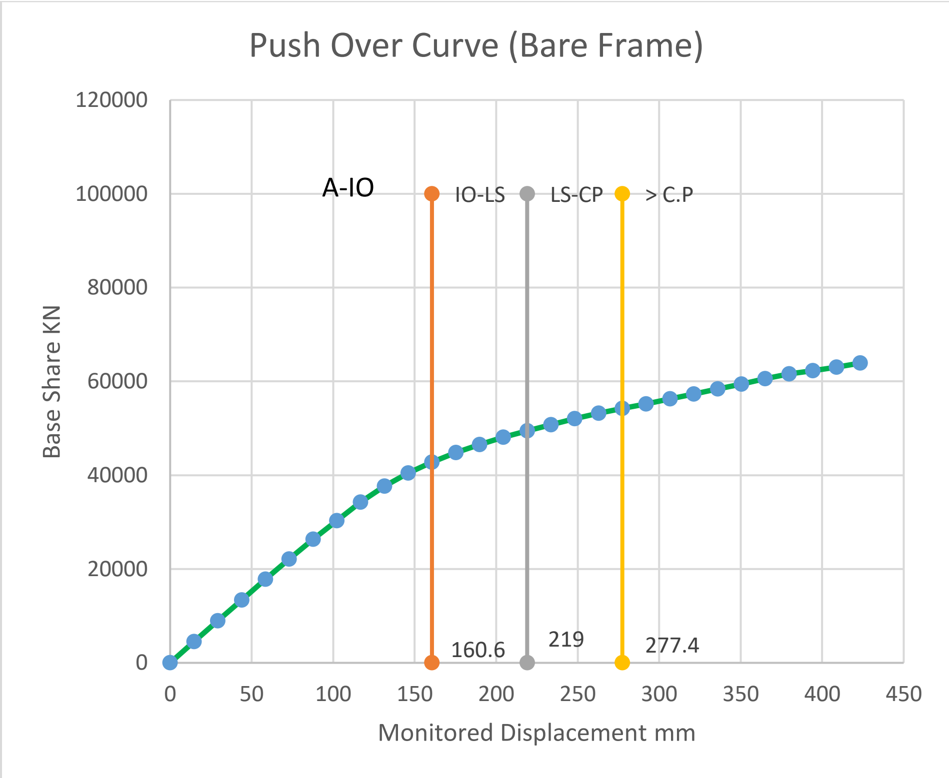

Fig 6.1 Push Over Curve Values for Bare Frame

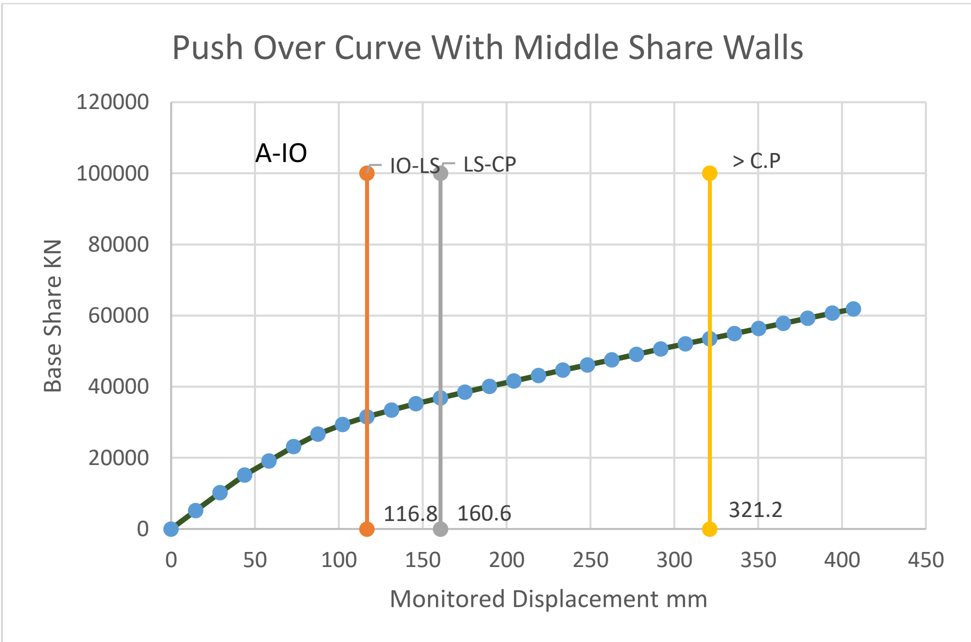

Fig 6.2 Push Over Curve Values for Bare Frame with Centre Shear Walls

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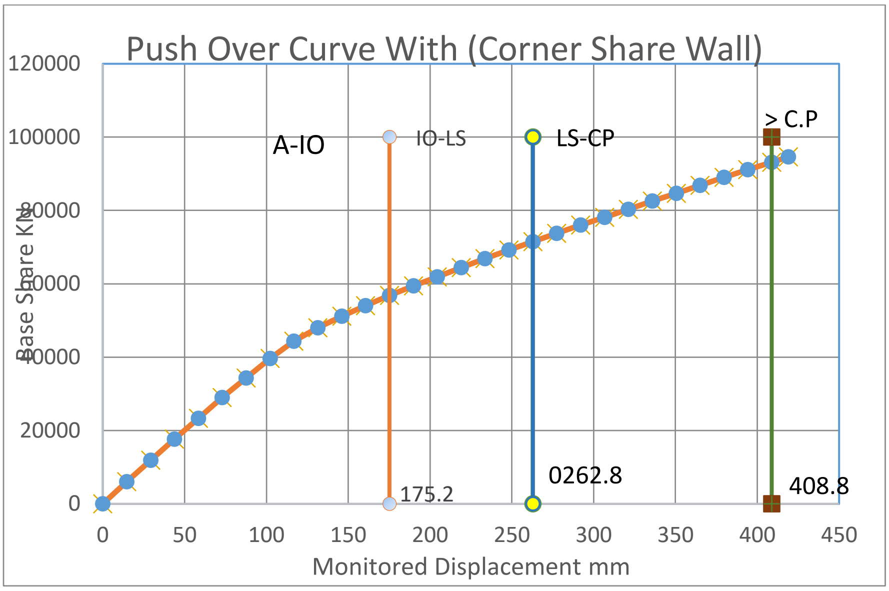

Fig 6.3 Push Over Curve Values for Bare Frame with Corner Shear Walls

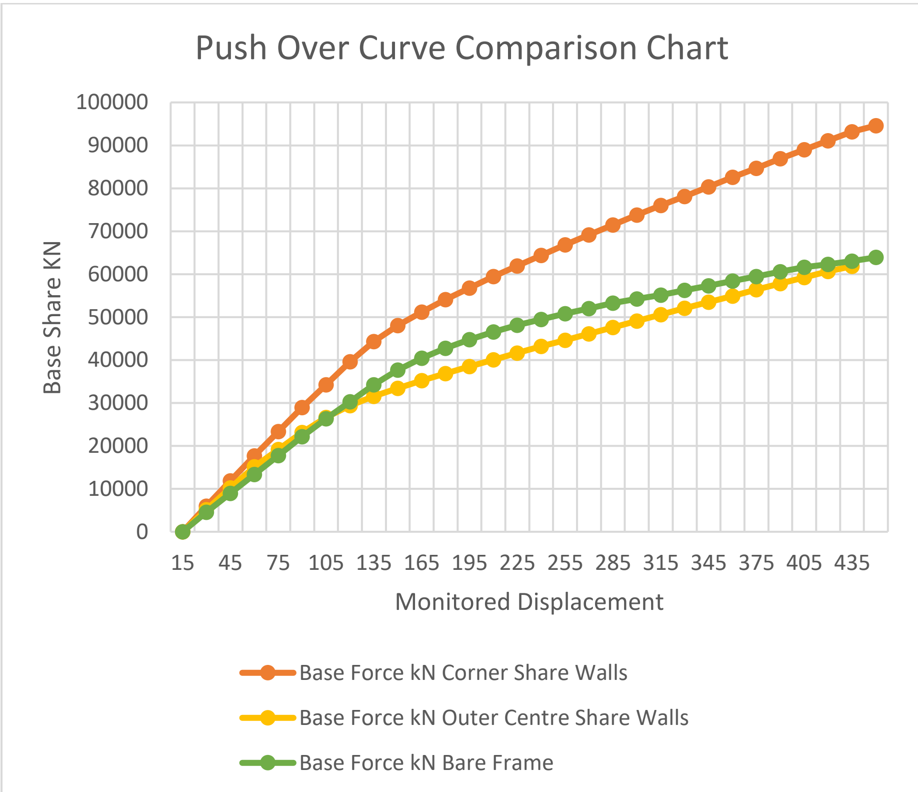

Fig 6.4 Comparison of Push Over Curve for Bare Frame, Middle Shear wall, Corner Shear Walls Structures

6.2 Number of hinges form in different cases

As plastic hinges as per ASCE 41-17 is provided for beams and Fiber hinges are provided for column and shear walls at distance prescribed by ASCE (i.e. d/4 for column and beams and d/2 to shear walls where d is the maximum dimension) are applied in column, beam and walls to create nonlinear cases, they show structural condition through

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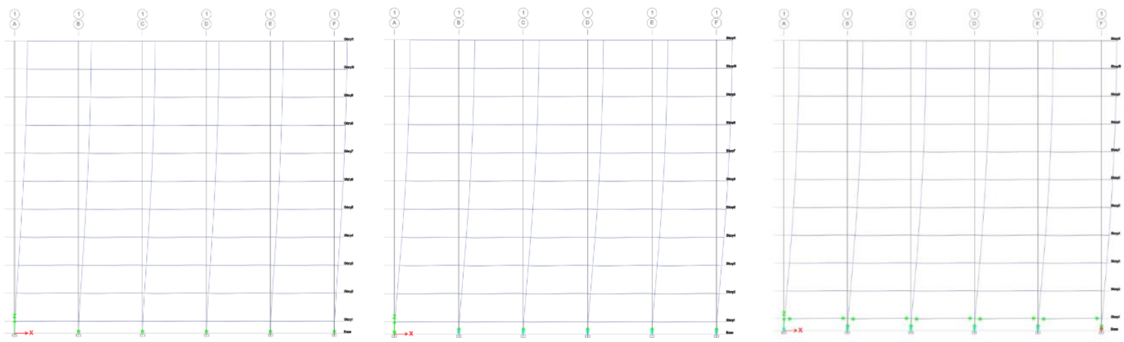
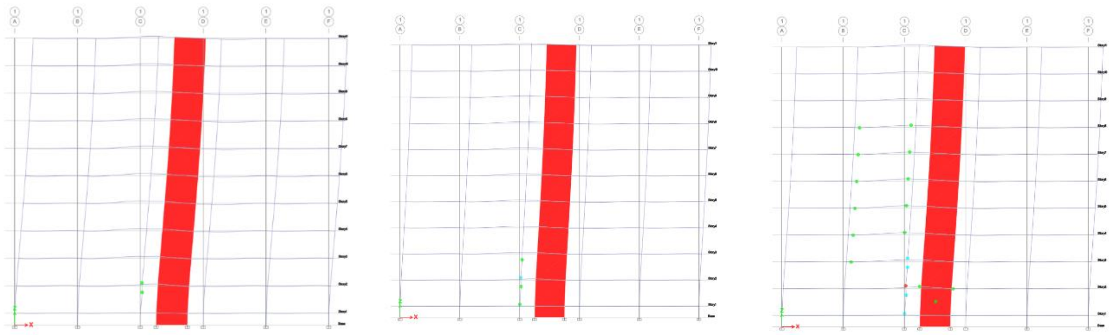
several stages (Fig 5.1 to 5.10). Hinges go to collapsible condition after passing a few intermediate stages i.e. immediate occupancy and life safety.
Formation of maximum number of hinges in early stage is not good for structure which eventually represents that early reaching to the collapsible condition. From this point of view, it is seen that for bare frame with middle shear wall early hinges are form while other are delayed.



Push Step	Horizontal Deflection mm	Base Shear KN	A-IO	IO-LS	LS-CP	>CP	Total
11	160.6	42765.5925	2087	25	0	0	2112
15	219	49459.4158	34	2064	23	25	0
19	277.4	54235.3757	35	1944	132	35	1

Fig- 6.5 Hinges Formation Bare Frame



Push Step	Horizontal Deflection mm	Base Shear KN	A-IO	IO-LS	LS-CP	>CP	Total
8	116.8	31553.2092	2288	4	0	0	2292
11	160.6	36881.0053	2284	6	2	0	2292
22	321.2	53520.2487	2253	29	8	2	2292

Fig- 6.6 Hinges Formation Bare Frame with Middle peripheral wall

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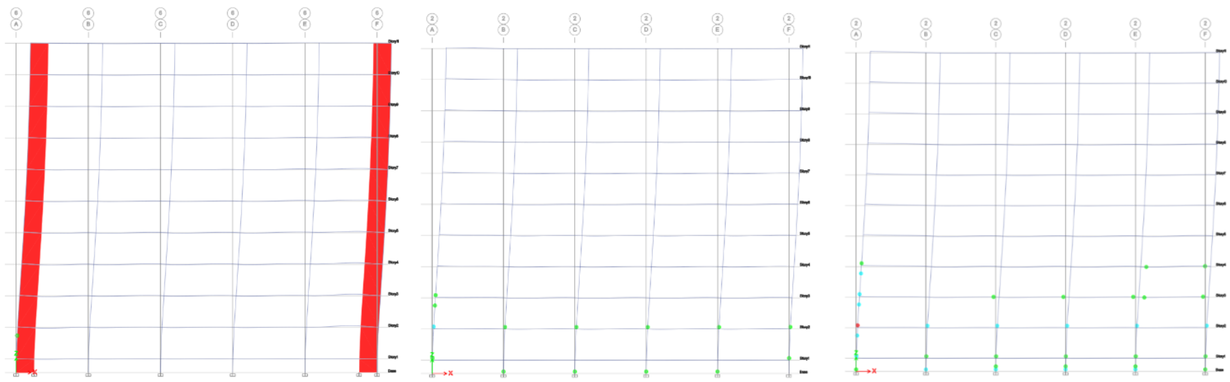

Push Step	Horizontal Deflection mm	Base Shear KN	A-IO	IO-LS	LS-CP	>CP	Total
12	175.2	56798.94	2119	1	0	0	2120
18	262.8	71482.43	2038	81	1	0	2120
28	408.8	93161.3	1688	367	64	1	2120

Fig- 6.7 Hinges Formation Bare Frame with Corner walls

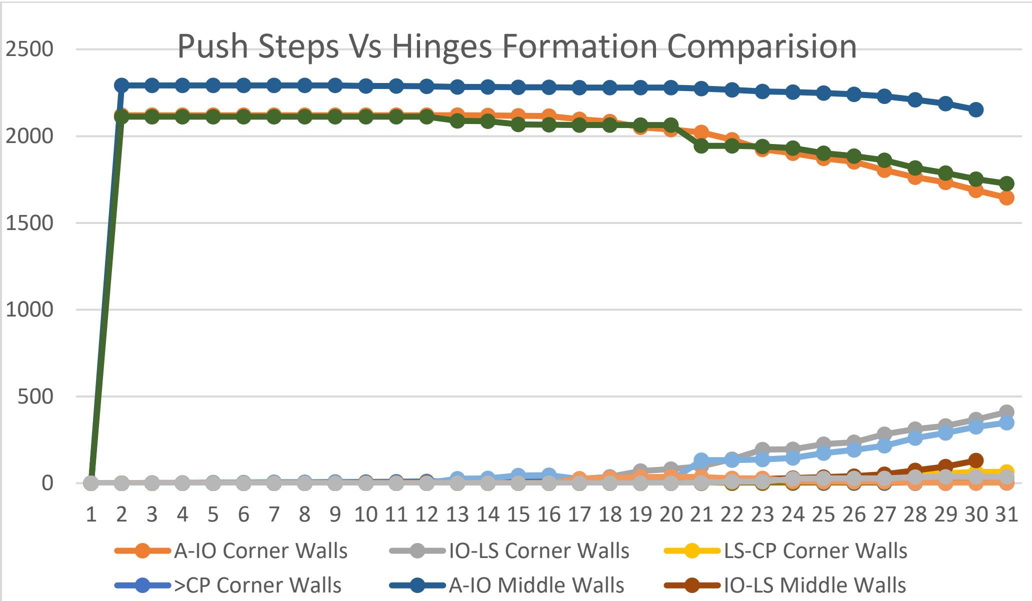

Fig 6.8 Hinges Formation Curves for All Structures

6.3 Performance Points.

All the three structures are analyzed to find performance point (Fig 5.21, 5.22, 5.23) and compare the structure performance. Performance point is the intersection of demand curve to the capacity curve as explained earlier. It can be seen that the maximum base shear is resisted by the frame with corner shear wall structure (Fig 5.17) while lowest is resisted by the middle shear wall. It is due to the weak beam junction between the column and the shear wall. For better performance the shear wall should be extend to column to column.

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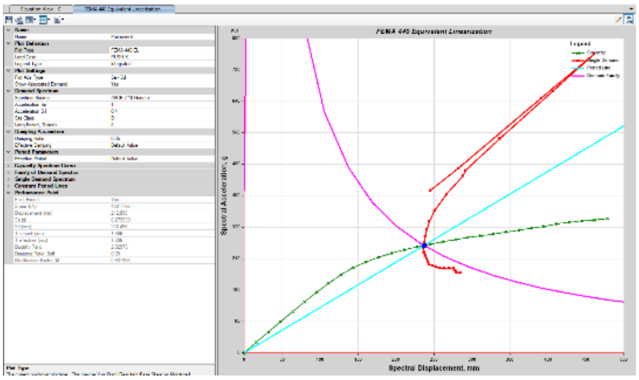

Fig 6.9 Performance point of Bare Frame as per FEMA 440

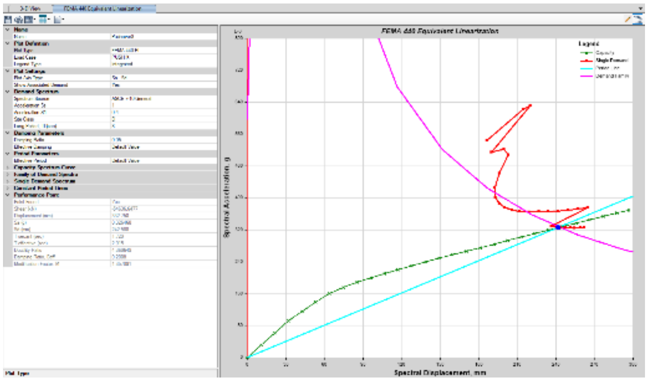

Fig 6.10 Performance point of Middle Shear wall as per FEMA 440

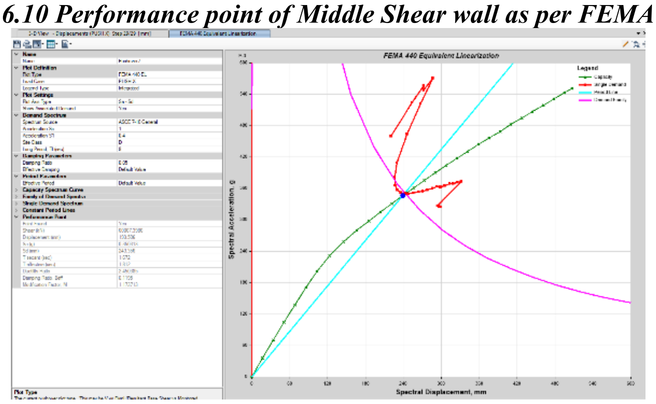

Fig 6.11 Performance point of Corner Shear Walls Structure as per FEMA 440

	Performance Point as per FEMA 440		
		Displacement	Base Shear
		mm	KN
1	Bare Frame	212.096	48817.6
2	Bare Frame with Centre Shear Walls	332.246	54636.6
3	Bare Frame with Corner Shear Walls	193.506	60067.3

Table6.12 Performance Points as per FEMA 440

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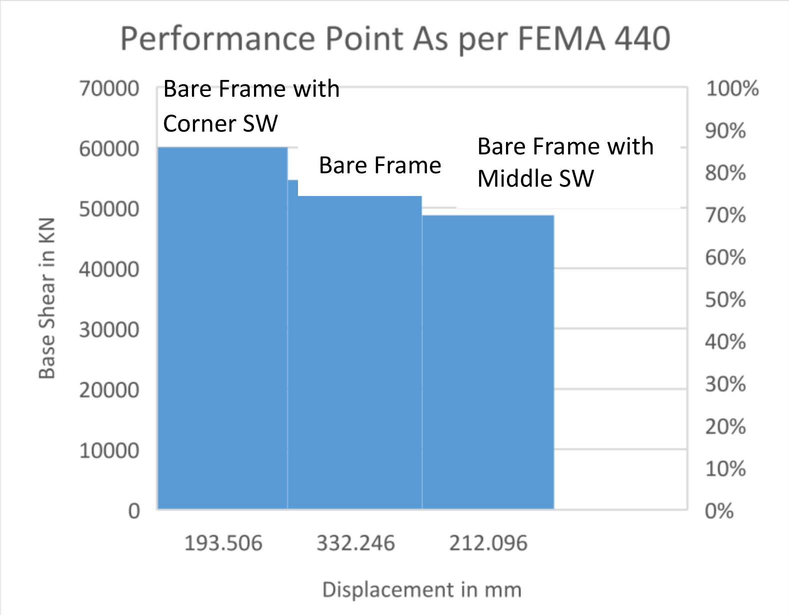

Fig 6.13 Comparison of Performance point of Bare Frame, Centre peripheral wall and Corner Shear Walls.

6.4 Deflection and Storey drift

This section is use to compare the storey deflection for all three buildings. Building is pushed for various steps and last step deflection is compared in X and Y direction for individual structure and at the end all the three-deflection are compared. For middle shear wall structure, we can conclude that by pushing the structure in X direction, the shear wall in the Y direction restrict the deflection to low values whereas on the other two structures the deflection on both the direction is high and the difference between the X and Y deflection is low.

Storey drift which is the total lateral displacement that occurs in a single story of a multistory building. Gradual displacements changing ensures structural stability, uniform stiffness and less probability to the evaluation of plastic hinges. Plastic hinges eventually go to collapsible condition and cannot stand with load.

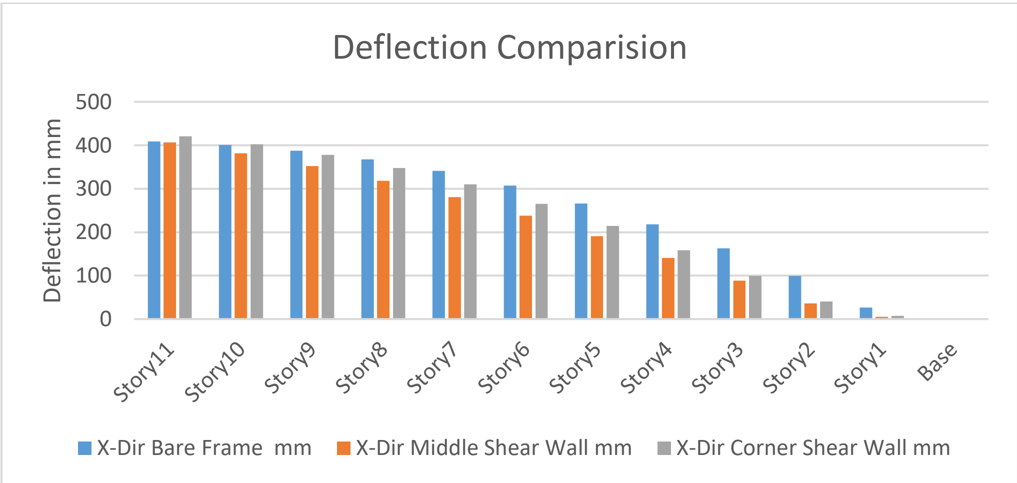

Fig 6.14 lateral deflection Comparison X

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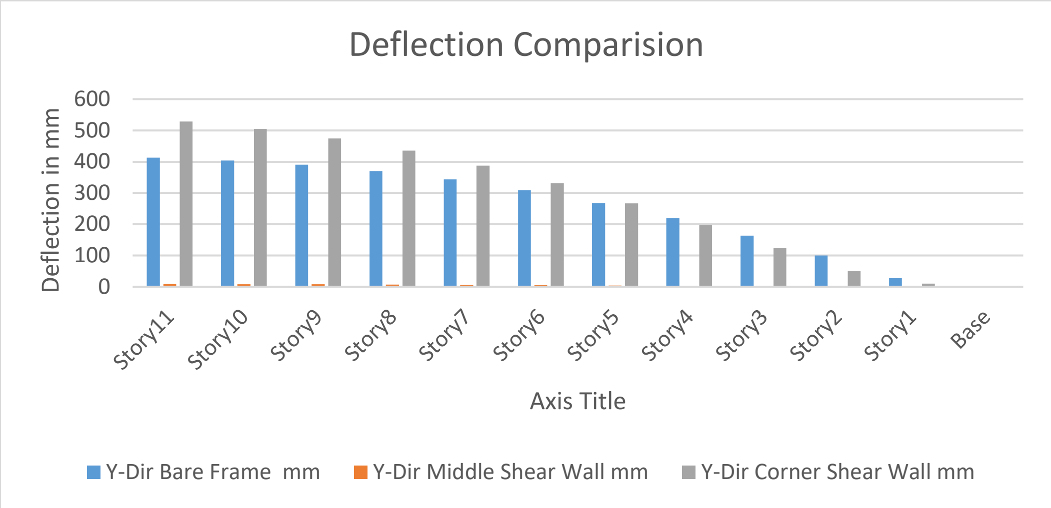

Fig 6.15 lateral deflection Comparison Y

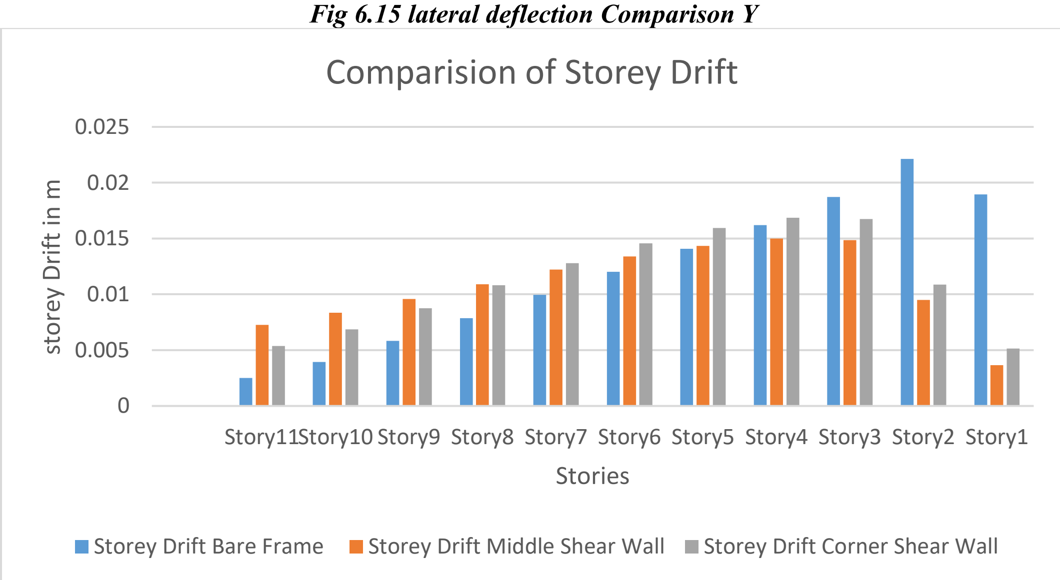

Fig 6.17 Comparison of Storey drift of Bare Frame, Centre peripheral wall and Corner Shear Walls.

7. Summary and Conclusions

Metropolitan city densely crowded with medium to high rise RC buildings, is frequently facing earthquakes of low to medium intensity and expecting some serious seismic threats in the near future. This emphasizes the importance of using an appropriate numerical model such as one presented in this study for the actual seismic assessment of the RC constructions. There are good reasons for advocating the use of the inelastic pushover analysis for demand prediction, since in many cases it will provide much more relevant information than an elastic static or even dynamic analysis and encourage the design engineer to recognize important seismic response quantities and to use them for exposing design weaknesses.

Performance Parameters	**Bare Frame**	**Bare Frame Middle Shear Walls**	**Bare Frame Corner Shear Wall**
Performance Point FEMA 440 KN	48817.6	54636.6	60067.3
Deflection in mm as per FEMA 440	212	332	293

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Base shear KN at IO	42765.5925	31553.2092	56798.94
Base shear KN at LS	49459.4158	36881.0053	71482.43
Base shear KN at CP	54235.3757	53520.2487	93161.3
Displacement mm at IO	160.6	116.8	175.2
Displacement mm at LS	219	160.6	262.8
Displacement mm at CP	277.4	321.2	408.8
Drift Maximum mm	22.123	14.84	16.74

Table 7.1 Comparison of performance parameters of all three buildings

8. CONCLUSION AND RECOMMENDATIONS

The maximum base shear is resisted by bare frame corner shear wall structure before reaching to IO, LS and CP limits on the other hand, the early hinges are formed in bare frame middle shear wall structure among all three structures. The Minimum base shear is resisted by bare frame with middle shear wall structure. It is observed that the early hinges in bare frame middle shear wall structure is due to discontinuity of shear walls before the columns so that it is the good practice to continue the shear wall up to columns to utilize full potential and benefits of shear walls to have optimum design.

All the performance parameters are show in table 10. All the IO, LS, CP base shear and deflection is shown in the table 7.1. Here we can conclude that using corner shear walls in RCC buildings enhance the performance of the building up to considerable limits which can be seen that base share is around 42% higher in corner shear wall structure as of other two structures and Collapse hinges are delayed up to 28 steps which leads to high performance of structure and efficient use of materials.

It can also see that higher lateral deflection is resisted by corner shear wall structure before collapse mechanism is developed.

The highest performance point is achieved by corner shear wall structure as shown as per FEMA 440 at deflection of 293 mm.

Storey drift is higher in bare frame followed by corner shear wall structure and middle shear wall structure. Middle shear wall structure performance best to resist storey drift and deflection specially in Y direction as compare to other two structures.

9. REFERENCES

1] ASCE 41-17

2] ATC. 1996. Seismic Evaluation and Retrofit of Concrete Building. Volume 1. Report (ATC-40), Applied Technology Council, California, USA.

3] Indian National Codes (IS-875, IS-456, IS-1893-2016).

4] FEMA 440, 356, 273. 2002. Pre-standard and Commentary for the Seismic Rehabilitation of Buildings. Federal Emergency Management Agency, Washington D.C., USA.

5] Practical Three-Dimensional Nonlinear Static Pushover Analysis. Ashraf Habibullah, S.E., and Stephen Pyle, S.E. 1988 Structure Magazine.

6] Performance Based Evaluation of Shear Walled RCC Building by Pushover Analysis International Journal of Modern Engineering Research (IJMER) www.ijmer.com Vol. 3, Issue. 4, Jul - Aug. 2013 pp-2522-2525 ISSN: 2249-6645

7] Dynamic Analysis of RCC Buildings with Shear Wall
International Journal of Earth Sciences and Engineering 659 ISSN 0974-5904, Volume 04, No 06 SPL, October 2011, pp 659-662

iJETRM
International Journal of Engineering Technology Research & Management
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https://www.ijetrm.com/

8] Performance Based Analysis of RC Building Consisting Shear Wall and Varying Infill Percentage. Yousuf Dinar, Md. Nazmul Alam, Suvash Chandra Paul - EUROPEAN ACADEMIC RESEARCH - Vol. I, Issue 9 / December 2013 2945

9] Performance-Based Seismic Design of Nonstructural Building Elements Andre Filiatrault, Daniele Perrone, Roberto Javier Merino & Gian Michele Calvi (2018): Journal of Earthquake Engineering, DOI: 10.1080/13632469.2018.1512910

10] Rahul RANA1, Limin JIN2 and Atila ZEKIOGLU313th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004 Paper No. 133

11] Deformation Capacity and Performance-Based Seismic Design for Reinforced Concrete Shear Walls Ying Zhou, Dan Zhang, Zhihua Huang & Dan Li (2014), Journal of Asian Architecture and Building Engineering, 13:1, 209-215, DOI: 10.3130/jaabe.13.209 To link to this article: https://doi.org/10.3130/jaabe.13.209

12] Etabs Version 21

13] Push-over analysis for performance-based seismic design R. Hasan, L. Xu, D.E. Grierson Department of Civil Engineering, University of Waterloo, Waterloo, Ont., Canada N2L 3G1 Received 6August 2001; accepted 22 July 2002

14] Performance-Based Seismic Design Of 3d R/C Buildings Using Inelastic Static and Dynamic Analysis Procedures Andreas J. Kappos and Georgios Panagopoulos Department of Civil Engineering Aristotle University of Thessaloniki 54124 Thessaloniki, Greece ISET Journal of Earthquake Technology, Paper No. 444, Vol. 41, No. 1, March 2004, pp. 141-158

15] Performance Based Seismic Design of RCC Building Mr. Chetan Ingale, Prof. M.R.Nalamwar *(M.S.) India. Civil Engineering Department, Jagadambha college of Engineering and Technology, Yavatmal, 445105,* International Research Journal of Engineering and Technology (IRJET) Volume:04 Issue:10 Ct-2017.

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