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RESEARCH ARTICLE

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# ANALYTICAL INVESTIGATION FOR UNCERTAIN PARAMETERS TO CHECK SENSITIVITY OF PUSHOVER ANALYSIS

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**ABSTRACT**

A huge damage to RC building during the earthquake around everywhere generated a great demand for improving a easy and accurate new method known as "Pushover Analysis" for seismic evaluation. The previously known "Non-linear Static Analysis" is now popularly known as ,"Pushover Analysis". It now become a successful tool for seismic performance evaluation of existing and new structures. But in real structures the characteristic strength for steel and concrete may not be same as taken in the analysis, it may be more or less than assumed. Thus the output of the analysis is much sensitive to these design parameters .In this paper the focus has been made to understand the sensitivity of design parameters like characteristics strength of concrete, steel And the results were compared with the analysed building frame with standard parameters.

**Key Words:** Pushover analysis, uncertain parameters, seismic evaluation, geometric modelling ,base shear


## INTRODUCTION

Pushover analysis is an approximate analysis method in which the structure is subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is reached. Pushover analysis consists of a series of sequential elastic analysis, superimposed to approximate a force-displacement curve of the overall structure. A two or three dimensional model which includes bi-linear or tri-linear load-deformation diagrams of all lateral force resisting elements is first created and gravity loads are applied initially. A predefined lateral load pattern which is distributed along the building height is then applied. The lateral forces are increased until some members yield. The structural model is modified to account for the reduced stiffness of yielded members and lateral forces are again increased until additional members yield. The process is continued until a control displacement at the top of building reaches a certain level of deformation or structure becomes unstable. The roof displacement is plotted with base shear to get the global capacity curve. In recent years, the seismic design criteria's for construction of new structures and rehabilitation of existing structures have been addressing some rapid changes. Now days, to evaluate the current seismic design methodology comprehensive is conducted implemented in different codes and standards. After the starting of damage in the building, the force and deformation distributions cannot realistically predict by the elastic analysis. Inelastic analytical procedure become necessary to identify the modes of failure and potential of collapse.

The static non-linear analysis is known as Pushover analysis under permanent vertical loads and gradually increasing lateral loads. The load is incrementally increased in accordance to a certain predefined pattern .Up to failure the analysis is carried out, thus it enables determination of collapse load and ductility capacity. On a building frame, plastic rotation is monitored, and plot of the total base shear versus top displacement in the structure is obtained by this analysis that would indicate any premature failure and weakness.

**2.Scope and Objective**

Objective of the present work is to analyze uncertainty of pushover method for G+5 structure symmetric in plan and elevation situated in earthquake zone III.

1. To understand the sensitivity of pushover curve bye considering effective moment of inertia and comparing it with result of gross moment of inertia.
2. Compare the analytical results with standard pushover curve.

**3.Modelling and Loadings:**

The finite element based software SAP2000(version-15) has been used for modeling and analysis. It is a very user friendly and having features like static and dynamic analysis, including static linear as well as non-linear and dynamic linear as well as non-linear, etc and much more which makes SAP2000 an art program in structural analysis.

**a. Section Properties:**

The size of all beam sections are 300mm X 450mm in size with 2-12mmφ bars at top and 3-12mmφ bars at bottom are used. While the size of all column sections are 600X600mm with 3-16mmφ at top and bottom.

**b.Geometry:**

A G+5 RC building frame shown in fig.1 is taken for analysis.

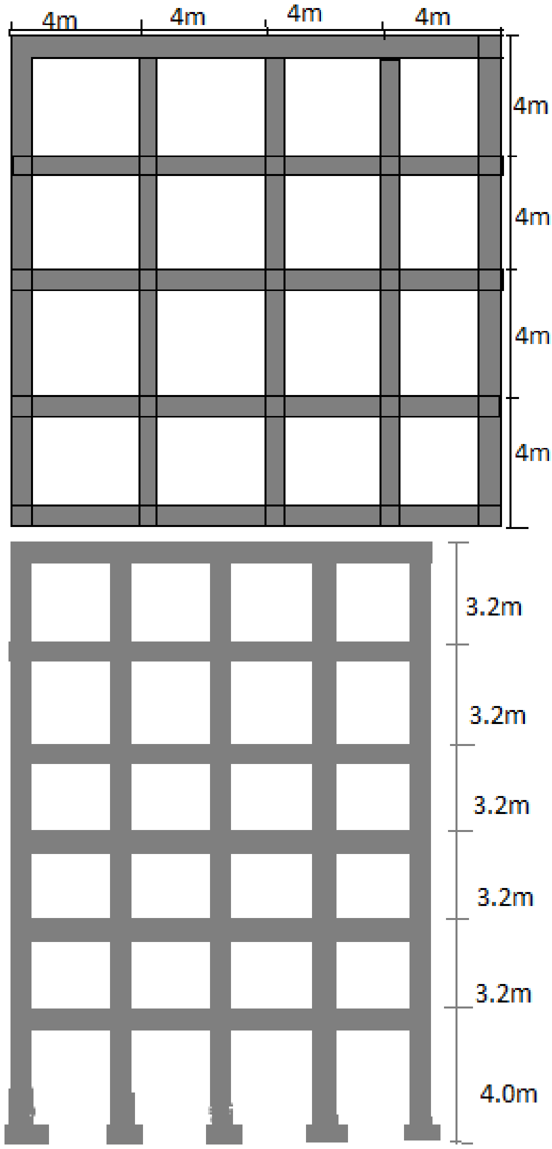



Fig.1 G+5 RC building

**c.Design loads:**

i.Live loads : 2kN/m$^2$ at typical floor.
1kN/m$^2$ at roof.

ii.Floor finish : 0.5 kN/m$^2$.

iii.Earthquake loads: As per IS1893:2002(Part-I)

iv.Floors : G+5

v.Storey height: 3.2m typical
4.0m ground including plinth.

vi.Wall:230mm thick brick masonary walls.

**4.Analysis considering effective moment of inertia:**

In concrete members the variables moment of inertia and modulus of elasticity are subjected to change while applying loading. The variation in moment of inertia is due to cracking of concrete because of the tensile strains greater than the cracking strains of concrete. The stress generated from applied loads are giving rise to cracking in concrete member which decreases resistance of member to loading. When the maximum moment($M_u$) in the beam does not exceed cracking moment ($M_{cr}$), the beam is in uncracked condition. The uncracked moment is obtained from following equation:

$$I_g = \frac{b \times d^3}{12} \quad \text{.......(a)}$$

While during course of loading if in-plane bending moment (M) at cross section reaches cracking moment ($M_{cr}$), vertical flexural cracks developed in outermost layer of tension zone. These cracks propagates upwards as M increases. The section become fully cracked, when these flexure cracks reaches at neutral axis the entire tension zone becomes very weak and ineffective to resist loading . The moment of inertia of this fully cracked condition is determined by $I_{cr}$.

$$I_{cr} = \left(\frac{b \times x_u^3}{3}\right) + (A_{st} \times m \times (d - x_u)^2) + (A_{sc} \times m \times (x_u - d')^2)$$

b= width of web
d=effective depth
$x_u$=neutral axis depth
$A_{st}$=Tension reinforcement
$A_{sc}$=Compression reinforcement

$$M = \text{modular ratio} = \frac{280}{3 \times \sigma_{cbc}}$$

$d'$= effective cover

From uncracked moment of inertia to a fully cracked moment of inertia ,the overall moment of inertia of concrete beam is decreasing gradually. This gradual decreasing is taken into consideration by effective moment of inertia approach . The following effective moment of inertia is derived from the following equation from *IS456-200* codal procedure:

$$I_{eff} = \frac{I_{cr}}{1.2 - \left(\frac{M_{cr}}{M} \times \left(\frac{z}{d}\right) \times \left(1 - \frac{x}{d}\right)\left(\frac{b_w}{b}\right)\right)}$$

$I_{cr}$ = cracking moment of inertia

$$M_r = \text{Cracking moment} = \frac{f_{cr} \times y_{gr}}{y_t}$$

$f_{cr}$ = modulus of rupture of concrete.
$= 0.7\sqrt{f_{ck}}$
M = maxium moment under service load
Z = lever arm
d = effective depth
$b_w$= width of web
b = width of compression face

**5.Calculations of effective moment of inertia as per IS 456-2000 procedure:**

**5.a) Effective moment of inertia for Beam:**

According to IS 456-200, Annexure –C,C-2.1 the effective moment of inertia is given by:

$$I_{eff} = \frac{I_{cr}}{1.2 - \left(\frac{M_{cr}}{M} \times \left(\frac{z}{d}\right) \times \left(1 - \frac{x}{d}\right)\left(\frac{b_w}{b}\right)\right)}$$

$f_{ck}$ = 25 N/mm$^2$
$f_y$ = 415 N/mm$^2$

$$\therefore m = \frac{280}{3 \times 8.1} = 11.524$$

$$\left(\frac{bx^2}{2}\right) + (1.5m - 1) \times A_{sc} \times (x - d') = (m \times A_{st} \times (d - x))$$

$$\frac{300 \times x^2}{2} + (1.5 \times 11.524 - 1) \times 227 \times (x - 20) = (11.524 \times 340 \times (430 - x))$$

Solving above equation we get,
$x$=85.83mm or $x$ = -136.62mm
hence **$x$ = 85.83mm.**
Now,

$$I_{cr} = \left(\frac{b \times x_u^3}{3}\right) + (A_{st} \times m \times (d - x_u)^2) + (A_{sc} \times m \times (x_u - d')^2)$$

$$I_{cr} = \frac{300 \times 85.83^3}{3} + 11.524 \times 340 \times (430-85.83)^3 + (1.5 \times 11.524 - 1)$$

**$\therefore I_{cr}$ = 543.4 x 10$^6$ mm$^4$**

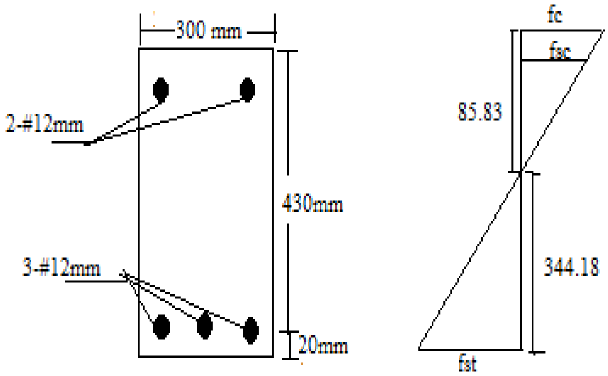



Fig.2.Stress variation on beam section

$$\frac{fst}{m} = \frac{230}{11.524} = 19.962$$

From fig.2 ,

$$fc = \frac{19.96}{344.17} \times 85.83 = 4.978 \text{ N/mm}^2$$

$$\frac{fsc}{65.83} = \frac{4.978}{85.83} = 3.818 \text{ N/mm}^2$$

Now,

$$M_{max} = \frac{300 \times 85.83 \times 4.978}{2} \times \left(430 - \frac{85.83}{3}\right) + (1.5 \times 11.524 - 1) \times 227 \times 3.818 \times (430-20)$$

$M_{max}$ = 34.36 kNm
Now,

$M_{cr} = 0.7 \times \sqrt{25} \times \frac{300 \times 450 \times 450}{6} = 35.47$kNm

$\therefore \frac{Mcr}{Mmax} = 1.04.$

Z = d – (x/3) = (430- 85.83/3) = 401.39mm.

$\frac{Z}{d} = \frac{401.30}{430} = 0.939$

$1 - \frac{x}{d} = 1 - \frac{85.83}{430} = 0.809$

$\therefore Ieff = \frac{5.434 \times 10^8}{1.2 - (1.04 \times 0.939 \times 0.809 \times 1)}$

$= 13.25 \times 10^8 mm^4$.

Hence $I_{cr} < I_{eff} <$ Igross is satisfied.

**5.a.i) Calculation of width of beam equilivalent to $I_{eff}$ keeping depth constant.**

i.e.

$\frac{b \, X \, d3}{12} = Ieff$

$\frac{b \times 430^3}{12} = 13.25 \times 10^8$

∴ b = 200.05 = 200mm.

**5.a) Effective moment of inertia for Column:**

According to IS 456-200, Annexure –C,C-2.1 the effective moment of inertia is given by:

$$I_{eff} = \frac{I_{cr}}{1.2 - \left(\frac{M_{cr}}{M} \times \left(\frac{z}{d}\right) \times \left(1 - \frac{x}{d}\right)\left(\frac{b_w}{b}\right)\right)}$$

$f_{ck} = 25$ N/mm$^2$

$f_y = 415$ N/mm$^2$

$\therefore m = \frac{280}{3 \times 8.1} = 11.524$

$$\left(\frac{bx^2}{2}\right) + (1.5m - 1) \times A_{sc} \times (x - d') = (m \times A_{st} \times (d - x))$$

$\frac{600 \times x^2}{2} + (1.5 \times 11.524 - 1) \times 604 \times (x - 20)$

$= (11.524 \times 604 \times (430 - x))$

Solving above equation we get,

*x*=94.33mm or *x* = -163.62mm

hence ***x* = 94.33mm.**

Now,

$$I_{cr} = \left(\frac{b \times x_u{}^3}{3}\right) + (A_{st} \times m \times (d - x_u)^2) + (A_{sc} \times m \times (x_u - d')^2)$$

$I_{cr} = \frac{600 \times 94.33^3}{3} + 11.524 \times 604 \times (570-94.33)^3$

$+ (1.5 \times 11.524 - 1)$

**$\therefore I_{cr} = 17.83 \times 10^8$ mm$^4$**

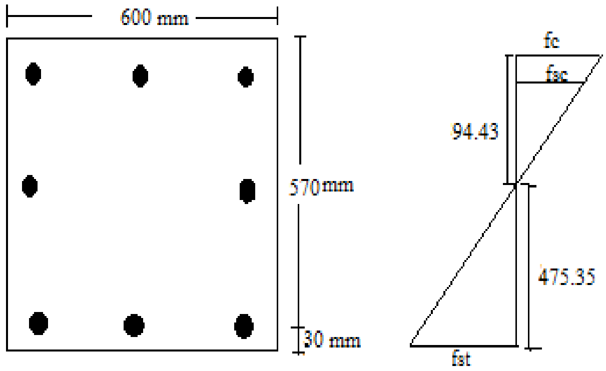



Fig.3.Stress variation on column section

$\frac{fst}{m} = \frac{230}{11.524} = 19.96$

From fig.2 ,

$fc = \frac{19.96}{475.56} \times 94.43 = 4.82$ N/mm$^2$

$\frac{fsc}{64.43} = \frac{4.82}{94.43} = 3.28$ N/mm$^2$

Now,

$M_{max} = \frac{600 \, X \, 94.43 \, X \, 4.82}{2} \times \left(570 - \frac{94.43}{3}\right) + (1.5 \times 11.524 - 1) \times 604 \times 3.28 \times (570-30)$

$M_{max} = 90.94$ kNm

Now,

$M_{cr} = 0.7 \times \sqrt{25} \times \frac{600 \times 600 \times 600}{6} = 113.71$kNm

$\therefore \frac{Mcr}{Mmax} = 1.25.$

Z = d – (x/3) = (570- 94.43/3) = 538.52mm.

$\frac{Z}{d} = \frac{538.52}{570} = 0.94$

$1 - \frac{x}{d} = 1 - \frac{94.43}{570} = 0.83$

$\therefore Ieff = \frac{17.83 \times 10^8}{1.2 - (1.25 \times 0.94 \times 0.83 \times 1)}$

$= 79.59 \times 10^8 mm^4$.

Hence $I_{cr} < I_{eff} <$ Igross is satisfied.

**5.a.i) Calculation of width of beam equilivalent to $I_{eff}$ keeping depth constant.**

i.e.

$$\frac{b\ X\ d3}{12} = Ieff$$

$$\frac{b \times 570^3}{12} = 79.59 \times 10^8$$

∴ b = 515.74 = 515 mm.

**6.**Generally in practice we observe that the strength of $M_{25}$ concrete is not exactly same, either more or less, lets take $F_{ck}$=35mpa. With reference of above calculations we get the width of beam=180mm and that of column is 475mm.

**7.Modelling in SAP200:**

**Step.1:** Create the basic computer model (without pushover data) and define the material properties, geometric properties. While defining width of beam and column first of all define the standred i.e. 300x 450mm for beam and 600 x 600mm for column.

**Step.2:** After creating a model apply the loads to beams. Run the static analysis. After static analysis define the response spectrum function, give the proper load combinations as per IS 1893:2002. And run the response spectrum analysis.

**Step.3**: After response spectrum analysis design the building with the reference of IS 456:200. After designing select the all beams and apply the default M3 hinge and for all columns apply default P-M2-M3hinge.

**Step.4:** Define the push over load cases. Basically the first pushover load case defined is for gravity load and then remaining load cases are defined to start from final condition of gravity pushover.

**Step.5:** Run the analysis and obtain the Base shear vs displacement curves along with ACT-40 capacity curve having successive Demand curve.

**8.a) For $M_{25}$ taking $F_{ck}$=25mpa with effective moment of inertia:** Second analysis is carried out taking width of beams and columns calculated based on effective moment of inertia. Further procedure is same as above and here get base shear value with curve drawn between base shear Vs displacement.

**8.b) For $M_{25}$ assuming $F_{ck}$=35mpa with effective moment of inertia:** Third analysis is carried out considering width of beams and columns according to effective moment of inertia of $M_{25}$ concrete with $F_{ck}$ =35mpa. Here also get base shear value and nature of curve, drawn between Base shear Vs displacement.

**9.Base shear calculations:**

Structure is subjected to lateral load distributed across the height of building. According to IS 1893:2002(part-1) the base shear is calculate bye using formula given below:

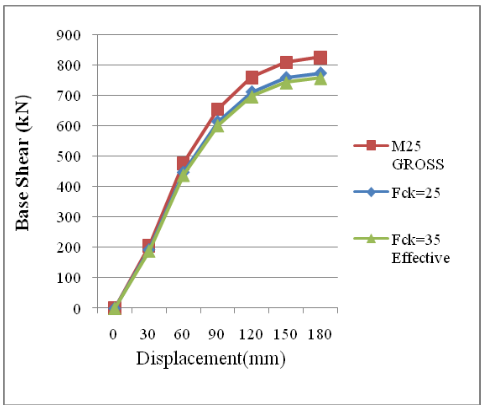
$$F_x = \frac{W_x h_x^k}{\sum_{i=1}^{N} W_i h_i^k} V$$

**10.Result and discussion:-**

The base shear values according to IS 1893:2002(part-1) procedure for above three cases are as below:

| Grade of concrete | Base shear in kN |
|---|---|
| $M_{25}$ with gross MI | 825.1195kN |
| $M_{25}$ with $F_{ck}$ = 25 mpa with MI | 772.71kN |
| $M_{25}$ with $F_{ck}$ = 35 mpa with MI | 756.71kN |

From above values if we plot the graph between Base shear and displacement the different natures of graphs are seems as follows:




1.For model with Fck = 25mpa and considering gross moment of inertia the base shear and displacement observed to be 825.152kN and 187.43mm.

2.For model with Fck = 25mpa and taking width of beam according to effective moment of inertia the base shear and displacement observed to be 772.71 kN and 193.43mm.

3.For model with Fck = 35mpa and taking width of beam according to effective moment of inertia the base shear and displacement observed to be 756.81 kN and displacement 198.66mm.

4.Thus from the above results it is clear that there is some variation in base shear and displacement values for the various geometric model considered.

Hence result is highly sensitive to geometric modeling.

5.The values of displacement for Fck=25mpa and Fck=35mpa with effective moment of inertia increased with 1.04% and 1.1% as that of Fck=25 with gross moment of inertia.

**11.Conclusion**

It has been observed that there is a variation between analytically obtained pushover results when compared to actual grass values taking for geometric modeling. The large variation observed between the analysis results. It can be concluded that the variation is because the pushover analysis is very sensitive to geometric model and material adopted. Further study needs to be carried out by considering other material models. And the results compared with the analytical value based pushover analysis.

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