Design & Seismic Analysis of Single Storey 3-D Frame using Sap 2000

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Abstract - *The purpose of the presented work is the behaviour assessment of reinforced concrete 3D frame structure with sixteen degree of freedom was designed with minimum reinforcement requirement as per the code. In this study, the effects of the variation of software and manual result were investigated. In addition , a structure was defined and designed using current Indian code to perform a design approach and structural performance was assessed by comparing displacements , inter -storey drifts and damage indices of the frame. In this study was done by using SAP2000 software*.

***Key Words*: SAP2000, 3D frame, Degree of Freedom, Displacement**

1. INTRODUCTION

Since earthquake forces are random in nature and unpredictable, the static and dynamic analysis of the structures have become the primary concern of civil engineers. Seismic analysis is a subset of structural analysis and is the calculation of the response of a building (or non-building) structure to earthquakes. It later became clear that the dynamic properties of the structure affected the loads generated during an earthquake. Earthquake-resistant or a seismic structure is designed to protect buildings to some or greater extent from earthquakes. According to building codes, earthquake-resistant structures are intended to withstand the largest earthquake of a certain probability that is likely to occur at their location.
The analysis can be performed based on the external action, the behaviour of structural materials, structure and the type of structural model selected. Based on the type of external action and behaviour of structure, the analysis can be further classified as:

Linear Static Analysis : This method is also known as Equivalent Static Analysis method, the design base shear is computed for the entire building and it is then distributed along the height of the building. The lateral forces at each floor levels thus obtained are distributed to individual lateral load resisting elements. The equivalent static analysis procedure involves the following steps: Calculation of the Design Seismic Base Shear, Vertical distribution of base shear along the height of the structure Horizontal distribution of the forces across the width and breadth of the structure Determination of the drift and overturning moment.

Nonlinear Static Analysis: Nonlinear static analysis also known as Pushover Analysis procedure is mainly used to estimate the strength and drift capacity of existing structure and the seismic demand for this structure subjected to selected earthquake. Pushover Analysis Procedure The magnitude of the lateral load to be applied is increased monotonically maintaining a predefined distribution pattern along the height of the building for the pushover analysis procedure. Building is displaced till the “control node” reaches the “target displacement” or building collapses. The sequence of cracking, plastic hinging and failure of the structural components is observed throughout the procedure. The relation between base shear and control node displacement is plotted for all the pushover analysis. For the generation of base shear, control node displacement curve is single most important part of pushover analysis. This curve is called as pushover curve or capacity curve. The capacity curve is the basis of “target displacement” estimation.

Linear Dynamic Analysis : Response spectrum method is a linear dynamic analysis method. Based on the modal frequency and the modal mass, for each mode a response is read from the design spectrum, and they are then combined to provide an estimate of the total response of the structure using modal combination methods. In this we must calculate the magnitude of forces in all directions i.e., X, Y & Z and then see the effects on the building. Combination methods include the following: Square Root Sum of Squares (SRSS) Complete Quadratic Combination (CQC) Absolute Sum method. Modal analysis is an alternative procedure to the equivalent lateral force method performed to obtain the design lateral forces at each floor level along the height of the building and its distribution to individual lateral load resisting elements.

Nonlinear Dynamic Analysis : Nonlinear dynamic analysis is also referred as Time history analysis. The time-history method can be applied to both elastic and inelastic analysis. In elastic analysis the stiffness characteristics of the structure are assumed to be constant for the whole duration of the earthquake. In the inelastic analysis, the stiffness is assumed to be constant through the incremental time only. Modifications to structural stiffness caused by cracking, forming of plastic hinges, etc are incorporated between the incremental solutions. Even with the availability of sophisticated computers, the use of this method is restricted to the design of special structures such as nuclear facilities, military installations, and base-isolated structures.

This study focuses on the seismic analysis of the single storey 3D frame, variation in the manual calculation and the software analysis were discussed. Also, the suitable method for investigating seismic analysis of the single storey 3D frame was studied.

2. LITERATURE REVIEW

David Dominguez-Santos, Pablo Ballesteros-Perez and **Daniel Mora-Melia**(1)This paper highlights the seismic vulnerability of buildings constructed between 2002 and 2010 and the results indicate that a higher density of infill walls (walls whose bricks are not part of the main structure) is the feature that most significantly improves the seismic behaviour of the structures analysed. Moreover, counter intuitively, incorporating stronger concrete and reinforcing steel and using alternative column arrangements only have a small positive effect on the seismic behaviour of these types of buildings. The objective of this work is to illustrate that most buildings dating from 2002–2010 constructed from wide beams, which were designed to previous earthquake resistance codes, do not offer a satisfactory seismic behaviour, and to identify which structural attributes can best help alleviate this problem. In this work the effect of a real earthquake of medium magnitude (Lorca, 2011) on buildings of three, five and eight stories with unidirectional frames of wide-beam concrete were assessed. The methodology included non-linear static (pushover) analyses and dynamic response simulation with the aim to understand the effect on the seismic performance of changing some of the geometrical and material parameters. Maximum displacements and capacity curves for the top floor of a set of representative buildings were evaluated and compared. Capacity curves obtained from non-linear static (pushover) analysis are compared for different building configurations, as well as the maximum displacements obtained through non-linear dynamic analysis.

Arindam Sahu, Rohit Bose(2)In various parts of the world, Reinforced Concrete (RC) structures, even in seismic zones are still being designed only for gravity loads. Such structures, though performing well under conventional gravity load case, could lead to a questionable structural performance under seismic or wind loads. In most cases, those structures are highly vulnerable to any moderate or a major earthquake. Along with the seismic prone zones like Himalayan region in India, Iran, Turkey, New Zealand and fault regions in US etc., devastation from earthquake have also been seen at the places believed to be seismically not-so active. Therefore, in the design of the reinforced concrete beam column joints against seismic load, it is desirable to limit joint strength degradation until the ductility capacity of the beam reaches the designed capacity. The repair and retrofit materials can be classified into three categories:

1. Grouts
2. Bonding Agents
3. Replacement and Jacketing Material

Present work includes experimental investigation to study the structural behaviour of Beam Column Joint by wrapping technique. There are two types of Wrapping Techniques Type I Retrofitting & Type II Retrofitting. The study is carried out to analyse the Effect of Different Wrapping Techniques on Retrofitting of RCC Beam Column Joints Using Ferrocement. After experimental investigation, observation Type I and Type II are better mechanical properties than control specimen. Type II has better properties than Type I.

ImanHajirasouliha, PayamAsadi and **KyprosPilakoutas** (3) In this paper, a practical method is developed for performance-based design of reinforced concrete (RC) structures subjected to seismic excitations. More efficient design is obtained by redistributing material from strong to weak parts of a structure until a state of uniform deformation or damage prevails. By applying the design algorithm on 5, 10 and 15 storey RC frames, the efficiency of the proposed method is initially demonstrated for specific synthetic and real seismic excitations. The results indicate that, for similar structural weight, designed structures experience up to 30% less global damage compared to code-based design frames. The method is then developed to consider multiple performance objectives and deal with seismic design of RC structures subjected to a group of earthquakes. The results show that the proposed method is very efficient at controlling performance parameters and improving structural behaviour of RC frames.

SKatyaNarasimhaRao and Dr.ShaikYajdani(4) The effect of masonry infill panel on the response of RC frame subjected to seismic action is widely recognized and has been subject of numerous experimental investigations, while several attempts to model it analytically have been reported. In analytically analysis infill walls are modelled as equivalent static approach there are various formulae derived by research scholars and scientist for width of modelling. Infill behaves like compression between column and beam and compression forces are transferred from one node to another. In this study the effect of masonry walls on high rise building is studied. Static analysis on high rise building with different arrangement is carried out. For the analysis G+9 R.C.C framed building is modelled. The width is calculated by using equivalent static method. Various cases of analysis are taken. All analysis is carried out by software STAAD-PRO. Axial Force, Shear Force, Storey drift, Nodal displacement, bending moment is calculated and compared for all models. The results show that infill walls reduce displacement, time period and increase base shear. So, it is essential to consider the effect of masonry infill for the seismic evaluation of moment resisting reinforced concrete frame.

Ayesha Siddika and **Abdullah Al Mamun**(5) This study investigates the parameters which affecting the natural frequency of moment resisting frame structures. Steel and concrete MRF structures were studied theoretically analysed numerically to obtain their mode shapes and frequency of vibration for each mode. From the theoretical and analytical results, a model equation for approximation of natural frequency of these types of MRF structures is proposed. The proposed model expressed the relationship of natural frequency of MRF structure with its total mass, lateral dimension in the direction of vibration and total height. The proposed equation will be helpful and easy to calculate the fundamental frequency for study on dynamic behaviour of structures. Comparison between the current guidelines and proposed model is also discussed. The proposed model is satisfying the general concept of free irrational response can be applied for analysing small- and full-scale structures.

Santhanam Needhidasan(6)In this project seismic response of a residential G+8 RC frame building is analysed by the linear analysis approaches of Equivalent static lateral force and Response spectrum methods using Staad Pro 2016 software as per the IS- 1893-2002-Part-1. These analyses are carried out by considering different seismic zones, medium soil type for l zones 2 &4. Different response like lateral force, overturning moment, story drift, displacements, base shear are. plotted to compare the results of the static and dynamic analysis. Seismic analysis of zone 2&4 are performed by equivalent static method and response spectrum method and result of seismic analysis in both zones is compared the basis of story drift, modal frequency, base shear, and nodal displacement.

3. NUMERICAL SIMULATION

3.1 General Statement of the Frame

Base plate: 250 x 250 mm

Footing: 150 x 150 mm (depth of 60 mm)

Beam: 100 x 100 mm

Column: 100 x 100 mm

Frame Height: 0.5 m

Bay width: 0.5 m

Materials: Concrete

Concrete grade: M20

All steel grade: Fe 415

3.2 Seismic Parameter

- Zone Factor: 0.16
- Damping Ratio: 0.05
- Importance Factor: 1
- Time of vibration in both x and z axis :0.05
    - Response Reduction Factor: 5 (RC building with special moment as per IS1893 :2016)
    - Storey -weak storey (A weak storey is one in which the storey lateral

strength is less than 80 percent of that in the storey above, the storey lateral strength is the total strength of all seismic force resisting elements the storey shear in the considered direction.)

- Natural period:

For RC frame building,

Ta = 0.075 h0.75 sec (as per IS1893 :2016)

Hence h=0.5, Ta =0.446 sec.

- Stiffness of the frame:

k = Number of column×12EI/hi3

Where, I=Moment of inertia of the column section and hi = height of each storey

Number of columns =4

Modulus of Elasticity of concrete =5000√fck Mpa. (as per IS: 456)

fck =0.446 x [characteristic strength of concrete = 20] (for a concrete element) fck = 8.92

E = 5000 x √8.92 =14933.18 Mpa

I=bh3/12(in x axis) I = bh /12(b2 + h2) (in z axis) [b=100, h=500]

I=1.042 x 109(in x axis) I=1.083 x 109 (in z axis)

hi= 500

Hence k = 5975184

Ktot= 1/k-1=0.999

- Seismic weight of the frame:

Member self-weight:

Beam (100 x 100) = 0.1x0.1x 25 =0.25 kN/m =0.25 x 0.5 =0.125 kN

Column (100x 100)= 0.1 x 0.1 x 25 =0.25 kN/m = 0.25 x 0.5 =0.125kN

Total self-weight = 0.250kN

- Natural frequency of the frame:

f =1/2 √ ktot/Mtot Hz

MTot=Total mass of the frame= seismic weight of the frame /9.81

MTot = 0.25 x 103 / 9.81 = 25.493 kg

f= 0.0315 Hz

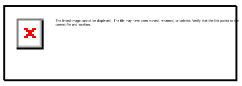
- Response acceleration coefficient

For medium stiff soil sites (as per IS code 1893-2016)

Ta=0.446 sec (0<T<0.55s)

Sa/g=2.5

- Design horizontal seismic coefficient



Ah = 0.16 x 1 x 2.5/ (2 x 5) = 0.04

- Base shear force (vb)

vb = Ah x w

=0.04 x 0.25 kN = 0.01 kN

- Design storey shear calculation

=0.01.

- Storey drift

The ratio of Difference between the storey displacement and storey height .

=difference in the displacement of the element / storey height

=-3.196e-7mm

Maximum drift permitted = 0.004 x storey height

=2mm >-3.196e-7mm

Hence storey drift is within the permissible limit.

- Distribution of horizontal load

Qi=vi (for a single storey frame there is no distribution of horizontal load)=0.01

- Stability index

Qi=∑pu▲u/H uhi

=0.25 x 0.00003196 / (500 x 0.01) = 1.598e-6

Qi< 0.04 mm (non-sway)

Hence the frame is non-sway.

3.3 Designing of Single Storey 3D frame

Beam design :

Width of the beam b = 100 mm

Depth of the beam d = 100 mm

Clear cover =20 mm

Effective depth d' = 80 mm

Self-weight of beam = 0.1 x 0.1 x 25 = 0.25 kN / m

Factored load wu = 1.5 x 0.25 =0.375 kN/m

Factored moment = wu x l2/8 = 7.5 x 10-3 kN.m

For fe 250 steel member, Mu = 0.149 fck bd2

d = 50.66 < 80 mm.

Hence effective depth of the beam is safe.

Reinforcement requirement

R= Mu / bd2 = 0.01172

Ast = fck /2fy [1 - √1-4.598 R/fck] bd = 0.43 mm2

As per the codal provision IS 456: 2000, Minimum reinforcement Ast=0.85db/fy = 27.2 mm2

For a mild steel Ast should not be less than 0.34% =0.34/100 x100x100

Hence, provide 2 nos' of 6mm rods Ast = 56.54mm2.

And the hanger bars of 2 no's of 6mm rods were provided.

Shear reinforcement

d = 3mm, as per the code Asv> 0.4 b Sv/0.87 x fy =30.99

shear force Vu= 0.0125 kN

Ʈv=Vu/bd=1.866 x 10-3, pt = Asr/bd x 100 =0.75%

By referring the table 19, IS :456, Ʈc=0.56

Ʈv < Ʈc , minimum reinforcement were provided .

Development length Ld=ɷ6s/ 4Ʈbd =31.2 provide 40mm

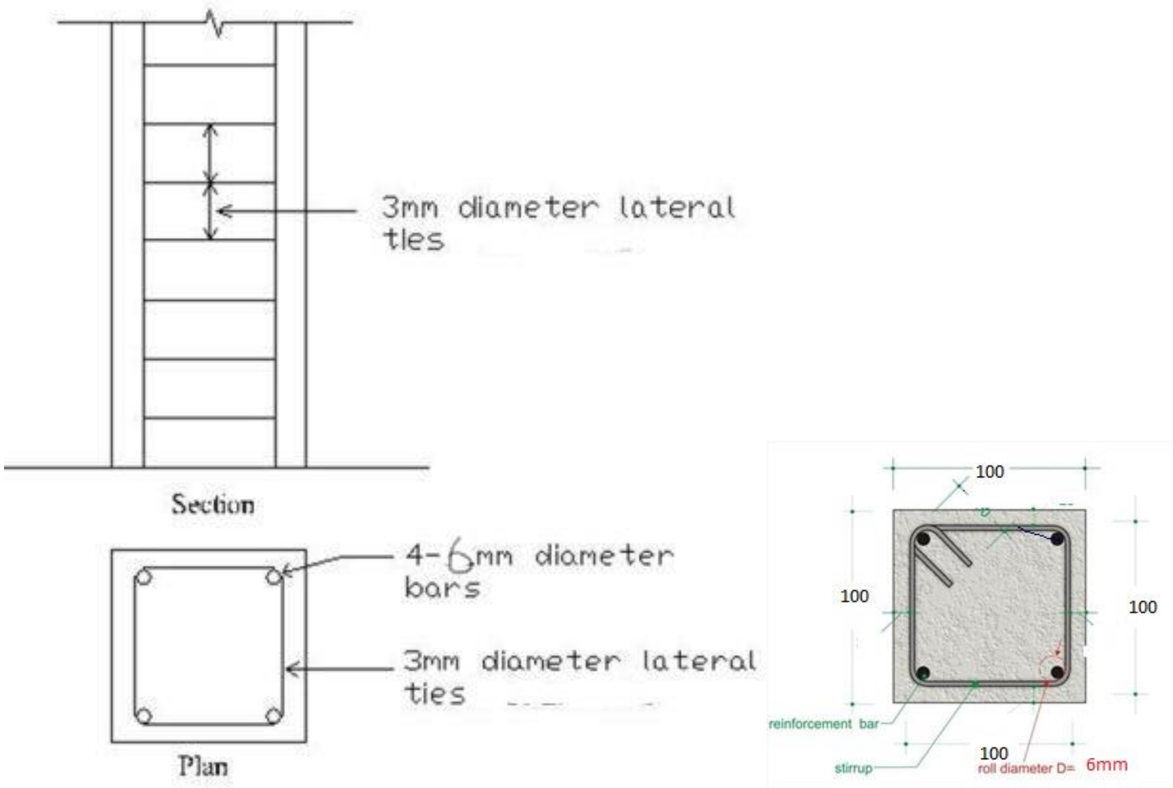


Figure 4 Beam Cross Section

Column design

Fck= 20 N/mm2, fy = 250

Lex = Ley = 400 mm

Dx=Dy= 100 mm

Slenderness ratio ʎ= Lex/D= 4 <12

Column member is short.

Minimum eccentricity, emin = Lex/500 + Dx /30 = 2.47

0.05 D = 0.05 x 100 = 5> 2.47 mm

hence, axially loaded short column.

use of design formula.

pu=0.4fckAg + (0.67fy – 0.4 fck)Asc   Ag= 100 x 100

now axial load, pu = 0.014kN hence Asc=33.57mm2

as per the codal provision Asc should not be less than 0.8%0f the cross area = 0.8/100 x 100 x 100 =80 mm2 and should not be greater than 6% of the cross area =6/100 x100x 100 = 600 mm2.

Hence, provide 4- 6mm diameter bars at the corners Asc= 113.09mm2

Lateral ties should not be less than 1/4x 6 = 1.5 mm < 3 mm hence safe.

Pitch a) least lateral dimension =100mm

b)16 x diameter of the main bar =96mm

c)48 x transverse diameter of bar = 48mm

hence, provide 40mm centre to centre distance.

Footing Design

Pu = 0.353 kN, Mu = 0.002 kNm

Assume weight of the foundation pf = 10% of p= 0.1x p =0.1 x 0.353

= 0.0353 kN

Area foundation required = 1.1p/qo= 38.83mm2

Depth of footing, Mu = 0.149fckbd2

d = 1.93 mm adopt has d = 40mm

overall depth D = 60 mm.

reinforcement required Ast = fck /2fy [1 - √1-4.598 R/fck] bd

= 0.46 mm2

Minimum reinforcement (as per the code IS 456 - 2000)

Should not be less than 0.15% of the area =5.4mm2

Spacing should not be less then greater then 5d =38 mm (transverse rod) hence provide 20mm for spacing.

4. MODELLING OF 3D FRAME (SAP2000)

In sap2000 provides a easy way to model a frame structure through the basic commands and this are the procedure to model a frame structure in sap2000.

1.file → new model through this command new model dialogue box will be visible in this wizardclick the initialize model from defaults with units of KN,m,c. then click the grid only template from the select template option.

2. by using quick grid lines wizard number of grid lines (2), grid line spacing (0.5) and first grid line location (0,0,0) were given.

3. define → materials in that select add new material to add a material property of frame M20 grade of concrete and fe 250 grade of steel were used in the frame.

4.define → section properties then click on add new property by using this command column and beam property were assigned each 100*100mm with the clear cover of 20mm.

5. draw → draw frame/cable /tendon with this command beam and column were drawn.

6.define → load pattern by using this wizard dead load of the frame to be created in the program, here we can include the another load pattern lateral load in the codal provision of IS 1893-2016, with the response spectrum of 0.5 and the seismic zone of the frame.

7.assign → frame loads with this dead load of the frame to be considered in the analysing part.

8. analysis → run analysis with this result we can get all the information like deformed shape as well as the values of the shear force and bending moment diagram, deflection of the frame and the seismic weight of the frame also be calculated by using the following command.

9. In the define load pattern we can also make load combination here we can also add a mass source of the frame in the seismic weight only dead load of the structure to be considered. In the result by choosing seismic load pattern, we can get the seismic weight of the frame.

10. For defining the response function choose the define menu in the function tool and select the function to response spectrum there we need to select all the criteria like load condition and time period, seismic zone of the structure.

A Single storey RCC frame was created, and it is subjected to load to derive the behaviour of the structure on application of load.

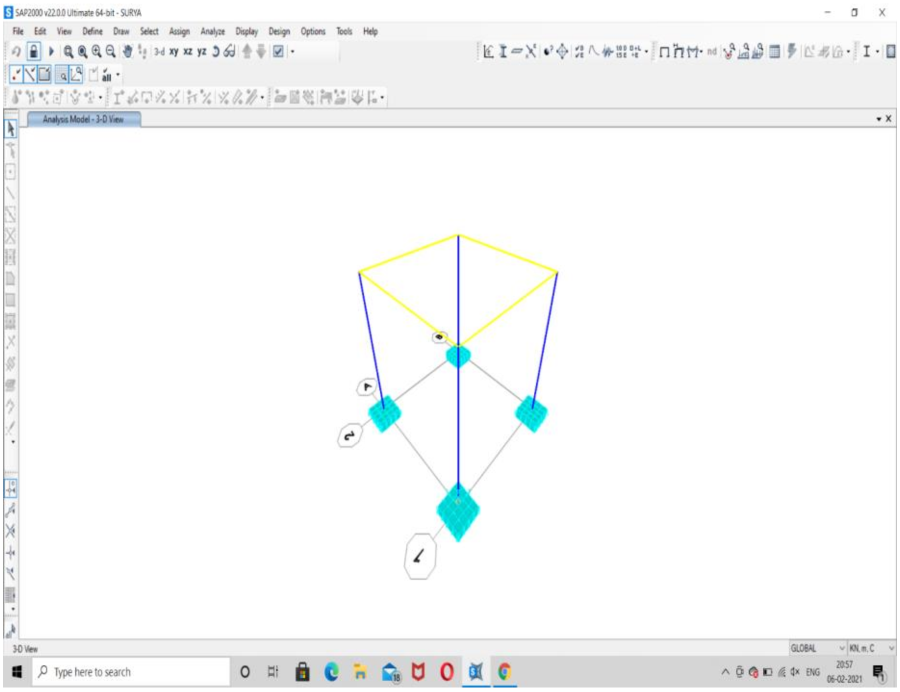


Fig -1: modelling of Single Storey 3D Frame

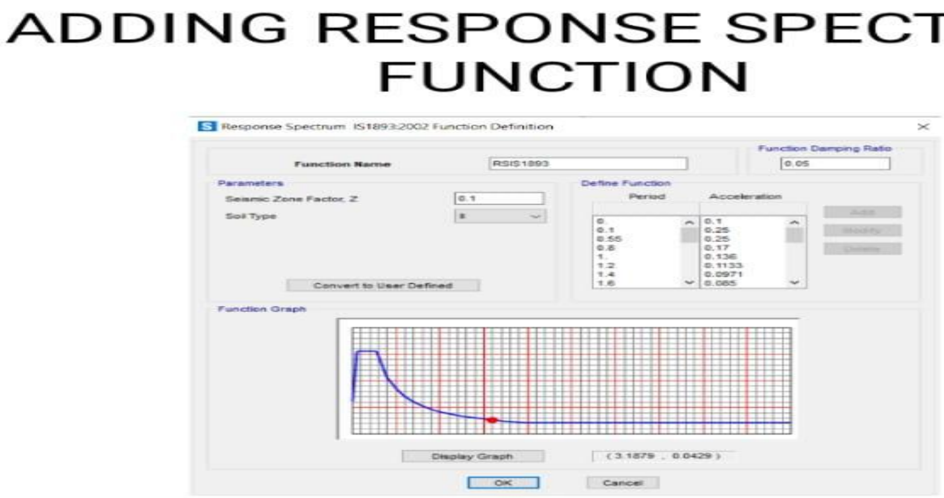


Fig -2: Response Spectrum Function

The Stress, Strain and Base Reaction values are obtained from SAP 2000. From the Analysis of Single Storey RCC Frame the Maximum shear Stress and Bending Moment values obtained was 0.0128kN and 3.432Nm .The final output indicates that structure is safe in Seismic loading and predict the maximum Deformation in the Seismic condition by using the software .

5. COMPARISION OF MANUAL AND SOFTWARE RESULTS

Difference of the manual calculation and the software output of single storey 3D RCC frame were discussed below.

Table -1: comparison between manual calculation and software result

S.NO	PARAMETER	MANUAL CALCULATION	SAP2000 OUTPUT	ACCURACY = MANUAL /SAP2000
1	Shear force	0.0125kN	0.0128kN	0.97
2	Bending moment	$3.125\ e^{-3}$kNm	$3.432e^{-3}$kNm	0.91
3	Seismic weight of the frame	0.25 kN	0.2832kN	0.88
4	Displacement {zone III}	(consider only lateral load [seismic load])	$3.1768\ e^{-7}$mm	-
5	Storey drift	$-3.1768e^{-7}$mm	$3.1768\ e^{-7}$mm	-
6	Stability index	Non-sway	Non -sway	-
7	Natural period T_a	0.446sec	0.45 sec	0.99
8	Response acceleration co-efficient (S_a/g)	2.5	2.52	0.992

6. CONCLUSIONS

From the Numerical study of the single storey 3D frame carried out, the following conclusions were attained:

- From the result it can be concluded that the Single Storey 3D RCC Frame modal is safe in Seismic condition and Shear Force, Bending Moment and base reaction are in expected range.
- The results of a study dealing with the assessment of the dynamic behaviour of Single storey RCC frame structure were presented in this paper. The effects of the variations in the software and manual calculation were investigated for seismic zone III condition.
- Basic Information are collected from literature. Modelling of single storey RCC frame using SAP2000 were carried, and the results were presented.
- Accuracy between the manual and software output for a seismic study of Single Storey 3D Rcc Frame in the averange of above 93.5%.hence, the variation between SAP2000 Software and Manual Calculation values in the acceptable range

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