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Comparative Seismic Analysis of Bare Frame and Frame with Infill Model of Existing State Library Building

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***Abstract*: The response of an existing structure when subjected to seismic excitation can be evaluated its performance and safety. There are different elastic & inelastic approaches to analyse a structure using Equivalent Static Analysis, Linear dynamic analysis, Nonlinear Static Analysis, Nonlinear dynamic analysis. In equivalent static analysis method or linear static analysis, the stiffness of the structure remains constant whereas in Nonlinear Analysis, the stiffness of the structure varies and the total force is plotted against a reference displacement to obtain a capacity curve. In nonlinear dynamic analyses, the detailed structural model subjected to a ground-motion provides estimates of t deformations at each degree of freedom in the model. A numerical simulation is carried out to evaluate the seismic performance of a 3-storey already existing state library in Andaman & Nicobar Island. As Andaman & Nicobar Island is located in soft to medium soils, response of the building is analyzed under a simulated earthquake ground motion at Andaman & Nicobar Island site is compared with that under a measured earthquake ground motion of EI-Centro.**

In this paper, a comparative study of seismic response of a library building modeled as both bare frame and frame with infill is analyzed by the linear analysis, pushover and time history analysis has been performed using SAP 2000 v18 software as per the IS- 1893-2016-Part-1.

Keywords: Equivalent Static Analysis, Linear Static Analysis (Push over Analysis), Non Linear Dynamic (Time History Analysis), Base Shear, Capacity curve.

1. INTRODUCTION

All over the world, there is a high demand for construction of tall buildings due to increasing population and urbanization. Earthquakes have the potential for causing the greatest damages to tall structures. Reinforced concrete multi-storied buildings are very complex to model as structural systems for analysis. Usually, they are modeled as two-dimensional or three-dimensional frame systems using finite beam elements. Since earthquake forces are random in nature and which cannot be predicted, the engineering tools need to be sharpened for analyzing structures under the action of these forces.(Krishna G Nair & Akshara S P,2017)

According to the Seismic Zoning Map of IS: 1893-2002, India is divided into four zones on the basis of seismic activities. They are Zone II, Zone III, Zone IV and Zone V. Andaman & Nicobar Island lies in Zone V.

Most of existing buildings do not meet the current design standards due to design shortage or construction shortcomings. There are various reasons such as the lack of a national code, the noncompliance with applicable code requirements, the updating of codes, the design practices and changes in the use of buildings. Therefore, existing buildings should be evaluated regarding their capacity for resisting expected seismic effects before rehabilitation works.(Riza Ainul Hakim , Mohammed sohaib alama and Samir Ashour ,2014)

In conventional elastic design analysis method many important aspects that affect the seismic performance of the building cannot be determined. When a building undergo inelastic deformations under seismic ground motions determines the structural behavior of building. Due to this reason the evaluation of the building is carried on the basis of inelastic deformation applied demanded by an earthquake, besides the stresses induced by the equivalent static forces as specified in seismic regulations and codes.

Nowadays to estimate seismic demands for a building pushover analysis is performed. It is a commonly used technique, which provides acceptable results.

Pushover analysis is a series of incremental static analysis carried out to develop a capacity curve for the building. This procedure needs the execution of a nonlinear static analysis of the structure that allows the monitoring of the progressive yielding of the structure component. The building is subjected to a lateral load. The load magnitude increases until the building reaches the targeted displacement. This target displacement is determined to represent the top displacement when the building is subjected to design level ground excitation. [Riza Ainul Hakim , Mohammed sohaib alama and Samir Ashour ,2014]

Pushover analysis produces a pushover curve or capacity curve that presents the relationship between the base shear (V) and roof displacement (Δ). The Pushover curve depends on the strength and deformation capacities of the structure and describes how the structure behaves beyond the elastic limit.

Nonlinear dynamic analysis is a principally convenient approach. In this structure is subjected to real time ground motion of an earthquake which determine the seismic response of a structure. 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.

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2. DESCRIPTION OF STRUCTURE

In this report a RC framed building was taken for analysis: G+2. The RC frame model is subjected to earthquake located in seismic zone V. In the above model, the support condition was assumed to be fixed and soil condition was assumed as medium soil.

2.1 MODEL OF LIBRARY BUILDING

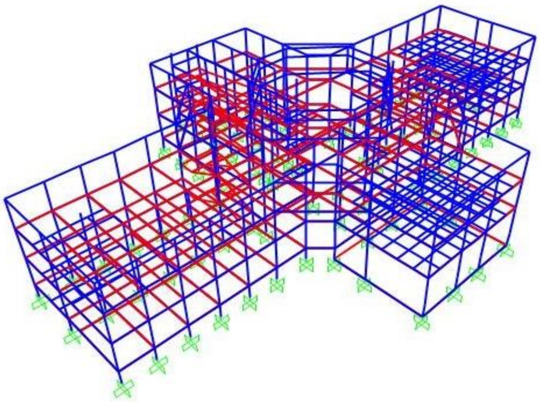

Fig. 2.1 3D model of the building

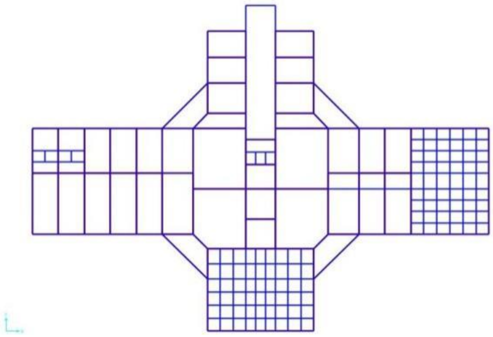

Fig. 2.2 First floor

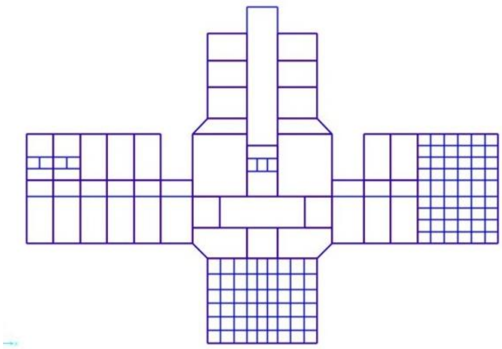

Fig. 2.3 Second floor

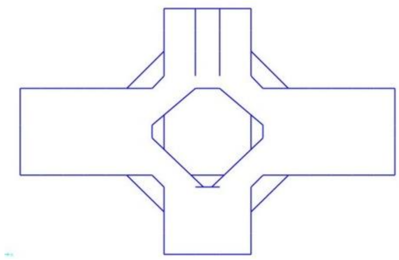

Fig. 2.4 Roof level

2.2 MODELLING AND ANALYSIS OF BUILDING

A Ground with three storied (G+3) existing reinforced concrete building located in zone V of India was taken for the investigation. This existing building is designed and constructed using IS 456-1978 only for the gravity loads i.e., without considering the previous seismic code IS1893-1984.First the equivalent static analysis of building was done under gravity loads and seismic loads. Then compare the critical forces and moments of beams and columns at face of joint. The modeling and analysis was carrying out first in SAP 2000.

Modeling consisted of following steps.

2.2.1. Structural Discretization The beams and columns layout were available. Then the structure was discretized. Discretization includes fixing of joint coordinates and member incidences.

2.2.2. Property Specification and Support Condition Properties were assigned to the members. The member properties were given. Then support conditions were given to the structure. The support condition given was fixed.

2.2.3. Loading: The self-weight of the members will be taken automatically by the software. Live loads of slabs were entered as floor loads. Live loads were considered as per IS: 875 (Part 2)-1987. The wall loads were provided to the beam based on provisions in IS: 875 (Part 1)-1987. Seismic loads were applied automatically by the software and is based on IS 1893 (Part I)-2002.

a) Live load- As per IS: 875(Part 2)-1987[11]

Table 3.1: Live Load of Different Room

Name of the area	Wt of Slab(kN/m2)
Stack room	8
Reference section	4
Magazine section	3
Toilet	2
Passage	4
Stair case	4
Ramp	4

b) Dead load- As per IS: 875(Part 1)-1987[10]

c) Load Combinations

The different Load combinations used were:

- 1.5 (DL + LL)
- 1.2 DL + 1.2 LL + 1.2 EQX
- 1.2 DL + 1.2 LL + 1.2 EQ(-X)
- 1.2 DL + 1.2L.L-1.2 EQ(-Y)
- 1.2 DL + 1.2L.L+ 1.2EQ(-Y)
- 1.5(DL+EQ-X)
- 1.5(D.L-EQ-X)
- 1.5(D.L+EQ-Y)
- 1.5(DL-EQ-Y)

3. METHODOLOGY

3.1 Linear Static Method

The static method is the simplest one among all the other analysis procedures. It requires less computational efforts and is based on formulas given in the code of practice [Krishna G Nair & Akshara S P,2017].

The equivalent static analysis procedure involves the following steps:

1. Calculation of the Design Seismic Base Shear, VB

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2. Vertical distribution of base shear along the height of the structure
3. Horizontal distribution of the forces across the width and breadth of the structure
4. Determination of the drift and overturning moment

3.1.1Calculation of the Design Seismic Base Shear, VB

The total design lateral force or design seismic base shear, V_b as per Clause 7.5.3, IS 1893(Part 1)-2002, along any principal direction shall be determined by:

$$V_b = W \times A_h$$

Where, W is the seismic weight of the building, Ah is the horizontal seismic coefficient.

3.1.2Horizontal Seismic Coefficient, Ah

The horizontal seismic coefficient, Ah depends on several factors and can be written in different manner according to the seismic codes. In all cases the controlling parameters are the same. As per Clause 6.4.2, IS 1893(Part 1)-2002,

$$A = \frac{ZIS_a}{2Rg}$$

Provided that for any structure with T < 0.1 s, the value of Ah will not be taken less than Z/2 whatever be the value of I/R where, Z - Zone factor

I - Importance factor
Sa/g=Average response acceleration coefficient
T - Undammed Natural period of the structure
R - Response Reduction factor

3.1.7Vertical Distribution of Base Shear to Different Floors

After the total base shear is known, it is used to determine the forces on the various building elements. The sum of the loads at each level equals the total base shear. Since the greatest force is at the top, the shear increases from zero at the top to its maximum at the base of the building. Each floor shear is successively added to the sum from above. As per IS 1893(Part 1)-2002, Clause 7.7.1, the lateral force induced at any level hi can be determined from the following equation:

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{n} W_i h_i^2}$$

Where,
Q_i - Design lateral force at floor i
W_i- Seismic weight of floor i
n - Number of storey's in the building is the number of levels at which the masses are located
h_i - Height of floor i measured from base

3.1.8 Overturning Moment There is a tendency for the moment created by the

$$M_u > M$$

Where,
M_u is maximum bending moment capacity
M is over turning moment

Equivalent lateral force acting above the base to overturn the structure. This overturning force must be counteracted by stabilizing load. Usually, the dead weight of the building also acting through the center of mass of the structure is sufficient to resist the overturning force, but it must always be checked.

3.1.9 Calculation of the Design Seismic Base Shear for library building

Table 3.2: Seismic Base Shear

H (Height of the building)	Ta (Time Period)	W (Seismic Weight)	Z (Zone Factor)	I (Importance Factor)
9.7	0.41	21852.70	0.36	1.5

R (Response Reduction factor)	Sa/g (Structural Response Factors)	Ah (Design Horizontal Seismic Coefficient)	VB (Design Base Shear) (KN)
5	2.5	0.135	2950.11

3.2 Non-Liner 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 which is an iterative procedure is looked upon as an alternative for the conventional analysis procedures. Pushover analysis of buildings subjected to increasing lateral forces is carried out until the preset performance level (target displacement) is reached. The promise of performance-based seismic engineering (PBSE) is to produce structures with predictable seismic performance. The recent advent of performance based design has brought the non-linear static push over analysis procedure to the forefront. Pushover analysis is a static non-linear procedure in which the magnitude of the structural loading along the lateral direction of the structure is incrementally increased in accordance with a certain pre-defined pattern. It is generally assumed that the behavior of the structure is controlled by its fundamental mode and the predefined pattern is expressed either in terms of story shear or in terms of fundamental mode shape. With the increase in magnitude of lateral loading, the progressive non-linear behavior of various structural elements is captured, and weak links and failure modes of the structure are identified. In addition, pushover analysis is also used to ascertain the capability of a structure to withstand a certain level of input motion defined in terms of a response spectrum. Pushover analysis is of two types:

(i) Force Controlled
(ii) Displacement Controlled.

In the force control, the total lateral force is applied to the structure in small increments. In the displacement control, the displacement of the top storey of the structure is incremented step by step, such that the required horizontal force pushes the structure laterally. The distance through which the structure is pushed, is proportional to the fundamental horizontal translational mode of the structure. In both types of pushover analysis, for each increment of the load or displacement, the stiffness matrix of the structure may have to be changed, once the structure passes from the elastic state to the inelastic state. The displacement controlled pushover analysis is generally preferred over the force controlled one because the analysis could be carried

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out up to the desired level of the displacement [Riza Ainul Hakim , Mohammed sohaib alama and Samir Ashour ,2014].

3.2.1 Pushover Analysis Results of Bare Frame of Library Building

3.2.1.1ATC-40 Capacity Spectrums

The objective of performing the pushover analysis is to determine the performance level of the building which will define the state of damage of the structure under seismic loads. The ATC-40 code has defined several performance levels according to the damage occurred and the stiffness of the structure. The fig 3.1 shows the performance point of the building which is the intersection point of the two curves i.e., the capacity curve and the demand curve. For getting the intersection point i.e., the performance point, both these curves are converted into a single format which is known as the ADRS (Acceleration Displacement Response Spectrum) format.

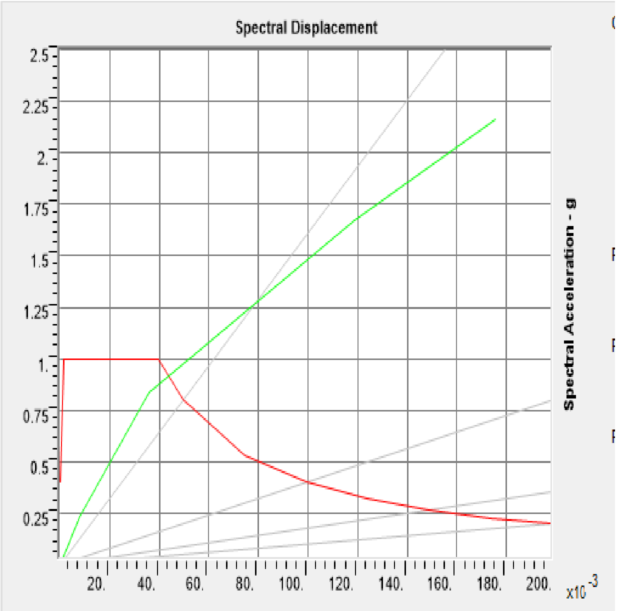

Fig. 3.1: ATC-40 Capacity Spectrum of Bare Frame Model.

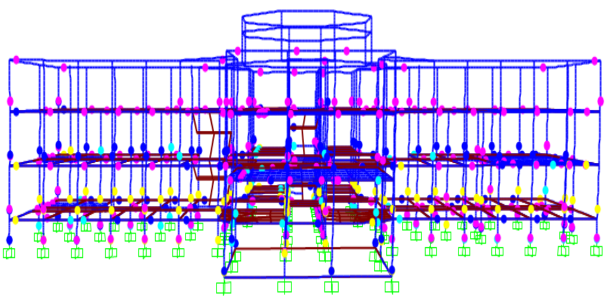

Fig. 3.2: Hinge Formation of Bare Frame Model.

3.2.2 Pushover Analysis of the Structure with Infill

3.2.2.1 Modelling of Infill

Masonry infill used to fill the voids between the vertical and horizontal load resisting elements of the building, are considered as non-structural elements and hence its significance in the analysis of frame is generally neglected. But, an infill wall enhances considerably the strength and rigidity of the structure. Non- availability of realistic and simple analytical models of infill is a hurdle for its consideration in analysis. Presence of masonry infill causes:

a) Unequal distribution of lateral forces.

b) Vertical irregularities in strength and stiffness and

c) Horizontal irregularities – torsion.

Equivalent diagonal strut is one of the simple and best ways to consider the effect of infill. When a frame sways as shown in figure portion of the wall along one diagonal remains in contact and there is a loss of contact between the frame and the wall along the other diagonal. Thus the wall becomes ineffective in tension and hence modeled as an equivalent diagonal strut carrying only compression. The elastic in-plane stiffness of a solid unreinforced masonry infill panel prior to cracking shall be represented with an equivalent diagonal compression strut of width, a, given by Equation.

$$W = \frac{1}{2}\sqrt{\alpha_h^2 + \alpha_l^2}$$

Where α_h and α_l

$$\alpha_h = \frac{\pi}{2}\left[\frac{E_f I_c h}{2E_m t \sin 2\theta}\right]^{\frac{1}{4}}$$

$$\alpha_h = \frac{\pi}{2}\left[\frac{E_f I_c h}{2E_m t \sin 2\theta}\right]^{\frac{1}{4}}$$

$$\theta = \tan^{-1}\frac{h}{l}$$

W = width of the strut

E_f = Elastic modulus of the frame materials

E_m = Elastic modulus of masonry wall

t = thickness of the wall

h = Height of the infill wall

l = length of the infill wall

l_b = Moment of inertia of the columns

l_c = Moment of inertia of the beams

The required dimensions of the bracings are determined using the previously mentioned procedure in section 2.2.2.1 and the infill walls are modeled in SAP2000 in the form of bracings.

3.2.2.2 ATC-40 Capacity Spectrums

The fig 3.2 shows the performance point of the building which is the intersection point of the two curves i.e., the capacity spectrum and the demand spectrum. After adding the infill, the stiffness has increased and the load carrying capacity of the building is increased. This plot shows the actual behavior of the structure under seismic loads.

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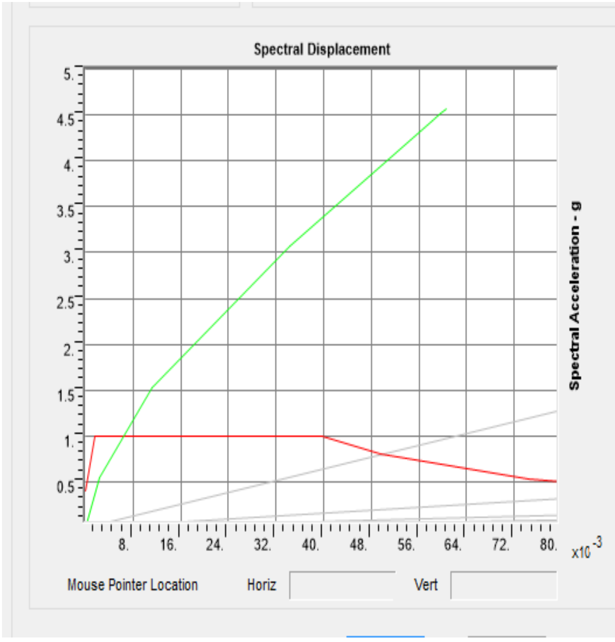


Fig 3.3 ATC-40 Capacity Spectrum of Structure with Infill.

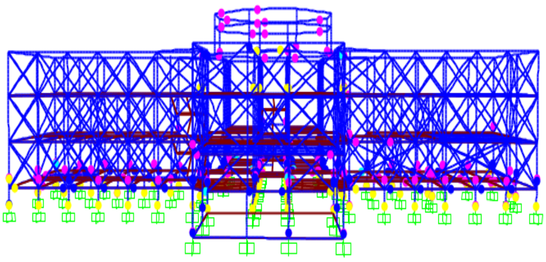


Fig 3.4 Hinge Formation of Structure with Infill

3.3. Nonlinear Dynamic Analysis

Nonlinear dynamic analysis is also referred as Time history analysis. It is an important method for structural seismic analysis especially when the evaluated structural response is nonlinear. To perform this analysis, a representative earthquake time history data is required for a structure being evaluated. Time history analysis is a step-by step analysis procedure of the dynamic response of a structure for a specified loading that may vary with time. Time history analysis is used to determine the seismic response of a structure under dynamic loading for a representative earthquake. Although the spectrum method, outlined in the previous section, is useful technique for the elastic analysis of structures, it is not directly transferable to inelastic analysis because the principle of superposition is no longer applicable. Also, the analysis is subject to uncertainties inherent in the modal superimposition method. The actual process of combining the different modal contributions is a probabilistic technique and, in certain cases, it may lead to results not entirely representative of the actual behavior of the structure. The THA technique represents the most accurate method for the dynamic analysis for buildings. In this method, the mathematical model of the building is subjected to accelerations from earthquake records that represent the expected earthquake that may occur at the base of the structure. The method consists of a step- by- step direct integration over a time interval; the equations of motion are solved with the accelerations, velocities and displacements of the previous step serving as initial functions. The equation of motion can be represented as

$$\boldsymbol{kx(t) + c\dot{x}\,(t) + m\ddot{x}(t) = p(t)}$$

Where, k is the stiffness matrix, c is the damping matrix, and m is the diagonal mass matrix.

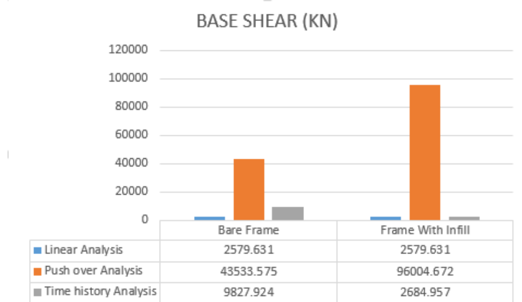
In case of an earthquake, p(t) includes ground acceleration and the displacements, velocities and accelerations are determined relative to ground motion. The time-history method can be applied to both elastic and inelastic analysis. In elastic analysis the stiffness characteristics of the structure are 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 [Krishna G Nair & Akshara S P,2017].

4. RESULTS

The results of various simulations done are presented below:

4.1 Comparison of Base shear of Bare Frame and Frame with Infill

It was seen that the Frame with Infill performed better than the Bare Frame under Seismic Excitation.



4.2 Time History Analysis Graphs

The response of the Modelled State Library Building excited with Elcentro Vibration were observed. As time history is a realistic method used for seismic analysis ,it provides the better check on safety of the structures analysed and designed using IS Codes.

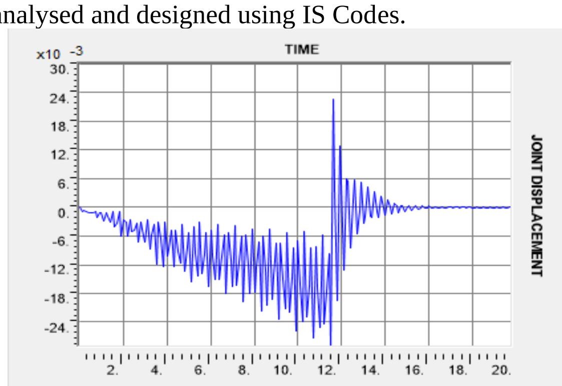


Fig 3.5 Time vs Joint Displacement Plot of Bare Frame Structure

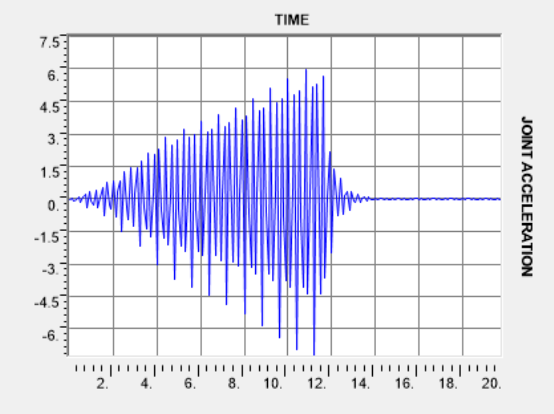


Fig 3.6 Time vs Joint Acceleration Plot of Structure with Infill

5. CONCLUSION

The base shear obtained from the Pushover analysis is maximum among Equivalent static and Time history analysis.

By comparing the base shear obtained from three analysis for both bare frame model and frame with infill model it is concluded that frame with infill model possess high base shear than the bare frame model.

In linear analysis, the structure will undergo elastic deformation where all the fibers does not undergo complete deformation whereas in pushover analysis collapse mechanism makes all the fiber to yield causing plastic hinges to be formed with unlimited deformation due to rotation of the member.

The hinge formation in the bare frame model is more as compare to the frame with infill.

In time history analysis, the structure is analyzed for real time peak ground acceleration(EL-CENTRO), the structure was safe under the seismic motion as it is designed for its ductile behavior considering zone V as per IS 1893:2002.

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