ANALYSIS FOR NODAL RESPONSE OF MULTISTORIED BUILDING USING SYNCHRONOUS NOISE

A DISSERTATION
Submitted in partial fulfillment of the requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
EARTHQUAKE ENGINEERING
(With Specialization in Structural Dynamics)

By
SANJIV LAHUJI BHAWARE

DEPARTMENT OF EARTHQUAKE ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE-247 667 (INDIA)
JUNE, 2004

CANDIDATE'S DECLARATION

I hereby certify that the work presented in this dissertation entitled **"ANALYSIS FOR NODAL RESPONSE OF MULTISTORIED BUILDING USING SYNCHRONOUS NOISE"** is accepted in the present form by the *Department of Earthquake Engineering, Indian Institute of Technology Roorkee, Roorkee,* in partial fulfillment of the requirements for the award of the degree of **Master of Technology** in **Earthquake Engineering** with specialization in **Structural Dynamics**.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Date: June 30, 2004

Place: Roorkee

(Sanjiv Lahuji Bhaware)

CERTIFICATE

This is to certify that the above statement made by the candidate is true to the best of my knowledge.

Ashok Kumar
Associate Professor
Earthquake Engineering Department
Indian Institute of Technology Roorkee, Roorkee

Date: June 30, 2004
Place: Roorkee

AKNOWLEDGEMENT

It is my proud privilege to acknowledge with deep sense of gratitude and sincere thanks to **Dr. Ashok Kumar**, *Associate Professor, Earthquake Engineering Department, Indian Institute of Technology Roorkee, Roorkee*, for his invaluable guidance, persistent encouragement and kind help at all stages to complete this dissertation work.

I am thankful to my friends and all who have directly and indirectly helped me in completion of this work, without whose assistance it was impossible to complete this dissertation work.

Last but not the least; I would to express my love and gratitude to my family who was consistently a source of encouragement and strength to me.

Date: June 30, 2004

Place: Roorkee

(Sanjiv Lahuji Bhaware)

ABSTRACT

A Synchronous noise is a broad – band time series, which looks like random noise but has an absolutely flat power spectrum. It is a much stronger version of the white noise as it has exactly equal magnitude at all the calculated frequencies of its Desecrate Fourier Transformation (DFT). A synchronous noise is effectively used in this work to study the single input and single output nodal response of a structure in detail for different excitation without analyzing the whole structure for each excitation.

Synchronous noise, of same duration and sampling period as that of earthquake, is first generated. This is to excite the fixed node of the model of structure. The structure is then analyzed and response of the required node for synchronous noise input is determined. Fourier transformation of this nodal response is really the transfer function of the node with respect to the ground motion. Frequency domain convolution between this transfer function and the DFT of any other earthquake excitation of any fixed node gives DFT of the nodal response for earthquake excitation. Inverse DFT of this sequence thus yields the time history response of the node. Thus, for studying the response of a node for different earthquakes, one has to only analyze the structure once with synchronous noise input.

In this dissertation work a plane frame, and then space frame (multistoried building) is studied for earthquake excitation. All this cases, first, time history response of a node is determined analytically using commercially available software for synchronous noise input as well as for a given earthquake excitation. Nodal response of the synchronous noise input is then used to fine the nodal response for the earthquake using the proposed transfer function approach. Earthquake responses determine through analysis and through transfer function is then compared. It shows exactly matches the responses for each case of excitation.

CONTENTS

LIST OF SYMBOLS

k	Stiffness of system in N/m
ζ	Damping ratio
$F(\omega)$	Fourier transform of excitation function
$V(\omega)$	Fourier transform of response
$\Delta\omega$	Frequency
η	Frequency ratio
b	Imaginary part of Fourier transform of excitation
d	Imaginary part of Fourier transform of response
$f(t)$	Input excitation function
a	Real part of Fourier transform of excitation
c	Real part of Fourier transform of response
$v(t)$	Response of the system
t	Time interval
Δt	Time interval at discrete points
T	Time period
N	Total number of samples
$H(\omega)$	Transfer function of the system
M	Mass of SDOF system in Kg
n	Samples
SPS	Samples per second

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 GENERAL

In the recent many earthquakes are visited, in this context the study particularly in structural dynamics becomes vital. However the multistoried buildings are the most common structure whose safety and stability is important during earthquake, in view of human life and costs. Therefore the analysis of multistoried building under earthquake is obvious.

The analysis to evaluate the structural response of such structures to any type of dynamic loading has been performed by several methods in time domain using large matrices. Also different approaches namely response spectra method and time history method are available to evaluate the response of the multi degree of freedom system. Time history analysis in time domain is most commonly used approach for finding response of structures and has resulted into development of several commercial software which includes a great variety of strategies for linear and non-linear analyses.

Frequency domain analysis of structures has nowadays become another popular method for linear analysis of single degree of freedom as well as multi degree of freedom systems. Biggest advantage of using frequency domain approach over time domain is the simplicity through which convolution for determining system response is obtained. Such methods, also provides insight to the effect on various frequency components of system response i.e. transfer function of system. With the advent of modern and fast computers and ease of availability of Discrete Fourier Transform (DFT) subroutines, frequency domain approach is becoming very useful for analysis of structures.

1.2 OBJECTIVES OF THE STUDY

A broad-band time series, which looks like random noise but has an absolutely flat power spectrum, is called synchronous noise. It is a much stronger version of the white noise as it has exactly equal magnitude at all the calculated frequencies of its Desecrate Fourier Transformation (DFT).

In this work, first of all a comparative study of time domain and frequency domain approach for finding response of a single degree of freedom (SDOF) system is done using first half sine pulse excitation and then earthquake excitation. Response of SDOF system is found using following methods:

1. Newmark's linear acceleration method in time domain with excitation of half sine pulse as well as synthetic accelerogram.
2. Convolution in frequency domain of Fourier transform of synthetic accelerogram excitation with analytically determined transfer function of SDOF system.
3. Time history analysis using commercial software for synthetic accelerogram excitation.
4. Convolution in frequency domain of Fourier transform of synthetic accelerogram excitation with transfer function of SDOF system determined using synchronous noise input. Transfer function was determined by finding Fourier transform of its response for synchronous noise input using commercial software.

Next, an attempt is made to compare response of a single bay single storey frame using time history analysis and frequency domain analysis for earthquake excitation. Time domain response of frame was determined using commercial software whereas in frequency domain single input single output (SISO) transfer function was determined using synchronous noise input. Subsequently, response of some specified nodes of model of ten storied passport building of Ahmedabad was determined using transfer function found through synchronous noise and the same is compared with response found through time history analysis of commercial software.

1.3 USE OF SYNCHRONOUS NOISE TO FIND RESPONSE

In the present work it has been shown that using frequency domain approach, synchronous noise (Kumar (2000)) can be efficiently used to find nodal response of a structure for different excitation without analyzing the whole structure for each excitation. This problem of analyzing the nodes for different excitation can often arise if some locations in structure are required to be studied in detail – For example these locations are subjected to concentration of stresses.

Synchronous noise, of same duration and sampling period as that of earthquake, is first generated. This is used to excite the fixed node of the model of structure. The structure is then analyzed and response of the required node for synchronous noise input is determined. Fourier transformation of this nodal response divided by Fourier Transform of synchronous noise is really the transfer function of the node with respect to the ground motion. Frequency domain convolution between this transfer function and the DFT of any other earthquake excitation of fixed node gives DFT of the nodal response for earthquake excitation. Inverse DFT of this sequence thus yields the time history response of the node. Thus, for studying the response of a node for different earthquakes, one has to only analyze the structure once with synchronous noise input.

CHAPTER 2

LITERATURE REVIEW

The behavior of structure under seismic excitation has been thoroughly studied in past. The analysis is performed in time domain and frequency domain.

Kawamoto (1983) presented the hybrid time-frequency method, where the original system is replaced by a pseudo-linear system. Equation of motion is being solved in the frequency domain and non-linear contribution being dealt with in the time domain through the pseudo-force method.

Aprile (1994) modified the Kawamoto procedure and making it generalized to possible to consider the hysteretic and frequency dependent damping. Iton used the frequency domain procedure to obtain response of system with non-proportional damping using a complex based modal basis to uncouple the equation of motion. In 1987, Chen and Taylor used the uncoupling the dynamic equations for systems with non-proportional damping, through basis composed by Ritz vectors instead of the complex modal basis. Chang and Mohraz (1990) applied the mode superposition method to deal with physically non-linear structural system with non-proportional damping where they established an iterative procedure through Taylor series expansion.

Claret and Venancio-Filho (1991) considered non-proportional damping via the force pseudo-force concept; this pseudo-force method leads to an iterative process, which was solved in the time domain via Duhamal integral in which convergence of the iterative process was quite good. In addition to this Jangid and Datta (1993) performed the iterative process in frequency domain. The solution of either linear or non-linear single degree of freedom system (SDOF) is obtained by the matrix formulation in frequency domain presented by Venancio-Filho and Claret (1992), using implicit Fourier transform (ImFT). In this formulation the DFTs (Discrete Fourier Transforms) are implicitly executed in the same procedure that leads to the response in time domain. This is concept of IFT (Implicit Fourier Transform).

Further in 1995, Venancio-Filho and Claret presented a technical note on general formulation for the frequency domain dynamic analysis of multi degree of freedom systems (MDOF) in nodal and modal coordinates. They considered the most general damping including non-proportional and hysteretic damping. In the modal coordinate formulation an efficient pseudo-force concept is used to obtain the complex frequency response function.

Clough and Penzine (1993), provided a thorough treatment of frequency domain methods for SDOF and MDOF systems. Lunden and Dahlberg (1982), has done Frequency-dependent damping in structural vibration analysis by the use of complex series expansion of transfer functions and numerical Fourier transformation. Kumar and Xia (1993), performed dynamic response analysis in the frequency domain and Hall and Beck (1993) presented work on linear system response by DFT: analysis of a recent modified method. They all covered other pertinent aspects of frequency domain methods in dynamic analysis.

In the year 2000, the team of Mansur and Carrer, Ferreira, A.M. Claret and Fenancio-Filho developed a generalized new frequency-domain method to analyze the linear or non-linear structural system having non-proportional damping in single and multi degree of freedom systems subjected to time dependent excitation. They employ the time-segmented procedure in the modal co-ordinate in the frequency domain and solution is being obtained by an iterative process. In the procedure for linear MDOF systems the mode superposition method was employed. The final system is uncoupled and the same frequency domain algorithm as used for the SDOF could be employed. (When the system is non-linear and non-proportional damping, the system of equations in modal co-ordinate is not uncoupled anymore. In this case, terms responsible for coupling are transferred to R.H.S. for the equations, which being considered as pseudo-forces. An iterative procedure arises in which the L.H.S. of the final system of equations is uncoupled, and thus the modal matrix needs to be computed only once.). They noticed that when computer time is concerned, time domain approaches are cheaper. However, they opined that two approaches can not be competed rather they are complementary to each other. Time domain procedures do not apply when damping properties have to be defined in the frequency- domain where hysteretic damping is considered.

And in the recent (2002), Venancio-Filho and Claret the same authors presented the study of convergence of the response obtained through the frequency domain by developing matrix formulations for the dynamic analysis of SDOF systems. The analysis is performed using the concept of implicit Fourier transform (ImFT) or complex-frequency response matrix. According to this concept the direct and inverse discrete FT's are implicitly performed by a compact and elegant matrix expression.

Kumar et. al (2000) introduced the use of synchronous noise in the field of earthquake engineering. They explained in detail the method to generate synchronous noise and used the same for comparison of frequency response of different schemes of processing of strong motion data. They opined that synchronous noise could become an important tool in finding the transfer function of systems, which are analyzed for finding their earthquake response.

CHAPTER 3

ANALYSIS OF SINGLE DEGREE OF FREEDOM SYSTEM

The analysis to find out the response of structures to any type of dynamic loading can be performed in time domain or in frequency domain.

3.1 TIME DOMAIN METHOD

Closed form analytical solution in time domain for finding response of linear or nonlinear systems for random excitations like earthquakes, is usually not possible. Therefore the numerical methods are developed to solve such problems. Numerical time stepping method is one such commonly used method.

There are three types of numerical time stepping methods (Chopra 2001), first method is based on Interpolation of excitation function over each time interval. It is useful where excitation is defined at closely spaced time intervals so linear interpolation is quite valid. Second method is based on finite difference approximation of the time derivatives displacement i.e. velocity and accelerations. And third method is based on assumed variation of acceleration. Using variation of acceleration, in 1959, N.M. Newmark developed a time stepping method, so called Newmark's Method where the derived parameters β and α defines the variation of acceleration over a each time step. There are two special cases of Newmark's Method, average acceleration method and linear acceleration method. In this work, linear acceleration method is used.

3.2 FREQUENCY DOMAIN METHOD

Frequency domain approaches, which are based on Fourier transform are equivalent to time domain procedures in a great deal of applications and more adequate in many others, and hence has nowadays become another popular method for linear analysis of single degree of freedom as well as multi degree of freedom systems. In this work, transfer function in frequency domain is obtained analytically for SDF system which is then convoluted with Fourier transform of excitation to get the Fourier transform of the response – which on inverse Fourier transform yields response in time domain.

3.2.1 ANALYTICAL TRANSFER FUNCTIONS

This is method is valid for linear SDOF systems and following are steps of this method.

1. First find the Fourier transform $F(\omega)$ of the input excitation function $f(t)$ and then find the transfer function of the system $H(\omega)$. For SDOF system, transfer function can be found out using equation of motion in frequency domain.
2. Product of these two functions at each bin frequency interval in frequency domain will yield Fourier transform of response.

   $V(\omega) = F(\omega)H(\omega)$

3. Then Inverse Fourier transforms of the product, is the response of the system, $v(t)$.

Mathematically

$$F(\omega) = \int_{-\infty}^{\infty} f(t) e^{-i\omega t} dt \tag{3.1}$$

$$H(\omega) = \int_{-\infty}^{\infty} h(t) e^{-i\omega t} dt \tag{3.2}$$

Which, is equal to complex frequency response function of SDOF system,

$$H(\omega) = \frac{1}{k\left(1 - \eta^2 + 2i\zeta\eta\right)} \tag{3.3}$$

The response of the system i.e. inverse transfer function of the product, $V(\omega)$ is

$$v(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(\omega)H(\omega)e^{i\omega t}\,d\omega \tag{3.4}$$

3.2.2 DISCRETE FOURIER TRANSFORM

Evaluation of the Fourier transform is tedious as it involves complex integral; hence numerical evaluation of the transforms is particularly possible.

Also the Fourier transforms of the unit impulse response function are only available in discrete form at regular interval of time. Therefore, develops a Fourier, discrete Fourier transform to relate continuous and discrete transforms.

Let, excitation function $f(t)$ is time function at N equal interval.

n = 0, 1, 2, 3 ...N-1. And time interval, t = 0, Δt, $2\Delta t$,............ (N-1) Δt.

With time period, $T = N.\Delta t$ and frequency, $\Delta\omega = \frac{2\pi}{T}$

Now, periodic extension of function at $T = N.\Delta t$

$$f(k.\Delta t) = \frac{1}{2\pi}\sum_{n=0}^{N-1} F(n.\Delta\omega).e^{2\pi ikn/N}.\Delta\omega \tag{3.5}$$

Hence, discrete Fourier transform of the $f(t)$ is,

$$F(n.\Delta\omega) = \sum_{k=0}^{N-1} f(k.\Delta t).e^{-2\pi ikn/N}.\Delta t \tag{3.6}$$

3.2.3 TRANSFER FUNCTION USING SYNCHRONOUS NOISE INPUT

Transfer function in frequency domain of any system is defined as Fourier transformation of response divided by Fourier transformation of excitation. Let *F(ω)* be the Fourier transform of excitation f(t) at ant discrete frequency ω and let

$$F(\omega) = a + ib \tag{3.7}$$

where a is the real part of *F(ω)* and b is the imaginary part of *F(ω)*

Let *V(ω)* be the Fourier transform of response of system *v(t)* at any discrete frequency ω and let

$$V(\omega) = c + id \tag{3.8}$$

where c is the real part and d is the imaginary part of *V(ω)*.

Then, transfer function of the system *H(ω)* at any discrete frequency ω is given by

$$H(\omega) = \frac{V(\omega)}{F(\omega)} = \frac{c + id}{a + ib} \tag{3.9}$$

$$H(\omega) = \frac{(c + id)(a - ib)}{a^2 + b^2} \tag{3.10}$$

$$H(\omega) = \frac{ac + bd}{a^2 + b^2} + i\frac{ad - bc}{a^2 + \_b^2} \tag{3.11}$$

Theoretically, giving any random excitation to the system and finding its response can be used to find out transfer function of any system. However, problem with using any random excitation is that the denominator of Eq. 3.11for some discrete frequencies may become nearly zero causing problem of division by zero. Here, the use of synchronous noise as input excitation becomes very handy due to the fact that in synchronous noise the term a^2+b^2 will always be unity at all discrete frequencies and thus an accurate transfer function can be found out at all the frequencies.

3.3 EXAMPLES

Single degree of freedom system is analysed in time domain using linear acceleration method and in frequency domain using transfer functions method. First the system is excited by sinusoidal half sine pulse and then by synthetic time history.

3.3.1 HALF SINE PULSE EXCITATION

In this example, response of a SDOF system is being analyzed in time domain (linear acceleration method) and in frequency domain (analytical transfer function method) for half sine pulse excitation as well as for earthquake type excitation. In all the examples used in this chapter, the SDOF system taken has a mass of 100 Kg, stiffness of 3947.6089 Newton per meter (Natural Frequency 1 Hz) and a damping ratio of 5%. Mass of this system is first subjected to a forcing function of half sine pulse having amplitude of 100 Newton and duration of 0.6 seconds as shown in Figure 1.

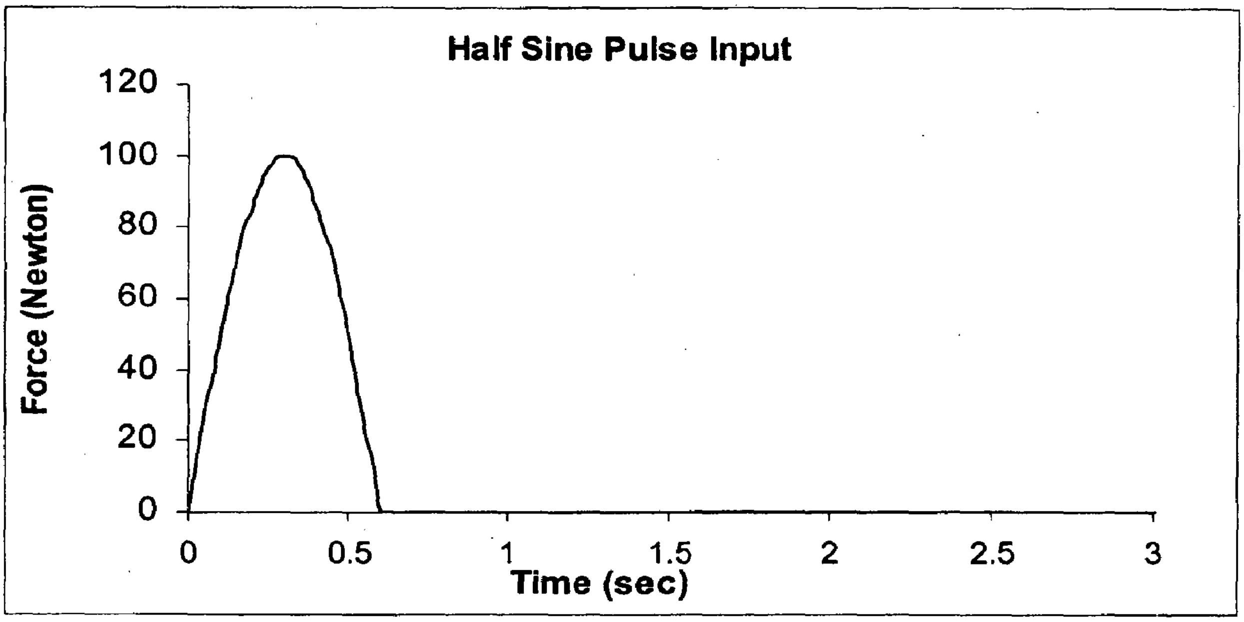

Fig. 1 Half Sine Pulse Excitation

This excitation is equally sampled at 100 SPS and 1024 sample points are used for calculation of the response.

This example is first solved analytically in time domain using linear acceleration method. The same example is then solved in frequency domain method using analytical transfer function approach.

The comparison for displacement response of the mass for above two approaches is shown in Figure 2.

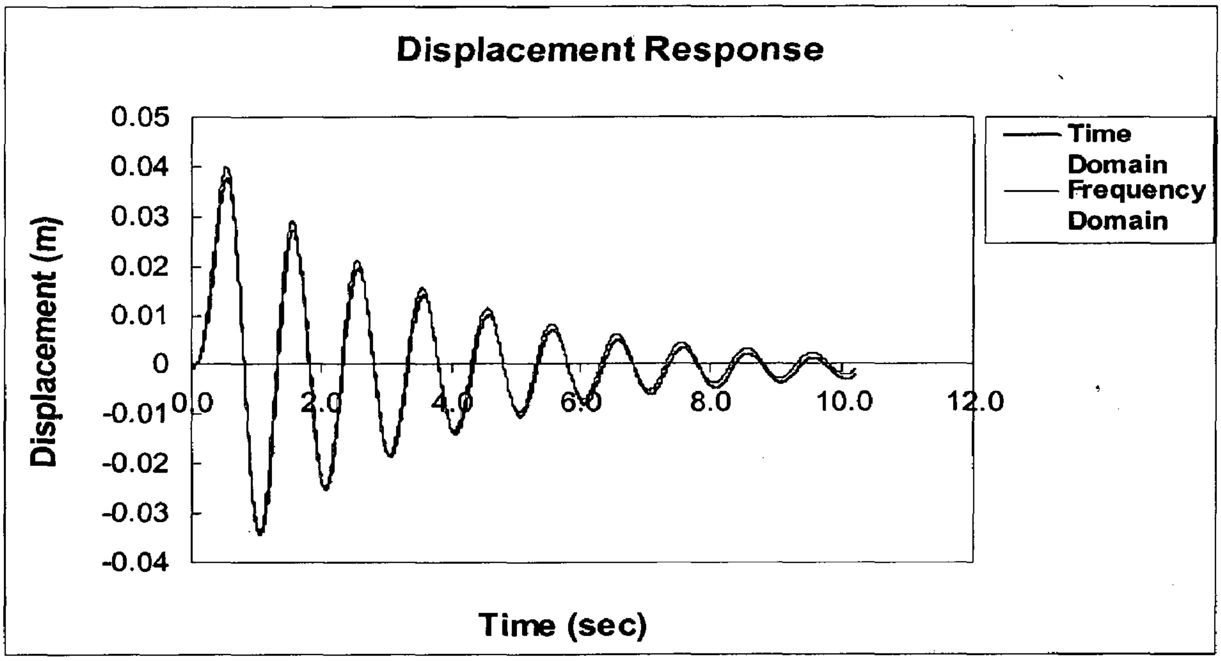

Fig. 2 Comparison of Time and Frequency Domain Approach for Displacement Response of SDOF System for Pulse Excitation

3.3.2 EARTHQUAKE EXCITATION

Base of the SDOF system used in the previous example (M=100Kg, K=3947.6089 N/m and damping ratio =0.05) was then subjected to a spectrum compatible synthetic time history of 40.96 second duration derived for Bhuj earthquake at Anjar (Kumar 2000). Time history used as excitation is shown in Fig. 3, which has a sampling rate of 100 SPS.

Displacement response of the mass was calculated using linear acceleration time stepping method in time domain and then the same was found in frequency domain using analytical transfer function. Comparison of the response found by these methods is shown in Fig. 4.

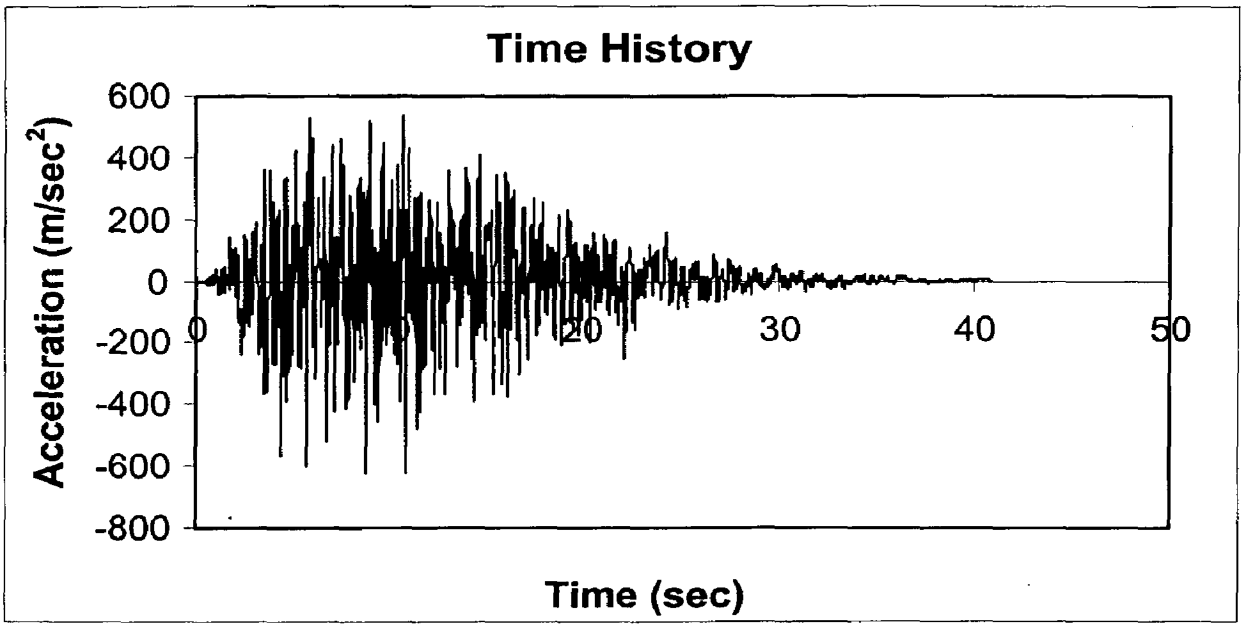

Fig. 3 Synthetic Time History Used for Analysis

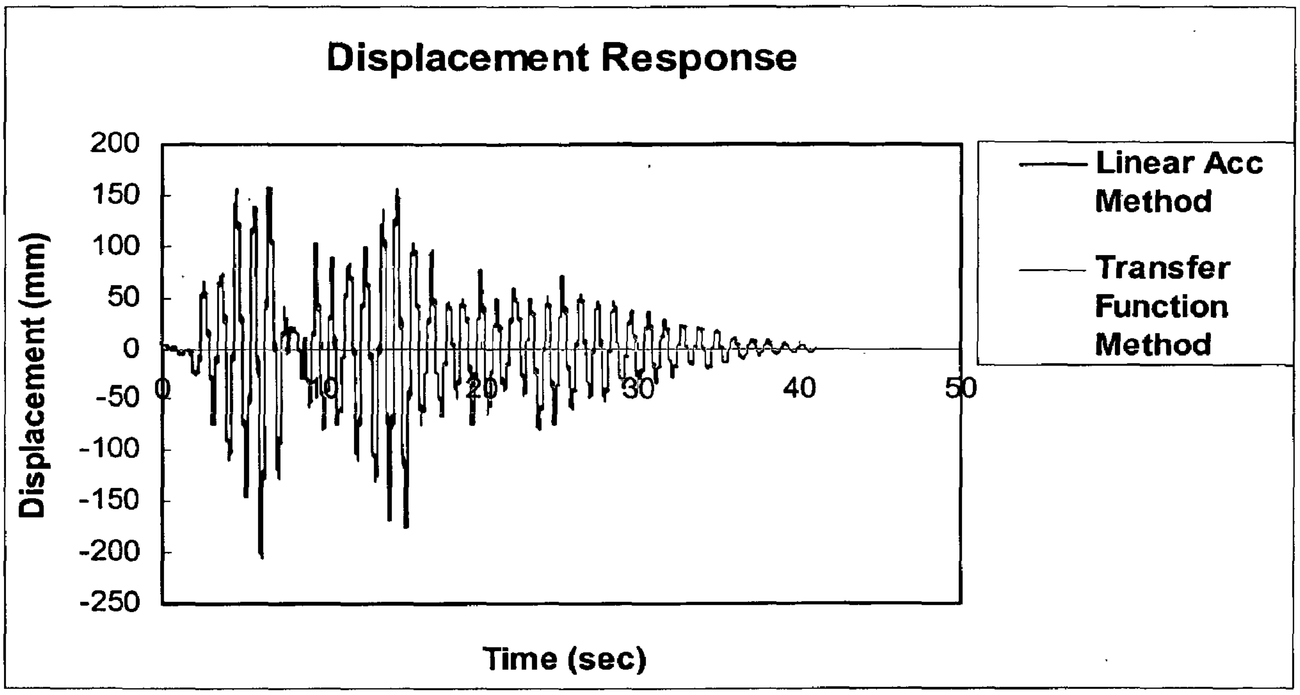

Fig. 4 Comparison of Response of SDOF system Determined Through Linear Acceleration Method and through Analytical Transfer Function Method

3.4 SAP 2000 RESPONSE AND RESPONSE USING SYNCHRONOUS NOISE

Response of the same single degree of freedom system as used in previous examples (natural frequency 1 Hz and damping 5% of critical) was then found for synthetic accelerogram of Fig. 3 using SAP2000 software.

Subsequently, response of above system was determined for excitation input of synchronous noise of same duration and sampling rate as that of synthetic accelerogram (40.96 sec and 200 SPS) using SAP 2000 software. Transfer function in frequency domain of the SDOF system was then determined using Eq. 3.11. This transfer function was then convoluted in frequency domain with Fourier transformation of synthetic accelerogram of Fig. 3 and then inverse Fourier transformation done to get the time domain response of SDOF system. Figure 5 gives comparison of response of SDOF system for synthetic accelerogram found directly by SAP 2000 and that found indirectly using synchronous noise.

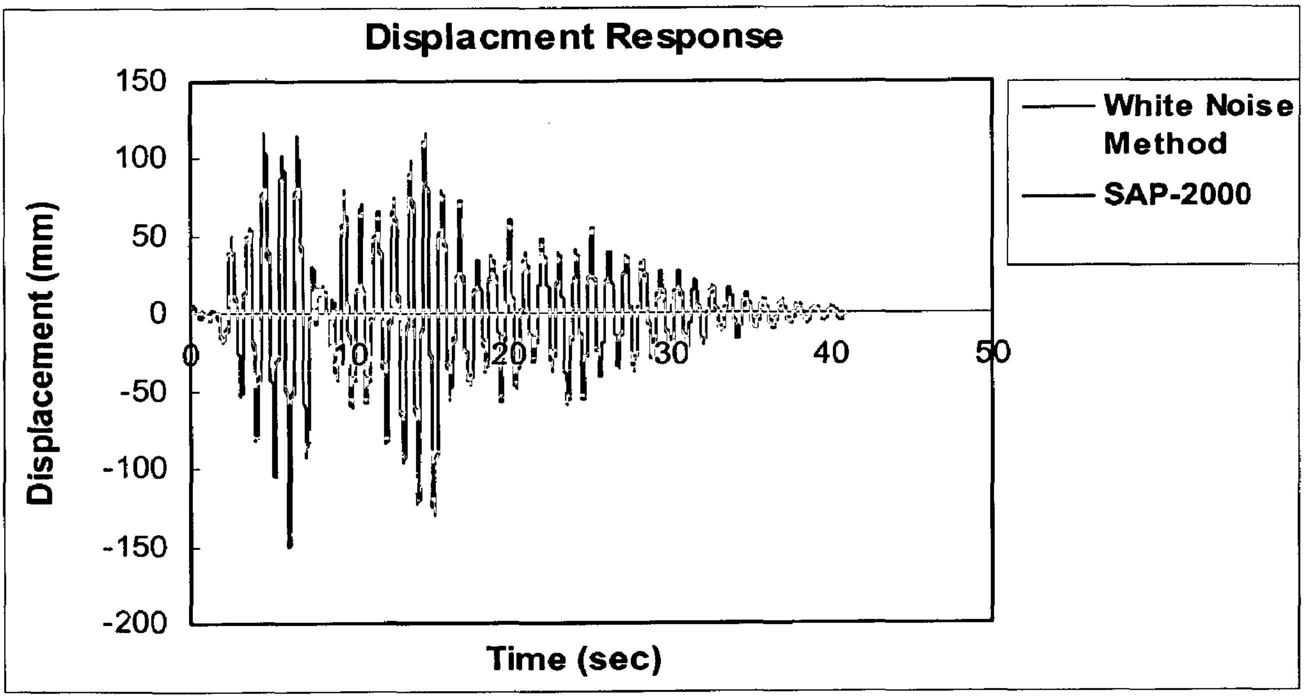

Fig. 5 Comparison of Response Found Directly Through SAP 2000 and Indirectly Using Synchronous Noise

3.5 CONCLUSIONS

1. Response of SDOF system for half sine pulse excitation as well as earthquake type excitation found by Newmark's linear acceleration method and response of the same system for the same excitations using analytically determined transfer function have been found to be almost same.
2. Response of SDOF system for synthetic accelerogram excitation was found by SAP 2000 software. It was also found by transfer function approach – transfer function being found with synchronous input. Response of the system for two approaches was found to be exactly same for SDOF system.
3. It may be mentioned that transfer function found with synchronous noise input has not used any analytical equation of the system and has merely been found by dividing the response by excitation in frequency domain. It implies that for SISO case transfer functions determined in this manner using synchronous noise input should be valid for multi degree of freedom systems also. With this conclusion attempts were made to study response of plane frame and then a multistoried building using transfer function determined through synchronous noise. These have been reported in subsequent chapters.

ANALYSIS OF PLANE FRAME

4.1 PLANE FRAMES

Use of SISO transfer function approach with synchronous noise input for multidegree of freedom system is being studied first on plane frames. Two plane frames were used for this study namely single bay single storey and single bay two storied frames. Response of these frames was determined using transfer function approach with two earthquake excitations (Synthetic Accelerogram and recorded accelerogram at Gopeshwar during Chamoli earthquake). Response of the system was also determined for above excitations directly by using STADD PRO-2003 Software and comparison for response found by two methods were done.

STADD PRO-2003 Software provides ASCII file at designated node only at 720 SPS. Therefore, for all our subsequent studies, synchronous noises as well as excitations of synthetic accelerogram and recorded accelerogram were converted into 720 SPS sequences. To get this, standard signal processing procedures for band limited interpolation and decimation was performed. First band limited interpolation was done for the given sequence to get the sampling rate of 3600 SPS and then decimation was performed to get 720 SPS.

4.1.1 SINGLE BAY-SINGLE STORIED FRAME

The single bay single storied frame as shown in fig.6 was analysed. Details of frame are given below:

Dimensions: Columns size 170.7 mm x 170.7 mm, Height of column = 4.572 m

Beam is to be assumed as infinitely rigid in its own plane.

Materials property: Modulus of Elasticity of Concrete, E = 2.068e+5 MPa

Density of concrete = 24 kN/m^3

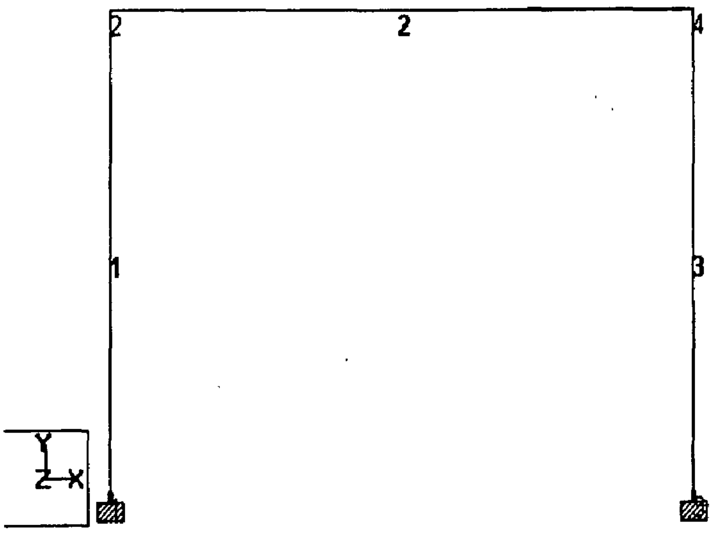

Fig. 6 Plane Frame Model - Single bay Single Storey

Fundamental frequency of the frame was found to be 2.259 Hz in X-direction and a damping of 5 % was used. Response of node no.2 of the frame in X-direction was first determined directly using STADD PRO-2003 Software for earthquake excitations. Then response of this node was determined using STADD Pro-2003 Software for synchronous noise input. Transfer function between node no.2 and ground was then found by dividing the Fourier transform of response by Fourier transform of synchronous noise. Transfer function was then convoluted with Fourier transform of earthquake excitations to get the Fourier transform of response which on inverse Fourier transform yielded the time history of response of node no.2

Response of node no.2 was then determined directly using STADD PRO-2003 Software and was then compared with response found by transfer function approach. For synthetic history excitations comparison of results is given in Fig. 7, while for Gopeshwar time history, comparison of two approaches is given in Fig.8

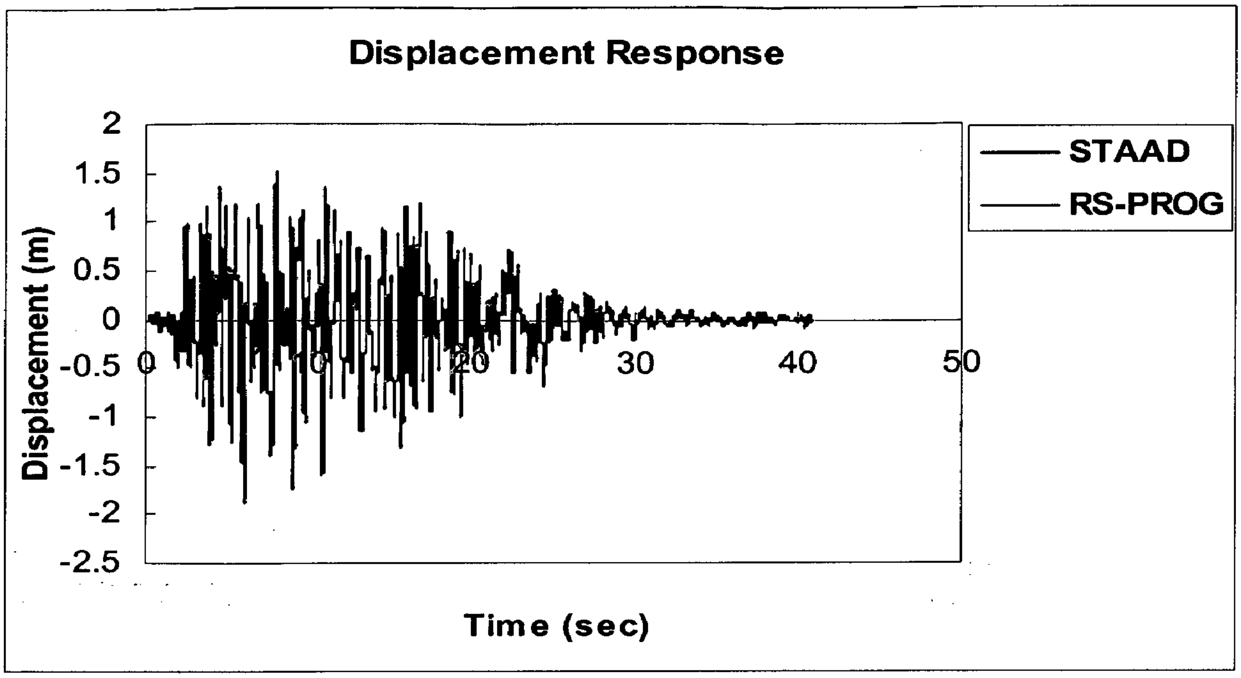

Fig. 7 Response to Synthetic Time History for Single bay Single Storey Plane Frame

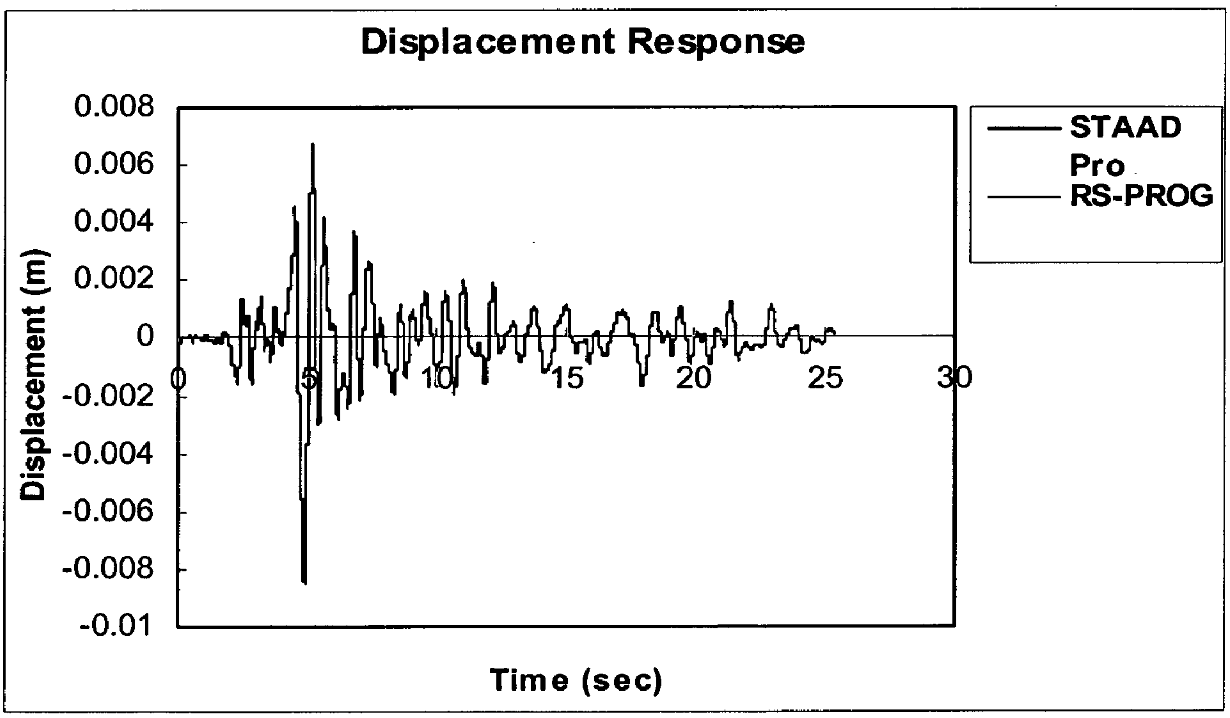

Fig. 8 Response to Time History recorded at Gopeshwar for Single bay Single Storey Plane Frame

4.1.2 SINGLE BAY-TWO STORIED FRAME

The single bay two storied frame as shown in fig.9 is then studied. Details of the frame are given below.

Dimensions: Columns size 170.7 mm x 170.7 mm, Height of columns = 4.572 m

Beams are to be assumed as infinitely rigid in theirs own plane.

Materials property: Modulus of Elasticity of Concrete, E = 2.068e+5 MPa

Density of concrete = 24 kN/m^3

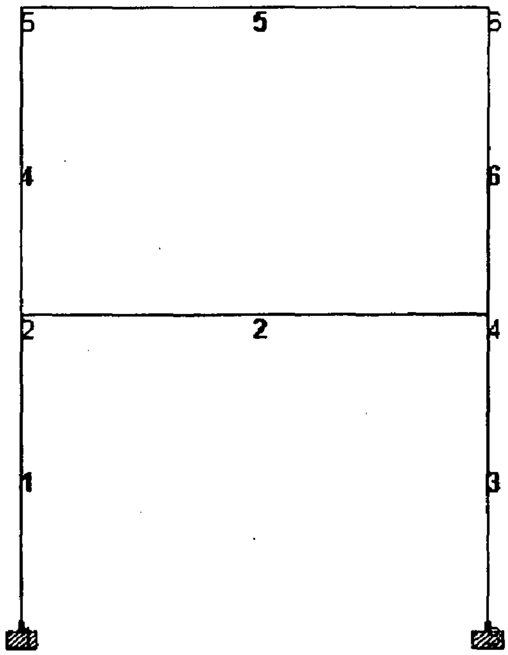

Fig. 9 Model of Two Bay-Two Storey Plane Frame

Response of the system for node no. 2 and node no.5 was studied for recorded time history at Gopeshwar. Transfer function between node no.2 versus ground and node no.5 versus ground were found in the same manner as described for earlier case. Response of node no.2 and node no.5 determined using two approaches were compared and shown in fig.10 and fig.11 respectively.

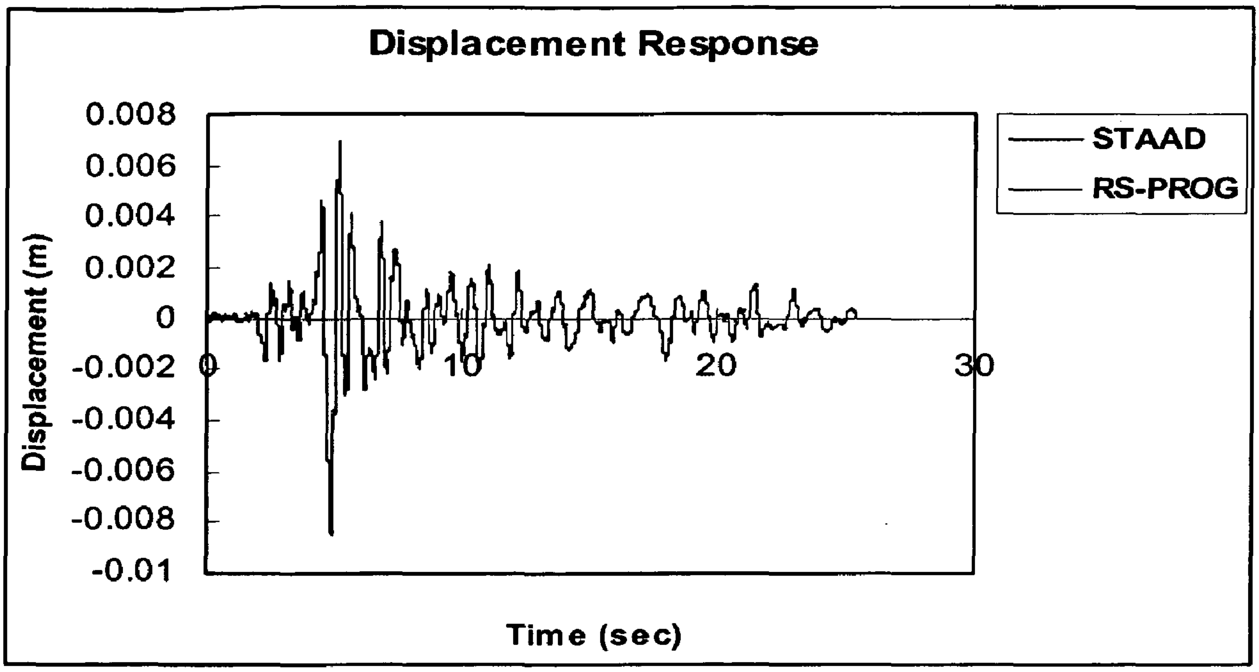

Fig.10 Response to Time History recorded at Gopeshwar Plane Frame 2Bay-2Storey Plane Frame at Node 2

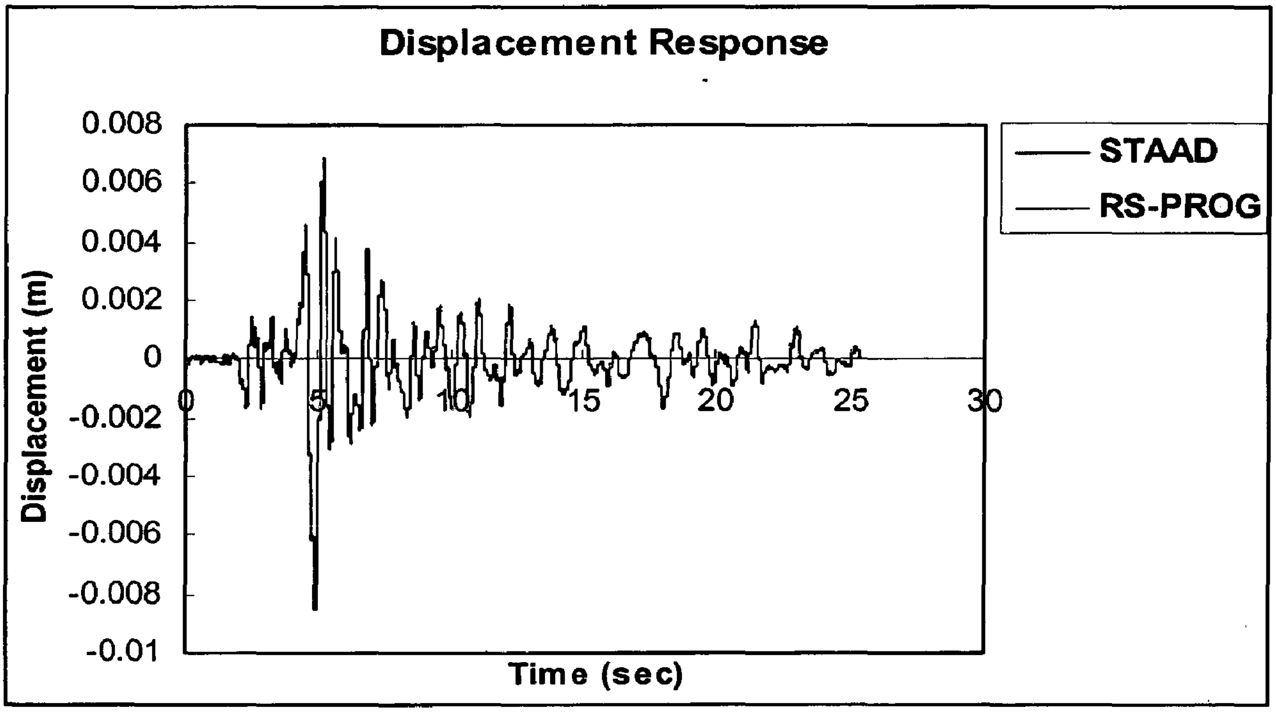

Fig.11 Response to Time History recorded at Gopeshwar Plane Frame 2Bay-2Storey Plane Frame at Node 5

ANALYSIS OF MULTISTORIED BUILDING

Finally a ten storey Passport Office Building located at Ahmedabad is taken for analysis. The analysis has been performed using software STAAD PRO-2003.Dispacement in X – direction for a node at 3rd Floor, 7th Floor, 9th Floor and 10th Floor were studied using two approaches. Fixed nodes at the base of structure were excited by synthetic ground history and then by time history recorded at Gopeshwar.

5.1 MODELING OF BUILDING

A 3-D space frame model of the building using available structural drawings was made (Kumar et. al 2003). Plan, elevation and isometric view of the model are shown in Figs 12 to 14 respectively. The space frame model comprised of 799 nodes out of which 67 nodes were fixed nodes at the base, 1572 beam elements and 219 plane stress slab elements.

The beam and column members are modeled as beam element. Material and section properties assigned to the members. The modeling of slab has special attention. It has to behave as rigid floor in its own plane hence it is modeled as rigid floor diaphragm. Thus floors have six degree of freedoms that is three translations, which are orthogonal to each other and three rotations about vertical axis.

For the analysis, the followings values of material properties of concrete has been taken

Young's modulus = $2.0\text{x } 10^{10}$ N/m^2

Poisson's ratio = 0.15 and

Density = 2.4×10^5 kN/m^3

5.1.1 Assumptions made in Modeling

The following assumptions are made in the mathematical model

1. The beams and column are idealized as 3-D beam element with six degrees of freedom at each node.
2. The stiffness of infill walls is ignored and only its mass is appropriately lumped at the relevant nodes.
3. The sectional properties of beams and columns are computed on the basis of gross cross-sectional area.
4. The reinforced concrete floor and roof slab is modeled as a 4 noded plane stress element of constant thickness.
5. The landing slab of staircase is modeled as a 4 noded plane stress element with its thickness equal to thickness of landing. The inclined stair slab and steps are modeled as truss elements.
6. The dead load of machine room at the roof of the building is lumped at appropriate nodes.
7. The dead load of water tank on the roof is lumped at appropriate nodes.
8. The live load on various floors and roof is considered to be 25% of design live load.
9. The base columns are assumed to be fixed at top of foundation raft.
10. Three components of the processed time history recorded at ground floor of the main shock of Bhuj Earthquake is simultaneously applied at all the base nodes.
11. The dynamic analysis is made on the assumption of elastic behaviour of the building.

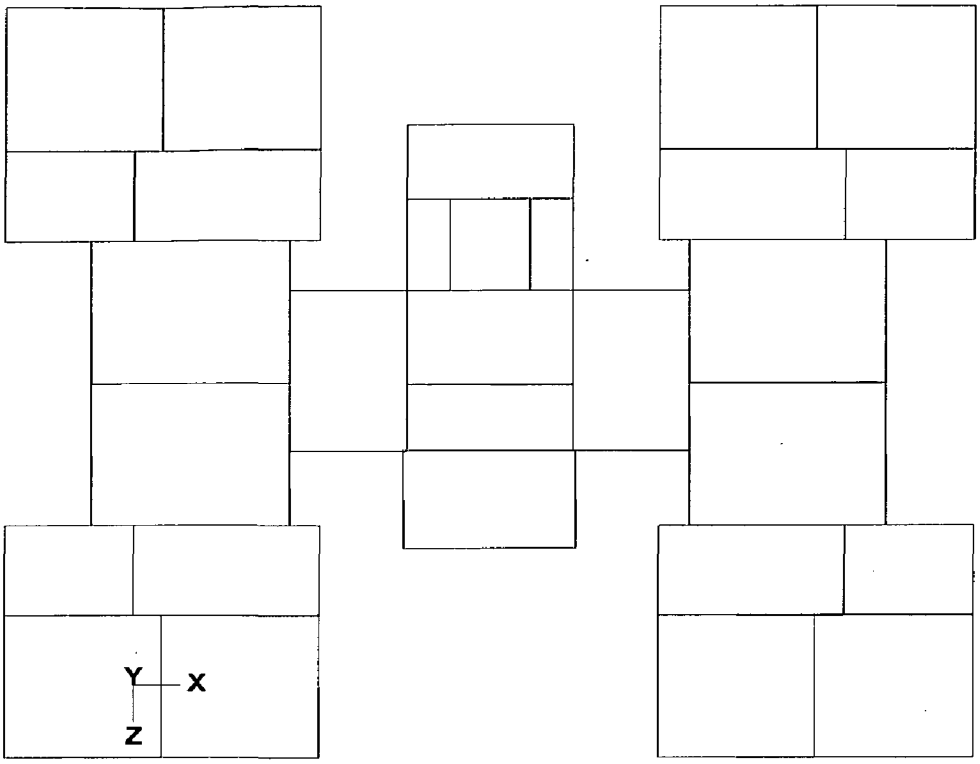

Fig. 12 Plan of 3-D Model of Regional Passport Office Staff Quarters Buildings

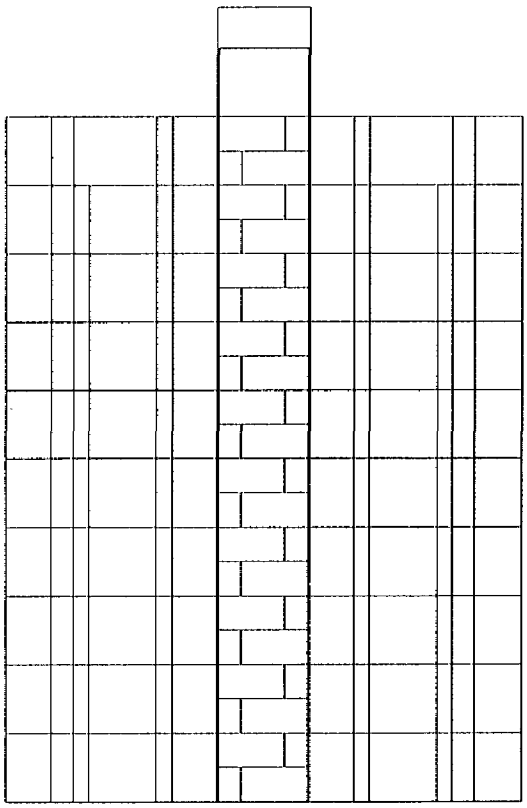

Fig. 13 Elevation of Model of Passport Building

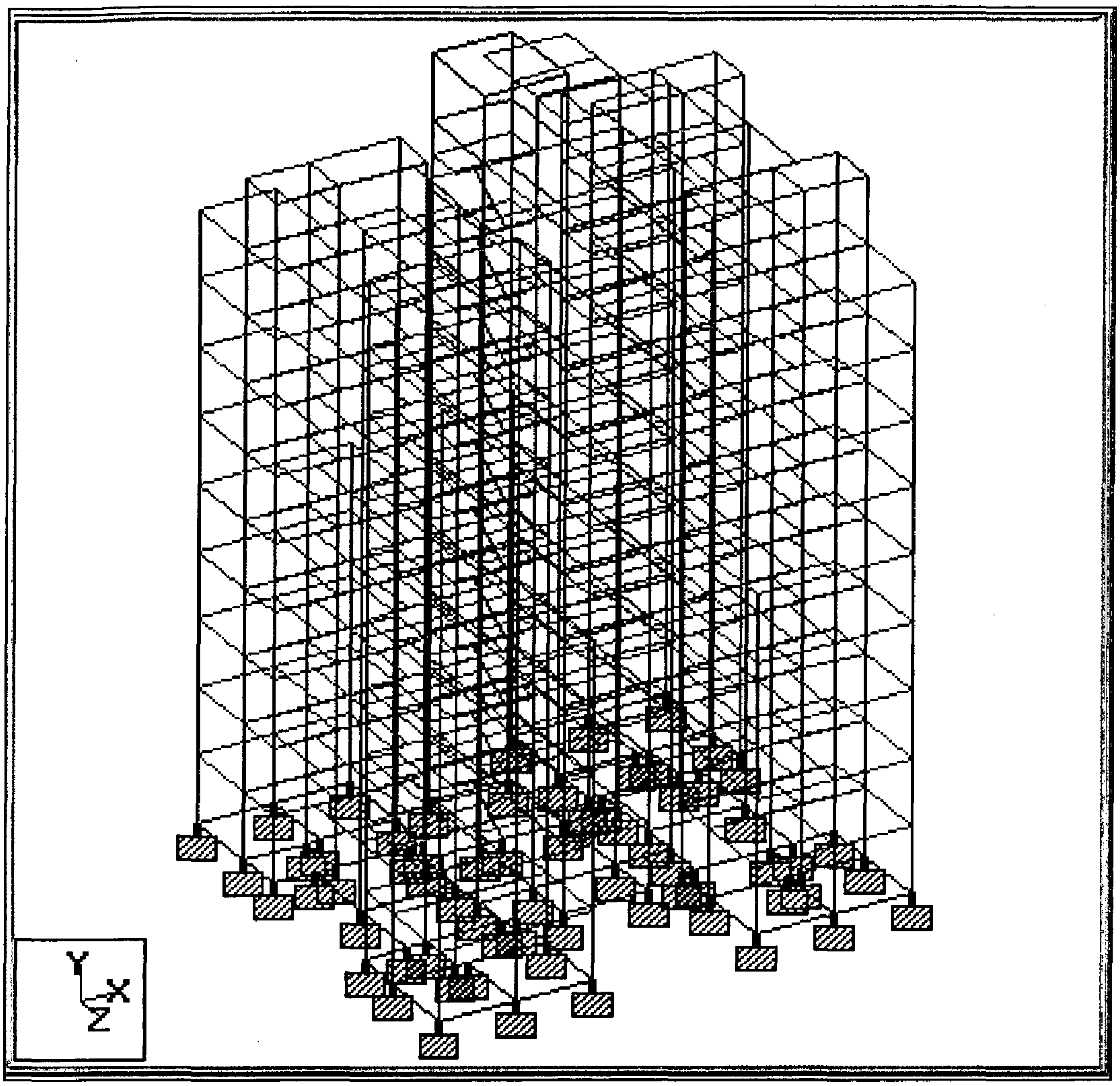

Fig. 14 Isometric View of Model of Multistoried Buildings

5.2 ANALYSIS FOR RESPONSE

Response of the building for various nodes at the different floors was studied for synthetic time history and recorded time history at Gopeshwar. The nodes taken for study are node nos. 119, 383, 507 and 569 at third, seventh, ninth and tenth (top) floors respectively.

Response was determined using STAAD PRO software first directly for time history excitation and then for synchronous noise input. Transfer functions between nodes versus ground were found using response to synchronous noise in the same manner as described for earlier cases. The plots for the response of these nodes determined using both approaches were compared and shown in fig.15 to fig. 18 for synthetic history excitation.

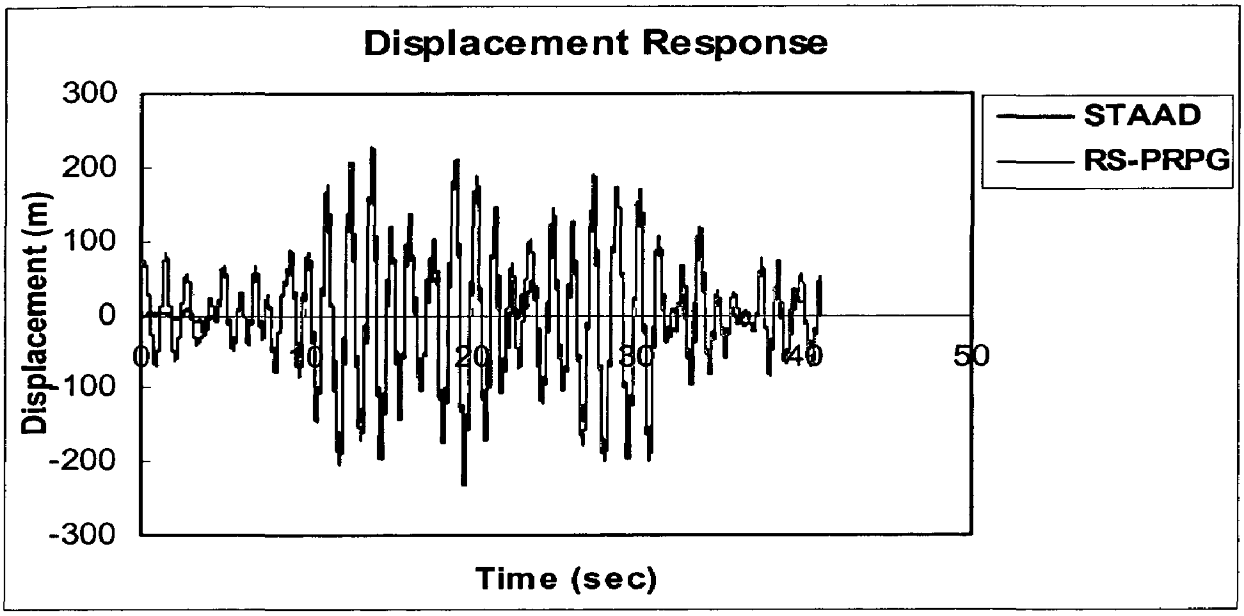

Fig.15 Responses for Node-569 to Synthetic Timer History

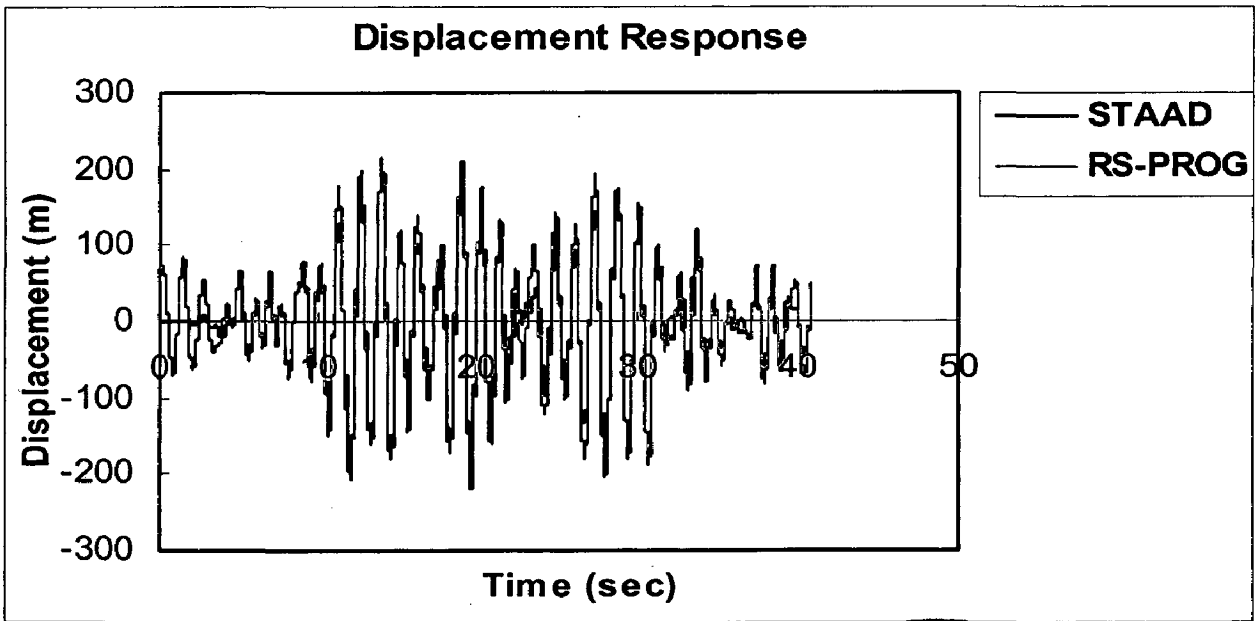

Fig.16 Responses for Node-507 to Synthetic Timer History

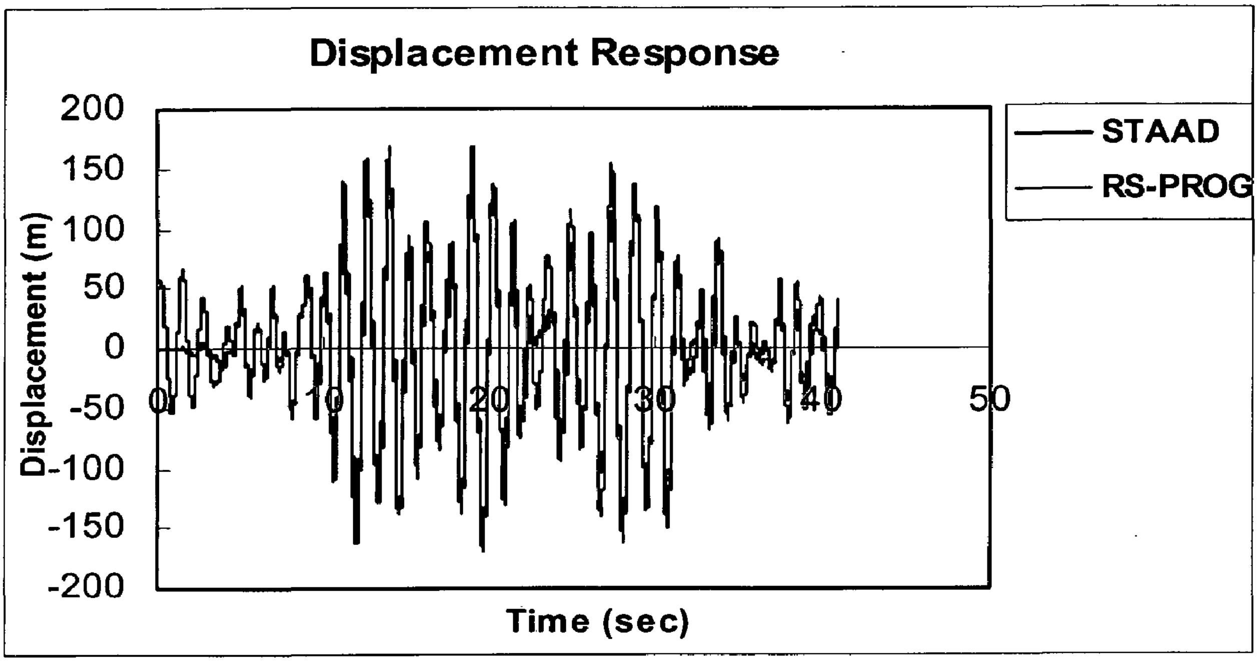

Fig.17 Responses of Node-383 to Synthetic Timer History

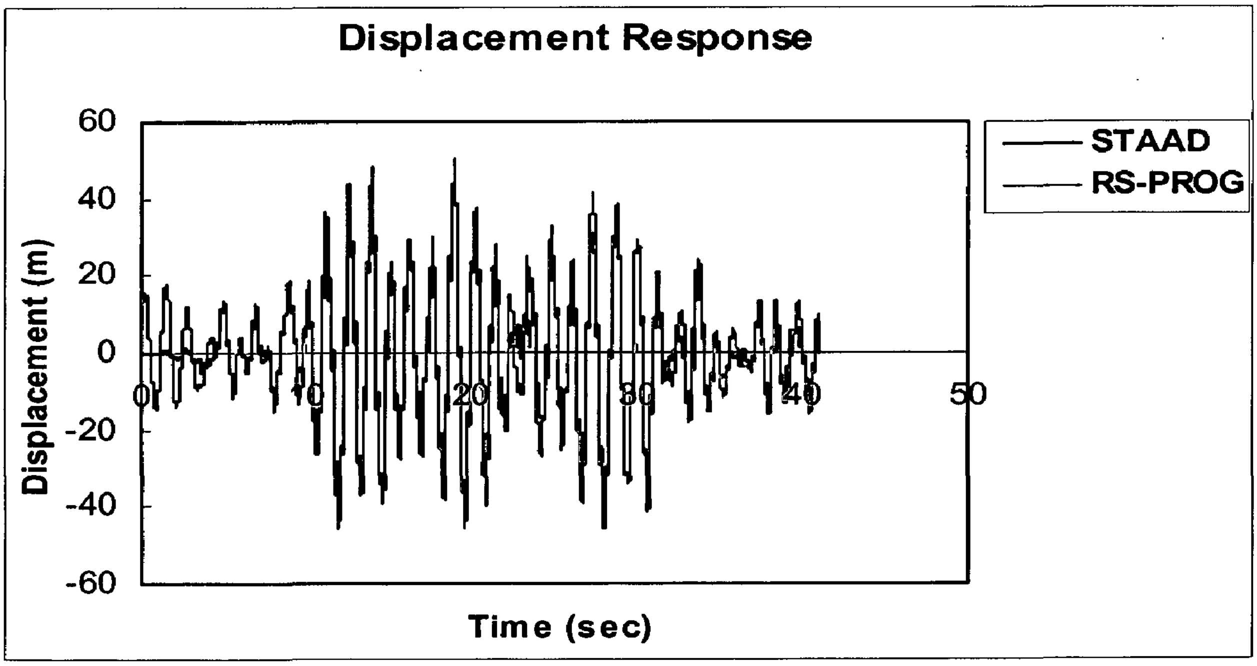

Fig.18 Response of Node-119 to Synthetic Timer History

The plots for the response to Gopeshwar time history are shown in Figs. 19 to fig. 22.

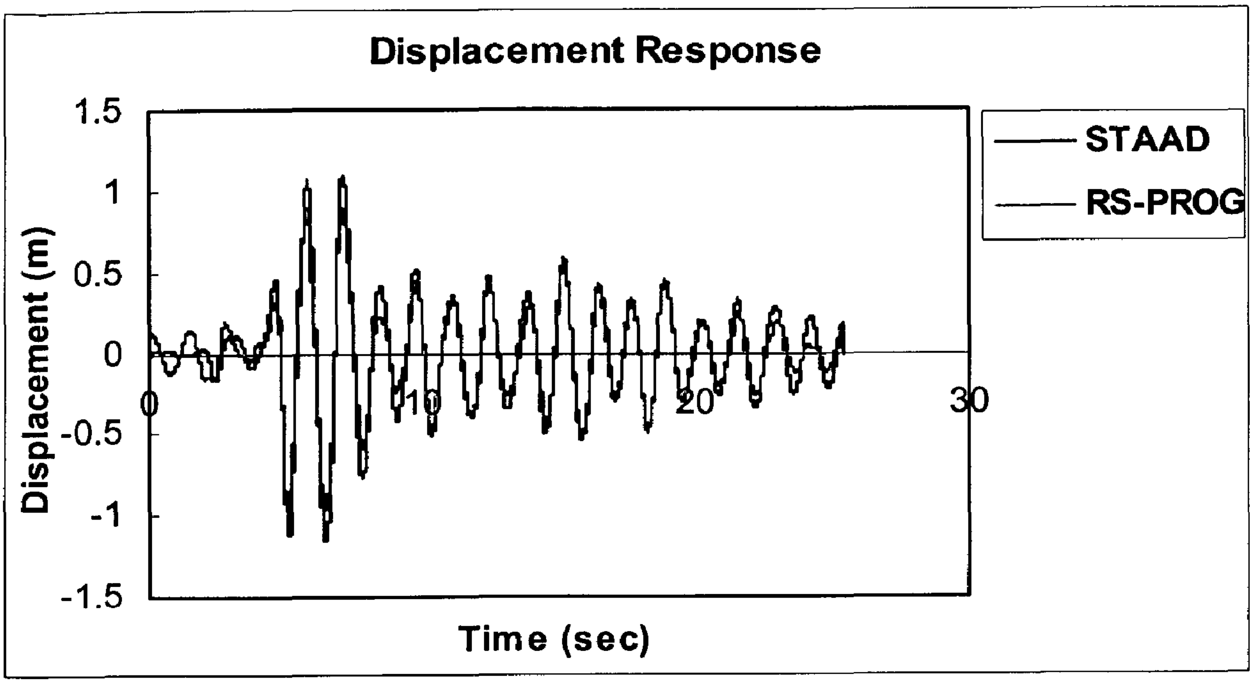

Fig.19 Responses of Node-569 To Time History Recorded at Gopeshwar

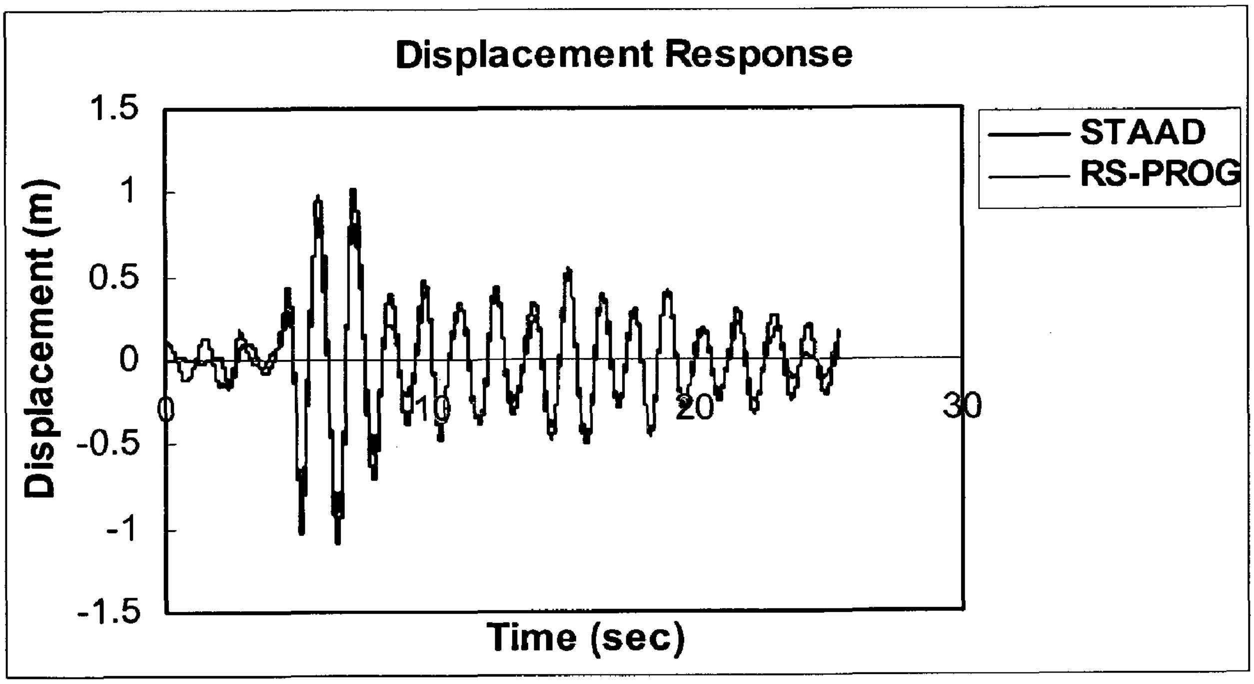

Fig.20 Response of Node-507 To Timer History Recorded at Gopeshwar

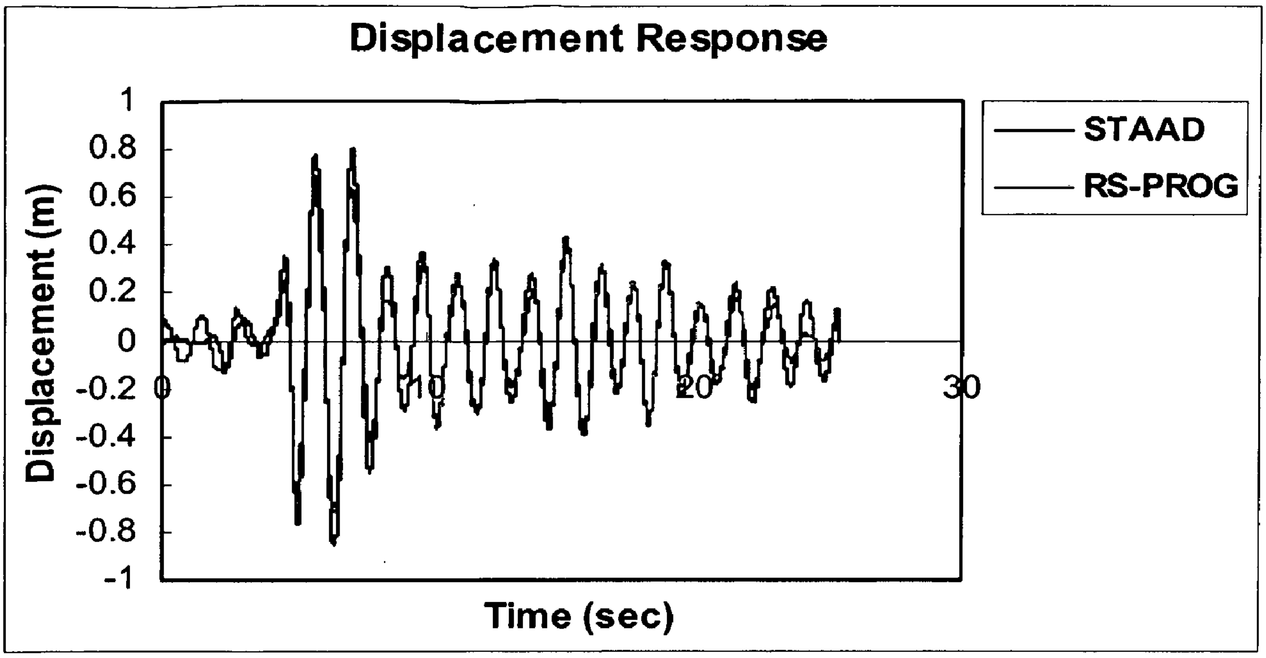

Fig.21 Response of Node-383 To Timer History Recorded at Gopeshwar

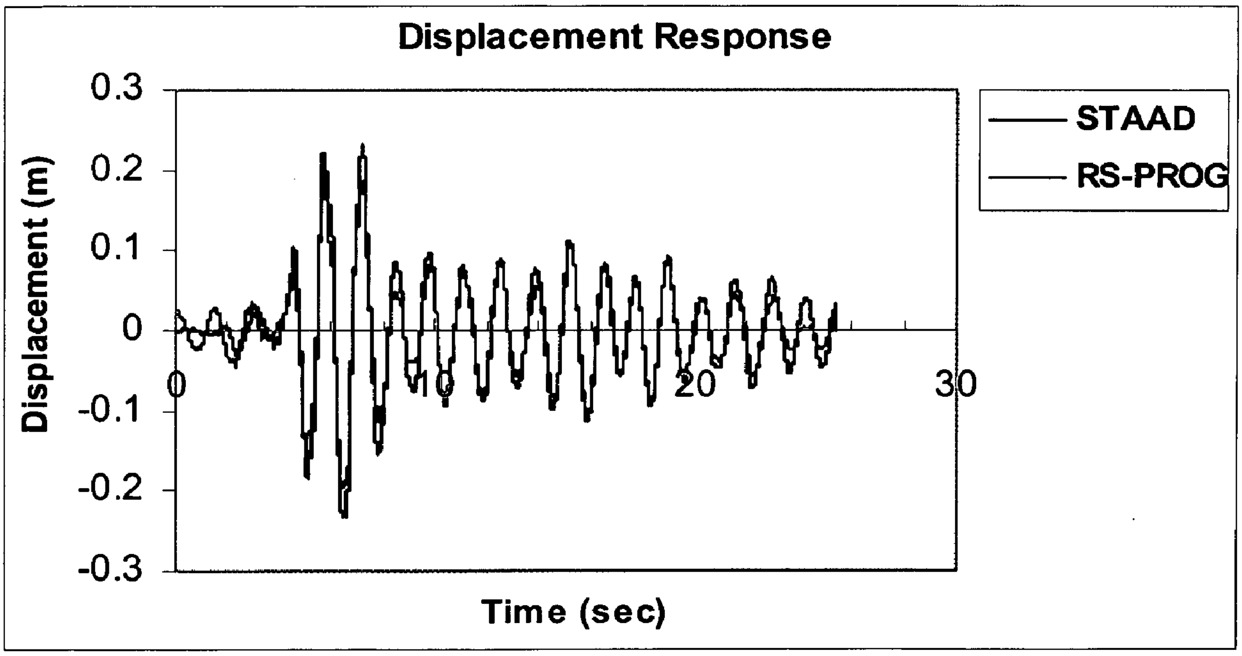

Fig.22 Response of Node-119 To Timer History Recorded at Gopeshwar

RESULTS AND DISCUSSIONS

In this work, SISO transfer function of SDOF and MDOF systems were found out using synchronous noise input. Transfer function so determined was then used to find response at designated locations of the system. It has been shown here that response found through above approach matches quite well with response found directly. Thus, this approach can be very useful in situations where a specific node of a system is required to be studied for several different excitations. In such situation, transfer function between the node and ground can be found for synchronous noise input using any commercial software and then for all subsequent analysis this transfer function can be used to find response of the node for all other excitation without use of commercial software. To show the working of the above approach, studies were carried out first on SDOF system using different excitations. For SDOF systems, response using analytically determined transfer function was also used for comparison. Subsequently studies were carried out on single bay single storey plane frame, single bay two storey plane frame and finally on ten storied building modeled as space frame. These studies clearly show that transfer function found through synchronous noise yields accurate response for all the cases. During the course of the work the following observations were made.

1. If transfer function is determined with any random input (like earthquake excitation) then there are always some problems at discrete frequencies where division by zero occurs. Obviously this problem will never occur if synchronous noise is taken as

input since synchronous noise has absolutely flat power spectrum at all the discrete frequencies.

2. Strangely, STAAD pro software provides ASCII output at the desired node at an unfamiliar sampling rate of 720 samples per second irrespective of sampling rate of excitation. It is expected that for linear analysis, the output sampling rate should be same as that of excitation. Obviously, STADD Pro software has done some digital signal processing (DSP) of output to provide output sequence at 720 SPS. Details of this processing are not available in the literature of the software. However, to match the sampling rate of output sequence we changed the sampling rate of input sequence to 720 SPS using standard DSP techniques.
3. It was noted that where STADD pro software has been used, two approaches are giving slightly different results. This difference is likely due to DSP methods used by STADD pro in converting their data sequence to 720 SPS. This difference was not found when SAP 2000 software was used.
4. Future work in this direction is use of transfer function approach with synchronous noise input for multi input multi output (MIMO) condition.

REFERENCES

1) Chopra A. K. (2001), "Dynamics of Structures - Theory and Applications to Earthquake Engineering", Prentice-Hall of India, Pvt. Ltd. New Delhi.

2) Chen H. and Taylor R. L. (1987), "Numerical Methods in Engineering Theory and Applications: Properties and Solutions of Eigen Systems of Non-Proportionally Damped Linear Dynamic Systems", (*NUMTA 87*), t5/1 2, 1-10.

3) Claret, A.M. and Venancio-Filho F. (1991), "A Modal Super-Position Pseudo-Force Method for Dynamic Analysis of Structural Systems with Non-Proportional Damping", *Earthquake Engineering and Structural Dynamics*, Vol. 20, 303-3 15.

4) Claret A. M and Venancio-Filho F. (1995), "Frequency Domain Dynamic Analysis of MDOF Systems: Nodal and Modal Coordinates Formulations", *Computers and Structures*, Vol. 56, 189-191.

5) Claret A. M. and Venancio-Filho F. (1992), "Matrix Formulation of the Dynamic Analysis of SDOF in Frequency Domain", *Computers and Structures*, Vol. 42, 853-855.

6) Clough R.W. and Penzien J. (1993), "Dynamics of Structures", *MacGraw-Hills*, New York.

7) Jangid, R.S. and Datta, V. (1993), "Spectral Analysis of Systems with Non-Classical Damping using Classical Mode Superposition Technique", *Earthquake Engineering and Structural Dynamics*, Vol.22, 723-735.

8) Mansur, W. J. And Carrer (2000), J. A. M., "Time-Segmented Frequency-Domain Analysis for Non-Linear Multi-Degree-of-Freedom Structural Systems", *Journal of Sound and Vibration*, Vol. 237(3), 457-475.

9) Kumar A., Basu, S. and Chandra, B. (2000) "Use of Synchronous Noise as Test Signal for Evaluation of Strong Motion Data Processing Schemes", *Proceedings 12th World Conference on Earthquake Engineering*, Auckland, New Zealand, Jan.3-Feb. 4, 2000. Paper no. 0931.

10) Kumar A., S.K. Thakkar, A. Bharagava, R.N. Dubey, P. Agarwal, S. Basu, and M. Shrikhande (2003). "Records of instrumented buildings and study of structural response of staff quarters building of regional passport office, Ahmedabad for Bhuj earthquake of January 26, 2001", Memoir of Geological Society of India entitled Earthquake Studies in Peninsular India (Memoir no 54); pp 143-174

11) Paz, M., "Structural Dynamics Theory and Computation" (1997), *fourth edition*, Chapman and Hall, New York.

12) Press, William H., Teukolsky S.A., Vellering W.T., Flannery B.P. (1992), "Numerical Recipes in C - The Art of Scientific Computing", Cambridge University Press.

13) Preumont A. (1982), "Frequency Domain Analysis of Time Integration Operators", *Earthquake Engineering and Structural Dynamics*, Vol.10, 691-697.

14) Venancio Filho F., Claret A.M., and Barbosa F.S. (2002), "Frequency and Time Domain Dynamic Structural Analysis: Convergence and Causality", *Computers and Structures*, Vol. 80, 1503 -1509.

15) Soares D., Mansur Jr., W.J. (2003), "An Efficient Time/Frequency Domain Algorithm for Modal Analysis of Non-Linear Models Discretized by the FEM", *Comput. Methods Appl.Mech.Engrg.*192, 3731-3745.

16) Skaar Johnnes (2003), "A Numerical Algorithm for Extrapolation of Transfer Functions", *Signal Processing*, Vol. 83, 1213-1221.