International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-2, December 2018

Influence of Stiffness and Mass Parameters on Seismic Damping of Structures

Rakshita R, Daniel C, Vincent Sam Jebadurai S, Sarala L, Arun Raj E, Hemalatha G

Abstract*: *The fundamental objective of this paper is to determine the dynamic response of the structure by the influence of stiffness and mass parameters. In this paper, we are presenting time stepping methods to obtain solutions for nonlinear dynamic problems in structural engineering using numerical evaluation. A benchmark structure having three degrees of freedom is considered and analyzed using Newmark's method for nonlinear system by implementing the El Centro Ground acceleration and time values. The results of the study detail the reduction in displacement of the structure for the arbitrary increase in percentage of the mass and stiffness of the system to obtain the optimum mass and stiffness that can be additional to the damping devices.

Keywords: Damper, Displacement, Earthquake, Newmark's.

I. INTRODUCTION

The importance of seismic design of building is essential to eradicate the risk and associated damage that may be caused due to earthquakes. As earthquake is a natural phenomenon, it is practically impossible to completely cease it from occurring [1-3]. However, we can resist its effects by building suitable structural models by using analytical methods like time stepping methods. Earthquake risk reduction is a complex task that involves many important decisions. It is important to understand the probability of occurrence of earthquakes to reduce its risk. Generally, the structures are designed for forces much lesser than its expected earthquake design forces. Hence when an earthquake ground motion approaches a structure it undergoes inelastic deformations. It is crucial to analyze the response of structures to ground motions caused by earthquakes [5].

The main objective of this paper is to determine the optimum mass and stiffness of a model to obtain the reduction in the displacement for arbitrary increase in percentage of mass and stiffness. In order to satisfy the objective, it is necessary to understand the fundamental principle that the displacement of the structure rely on the total weight of the structure. When the dead load is higher, the tendency of the structure to undergo displacement becomes minimum. But it is not advisable to inherently increase the dead load of the structure [6]. The load due to masonry infills in a building contributes to a certain portion of total structural load. These masonry fillings can be replaced by providing damping devices which are much less in weight but improves the seismic performance of the building. These damping devices helps us to achieve reduction in displacement of the structure.

Generally, the behavior of the structure to seismic forces is in the non-linear range. A non-linear dynamic analysis is the only method to describe the actual structural behavior during an earthquake. One of the methods of non-linear dynamic analysis is Time-History Analysis. Time History Analysis is a step-by-step analysis of the dynamic response of the structure by using a representative earthquake time history for evaluation [7-8]. In this paper we are analyzing the dynamic response of a structure in a non-linear system using the Newmark's time stepping method.

Newmark's method is one of the very few methods that is especially useful in the dynamic response analysis. A structural system that has the three reactive forces namely stiffness, damping and inertia that has non-linear variation with response parameters such as displacement, velocity and acceleration, a set of differential equations are arrived. There are two special cases for Newmark's method; average acceleration & linear acceleration [9-11].

We have considered the average acceleration case. The variations of acceleration over a time step is defined by the two parameters γ and β. The values of γ and β for linear acceleration method is 1/2 and 1/6 respectively. The results of this analysis will help in understanding the structural behavior with respect to stiffness and mass.

II. PROPOSED METHODOLOGY

All real structures exhibit dynamic behaviour when subjected to loads or displacements. According to newton's second law there may be additional inertial forces which is equal to mass times the acceleration. However, if the loads and displacements are applied slowly, the effect due to inertial forces may be neglected, and the analysis can be just static. Therefore, it can be summed up that dynamic analysis is just an extension of static analysis.

Manuscript published on 30 December 2018.
***** Correspondence Author (s)
Rakshita R, PG student, Department of Civil Engineering, Karunya Institute of Technology and Sciences, Coimbatore, India.
***Daniel C**, Research Scholar, Department of Civil Engineering, Karunya Institute of Technology and Sciences, Coimbatore, India,
Vincent Sam Jebadurai S, Assistant Professor, Department of Civil Engineering, Karunya Institute of Technology and Sciences, Coimbatore, India.
Sarala L, Research Associate, Department of Civil Engineering, Karunya Institute of Technology and Sciences, Coimbatore, India.
Arun Raj E, Assistant Professor, Department of Civil Engineering, Karunya Institute of Technology and Sciences, Coimbatore, India.
Hemalatha G, Associate Professor, Department of Civil Engineering, Karunya Institute of Technology and Sciences, Coimbatore, India.

In real structures, there may be infinite number of displacements. Hence it is particularly important to build effective computer models or programs for dynamic analysis of the structures. The methodology adopted here is that we are considering a 3DOF benchmark framed system possessing certain mass, stiffness and damping values. These values are taken into consideration to come up with accurate and numerical methods using computer programs to conduct a typical dynamic analysis [12]. The numerical method considered here is Newmark's time stepping method. This method helps to identify the dynamic response of the structure by numerical evaluation of differential equations. Using this method, a MATLAB program is developed to calculate the maximum displacement of the entire three storied structure for the initially considered stiffness and mass parameters, without considering a damper. Then, the stiffness and mass values are increased to a certain percentage arbitrarily at each storey to identify the reduction in displacement when a damping device is introduced. Naturally it is understood, that the maximum displacement of the structure reduces when a certain percentage of mass is added to the damper [13] . Similarly, there is also a reduction is displacement for increase in the stiffness of the structure. Hence, for a three storied structure, the mass and the stiffness of the structure at each storey is increased from its original mass to obtain this reduction in displacement at each level. After obtaining these values, they are plotted in the form of a graph to identify its pattern of structural behavior.

III. ILLUSTRATION

3.1 Type of Structure

Consider an MDOF structure with three degrees of freedom subjected to an earthquake ground acceleration. Here, K, M, C are the stiffness, mass and damping matrices of a certain size in the structure [14]. The example building frame is a benchmark frame generally taken to consideration for determining the dynamic response of similar structures. The details of the benchmark building frame are given below

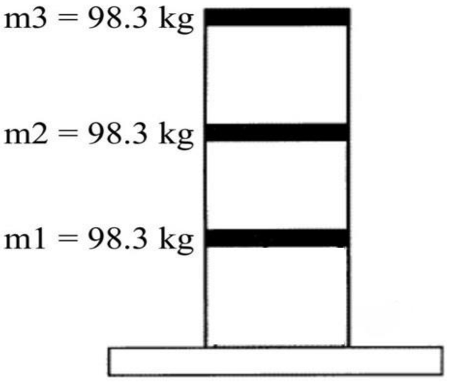

Fig. 1. Example Building Frame

$$K = 10^5 \begin{bmatrix} 12.0 & -6.84 & 0 \\ -6.84 & 13.7 & -6.84 \\ 0 & -6.84 & 6.84 \end{bmatrix} \text{ N/m} \qquad (1)$$

$$M = \begin{bmatrix} 98.3 & 0 & 0 \\ 0 & 98.3 & 0 \\ 0 & 0 & 98.3 \end{bmatrix} \text{ Kg} \qquad (2)$$

$$C = \begin{bmatrix} 175 & -50 & 0 \\ -50 & 100 & -50 \\ 0 & -50 & 50 \end{bmatrix} \text{ Ns/m} \qquad (3)$$

These three parameters and their numeric variations play an important role in controlling the response of the structure. Every structure will have these three parameters inherent in them. In a structure, the slabs and beams are associated with the mass and the columns are associated with the stiffness of the member. Hence these parameters are essential in a structure and its variations will have significant effects on the response of the structure to ground acceleration.

3.2 El Centro Ground Acceleration and Time Values

El Centro is a region in Imperial Valley of California in the United States. On May 18, 1940 an earthquake occurred at 21:35 pacific standard time. It was a believed to have a moment magnitude of 6.9. This data is called El Centro data. This earthquake occurred due to the result of failure along the imperial fault having its epicenter at a distance of 8 km north of the district Calexico in California. Hence as a result of this, a strong motion seismograph that was recorded during the earthquake still is considered as the first example which was recorded very close to the fault rupture when a major earthquake had occurred [15]. This record gives a detailed information of different types of earthquakes associated during the occurrence of the earthquake. Hence this data is universally considered as a standard data for the computation of displacement response of structures especially for the time history analysis of structures. The ground acceleration for a time period of upto 31.18 seconds can be obtained from the El Centro data and these values are used for the determination of the force at which the earthquake occurs, using the mass of the 3DOF frame building that we have considered above.

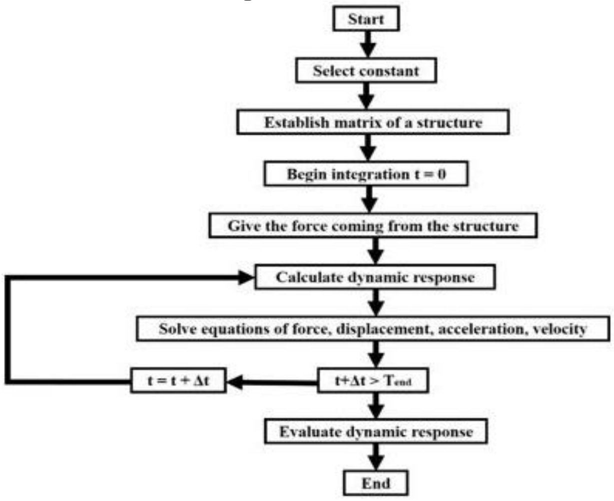

Fig. 2. Flow Chart of Dynamic Analysis

3.3 Non-Linear Analysis of Stiffness and Mass

In order to understand the complete structural behaviour, it is important to conduct time history analysis for structures having different degrees of freedom and non –linear characteristics. Here, we have typically attempted to model the seismic response for an MDOF structure having non-linear characteristics [16]. For any structural system, displacement, velocity and acceleration are the important response parameters.

Retrieval Number B5544128218/18©BEIESP
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-2, December 2018

When all of these reactive forces along with inertial/damping forces together has a non-linear variation in the structure with the response parameters the analysis will involve solving complex non-linear differential equation. The method that employs the numerical evaluation in determining this response is the Newmark's method. Newmark an American structural engineer and scientist developed certain time stepping methods in the year 1959 based on the following equations.

$$\dot{u}_{i+1} = \dot{u}_i + [(1-\gamma)\Delta t]\,\ddot{u}_i + (\gamma \Delta t)\,\ddot{u}_{i+1} \quad (4)$$

$$u_{i+1} = u_i + (\Delta t)\,\dot{u}_i + [(0.5-\beta)(\Delta t)^2]\,\ddot{u}_i + [\beta(\Delta t)^2]\,\ddot{u}_{i+1} \quad (5)$$

The procedure adopted by us is to provide time-stepping solution for non-linear systems which has in general two special cases; average acceleration and linear acceleration. There are two parameters γ and β for average acceleration method which have numerical values of 1/2 and 1/4 respectively.

IV. RESULTS AND DISCUSSION

The percentage increase in the mass and stiffness parameters of a structure helps us to arrive at the time and displacement graphs. For every arbitrary increase in these parameters there is a suitable variation. It is necessary for us to understand these graphs, in order to obtain the decrease in the displacement for every increase. The reference value of the frame is obtained without taking into consideration the reaction due to seismic forces. Using Mat lab, the decrease in displacement for every arbitrary increase in percentage of the mass and stiffness is found and tabulated. The obtained values for each percentage increase should be lesser than the reference frame values. It is important for us to understand that the increase in percentage of either mass or stiffness at any of the storeys/floors has suitable reactions at all the other floors. In our case, we have increased from 1 to 10% of both mass and stiffness, and obtained the reduction in displacement at each floor. We analyze these values to find out if they are lesser than our reference frame values. These values are plotted in the form of a graph, to identify if the maximum peak value at a particular floor is lesser than the reference value of our frame. The maximum reduction in displacement at any one of the floors is analyzed to find out the percentage reduction and its effectiveness. The mass and stiffness of the structure influences the displacement of the structure. More the self-weight of the structure, lesser is the tendency of the structure to undergo massive displacement. Our objective focuses on increasing the self-weight of the structure, by employing dampers, without inherently increasing the load of the structure. The load on the structure that produces the desired reduction in displacement is additioned to the dampers.

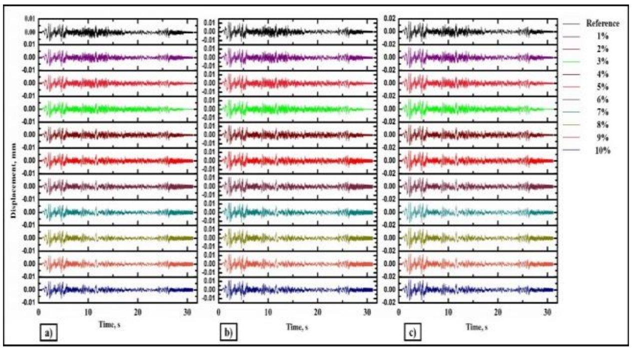

Fig. 3. Mass increased in Ground Floor 1 to 10% – Response a) Ground Floor, b) First Floor, c) Second Floor

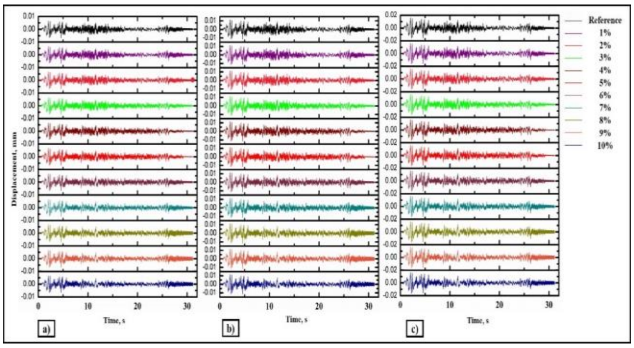

Fig. 4. Mass increased in First Floor 1 to 10% – Response a) Ground Floor, b) First Floor, c) Second Floor

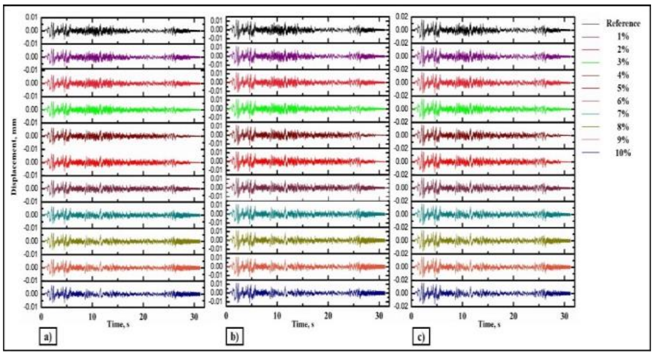

Fig. 5. Mass increased in Second Floor 1 to 10% – Response a) Ground Floor, b) First Floor, c) Second Floor

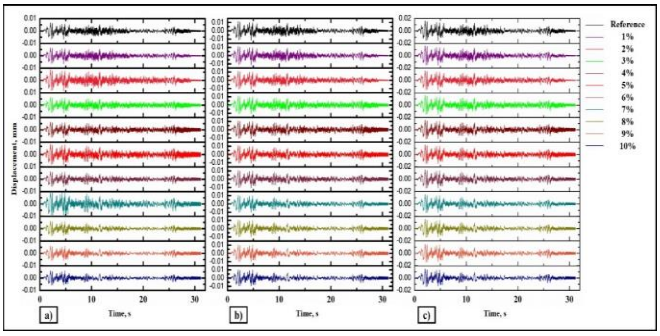

Fig. 6. Stiffness increased in Ground Floor 1 to 10% – Response a) Ground Floor, b) First Floor, c) Second Floor

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

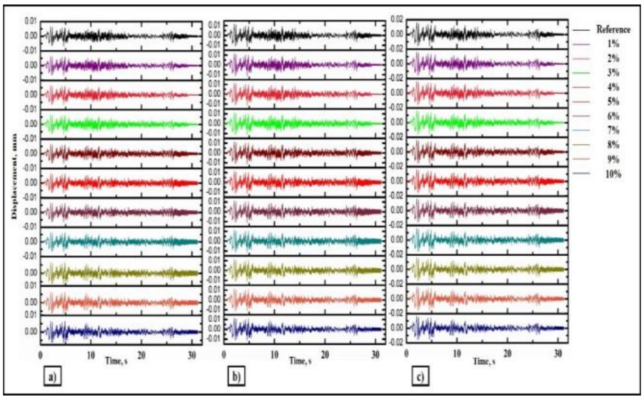

Fig. 7. Stiffness increased in First Floor 1 to 10% – Response a) Ground Floor, b) First Floor, c) Second Floor

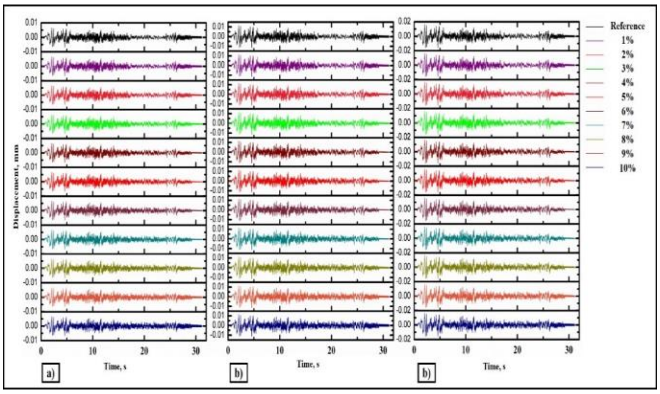

Fig. 8. Stiffness increased in Second Floor 1 to 10% – Response a) Ground Floor, b) First Floor, c) Second Floor

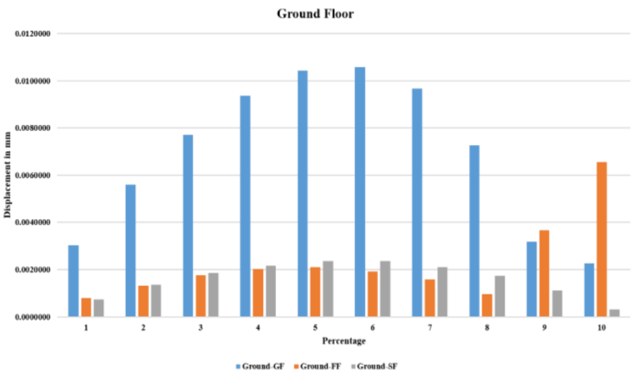

Fig. 9. Mass variations in Ground Floor - Percentage vs Displacement

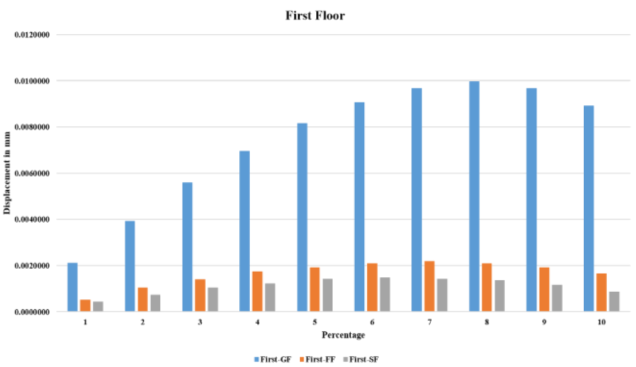

Fig. 10. Mass variations in First Floor - Percentage vs Displacement

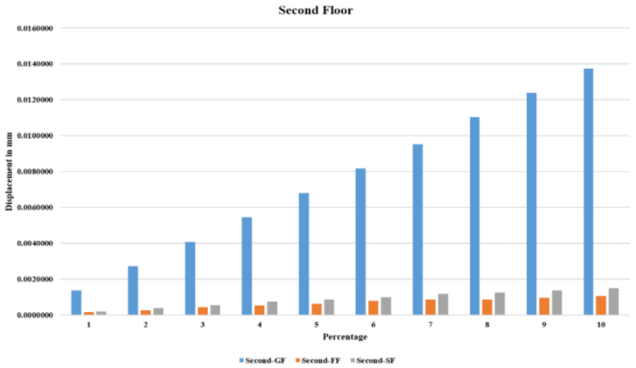

Fig. 11. Mass variations in Second Floor - Percentage vs Displacement

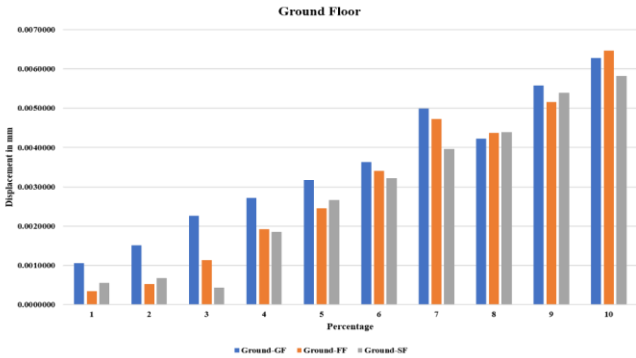

Fig. 12. Stiffness variations in Ground floor – Percentage vs Displacement

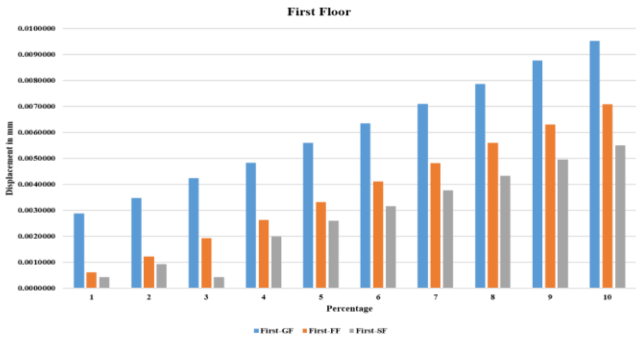

Fig. 13. Stiffness variations in First Floor - Percentage vs Displacement

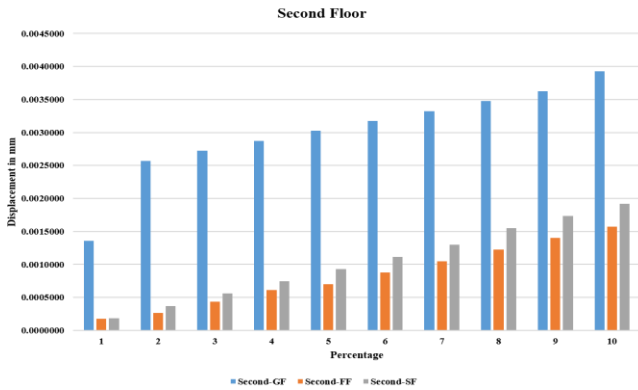

Fig. 14. Stiffness variations in Second Floor - Percentage vs Displacement

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

Table 1. Displacement in Top Floor (Second Floor)

MASS-DISPLACEMENT IN SECOND FLOOR	PERCENTAGE
Maximum percentage reduction in Ground Floor	95.32
Maximum percentage reduction in First Floor	92.41
Maximum percentage reduction in Second Floor	90.79
STIFFNESS-DISPLACEMENT IN SECOND FLOOR	**PERCENTAGE**
Maximum percentage reduction in Ground Floor	12.01
Maximum percentage reduction in First Floor	51.79
Maximum percentage reduction in Second Floor	88.113

V. CONCLUSION

From our study, we are able to identify that for every percentage increase in the mass of the structure, there is a corresponding reduction in the displacement also. The load due to masonry infills in a building contributes to a certain portion of total structural load. These masonry fillings can be replaced by providing damping devices which are much less in weight but improves the seismic performance of the building. These damping devices helps us to achieve reduction in displacement of the structure.

ACKNOWLEDGMENT

The authors would like to thank Karunya Institute of Technology and Sciences, Coimbatore for providing the necessary assistance for the successful completion of the work.

REFERENCES

1. Fajfar, P. (2000). A nonlinear analysis method for performance-based seismic design. Earthquake spectra, 16(3), 573-592.
2. Deierlein, G. G., Reinhorn, A. M., & Willford, M. R. (2010). Nonlinear structural analysis for seismic design. NEHRP seismic design technical brief, 4, 1-36.
3. Vamvatsikos, D., & Cornell, C. A. (2002). Incremental dynamic analysis. Earthquake Engineering & Structural Dynamics, 31(3), 491-514.
4. Neuenhofer, A., & Filippou, F. C. (1997). Evaluation of nonlinear frame finite-element models. Journal of structural engineering, 123(7), 958-966.
5. Ramlan, R., Brennan, M. J., Mace, B. R., & Kovacic, I. (2010). Potential benefits of a non-linear stiffness in an energy harvesting device. Nonlinear dynamics, 59(4), 545-558.
6. Zhang, N. (1995). Dynamic condensation of mass and stiffness matrices. Journal of Sound and Vibration, 188(4), 601-615.
7. Vamvatsikos, D., & Fragiadakis, M. (2010). Incremental dynamic analysis for estimating seismic performance sensitivity and uncertainty. Earthquake engineering & structural dynamics, 39(2), 141-163.
8. Richardson, M. H. (1977). Derivation of mass, stiffness and damping parameters from experimental modal data. Hewlett Packard Company, Santa Clara Division, 1, 1-6.
9. Flanigan, C. C. (1998, February). Model reduction using Guyan, IRS, and dynamic methods. In proceedings-spie the international society for optical engineering (Vol. 1, pp. 172-176).
10. Bao, Y., & Kunnath, S. K. (2010). Simplified progressive collapse simulation of RC frame–wall structures. Engineering Structures, 32(10), 3153-3162.
11. Kidder, R. L. (1973). Reduction of structural frequency equations. AIAA journal, 11(6), 892-892.
12. Aschheim, M. (2002). Seismic design based on the yield displacement. Earthquake spectra, 18(4), 581-600.
13. Ramsey, K. A. (1975). Effective measurements for structural dynamics testing. Sound and Vibration, 9(11), 24-34.
14. Aschheim, M., Tjhin, T., Comartin, C., Hamburger, R., & Inel, M. (2004). The scaled nonlinear dynamic procedure. In Structures 2004: Building on the Past, Securing the Future (pp. 1-8).
15. Kalkan, E., & Kunnath, S. K. (2007). Assessment of current nonlinear static procedures for seismic evaluation of buildings. Engineering Structures, 29(3), 305-316.
16. Yoshida, O., & Dyke, S. J. (2004). Seismic control of a nonlinear benchmark building using smart dampers. Journal of engineering mechanics, 130(4), 386-392.