DYNAMIC BEHAVIOR OF PRIMARY STRUCTURES ATTACHED WITH FLEXIBLY CONNECTED SECONDARY SYSTEMS

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Abstract

Researchers have studied the seismic behavior of the secondary systems (SS) or nonstructural elements (NSEs)attached to the main structural system or primary structure (PS)during seismic events and their protection during such type of events. An adverse effect on the dynamics of main structural system due to NSEs during seismic events is observed. These studies considered NSEs that are rigidly connected like masonry in-fills, claddings and term them as stiffening NSEs. NSEs which are not rigidly connected to the main structural system are called as flexible NSEs. During seismic events, NSEs which are rigidly connected to the main structure act integral to the main structure. These NSEs do not vibrate independent of the main structure. Whereas, flexibly connected NSEs vibrate relative to their point of attachments. In cases where the frequency of vibration of NSEs matches the natural frequency of the structure, it will result in resonance. This paper proposes and analyzes the effects of secondary systems which are not rigidly attached to the main structure on the dynamic behavior of the primary structure. Such secondary systems tend to change the dynamic behavior of primary structures especially when their mass is comparable to the primary structure. Designers tend to either completely ignore this effect or conservatively add the complete mass of the secondary system in the seismic analysis. This paper attempts to quantify this effect so that the seismic design of the primary structure can be more economical and accurate. In this paper free, undamped vibrations of a SDOF system attached with secondary system are analyzed. Damping is also considered in some problems for the former case. This paper concludes that secondary systems have a significant effect on the dynamics of the primary structure from the preliminary work conducted. This paper also presents the response time history plots of the primary structure with and without considering the effect of secondary system and inertial forces vs. time plots of the primary structure.

Keywords: *Dynamic Behavior, Primary Structure, Nonstructural Elements (NSEs), Stiffening NSEs, Flexible NSEs.*

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1. INTRODUCTION

A building consists of a primary structural system which is designed to resist a variety of loads. It also comprises of building elements which do not resist any loads. Such building elements generally are called Secondary systems or Non-structural elements (NSEs). In this proposal it is postulated to study the effect of such secondary systems on primary structures, especially during earthquakes.

Structural Elements (SEs) in buildings carry all earthquake-induced inertia forces generated in the building down to foundations. There are many items of buildings supported by SEs, which only generate inertia forces, but are not directly connected to the foundations, e.g., in-fill walls, contents of buildings, appendages to buildings, and services & utilities. Their inertia forces are carried down to foundations by structural elements. Such non load-bearing elements are NSEs or Secondary systems. These elements, in most cases, do not stiffen the structure. NSEs are "*those which are attached to or housed in a building or building system, but are not part of the main load-resisting structural system of the building*" [1] .

They define NSEs as three types, namely:
(i) *Architectural*, for example, walls, parapets, penthouses, appendages and ornamentations, veneer, cladding systems, suspended ceiling, sign boards, etc.,
(ii) *Mechanical*, for example, cranes, boilers, storage tanks, piping systems, fire protection systems,
(iii) *Electrical*, for example, electric motors, light fixtures, computers and data acquisition systems, machines, etc. [1].

During an earthquake, the above systems are subjected to large inertial forces and/or relative displacements depending on the nature of the former. The displacements are especially high when the connections are not rigid. During severe earthquakes along with the primary structure, secondary systems attached to these primary structures are also subjected to these earthquake forces. Such secondary systems influence the dynamic behavior of primary structures especially when their mass is comparable to the primary structure.

Review of existing literature and design practices show that the designers either completely ignore this effect or conservatively add the complete mass of the system in the seismic analysis. Several research studies show how these NSEs behave during earthquakes and their protection during earthquakes. Some researchers investigated the effect of NSEs on structures during seismic events. They mostly considered their NSE as a masonry infill walls and the stiffness associated with them [5, 6, 11, 12, 13]. This study discusses different kinds of NSEs that do not stiffen the structure. Hanging loads and heavy masses resting on the structures are examples of such elements.

2. ANALYTICAL MODELING

In order to understand the seismic behavior of primary structures due to flexible NSEs a basic model is defined as follows. The system used in this study is modeled as a Single Degree of Freedom (SDOF)connected with a secondary system or Non-Structural Element (NSE) through a flexible connection and is subjected to a free undamped and damped vibration separately.

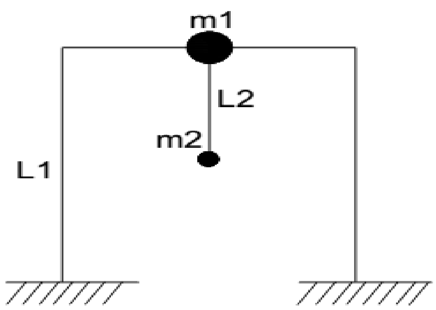

Fig -1: Primary structure with NSE

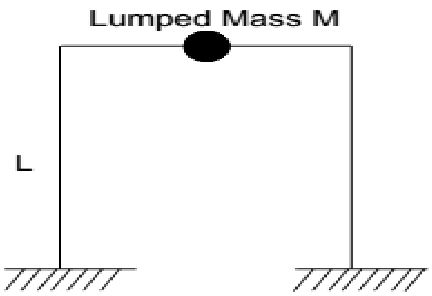

Fig.2. Lumped mass system

SDOF system with lumped mass ($M=m_1+m_2$) is considered to prove that the conservatively adding secondary mass (m_2) to the primary structure mass (m_1) in the current structural design leads to uneconomical design and also SDOF system with only mass m_1 also considered in this study to compare the results with the primary structure attached with secondary system and to see how these secondary systems affect the dynamics of the primary structure.

3. GOVERNING DIFFERENTIALEQUATION

The equivalent spring mass damper system for the fig.1 is shown below:

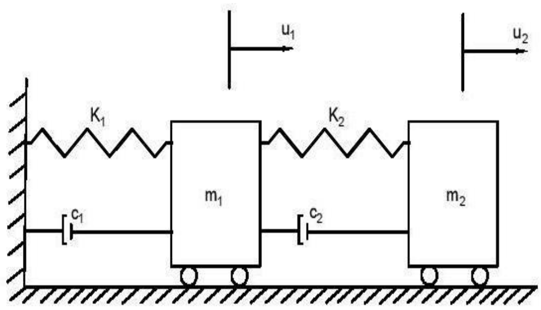

Fig -3: Equivalent spring mass damper system

The formulation of the case could be done by giving the direct dynamic equilibrium of all acting forces on themasses.The forces acting on the masses at some instant of time are external forces F(t),the elastic (or inelastic) resistingforces (ku),the damping forces ($C\dot{u}$),and the inertia forces ($m\ddot{u}$).The equation of motion can be written by dynamicequilibrium compactly in matrix form:

$$\mathbf{M}\ddot{u} + \mathbf{C}\dot{u} + \mathbf{K}u = F(t) \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

By introducing the following notation:

$$\mathbf{M} = \begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots.. \quad (2)$$

$$\mathbf{K} = \begin{bmatrix} (k_1 + k_2) & -k_2 \\ -k_2 & k_2 \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots.. \quad (3)$$

$$\mathbf{C} = \begin{bmatrix} (c_1 + c_2) & -c_2 \\ -c_2 & c_2 \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots.. \quad (4)$$

Where **M** is the mass matrix, **C** is the damping matrix; **K** is the lateral stiffness matrix.Setting F(t)=0 gives thedifferential equation governing free vibration of the system,which for systems without damping (c=0) specializes to:

$$\mathbf{M}\ddot{u} + \mathbf{K}u = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(5)$$

The solution to the homogeneous differential equation is obtained by standard methods.

The stiffness's k_1 and k_2 for the primary structure and hanging mass are defined as follows:

From the basic study of the frames the stiffness is given by$k_1 = \frac{24EI}{l_1{}^3}$ where E and I are the young's modulus and moment of inertia of the primary structureand therestoring force in the simple pendulum is given byFs = $m_2 g\theta$ and corresponding stiffness is given by spring constant $k_2 = \frac{m_2 g}{l_2}$.

4. RESULTS AND DISCUSSIONS

In this section results of the analytical study are presented. Response of primary structure in undamped and damped cases is shown. Similarly the inertial forces are also presented.

4.1 Free Undamped Vibrations

The system with secondary attachment is subjected to the free undamped vibrations and time history plots of the primary structure are presented to understand the dynamics of the primary structure due to secondary systems. The following cases are considered.

- Case (a): Mass of the secondary system is 50% of the primary structure and lengths of supports of the primary and secondary systems to calculate stiffness are 3m (height of storey) and 1m (length of pendulum) respectively.

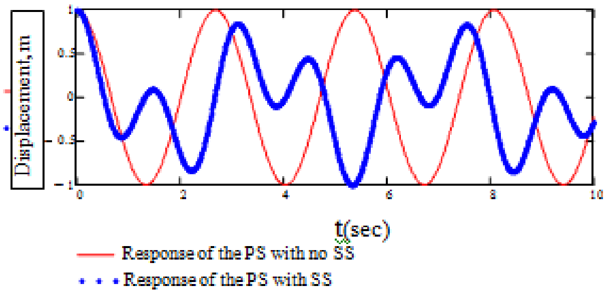

Fig.4. Displacement vs time curve

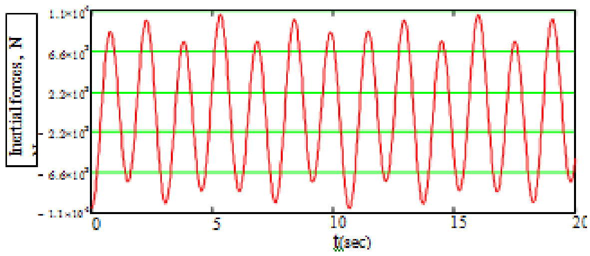

Fig.5. Inertial force of PS with SS vs time

- Case (b): Mass of the secondary system is 25% of the primary structure and lengths of supports of the primary and secondary systems are 3m(height of storey) and 1m (length of pendulum) respectively.

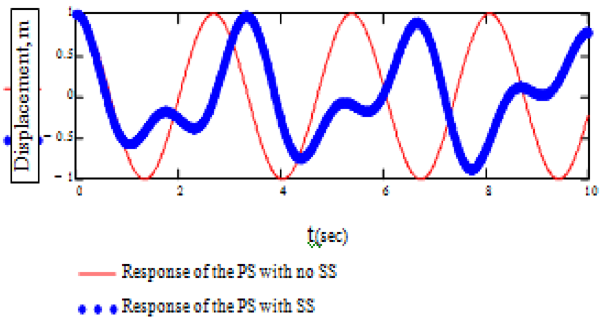

Fig.6. Displacement vs time curve

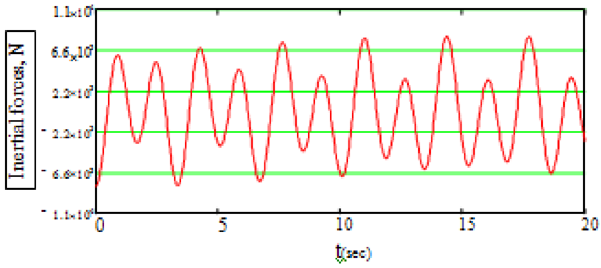

Fig.7. Inertial force of PS with SS vs time

From the above plots (Figs 4 and 6) it is clearly observed that the secondary system affects the response of the primary structure. As expected the effect of a larger mass is more on the primary structure. Inertial forces also vary as does the secondary mass (Figs 5 and 7). These inertial forces are essential to understand the effect of hanging masses on the primary structure during seismic events in further studies.

4.2 Free Damped Vibrations

The primary system was assumed to undergo free damped vibrations of 2% damping. The damping in the secondary system is considered to be 0.005% (almost negligible when compared to the primary structure).

- Case (c):Case (a) with the above damping:

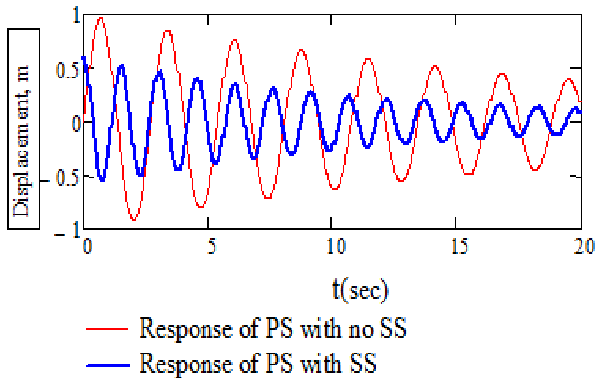

Fig.8. Displacement vs time curve

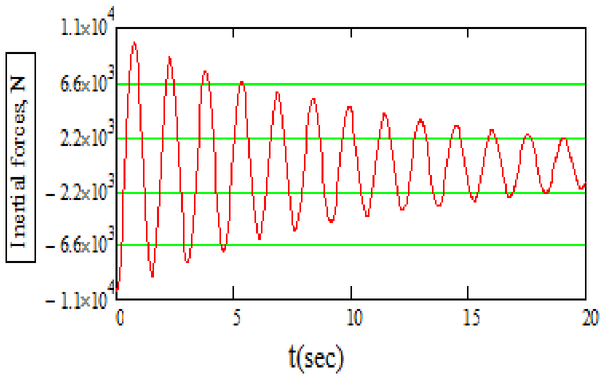

Fig.9. Inertial force of PS with SS vs.time

- Case (d): Case (b) with above damping:

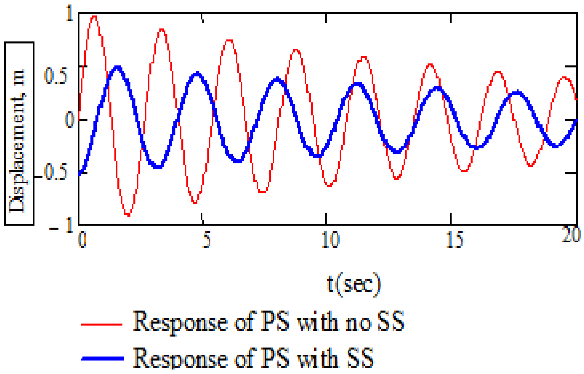

Fig.10. Displacement vs time curve

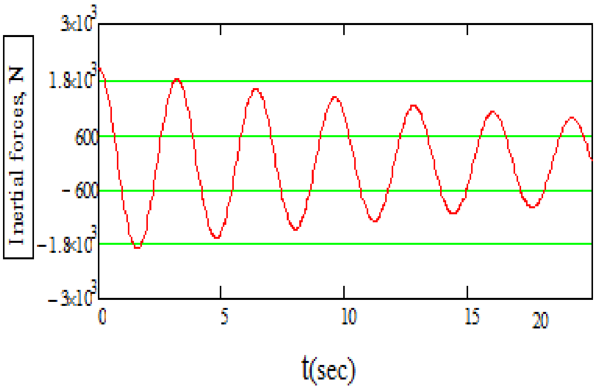

Fig.11. Inertial force of PS with SS vs time

From the above plots (Figs 8 and 10) it is clearly observed that the secondary system affects the response of the primary structure. The damping rate also is affected by the mass. As expected the effect of a larger mass is more on the primary structure. Inertial forces also vary as does the secondary mass (Figs 9 and 11). These inertial forces are essential to understand the effect of hanging masses on the primary structure during seismic events in further studies, as with damping is a more practical case. It should also be noted that damping in the system reduces the response of the primary structure significantly.

5. CONCLUDING REMARKS

- Based on the above results, it can be concluded that the effect of secondary systems on the response of the primary structure is significant.
- The inertial forces in the primary structure also are affected by the secondary system. This clearly gives an indication that a thorough study is required to analyze this effect.
- The analysis of free damped vibrations clearly shows that,with increasing secondary mass, the response in the primary structure is greatly affected and higher damping is observed. Inertial forces in the primary structure are also affected when the secondary mass is more. As the mass of the secondary system becomes significant compared to the primary structure, a requirement for the mass to be considered in seismic design increases.
- Due to resonance the inertial forces on the primary structure will increase or decrease depending on the vibrational properties of the pendulum. This effect needs further study.

ACKNOWLEDGEMENT

We would thank Birla Institute of technology and Science, Pilani – Hyderabad Campus and especially the Department of Civil Engineering for all the support in the above work.

REFERENCES

[1]. G. Mondal and K. S. Jain, "Design of non structural elements for buildings: A review of codal provisions," Indian Concrete Journal, pp.22-28, August 2005.
[2]. J. Lin and S. A. Mahin, "Seismic response of Light subsystems on Inelastic structures," Journal for Structural Engineering, vol. 111(2), pp. 400-417, 1985.
[3]. R. Villaverde, "Seismic design of secondary Structures," Journal for structural Engineering, vol. 123(8), pp. 1011-1019, 1997.
[4]. S. I. Pardalopoulos and S. J. Pantazopoulou, "Seismic response of non structural components attached on multistorey buildings," Earthquake engineering and structural dynamics, vol. 44, pp. 139-158, 2015.
[5]. P. Bazzurro, F. Mollaioli, A. D. Sortis and S. Bruno, "Effect of masnory walls on the seismic risk of reinforced concrete framed buildings," in 8th U.S.National Conference on Earthquake Engineering, San Francisco,California,USA, April 8-22,2006.
[6]. M. Z. Dolsek and P. Fajfar, "Effect of Masonry infills on the seismic response of a four storey reinforced concrete frame-a deterministic assessment," Engineering Structures, vol. 30, pp. 1991-2001, 2008.
[7]. F. Braga, V. Manfredi, A. Masi, A. Salvatori and M. Vona, "Performance of non-structural elements in RC buildings during L'Aquila 2009 earthquake," Bulletin of Earthquake Engineering, vol. 9, pp. 307-324, 2011.
[8]. T.Mahdi, "Performance of non-structural components in the 2012 varzaghan-ahar earthquake," in 2nd European conference on earthquake engineering and seismology, Istanbul, August, 2014.
[9]. A. Devin and P. J. Fanning, "Non-Load bearing elements and their contribution to a structures dynamic response," in EVACES 2011-Experimental Vibration Analysis for civil Engineering Structures, 2011.
[10]. A.Taheriand F. Behnamfar, "Interaction of connected Single degree of freedom systems," Procedia Engineering, vol. 14, pp. 3059-3068, 2011.
[11]. C.Duffield and G. Hutchinson, "The influence of non-structural components on the serviceability performance of high rise buildings," Australian journal of structural Engineering, vol. 10, 2009.
[12]. B.Li, G. L. Hutchinson and C. F. Duffield, "Contribution of typical non-structural components to the performance of high-rise buildings based on field

reconnaissance," Journal of Building Appraisal, vol. 6, no. 2, pp. 129-151, 2010.
[13]. B. Li, G. L. Hutchinson and C. F. Duffield, "The influence of non-structural components on tall building stiffness," The structural design of tall and special buildings, vol. 20, pp. 853-870, 2011.
[14]. E. Matta and A. D. Stefano, "Model calibration in the presence of resonant non-structural elements," Journal of Civil Structural Health monitoring, November27,2014.

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