

# Effect of High Frequency Modes on Pushover Analysis of Structures

Salsala Abubaker<sup>1</sup>

<sup>1</sup>Assistant Professor

Indira Gandhi Institute of Engineering and Technology for Women, Kothamangalam, Kerala, India  
salsala.vnb@gmail.com

**Abstract:** In order to get a better accuracy, engineers tend to add more number of modes for modal pushover analysis of irregular structures. The behavior of high frequency modal response is essentially static. Unlike linear analysis, the contribution of high frequency modes in pushover analysis is not fully developed and is a developing area of research. Further the effect of high frequency modal responses in nonlinear analysis of structures is not known. This paper discusses the behavior of high frequency modal responses in the nonlinear static pushover analysis of structures.

**Keywords:** pushover, modal response, high frequency, inelastic response

## 1. Introduction

At high frequencies, the damped periodic part of response becomes negligible and the rigid part of the response is the dominating part. In this region, the structural frequency is sufficiently higher than the input force and the spectral acceleration become equal to the peak ground acceleration (PGA) often referred to as zero period acceleration. The minimum frequency at which the spectral acceleration becomes approximately equal to ZPA is referred to as "rigid frequency", beyond which the curves for various damping ratios have same value of spectral acceleration [1]. Since the period of high frequency mode is very short, response is independent of the time period. Therefore the equation of motion in this region becomes

$$\mathbf{K}\mathbf{U} = -\mathbf{M}\{\mathbf{1}\}\ddot{u}_g \quad (1)$$

At high frequencies, the spectral displacement  $u(t)$  is given by

$$u(t) = \frac{\ddot{u}_g(t)}{\omega^2} \quad (2)$$

where,

$\ddot{u}_g(t)$  = input ground acceleration

$\omega$  = natural frequency

The responses of high frequency modes are essentially static than dynamic and can be determined by conducting a static analysis [2]. The high frequency modes are in phase to each other and their responses are combined algebraically [1]-[3]

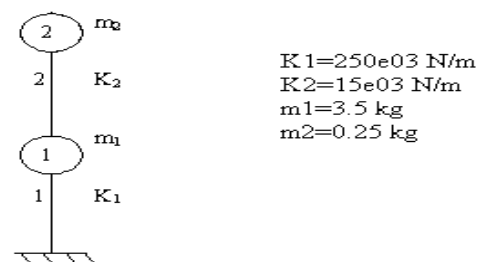
## 2. Modal response combination in high frequency region

In modal pushover analysis the modal responses are combined using SRSS [6]. This combination comes from the extension of SRSS from response spectrum method of seismic analysis. The high frequency modal responses in response spectrum method combine algebraically [7]. The behavior of high frequency modal response is static in nature. It is observed that the behavior of high frequency modal response in modal pushover analysis is also static in

nature. Since the high frequency nonlinear response is static in nature they will combine statically. This is investigated using the following numerical examples.

### 2.1. Numerical example 1

The properties of two degrees of freedom system shown in Figure 1 are given in the Table 1 and the system is subjected to pushover analysis



**Figure 1:** Properties of two degrees of freedom system-example 1

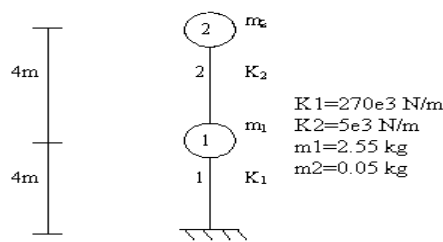
**Table 1:** Properties of example 1 shown in Figure 1

Variable	Mode1	Mode2
Frequencies, Hz	35.6	46.62
Modal mass participation factor (%)	0.533	0.4667

Then the performance points for mode 1 and mode 2 are 0.0166 and 0.00465. For combined modes, the performance point of the system is 0.011. From mode 1 and mode 2, using SRSS, the peak response is 0.0172. Combining the responses algebraically, the peak response is given by 0.011. This shows that the nonlinear modal responses in high frequency modes combine algebraically.

### 2.2. Numerical example 2

The properties of two degrees of freedom system shown in Figure 2 are given in the Table 2 and the system is subjected to pushover analysis



**Figure 2:** Properties of two degrees of freedom system - example 2

**Table 2:** Natural frequencies and frequencies of example 2 shown in Figure 2.

Variable	Mode1	Mode2
Frequencies, Hz	47.61	54.80
Modal mass participation factor (%)	0.5026	0.497

The performance points for mode 1 and mode 2 are 0.0120 and 0.001. For combined modes, the performance point of the system is 0.011. From mode 1 and mode 2, using SRSS, the peak response is 0.012. Combining the responses algebraically, the peak response is given by 0.011. This is the spectral displacement of combined modes. This shows that the nonlinear modal responses in high frequency modes combine algebraically.

### 3. Conclusion

The behavior of high frequency modal responses in linear and nonlinear analysis is static in nature. Generally the nonlinear static modal pushover responses are combined using SRSS. The combination of high frequency modal responses is studied with the help of numerical examples. It is observed that high frequency modal responses are combined algebraically.

### References

- [1] Gupta AK. Response Spectrum Method: In seismic analysis and design of structures. Boston: Blackwell Scientific Publications, 1992.
- [2] Morante, R., Wang, Y., Chokshi, N., Kenneally, R. & Norris W. Evaluation of Modal Combination Methods for Seismic Response Spectrum Analysis. 15th International Conference on Structural Mechanics in Reactor Technology, Seoul (KR), BNL-NUREG-66410, 1999, paper ID K4-A4-US.
- [3] USNRC. Combining modal responses and spatial components in seismic response analysis Regulatory guide 1.92, Office of nuclear regulatory research, US Nuclear Regulatory Commission R2, 2006.
- [4] Rui Carneiro Barros and Ricardo Almeida , Pushover Analysis of Asymmetric Three-Dimensional Building Frames, Journal of Civil Engineering and Management, Vol.XI, No. 1, 2005, pp. 3-12.
- [5] FEMA 356, 2000 Pre-standard and commentary for the Seismic Rehabilitation of Buildings, Building Seismic Safety Council for the Federal Emergency Management Agency (Report No. FEMA 356), Washington, D.C.
- [6] Chopra, A.K. (2008). Dynamics of Structures: Theory and applications to earthquake engineering. 3rd Ed., Prentice-Hall, New Delhi.

- [7] Dhileep, M., Bose, P.R. (2006). "A critique of various missing mass correction methods for seismic analysis of structures." Proc. of the Tenth Asia Pacific conf on Struct. Engg and Construction. Bangkok

### Author Profile



**Salsala Abubaker** received B. Tech degree in Civil Engineering from Calicut University in 2009 and M-Tech degree in Structural Engineering from Mahatma Gandhi University in 2011. During 2011-2012 she worked as design engineer in N M Salim and Associates Calicut. She is now working as Assistant Professor in Civil Engineering Department of Indira Gandhi Institute of Engineering and Technology, Kothamangalam, Kerala, India.