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A compression on parabolic and skewed mass distribution

Meena, Amit

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Abstract

Natural environmental forces like wind, earthquake forces and wave forces, along with loads that they are designed to resist. These forces are random and dynamic in nature. So the response of the structure is also dynamic and that is what causes the unsafe and uncomfortable conditions. The aim of study both methods are to compare the effectiveness and the response on the structure. It has been studied to seek for the mass dampers with high effectiveness and robustness for the reduction of the undesirable vibrations of structures under the ground acceleration.

Keywords: DMF | Parabolic mass | Skewed | Bell shape

For Correspondence:

Dept. of Mechanical Engg. Gurukula Kangri University Haridwar, India
Email :**amit08310004@gmail.com**

Introduction

Engineering structures have to withstand environmental forces like wind, earthquake forces and wave forces along with loads that they are designed to resist. All forces are random and dynamic in nature. So the response of the structure is also dynamic and that is what causes the unsafe and uncomfortable conditions. These are the factors due to this engineering structure play an important role.

Stringent performance requirements: Structures are required to respond to the forces acting on them within the safety limits. Hence for environmental loads, which are random and dynamic in nature, more stringent safety limits are generally set, which demand for control of vibrations of the structure.

Increased flexibility: There is also a growing tendency to use lighter and more flexible construction materials. These factors promote the idea of control of vibrations of structure.

3. Increased safety levels: As structure becomes more complex, costly and as it serves more critical function, it demands higher safety levels.

Tuned mass dampers (TMD) are widely used to control the vibrations in civil engineering structures. Although TMDs are effective in reducing the vibrations caused by stationary excitation forces, their performance to suppress seismic response is limited. This inefficiency is due to the fact that TMDs usually need some time interval before it becomes fully effective because they are initially at rest, while the strongest seismic ground motion is often observed at the earlier stage of an earthquake. Another drawback is that TMDs are sensitive to tuning error. Employing more than one tuned mass damper with different dynamic characteristics has then been proposed to further improve the effectiveness and robustness of the TMD.

Methodology

Parabolic Mass Distribution

A parabolic mass variation of the form

$$\mu_i = \left\{ \left[1 - \left(\frac{n+1}{2} \right)^2 \right] a - \left(i - \frac{n+1}{2} \right)^2 \right\} \quad (2.1)$$

where n is the total number of TMD's and 'a' is a constant whose value is taken to be 30 for the analysis. The idea here is to have maximum mass at the centre so as to damp out central peaks. The entire distribution can be adjusted so as to damp out all the secondary peaks as well.

Optimum Parameters for parabolic mass distribution

Three types of frequency distribution are considered for the analysis as shown in the Figure. Type I is linear whereas Type II and Type III are varying.

Frequency distribution (Type I)

The parameters were varied systematically and preliminary values for each parameter were arrived by choosing the one that gave the least value of maximum DMF and a flat response curve. A mass ratio of one percent has been assumed throughout the analysis. Graphs below compare the optimum DMF curves for three different cases, viz, parabolic mass, constant stiffness and constant mass for three types of frequency distributions as shown in Fig. 2.1. Structural damping is taken to be 1%.

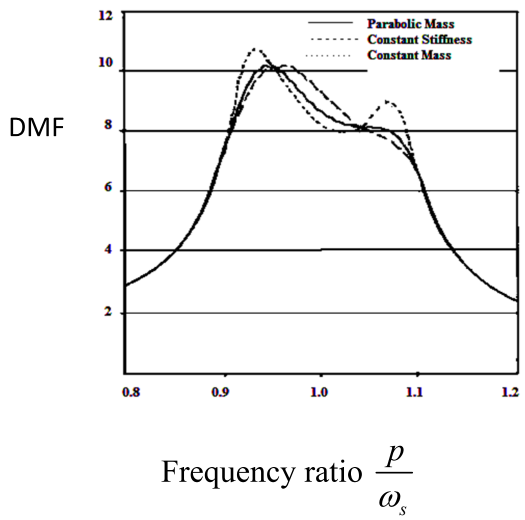
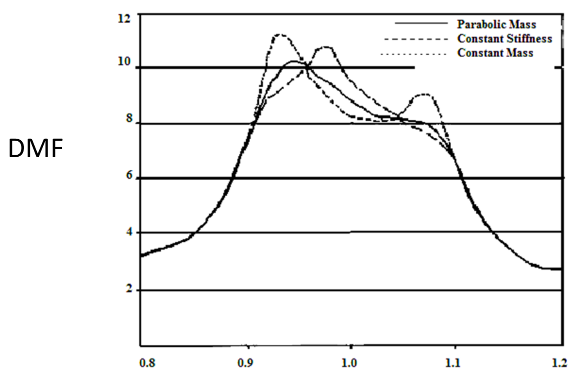
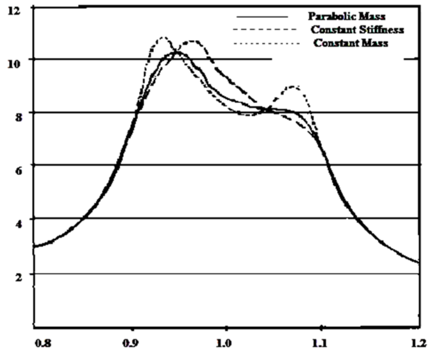


Fig. 2.1: Optimum parameter curve for linear frequency distribution

Frequency distribution (Type II and Type III)



DMF



Frequency ratio $\dfrac{p}{\omega_s}$

Fig. 2.2: Optimum parameter curve for frequency distribution of Type II and Type III

	Damping ratio ξ_d			Tuning frequency ratio γ			Spacing parameter β			DMF		
	Type I	Type II	Type III	Type I	Type II	Type III	Type I	Type II	Type III	Type I	Type II	Type III
Parabolic mass	0.0155	0.0172	0.1656	0.99875	0.99971	0.9982	0.2013	0.1986	02003	10.212	10.458	10.354
Constant Stiffness	0.0196	0.0163	0.0185	0.99642	1.0141	1.0023	0.1651	0.1751	0.1862	10.425	10.876	10.521
Constant Mass	0.0201	0.0156	0.0166	0.99321	1.0122	1.0081	0.1723	0.1353	0.1985	10.912	11.223	11.028

Table 2.1: Optimum values for three types of frequency distributions (Parabolic Mass)

Skewed Mass Distributions

Modified parabolic distribution

The parabolic distribution gave rise to families of response curves that had a higher DMF to the left of the natural frequency of the structure $\left(\dfrac{p}{\omega_s}<1\right)$ .This suggests that instead of having a symmetrical distribution we should use a skewed distribution with more mass towards left. A modified distribution of the form is used.

$$\mu_i=\left\{\left[1-\left(\frac{n+1}{2}\right)^2\right]a-\left(i-\frac{n+1}{2}\right)^2\right\}\gamma\left(i\right)^r \qquad (2.2)$$

The sign of parameter r would skew the distribution to either side and its magnitude can be used to alter the degree of shift in distribution. The results show that a correct combination of parameters yields a symmetrical and flat peak response. The parameters were varied systematically and preliminary values for each parameter were arrived at by choosing the one which gave minimum value for maximum DMF and a flat response.

From Fig 2.4, an 'a' value of 10 is chosen for further calculations. Fig 2.5 shows that small damping ratios give rise to large secondary peaks, caused by resonance in the TMD's one of which gives the maximum response of the structure. The secondary peaks flatten out with increasing damping ratios. This is then the maximum response of the structure. The maxmum structural response however increases if the damping ratio is increased too much. Therefore there exists an optimum value of the damping ratio for an MTMD-Structure which in this case is 0.01. As in previous cases, the optimum frequency bandwidth is found to be close to 0.2 for modified parabolic distribution also Fig 2.6.

A symmetrical and reasonably flat response is obtained at r=2.5. The optimum response is obtained at r=2.5, ξ_d=0.012, β =0.2, a= 10 (1% structural damping). The maximum DMF is 10.181 and bandwidth of flat portion is 0.1924. The optimum curve is plotted on linear scale. The total number of TMD's is taken to be 11 and the total mass is assumed to be one percent.

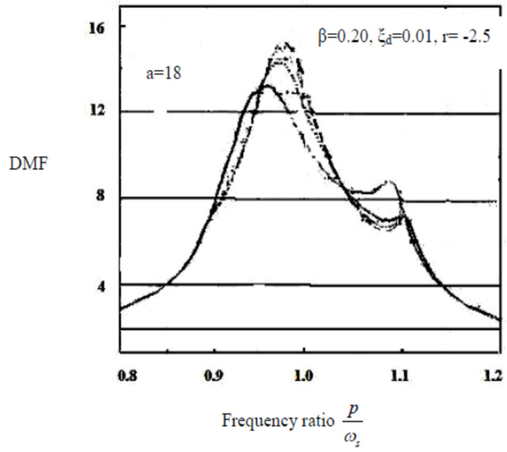


Fig. 2.4: Frequency response curves of structures for different shape factors for modified parabolic distribution while keeping other parameters constant

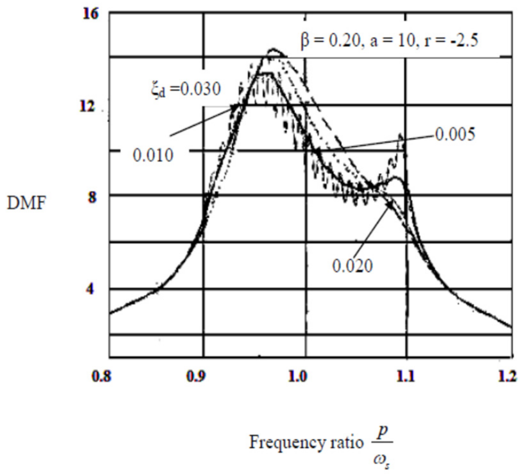


Fig 2.5: Frequency response curves of structures for different damping ratios factors of modified parabolic distribution while keeping other parameters constant.

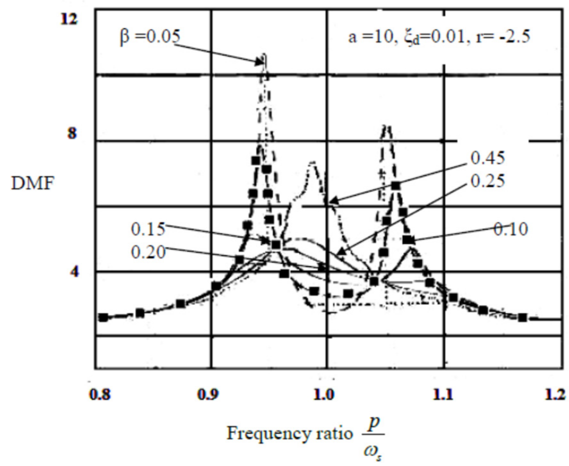


Fig 2.6: Frequency response curves of structures for different frequency bandwidth for parabolic distribution while keeping other parameters constant.

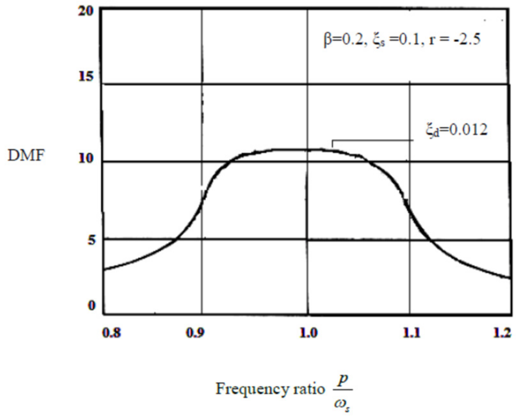


Fig. 2.7: Optimum parameter curve for modified parabolic distribution.

Bell shaped distribution

The modified parabolic distribution works well to give a reduced and a symmetrical distribution. However, a completely flat peak response was not being attained. This means that the idea of skewed mass distribution to achieve a symmetrical distribution holds. A better distribution is needed to get a perfectly flat response curve.

It can be seen that typical response of these systems is bell shaped. So it was decided to use a bell shaped distribution that is similar to the response of the system. The option of skewing the mass towards left is maintained.

Because of the above considerations a bell shaped distribution of the form

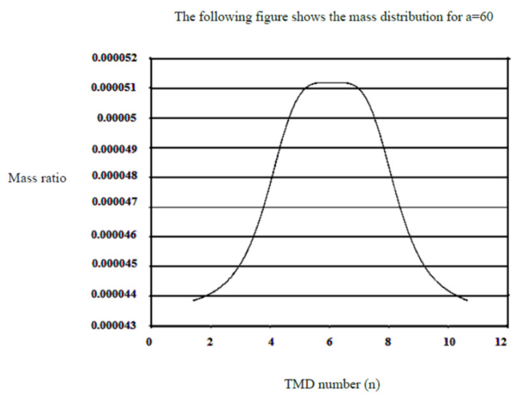


Fig 2.8: Bell shaped distribution for a = 60.

The sign of parameter n would skew the distribution to either side and its magnitude can be used to alter the degree of shift in distribution. The results show that a correct combination of parameters yields a symmetrical and flat peak response. The parameters were varied systematically and preliminary values for each parameter were arrived at by choosing the one which gave minimum value for maximum DMF and a flat response. Total mass ratio is again assumed to be one percent.

Fig. 2.9 shows that a reasonably low and flat response is obtained at about a=60. Fig 2.10 suggests a value of 0.015 for ξ_d. This is one of the possibilities although other solutions might exist. The best value for each parameter obtained from the graphs is used in every successive one. Therefore varying local skewing parameter gives us the local optima.

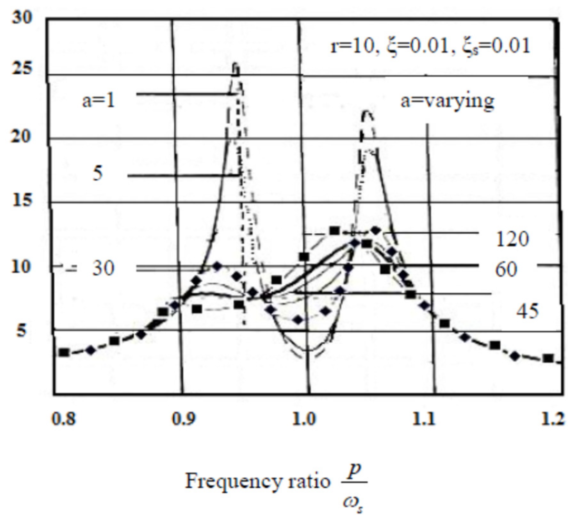


Fig 2.9: Frequency response curves of structures for different shape factors for bell shaped distribution while keeping other parameters constant.

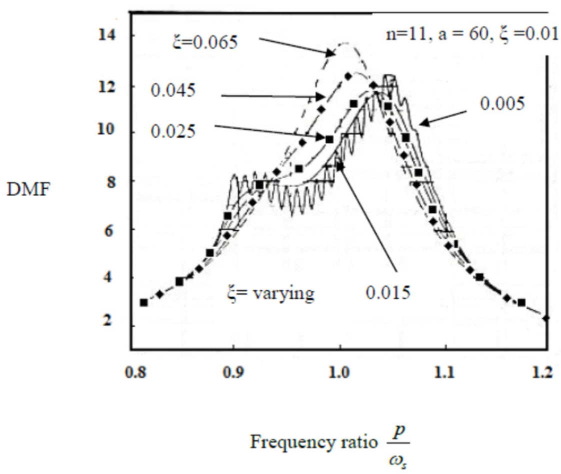


Fig. 2.10: Frequency response curves of structures for different damping ratios factors of bell shaped distribution while keeping other parameters constant.

A symmetrical and reasonably flat response is obtained at n=3.2. The optimum response Fig. 2.11 is obtained at ξ_d=0.015, β=0.2, a=60 (1% structural damping).The maximum DMF is 9.352 and bandwidth of flat portion is 2061. The optimum curve is plotted on linear scale.

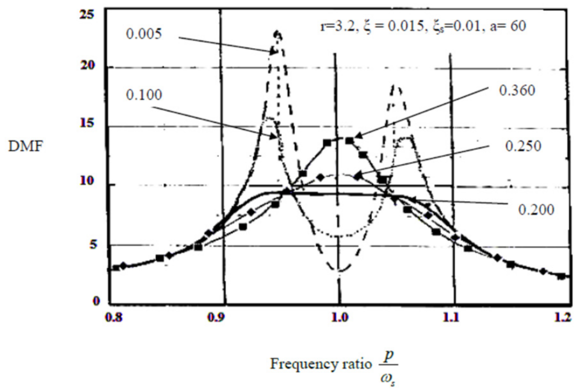


Fig. 2.11: Frequency response curves of structures for different frequency bandwidth for bell shaped distribution while keeping other parameters constant.

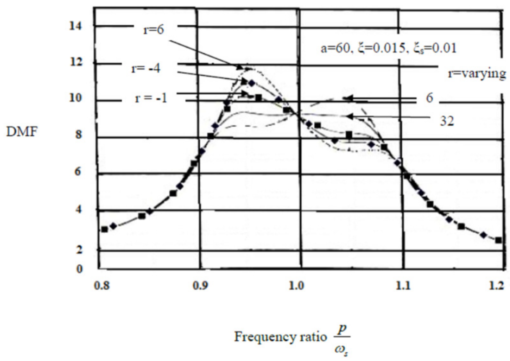


Fig 2.12: Response factors for varying n values while

keeping other parameters constant.

The best value of each parameter from the above graphs is taken and hence after varying the parameter 'r' a perfectly symmetrical and flat response curve is obtained with a reduced DMF as shown in the Fig. 2.13.

The maximum DMF obtained is 9.352 which is considerably lower than the value obtained for parabolic distribution (10.212) and modified parabolic distribution (10.181). Also the bandwidth of flat portion is 0.2061.

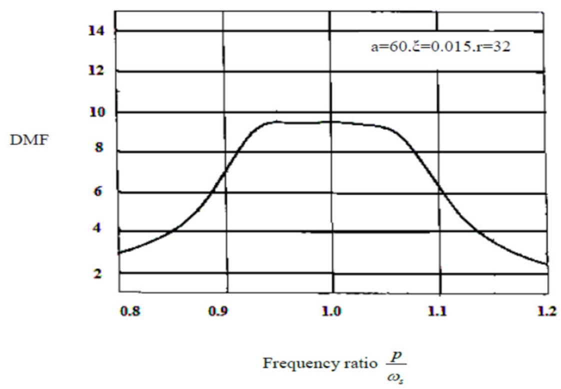


Fig. 2.13: Optimum parameter curve for bell shaped distribution

3. Result and conclusion:

The graph below compares the optimum curves given by Yamaguchi and Harnpornchai with the ones obtained for modified parabolic and bell shaped distributions.

Fig 3.1 Comparison of DMF curves for mass excited system with constant TMD masses (Yamaguchi and Harnpornchai)[3] modified parabolic distribution and bell shaped distribution.

It can be seen that maximum DMF for constant TMD masses is about 10.912 as obtained by Yamaguchi and Harnpornchai[3]. The response curve is also not flat. The modified parabolic distribution does not give us any significant improvement on the DMF; maximum value of which is still about 10.181. However, the response obtained using skewed parabolic distribution was considerably flatter than that obtained using constant mass MTMD system. Frequency bandwidth of flat region has improved from about 0.17 to about 0.19, and improvement of about 10.5%.

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