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Probabilistic characteristics of damping in buildings

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Abstract. This paper describes probabilistic characteristics of damping in a tall building based on the results of full-scale measurement. It is found, through statistical analysis of the damping data, that the probability density function(PDF) of damping at the high amplitude plateau can be well represented by Normal distribution (Gaussian distribution). A stochastic damping model is proposed to estimate amplitude-dependent damping for practical application.

Key words: damping; tall building; full-scale measurement.

1. Introduction

It has been recognized that damping in buildings usually exhibits amplitude dependent characteristics. The amplitude dependent behavior of damping in buildings has been investigated by many researchers (e.g., Jeary 1986, Tamura and Suganuma 1996, Jeary 1996). The damping data obtained by Fang *et al.*(1999) and Li *et al.*(1998) from full-scale measurement show that this amplitude dependent characteristics can be well described by Jeary's(1986) damping model and damping exhibits randomness, especially in certain amplitude ranges. The uncertainty or randomness of damping has been investigated by several researchers. Haviland(1976) reported a wide range of damping data for different response amplitude levels, structural systems and building heights. His study showed that the log-normal and Gamma distributions provided the best fit to the data including the damping collected at low and high amplitude levels. However, field damping data (Fang *et al.* 1999, Li *et al.* 1998) show that, in the low amplitude range, the damping in buildings is mainly dominated by determinant factors and at high amplitude level, governed by the random factors. This suggests that the PDF of damping at the high amplitude level can be only determined by the data measured at the high amplitude level.

This paper describes the amplitude dependent behavior and probabilistic characteristics of damping in a tall building. The probability analysis is performed based on the damping data measured at the high amplitude level.

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2. Instrumentation and measurements

The building studied is 120 meters tall, with 30 storeys. It is a composite structure with form very close to a square shape. Two accelerometers were placed orthogonally at the top of the building where the response of the building has been recorded continuously since 1995. Measurements are amplified and low pass filtered at 5 Hz before being digitized at 30 Hz.

Li *et al.*(1996) found that the acceleration response in each direction of the building is dominated by the first natural frequency. This suggests that the measured damping corresponds to the first mode. To obtain the damping samples at every amplitude level, the fundamental mode of the response is band-passed with an 8 pole filter and the random decrement analysis process is performed at 200 levels. The random decrement signature on each graph represents a one-month accumulation of result with a minimum of 1000 averages so that each point on the curve converges towards the mean, before performing curve filtering. The analysis presented here is based on the sampling of the two data channels from September 1995 to January 1997.

3. Amplitude dependent behavior and probabilistic characteristic of damping

Fig. 1 shows a typical damping sample measured from this building. It can be seen that the damping values are located in three regions, i.e., 'low amplitude plateau', 'nonlinear region' and 'high amplitude plateau' as pointed out by Jeary (1986). The damping values in different amplitude ranges can be expressed as

$$\zeta = \begin{cases} 0.249, & A < 0.0069 \\ 31.23A + 0.0355 & 0.0069 \le A \le 0.01455 \\ 0.4881A > 0.01455 \end{cases} \tag{1}$$

where ζ is damping ratio in % and A is amplitude in meter.

In the nonlinear region, according to the results of statistical analysis, the average rate of

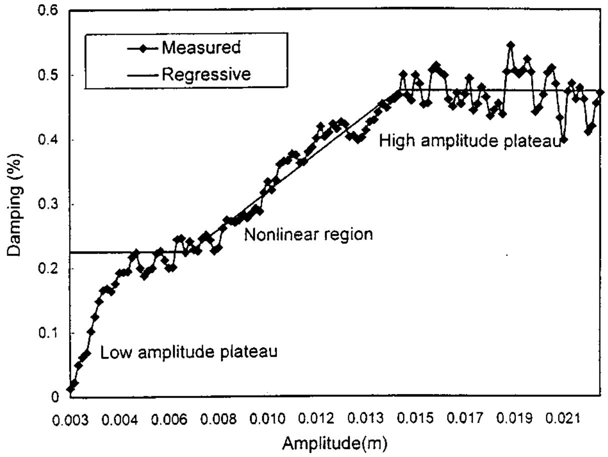

Fig. 1 Typical damping in building

change of damping with amplitude is equal to 31.54 (%/m). By using the interval estimate theory, the mean change rate of damping falls within the range [31.26, 31.82] with 99.95% confidence level.

Jeary (1986) suggested that the change rate of damping with amplitude can be expressed as $\log_{10}\sqrt{D}/2$ for tall buildigns. Where D(m) represents the dimension of the building, at ground level, in the direction of the motion. This dimension should include the main part of the structure and all attachments. Based on the results of statistical analysis, it is suggested that Jeary's formula should be modified as

$$k = \log_{10}\left(\frac{\sqrt{D} - 1.61}{2}\right) \tag{2}$$

where k is the change rate of damping with amplitude in (%/m).

For this building, D=33(m), then, k=31.54(%/m) calculated by Eq. (2), i.e., k falls within the range [31.26, 31.81].

The skewness coefficient S_k and the kurtosis coefficient K_u are useful parameters for characterizing a PDF curve. The normal distribution is a symmetric curve, so that presents S_k=0. For normal distribution, the kurtosis normally takes a value of K_u=3. It is more convenient to use the reduced variable when dealing with the probability distribution, defined as

$$z = \frac{(x - \bar{x})}{\sigma} \tag{3}$$

where x is the measured damping data in the high amplitude range.

Based on the measured damping data, for the reduced variable, the skewness coefficient S_k=-0.1434 and kurtosis K_u=3.0632. These values are very close to zero and 3, respectively, suggesting that the probability distribution of damping in the high amplitude range is close to a normal distribution. The Chi-square goodness-of fit test is used to confirm this hypothesis. The

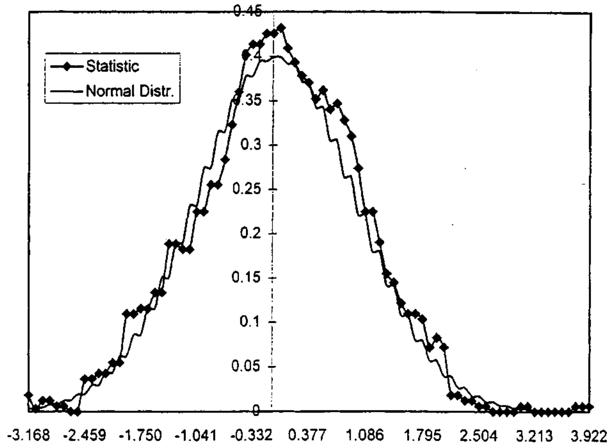

Fig. 2 PDF of damping at high amplitude level

test result shows that the hypothesis of normality is accepted with 99.95% confidence level. The comparison between the PDF obtained based on the measured damping data and the Gaussian PDF is shown in Fig. 2.

It can be seen from Fig. 2 that the actual PDF of damping is very close to the Gaussian PDF except at the peak point which coincides with K_u=3.0632>3, suggesting, therefore, that the PDF of damping can be considered to be Gaussian distribution in the high amplitude range.

Based on the results and discussions presented above, the following stochastic damping model is proposed to estimate amplitude-dependent damping for practical application.

$$\zeta = \begin{cases} \xi_0, & A < A_0 \\ kA + c, & A_0 \leq A \leq A_T \\ \zeta_m + \alpha, & A > A_T \end{cases} \tag{4}$$

where ζ_0 is damping at low plateau, A_0 and A_T are turning points of yield, k is the slope of nonlinear part of damping curve, c is a constant and ζ_m is mean damping value at the high amplitude plateau, as suggested by Jeary (1986) $\zeta_m(\%)=46/L$, in which L is the height of the builiding. α is a random variable with Gaussian distribution.

It is worth noting that the absolute values of damping presented above are particularly small. It is interesting to note that the low amplitude plateau values start at a much lower level of damping than had previously been considered normal. The rise through the nonlinear zone appears to be briefer than had been supposed and the final high amplitude plateau is at a small absolute value of damping that would be considered normal. It is entirely feasible that the structural form of the building is responsible for these observations.

4. Conclusions

Based on the full-scale measurements of damping in a tall building, the amplitude dependent characteristics of damping have been studied. The change rate of damping with amplitude in nonlinear region has been discussed. The probability density function (PDF) calculated from the recorded damping data shows that the actual PDF of damping in the high amplitude range can be represented by a Normal distribution (Gaussian distribution). A stochastic damping model is proposed to estimate amplitude-dependent damping for practical application. The obtained PDF distribution of damping and the stochastic damping model can be used to estimate the damping values and evaluate the dynamic response of structures with uncertain damping.

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