STRENGTH AND DISPLACEMENT CHARACTERISTICS OF STEEL COLUMNS SUBJECTED TO MODERATE EARTHQUAKE LOADS

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Introduction

Sri Lanka is considered to be an earthquake-free country hence the effects of earthquake induced loads have not been taken into account in structural designs of most of the structures. However, in recent past significant increase in frequency of occurrences of medium to large earthquakes around neighbouring countries, mainly in and around Indonesian islands have been observed. In addition, there is a concern that a new plate boundary is being developed 400km away from the southern coast of Sri Lanka, dividing the Indo-Australian plate. The 2004 tsunami disaster also reminded us the importance of preparing for unexpected natural hazards. Although the probability of occurrence of earthquake in Sri Lanka is very low we can not completely ignore the threat. An attempt is made in this study to initiate research work aiming at developing design guidelines for earthquake resisting steel columns representing bridge piers. Here, behaviour of steel columns subject to minor to moderate earthquake loads is studied emphasizing economical aspects.

The proposed method includes developing a suitable load-displacement hysteretic model and carrying out dynamic analyses using the proposed model to predict maximum displacement demand of steel columns subjected to a given earthquake. The proposed procedure can equally be adopted to check the safety of exiting structures or to carryout new designs. The performance of steel columns that have different sectional shapes is studied. Sectional configurations are decided by keeping equal steel volume in all the columns in order to identify the most economical sectional shape with respect to its deformation capacity. Pushover analyses and numerical analyses of the single degree of freedom system that idealizes bridge piers are carried out to this end. Nonlinear pushover analysis has been found to be a simple and reliable analytical method for predicting the capacity and structural demand of steel columns (Krawinkler and Seneviratna, 1998).

Methodology

Total of ten column models including four box-shaped sections and six circular-shaped sections were selected for the study. Sections were selected so that the total volume of steel per unit length remains constant. This was done by introducing longitudinal stiffeners and/or adjusting thickness of the plates in the case of box-shaped sections. In circular-shaped sections radius and thickness of plates were adjusted to maintain the constant volume. A series of pushover analysis were conducted considering material nonlinearity of steel for each column. The resulting lateral load-lateral deformation curves were used to develop a bilinear load-deformation model, which is to be used in dynamic analysis. Bilinear model is developed considering equal energy criterion, as shown in Figure 1, where the line *OA* is determined by the initial slope of the pushover curve and the line *AB* is determined in such a way that area under lines *OA* and *AB* up to the point *B* is equal to the area under pushover curve up to the point *B*. The failure point *B* is decided by a kind of failure criterion proposed by Zheng *et al.* (2000). The single degree of freedom system model assumed for dynamic analyses is shown in Figure 2. The bending stiffness of column, $\boldsymbol{k}$ is given by $\boldsymbol{k_1}$ and $\boldsymbol{k_2}$ as shown in Figure 1. The equation of motion, $m\ddot{U} + c\dot{U} + kU = -m\ddot{U}_g(t)$, was numerically solved (i.e., time history analysis) using MATLAB program. Here, $\ddot{U}g(t)$ is the acceleration records of two past earthquakes (i.e., Koyna-Dam Earthquake in India (1967) and Basso-Tirreno Earthquake in Italy (1978)). Then the maximum value of displacement response (U) of each column was obtained.

Results and Discussion

Pushover curves obtained from box- and circular-shaped columns are shown in Figures 3(a) and 3(b), respectively. Usually longitudinal stiffeners are introduced to box columns in order to increase the strength and ductility but in this study it is observed that unstiffened section carries higher loads than the stiffened sections. This is attributed to the constrain we imposed on steel volume when deciding the sectional configurations. When stiffeners are introduced while keeping constant steel volume the thickness of plates might decrease beyond a point where the performance decreases. The parameter R_t given by $R_t = d\sigma_y\sqrt{3(1-\upsilon^2)}/(2tE)$ where t, d, σ_y, v, E are thickness; diameter; yield strength; Poisson's ratio, and Young's modulus, respectively, is useful in analyzing deformation characteristics of circular columns. As per Figure 3(b) the section having R_t=0.069 shows the minimum energy absorption capacity. When R_t increases load carrying capacity increases but when R_t increases beyond 0.177 a sudden drop of load carrying capacity was observed.

The maximum displacement of pipe section columns when subjected to the selected two earthquake records were computed and it was found that the displacements are comparatively smaller when R_t is in the range of $0.10<R_t<0.08$. The maximum displacement observed in box-shaped columns did not show any specific pattern with respect to width-thickness ratio. It was apparent that the effect of sectional configuration highly depends on the range of width-thickness ratio of the section. Therefore, it will not be practicable to examine the best sectional shape by keeping constant volume and thereby imposing strict restriction on the thickness of plates. The proposed procedure will be very useful in analysing the dynamic behaviour of bridge piers.

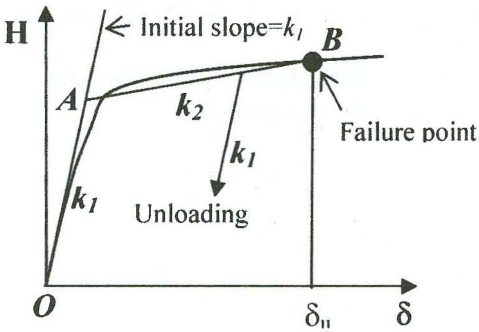


Figure 1. Development of bi-linear model

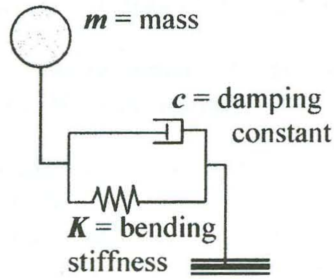
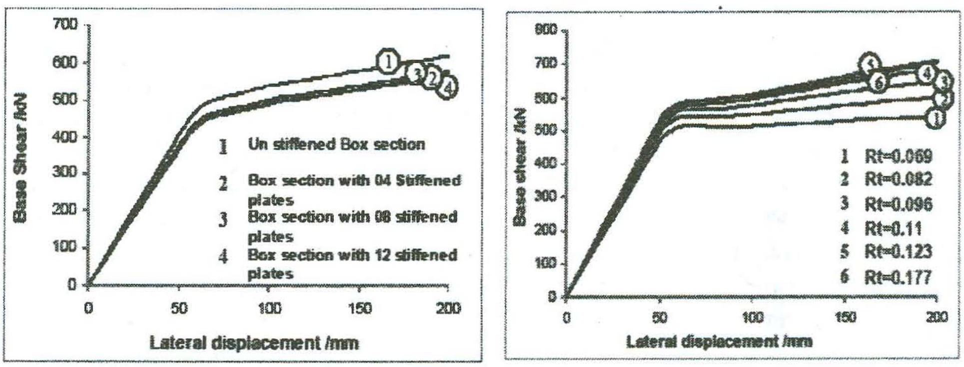


Figure 2. Analytical model



(a) Box-shaped columns

(b) Circular-shaped columns

Figure 3. Pushover curves for box-shaped and circular-shaped columns

References

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