APPLICABILITY OF EQUAL ENERGY ASSUMPTION TO STEEL ARCH BRIDGES

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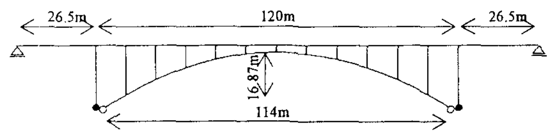
1. INTRODUCTION

Japanese seismic design code for highway bridges specifies Ductility Design Method, which is based on static analysis considering the material and geometrical non-linearity, as the design method against severe earthquakes such as the Great Kanto Earthquake and the Hyogo-ken Nanbu Earthquake. However, the application of this method is limited because the applicability of the equal energy assumption is not clear for some structures including the steel arch bridges. Nonlinear dynamic response analysis is required for the seismic design of steel arch bridges which generally needs a lot of calculation time and cost.

The main goal of this research is to examine the applicability of equal energy assumption for the seismic design of steel arch bridges as a simplified seismic design method which is based on static analysis and makes the use of dynamic response analysis redundant.

2. Studied Model

A steel arch bridge model shown in Fig.1 was studied by MSC.Marc non-linear finite element analysis software. Mass of the elements were considered as lumped masses concentrated at the nodal points. Fiber modal was employed in order to consider the material non-linearity. Throughout the research linear and nonlinear time history analysis was conducted. For the nonlinear case stress-strain relationship of the material is considered to be bi-linear where the slope of plastic portion was taken as 0.01 of elastic potion. For both cases kinematic hardening rule is used and Rayleigh damping was employed in order to consider the damping effect. The damping constant is assumed to be 0.03. Side sway modes shown in Table.1 were accepted as the principal modes.



	D_x	D_y	D_z	Θ_x	Θ_y	Θ_z
△	Free	Fixed	Fixed	Free	Free	Free
○	Fixed	Fixed	Fixed	Free	Free	Free
●	Fixed	Fixed	Fixed	Fixed	Free	Free

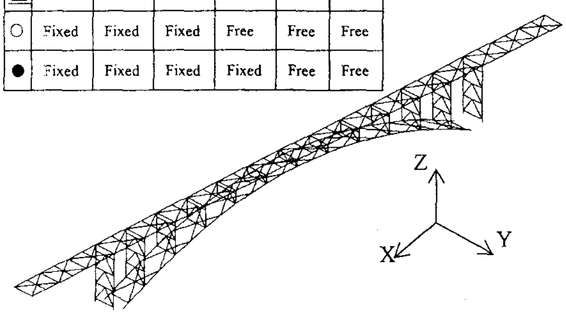


Fig 1: Analyzed Model

Table 1: Principal Natural Modes

Principal Mode periods(sec.)	Mode Shape Type
1.038	Symmetric
0.548	Asymmetric
0.383	Symmetric

3. Methodology

As a first step, free vibration modes and frequencies were obtained by performing free vibration analysis. Then elasto-plastic pushover analysis was performed in order to get the force-displacement relation curve by applying a force pattern in out-of-plane direction to each node of the model which is directly proportional to the side sway free vibration mode shown in Fig 2. As a next step, linear and nonlinear dynamic response analysis were carried out by using the spectral fitted 1995 KOBE JMA N-S ground motion for ground condition I (Ie2.t211). For this ground motion the response was completely elastic and maximum responses in linear and nonlinear analyses were found to be equal. In order to have discrete linear and nonlinear responses the ground motion was amplified by 1.5, 1.7, 2 and 5 respectively, and linear and nonlinear analysis with these ground motions were repeated. Then, maximum nonlinear response for the span center node of the deck was estimated by equal energy assumption by using force-displacement relation curve of the same node obtained by pushover analysis, and the maximum response displacement obtained by linear time history analysis. Finally, the estimated maximum nonlinear response (δ_{SP}) was compared with the one that was calculated by nonlinear time history analysis (δ_{DP}). δ_{SP}/δ_{DP} value was used as a basic governing factor that indicates the applicability of the equal energy assumption.

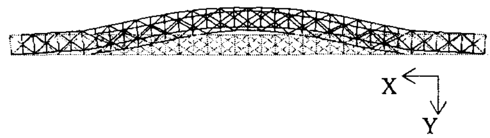


Fig. 2: Source free vibration mode for pushover analysis (T=1.038sec.).

4. RESULTS

In Table 1 δ_{SP}/δ_{DP} values and ductility factor μ_E ($=\delta_{SP}/\delta_y$, δ_y: yield displacement) values are shown together with the maximum linear response δ_{DE} and maximum nonlinear response δ_{DP}, which were calculated by time history analysis. For all the cases, maximum linear responses were found to be greater than the nonlinear response. So, the estimated maximum nonlinear response (δ_{SP}) was found to be larger than the calculated nonlinear response. Additionally, the relationship between δ_{SP}/δ_{DP} values and μ_E values are illustrated in Fig 3. According to this relationship the value of δ_{SP}/δ_{DP} becomes larger with the increase in μ_E. So it is possible to say that the accuracy of the assumption drops off with the increase in ductility factor.

Table 2: Analyses Results

Ground Motion	δ_{DE}(m)	δ_{DP}(m)	δ_{SP}(m)	μ_E	δ_{SP}/δ_{DP}
L2.t2111	0.353	0.353	0.353	0.876	1.000
L2.t2111×1.5	0.528	0.524	0.532	1.319	1.015
L2.t211×1.7	0.599	0.585	0.609	1.511	1.041
L2.t2111×2	0.704	0.665	0.732	1.816	1.101
L2.t2111×5	1.740	0.884	2.727	6.766	3.084

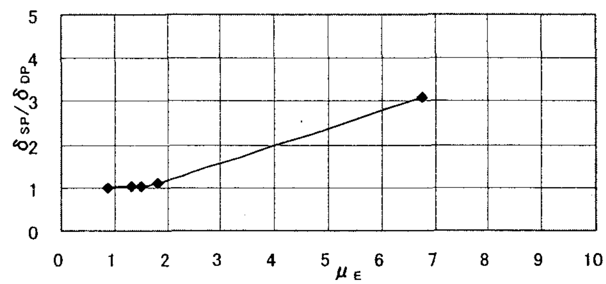


Fig 3: δ_{SP}/δ_{DP}- μ_E relationship

5. CONCLUSIONS

As it is stated in the results, the estimated maximum response was found to be greater than the calculated maximum nonlinear response. So it can be concluded that application of equal energy assumption resulted in a safe side estimation for this analysis. But more study with various structural models and input ground motions is necessary to reach a conclusion for the general behavior of steel arch bridges.

After generating more models, parametric analysis will be carried out with other different ground motions. And it could be possible to find a general pattern that represents the general behavior of steel arch bridges for the applicability of equal energy assumption.

6. REFERENCE

Nakamura, S., Ida, Y. and Takahashi, K.: A Prediction Method of Maximum Inelastic Seismic Response for steel Portal Frame Bridge Piers, *Proceedings of the First International Conference on steel & Composite Structures,* Vol.2, pp.1047-1054, 2001.6