APPLICABILITY OF EQUAL ENERGY ASSUMPTION TO STEEL ARCH BRIDGES

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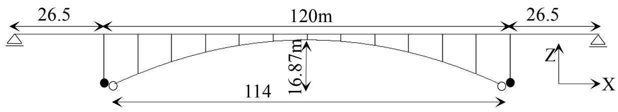
1. Introduction

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 develop a simplified seismic design method for steel arch bridges that is based on static analysis. As a first step to reach that goal, applicability of equal energy assumption has been studied.

2. Studied Models

Six steel arch bridge models were studied by MSC.Marc non-linear finite element analysis software. Model 1, shown in Figure.1 was used as the template model for the generation of model 2, 3, 4 only by changing the arch rise, and model 4, 5 only by changing the distance between two arch ribs. The models are generated by using JIP preliminary design software for steel arch bridges. All models with their structural parameters are shown in Table.1. Lumped mass approach was used for all models. Fiber modal was employed in order to consider the material non-linearity. Throughout the research linear and nonlinear time history analyses were conducted. For the nonlinear case stress-strain relationship of the material is considered as bi-linear where the slope of plastic portion was taken as 0.01 of elastic potion. Kinematic hardening rule was used and Rayleigh damping was employed. The damping constant was assumed as 0.03. Principle free vibration mode shapes and frequencies, which are two symmetric and one asymmetric



	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	Fixed

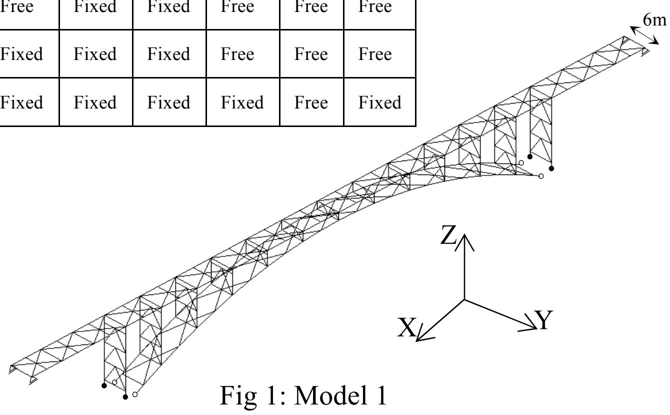
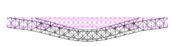
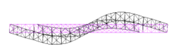
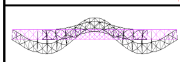


Fig 1: Model 1

Table 1: Analyzed model structural models.

	Span Length(m)	Arch Rise(m)	Arch Rise / Span Length	Width(m)
Model 1	114	16.87	0.15	6
Model 2	114	22.8	0.2	6
Model 3	114	34.2	0.3	6
Model 4	114	45.6	0.4	6
Model 5	114	16.87	0.15	9.5
Model 6	114	16.87	0.15	13

Table 2: Principle free vibration mode frequencies

Mode Shape	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	1.007	0.995	0.824	0.647	1.315	1.363
	1.474	1.502	1.328	1.127	1.905	1.739
	2.082	2.204	2.014	1.839	2.723	2.323

Keywords: Seismic Design, Equal Energy Assumption, Steel Arch Bridges.

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side sway modes are shown in Table.2.

3. Methodology

As a first step, free vibration mode shapes and frequencies were obtained by performing free vibration analysis. Then elasto-plastic pushover analysis was performed in order to obtain the force-displacement relation curve by applying a force pattern in out–of-plane direction which is directly proportional to the first symmetric side sway free vibration mode shape. As a next step, linear and nonlinear dynamic response analyses were carried out by using the spectral fitted 1995 KOBE JMA N-S ground motion for ground condition 1 (le2.t211).The same ground motion was amplified by 1.2, 1.5, 1.7, 2 and 5 respectively in order to see the tendency how the response varies with the increase in ground motion. 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.

4. Results

The analysis results for model 1 are shown in Table 3. δ_{SP}/δ_{DP} values and ductility factor μ_E ($=\delta_{SP}/\delta_y$, δ_y: yield displacement) values are illustrated 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 making it impractical to use the equal energy assumption directly for the design procedure although the method resulted in safe side estimation. Similar results were obtained for other models. The estimation accuracy versus ductility factor for all models is plotted together in Fig 2. Here it is seen that the estimation accuracy drops off with the increase in ductility factor. The values are gathered almost at the same accuracy values suggesting that the structural parameters have no apparent influence on the assumption's applicability. The final values for Model 4 and 5 (The ones for L2.t211×5 ground motion) can be excluded as the ductility ratios were found to be too large making it impractical for design.

Table 3: Analyses results for model 1.

Ground Motion	δ_{DE}(m)	δ_{DP}(m)	δ_{SP}(m)	μ_E	δ_{SP}/δ_{DP}
L2.t211	0.353	0.353	0.353	0.876	1
L2.t211×1.2	0.4231	0.423	0.423	1.05	1
L2.t211×1.5	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.t211×2	0.704	0.665	0.732	1.816	1.101
L2.t211×5	1.74	0.884	2.727	6.766	3.084

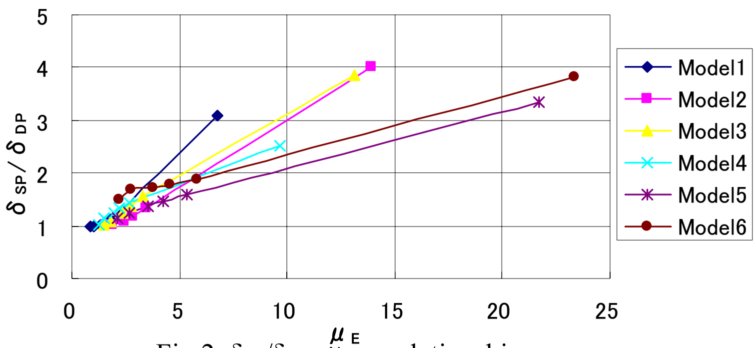

Fig 2: δ_{SP}/δ_{DP}- μ_E relationship

5. Conclusions

The direct application of equal energy assumption for the seismic design of steel arch bridges was found to be impractical for all models analyzed. But since the assumption accuracy varies almost in the same manner for different models it is though that more accurate and practical results could be obtained by developing some correction functions.

The correlation between the assumption accuracy and maximum non-linear response will be studied out and correction functions to improve the estimation accuracy will be developed at the forthcoming stages of the research.

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