

Short communication

Expansion of a static analysis-based out-of-plane maximum inelastic seismic response estimation method for steel arch bridges to in-plane response estimation

Osman Tunc Cetinkaya^a, Shozo Nakamura^{b,*}, Kazuo Takahashi^b

^a Nagasaki University, Graduate School of Science and Technology, 1-14, Bunkyo-machi, Nagasaki 852-8521, Japan

^b Nagasaki University, Department of Civil Engineering, 1-14, Bunkyo-machi, Nagasaki 852-8521, Japan

ARTICLE INFO

Article history:

Received 11 September 2007

Received in revised form

19 February 2009

Accepted 24 February 2009

Available online 24 June 2009

Keywords:

Seismic design

Equal energy assumption

Steel arch bridges

Dynamic response analysis

ABSTRACT

We have previously proposed a static analysis-based method for estimating the maximum out-of-plane inelastic seismic response of upper-deck steel arch bridges. The method is developed on the basis of the numerical examinations of 6 upper-deck steel arch bridge models. It employs free vibration analysis, response spectrum method and equal energy assumption for the estimation of maximum out-of-plane response. Correction functions are proposed to modify the estimates by the equal energy assumption. In the current study, applicability of the same procedure to the estimation of maximum in-plane response is discussed. It is found that the method can be used also for the maximum in-plane response estimation by only modifying the pushover analysis procedure. The validity of the method is demonstrated for the same parametric models through further numerical evaluations.

© 2009 Elsevier Ltd. All rights reserved.

1. Introduction

Japanese seismic design code for highway bridges [1] was revised after the Hyogo-ken Nanbu earthquake and a new design ground motion type called the Level 2 ground motion was introduced. The inelastic response demand of all structures is specified to be obtained for the verification of the design against this new ground motion. Steel arch bridges are no exception. Nonlinear dynamic response analysis became compulsory to obtain the inelastic seismic demand for them. This greatly complicates the design process for steel arch bridges, which are conventionally treated as structures for which earthquake loading is not predominant. A method that does not rely on dynamic response analysis will significantly simplify the seismic design.

In the previous research [2] we have developed a method for the estimation of maximum inelastic out-of-plane response of upper-deck steel arch bridges that do not require dynamic response analysis. The method combines pushover analysis, which is simpler than the conventional dynamic time-history analysis [3–9], with the response spectrum method by using the equal energy assumption [10] with some correction functions to improve the estimation accuracy. The correction functions are generated

through the numerical evaluations of 6 parametric upper-deck steel arch bridge models.

Although seismic deficiencies under longitudinal excitations in steel arch bridges are minor [11], a simplified approach for the in-plane response, which can be an additional tool for the evaluation of the overall seismic performance, is also necessary. For this purpose, in the present paper the applicability of our method to the maximum in-plane response estimation is studied by carrying out numerical examinations on the same bridge models studied previously. It is found that the method can be applied to the estimation of maximum inelastic in-plane response with a reasonable accuracy by only changing the pushover analysis procedure.

2. Proposed method

The basic application steps of the method to the in-plane response estimation are listed below. All of the steps are the same with the original out-of-plane estimation [2] except the modification of the load pattern for the pushover analysis.

Step 1. Establish a finite element (FE) model for the upper-deck steel arch bridge under investigation.

Step 2. Perform eigenvalue analysis to acquire the predominant vibration modes.

Step 3. Obtain the force-displacement relationship of the structure as well as the yield displacement (δ_y) by performing elasto-plastic

* Corresponding author. Tel.: +81 95 819 2613; fax: +81 95 819 2613.

E-mail address: snakamura@civil.nagasaki-u.ac.jp (S. Nakamura).

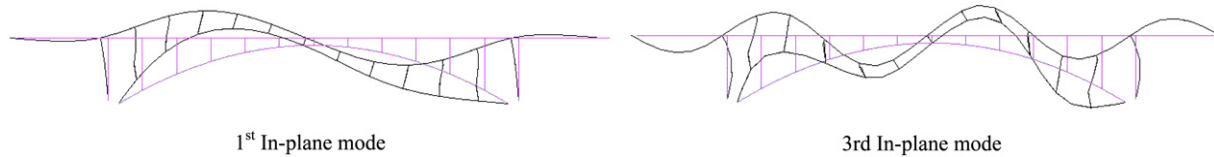


Fig. 1. Predominant in-plane eigenmodes (Model 1).

pushover analysis by using an incremental displacement load pattern placed at the mid point of the stiffening girder in the longitudinal direction (See 3.2).

Step 4. Obtain the maximum response from the response spectrum specified in the JRA code [1] for Level 2 ground motion depending on the corresponding ground condition and modal damping ratio. Calculate the corresponding elastic strain energy.

Step 5. Estimate the maximum inelastic response displacement (δ_{SP}) by applying the equal energy assumption to the force-displacement curve obtained in step 3 and the maximum strain energy obtained in Step 4. Calculate the estimated ductility factor μ_E , ($\mu_E = \delta_{SP}/\delta_y$).

Step 6. Calculate the value of the correction function $f(\mu_E)$ either for the average estimation (Eq. (1)) or the lower bound estimation (Eq. (2)).

$$f(\mu_E) = 1/(0.1843\mu_E + 0.8159), \quad (0 < f(\mu_E) \leq 1) \quad (1)$$

$$f(\mu_E) = 1/(0.1700\mu_E + 0.7050), \quad (0 < f(\mu_E) \leq 1) \quad (2)$$

$$\delta'_{SP} = f(\mu_E) \times \delta_{SP}. \quad (3)$$

The average estimation correction function is for the optimum estimation whereas the lower bound estimation correction function guarantees that the estimated maximum response is greater than or equal to the actual inelastic response. Correction is only necessary when the value of the correction function is less than 1. Correction is carried out by simply multiplying the estimated maximum inelastic response by the correction function of the desired type as shown in Eq. (3).

3. Numerical evaluation

3.1. Analyzed models

Applicability of the method to the in-plane response estimation is studied numerically on the six upper-deck steel arch bridge models originally generated to establish the method for the out-of-plane direction [2]. Some members of the models are enlarged in order to improve their strength against in-plane excitations. The models are again analyzed by using MARC nonlinear finite element (FE) analysis software [12].

The natural frequencies and modal participations of predominant eigen modes in the longitudinal direction are listed in Table 1 (The whole eigenvalue analysis results can be seen in the previous paper [2]). The first and the third in-plane modes have the greatest contribution to the overall in-plane response as they have larger effective mass ratios. However, it should be noted that the contribution of these two modes is quite small compared to that of the predominant modes in the out-of-plane direction [2] because of the significant participation coming from the higher modes. The shapes of these two modes are illustrated in Fig. 1 showing that they are asymmetric.

3.2. Pushover analysis

The applicability of the method greatly depends on selecting an appropriate load pattern for the pushover analysis that will

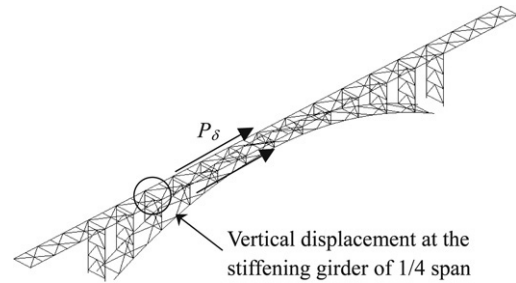


Fig. 2. Reference point and the load pattern for the pushover analysis.

deform the structure similar to maximum dynamic response. In the out-of-plane response estimation, the load pattern proportional to the product of the eigenvector of the dominant single mode and the distribution of the concentrated mass was adopted [2]. The same approach was applied to the in-plane pushover analysis by adopting a modal force distribution from the single dominant mode in the longitudinal direction (1st in-plane mode). The vertical component of this mode was also taken into account since vertical displacement is significant in the longitudinal excitations. However, analysis revealed that the deformed shape of the pushover analysis is significantly different from the displacement distribution of the dynamic response when such a load pattern is employed. The reason for this is basically that the participation of this mode in the overall in-plane response is small compared to the case of the out-of-plane response.

Although there are some improvements for pushover analysis proposed for better predictions such as considering more than one mode [7–9], they will result in more complicated procedures. Therefore, an alternative load pattern shown in Fig. 2 is adopted for the pushover analysis due to its simplicity which is likely to simulate dynamic response at its ultimate stage. This is an incremental displacement load (P_δ) applied at the mid-point of the stiffening girder from the both sides, as shown in the figure. To check the validity of this loading pattern, the displacement distribution obtained by pushover analysis is compared with that obtained from the dynamic response analysis. The comparisons are given in Fig. 3 only for the stiffening girder in each model since similar shapes are also observed for the arch ribs. The displacement distributions are obtained at the time increment representing the maximum value of the vertical displacement at the reference point in the dynamic response analysis and at the static force increment corresponding to the same value at the reference point in the pushover analysis. A Level 2 Type-II earthquake ground motion magnified with a factor of 5 is utilized in order to acquire enough plasticity in the members. The reference point is selected as the node at the 1/4 span on the stiffening girder since the maximum vertical displacement is observed at this node during dynamic response analysis. These comparisons demonstrate that the displacement distributions agree well with each other suggesting that the employed load pattern is sufficiently accurate to account for the in-plane dynamic behavior.

3.3. Estimation accuracy

The validity of the method for the in-plane response is illustrated through the numerical examples by comparing the

Download English Version:

<https://daneshyari.com/en/article/268521>

Download Persian Version:

<https://daneshyari.com/article/268521>

[Daneshyari.com](https://daneshyari.com)