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Using the Sinusoidal Shape Function in Analyzing the 3-Span Continuous Concrete Bridges in Lateral Direction

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ABSTRACT: With attention to the importance of the three-span continuous bridges and the complexity of analyzing structures with multi-degree of freedom, utilizing desirable numerical models to estimate the internal forces of this group of structures is highly effective. A new analyzing method is introduced in this study which can be used to the 3-span continuous bridges with constant section and heavy moment resistance in the transverse direction. The defined pattern is based on employing sinusoidal shape function both the bridge's deflection shape and its corresponding applied forces. This model is developed by assuming a simple beam on the elastic constraints and thereby its results can be earned by minimizing the created potential function of the whole structure. Creating a desirable manual method in calculating the internal shear forces of columns in the three-span bridges is a good comparative idea over the complicated method proposed by Aashto needing 3-dimensional modeling in related software. By considering 5 different states of an example sample and analyzing those, the obtained results of the suggested way prove its high precision and efficiency on controlling the calculations manually because of having mostly the errors less than 3 percent related to the exact method.

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INTRODUCTION

Since the process of calculating the column forces precisely is very complicated needing some specialty [1, 2, 3], Estimating the bridge transverse forces by a manual accurate method can help engineering societies find some of the analyzing results from other methods. The newly introduced pattern is based on defining a deformation shape function under the lateral forces and utilizing the Aashto formulas to analyze such bridges.

By assuming a sinusoidal shape for the bridge deck's deformation form, and also determining the actual transverse loading and its corresponding deflection configuration, the analysis process can be simplified clearly [5,4]. Thereby, the amounts of needing variables will be computed by minimizing the potential function of the whole structure. The potential function is originated by summing the kinematic energy related to the deformed components (U) and the potential energy (V) gathered in resisting components [6].

In this study, the internal shear forces of columns and the transverse vibration period are computed through proposed and Aashto methods for five different bridges, and the results will be compared together.

To estimate the precision of the energy method, each of the samples has been investigated in different conditions of column's transverse stiffness and the length of spans. Eventually, according to the above says five distinct cases are evaluated by both patterns. The results show that this way can be employed for all types of 3-span continuous bridges.

Some similar studies have been done about continuous bridges with insolated piers. In these researches, the suggested methods of Aashto, the seismic responses of bridges with several bays due to changing the stiffness of deck to piers and controlling the design based on deformation pattern or force one are investigated analytically [7,8,9].

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Introducing the Aashto SMSA method

The defined procedure of Aashto is single-mode spectral analysis (SMSA). In this way, a first step of the deformation shape of the structure will be gained by analyzing that in software under the unite uniform load imposed laterally, and then the new loading pattern which is according to the first mode deformation shape will be achieved. By applying the new loading shape to the bridge's deck transversally and analyzing the structure once again the internal forces of piers will be obtained.

Energy proposed method

In the first phase of the proposed method, the sinusoidal shape function with unknown amplitude ($V_s=V_0\sin\pi x/L$) is assumed under the effect of the uniform load. In the second phase, the process of solving will be repeated once again by

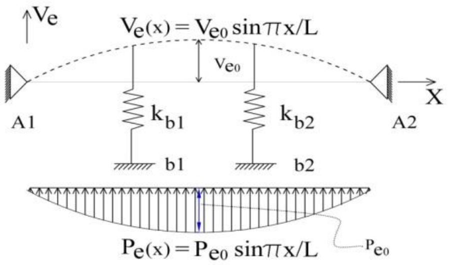

Fig. 1. Structure deformed model under sinusoidal transverse load.

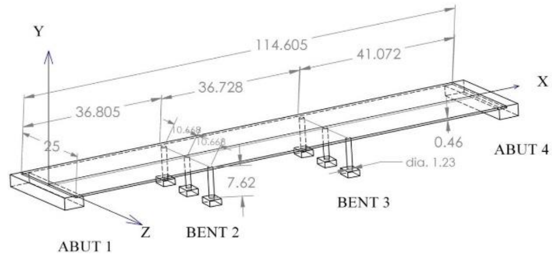

Fig. 2. Concrete bridge of Aashto example [1].

considering the sinusoidal shape function for both loading history ($P_e(x)=P_{e0}\sin\pi x/L$) and its corresponding deflection ($V_e(x)=V_{eo}\sin\pi x/L$). The unknown variables in each of the phases can be achieved by minimizing the total energy function due to the entering energy and the saved energy of resisting components against the assumed deformation. The entering energy is equivalent to the negative work due to external forces and the internal energy is equal to summing the strain energies due to bridge deck (U_d) and bridge piers (U_b). The equation of total energy function is offered in Eq. (1).

$$\Pi = U + V = U_d + U_b - W_{P_0} \tag{1}$$

By having the deformation shape, the columns' shear forces and the vibration period of the bridge will be gained. The ultimate deflection shape of the bridge can be modeled as Fig. 1. The shear forces of columns can be computed by having the column's lateral stiffness (K_b) and the deformation corresponding to the piers' location ($V_{e0}\sin\pi x/L$), as given in Eq. (2).

$$F_{b1} = k_b . V_{eo}\sin(\pi x/L) \tag{2}$$

Validating of Software modeling and comparing to energy method

To validate the 3dimentional modeling and solving process in the Aashto method, one of the Aashto examples analyzed in SAP software has been compared herein (Fig. 2). The modeling process has been done under part 2. All of the obtained outputs and the way of deformation have been compared quantitatively.

The elected example has been analyzed also by the energy method. All of the analyzing processes are according to part 3. This sample is the main one which is called in Table 1 as case 1.

Controlling the suggested method in several different models

To compare the precision of the proposed method, 5 different models have been considered. The main sample is the same as the Aashto example which is a 3-span continuous bridge with a deck having high flexural resistance in the transverse direction (Fig. 2) (case 1). The other four samples have been developed by changing the bays' length and columns' stiffness, where case 2 and case 3 models with lower and upper column stiffnesses, respectively, and case 4 and case 5 are samples with different bridge span lengths over the case1. The obtained outputs have been compared quantitatively in Table 1. According to Table 1, assuming sinusoidal shape for lateral deflection of the bridge with heavy deck, high flexural resistance, and using the energy conservation law in solving process will lead to reasonable results.

Table 1. Result comparisons between Aashto &energy.

Variables	sample	The Aashto method (SMSA)	Energy Method (Proposed pattern)	Error (%)
The maximum of deformation (V_0)	Case 1	1.05mm	1.07mm	1.9
	Case 2	0.858	0.864	0.7
	Case 3	1.3	1.317	1.3
	Case 4	1.229	1.255	2.11
	Case 5	1.5	1.515	1.0
Vibration period in the transverse direction(T)	Case 1	0.317s	0.318s	0.32
	Case 2	0.28	0.284	1.43
	Case 3	0.3487	0.351	0.66
	Case 4	0.3397	0.3427	0.88
	Case 5	0.3416	0.3766	10.25
The maximum of deflection under the $P_e(x)$ loading (V_{e0}	Case 1	32.08mm	32.03mm	0.15
	Case 2	25.71	25.56	0.58
	Case 3	38.4	38.95	1.43
	Case 4	36.552	37.12	1.55
	Case 5	51.6	44.83	13.12
The shear forces of columns in bent 1(F_C)	Case 1	170ton	174ton	2.35
	Case 2	214.4	219	2.15
	Case 3	125.5	125.8	0.24
	Case 4	165.97	171.05	3.06
	Case 5	166.98	146.9	12.03
The shear forces of columns in bent 2(F_C)	Case 1	182ton	185ton	1.65
	Case 2	229.6	239	4.09
	Case 3	134.4	134.2	0.14
	Case 4	165.97	171.05	3.06
	Case 5	166.98	146.9	12.03

CONCLUSIONS

The proposed energy method without needing 3D modeling in professional software can be intended as a desirable manual method for designers. Through this way, by assuming a sinusoidal deflection function and using the Aashto parameters, an accurate estimate of results can be achieved. The results in the introduced pattern showed mostly errors fewer than 3% over the exact one where it's investigated in 5 separate models through changes in piers' stiffness and spans' length.

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