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NONLINEAR INTERACTION MODELS FOR THE EVALUATION OF THE RESPONSE OF BRIDGE STRUCTURES

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SUMMARY

The impact between the bridge deck and the abutments has been the source of extensive damage during the 1971 San Fernando and more recent earthquakes. In this paper a model for the investigation of this impact is presented and analyzed. The focus of the model is to represent the nonlinear response of the bridge abutments, the foundation and the columns. The model is used for the investigation of the response of a short bridge located in California.

INTRODUCTION

The impact between the bridge deck and the abutments during strong earthquake shaking is a phenomenon that has attracted the interest for research during recent years. More specifically, during the 1971 San Fernando earthquake, several moderate span bridges with relatively large skew angles showed a tendency to rotate in a horizontal plane in a direction that increased their skewness, causing severe damage to the abutments and columns in some cases (Refs. 1, 2, 3). The resulting damage to skew bridges in the area included deck sections which slipped free from the supporting piers, permanent offset displacement of the deck in relation to the abutments, and severe spalling of concrete due to the flexural failure of piers. In more recent earthquakes, like the Coalinga and the Palm Springs earthquakes, more bridges exhibited the same behavior and suffered similar structural damage. Recent analytical studies, by Maragakis (Ref. 4, 5), concluded that the damage is a direct result of the in-plane motions of the bridge deck created by the impact between the bridge deck and the abutments.

The objective of this paper is to briefly present the development and analysis of a simple model, which was used to investigate the effects certain parameters have on the impact between the bridge deck and the abutments during earthquakes. By using this model, useful information can be obtained regarding the exact role that the nonlinear behavior of certain elements of the bridge has on the impact between the bridge deck and the abutments. The model was used for the analysis of the response of a short, two-span bridge, located in Riverside, California.

DESCRIPTION OF THE MODEL

Since the primary focus of the model centers on exploring the effects of the impact between the bridge deck and the abutments of short bridges, a simple bridge structure was chosen for analysis. The system to be considered is shown in Fig. 1a. It consists of the bridge deck, seat type abutments, and a single row of piers. The bridge deck is represented by a rigid block and a rotational spring, k_d. The rigid block has mass and mass moment of inertia properties which can be estimated from the geometric properties of the real bridge deck. The rotational spring, k_d, represents the resistance offered at the top of the pier against the rotation of the deck (see Fig. 2a). However, in most cases, the bridge deck may be assumed to translate as a rigid body without any rotation (Fig. 2b).

Each abutment is separated from the deck by a gap in the longitudinal direction. The abutment is represented by a longitudinal spring K_{ab}, which is allowed to yield at high displacement levels. The impact between the bridge deck and the abutment occurs when the longitudinal displacement of the deck exceeds the corresponding abutment gap. The model that is used for the representation at the abutment springs is shown in Figure 3. Since seat type abutments are considered in this analysis, the deck rests on the abutments on elastomeric pads. These pads are represented by springs. The force-deflection diagram of these springs is shown in Fig. 4. More details about the abutment and the elastomeric pad springs are provided in recent relevant studies (Ref. 6).

The single row of piers is represented by a continuous bending beam. This beam can be either elastic or nonlinear. At the bottom of the beam there are translational and rotational springs and dampers representing, respectively, the flexibility and the radiation damping respectively at the foundation level. The foundation springs can be nonlinear thereby accounting for the material damping of the foundation.

The model is excited by an earthquake excitation in the longitudinal direction applied at the base. To determine the response of the model to an applied excitation, the finite element method is employed.

Example of Response The model presented in the preceding section is used to investigate the response of the Nichols Road Overcrossing, Bridge #56-725, located at Riverside, California.

Translational Stiffness of Abutments The stiffness of each abutment is determined by treating the abutment as a rigid body and modeling the soil embankment as a Winkler foundation (Ref. 4). For the purpose of examining the yield of the soil, a global yielding criterion for the whole soil deposit behind the abutment is used. Based on these assumptions, an approximate force-deflection relation for each of the abutments is estimated. The gap value is typically in the range of 0 to 5 cm.

Translational and Rotational Stiffness of Foundation The precise evaluation of the translational and rotational stiffnesses of the foundation springs is very complex involving many hard to define parameters and tedious analytical work. However, using the following assumptions, the foundation stiffness parameters necessary for the purposes of this work can be obtained in a simple way with reasonable accuracy:

a. The footing experiences rigid body translational and rotational motion;
b. The footing is shallow and in the same level with the soil surface; and
c. The footing is resting on an elastic half-space.

Values for the stiffness of the soil springs in the elastic range can be found from elastic half-space solutions). Simplified methods are used to determine the yielding levels of the soil springs. Details about these methods can be found in recent relative studies (Ref. 6). Radiation damping for the foundation is determined using standard methods (Ref. 6).

Hysteretic Behavior of the Column Beam The Q-HYST model was used, which is shown in Fig. 5, to model the hysteretic behavior of the concrete column of the bridge. The methodology for evaluating all the parameters required for the implementation of the model was developed by Saiidi (Ref. 7).

Results The model, which was briefly described above, was used for the performance of several parametric studies in order to examine the effects that the values of certain parameters have on the impact between the deck and the abutments. Two different records were used for the performance of the parametric studies: the first ten seconds of the 1940 El Centro earthquake (N-S component) and sixteen seconds of the 1952 Pasadena earthquake (S90W component) (Ref. 6). Some samples of the parametric studies are shown in Figs. 6-8. In Fig. 6, the effects that the abutment stiffness has on the response of the model for various values of the abutment gap can be seen. In this figure, the variable KR expresses the ratio between the abutment stiffness and the column stiffness of the bridge. One can see that as the abutment stiffness increases, the magnitude of each of the maximum responses decreases. Increases in the gap diminish the influence of the abutment stiffness. In Figs. 7 and 8, selected displacement time histories are presented showing the effects of the elastomeric pads and the hysteretic behavior of the columns respectively. One can see that at low displacement levels, when impact does not occur both the pads and the hysteretic behavior of the columns influence the response of the bridge deck. However, when impact occurs at higher displacement levels, the response of the model is controlled by the impact; and the effects of the pads and the hysteretic behavior of the columns are insignificant.

ACKNOWLEDGMENTS

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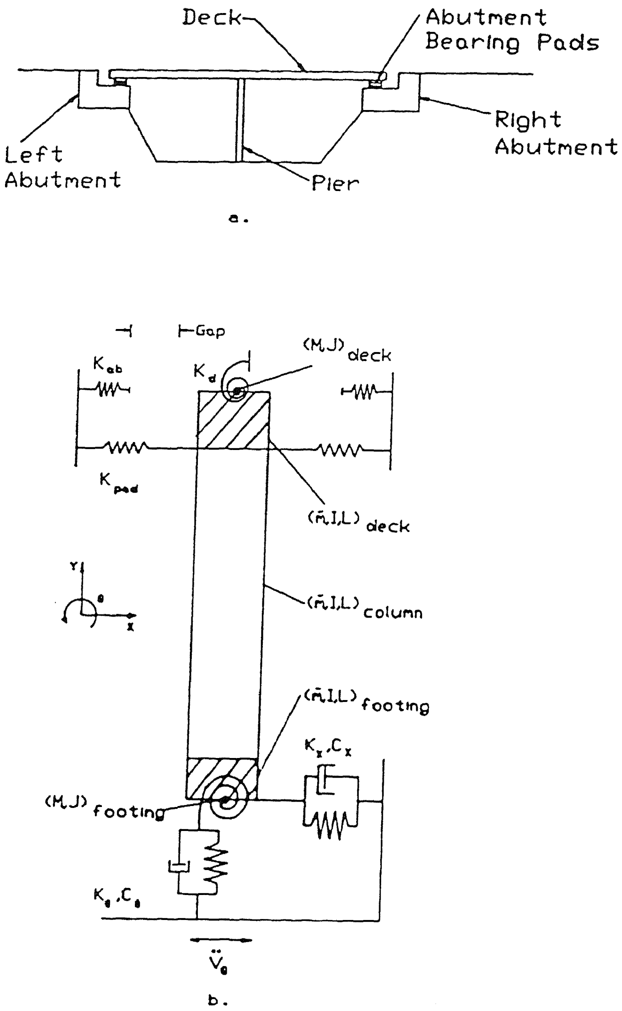

Fig. 1 Simplified Model of a Short Bridge Structure
a. Bridge Structure b. Model

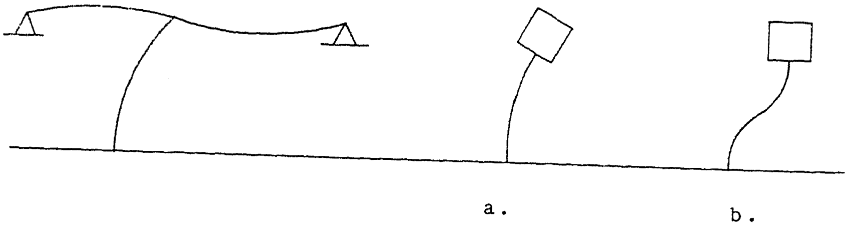

Fig. 2 Connection Between the Bridge Deck and Piers
a. Free to Rotate
b. Fixed Against Rotation

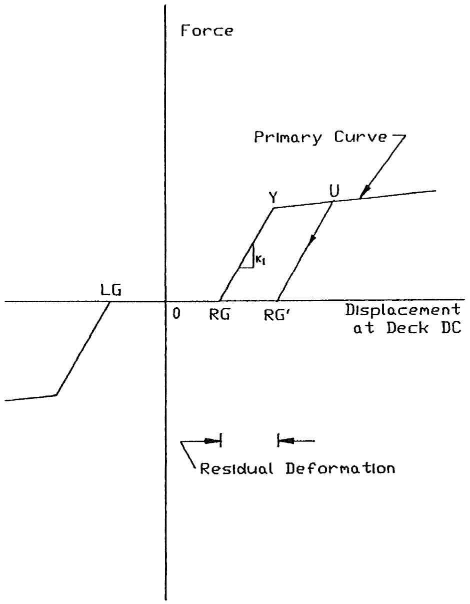

Fig. 3 Force Deflection Diagram of the Abutment Spring System

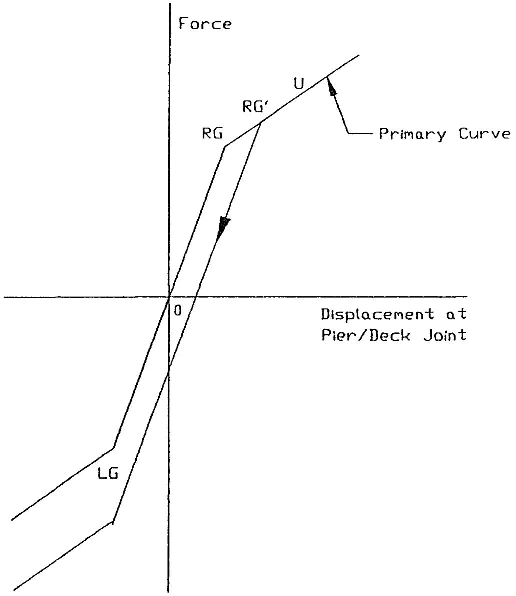

Fig. 4 Force Deflection Diagram of the Abutment Bearing Pad System

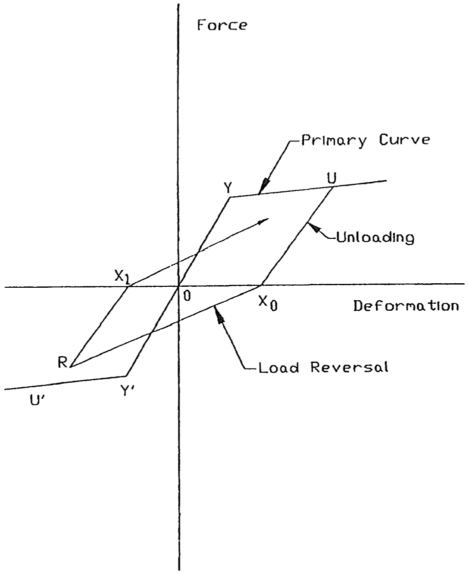

Fig. 5 Q-HYST Model

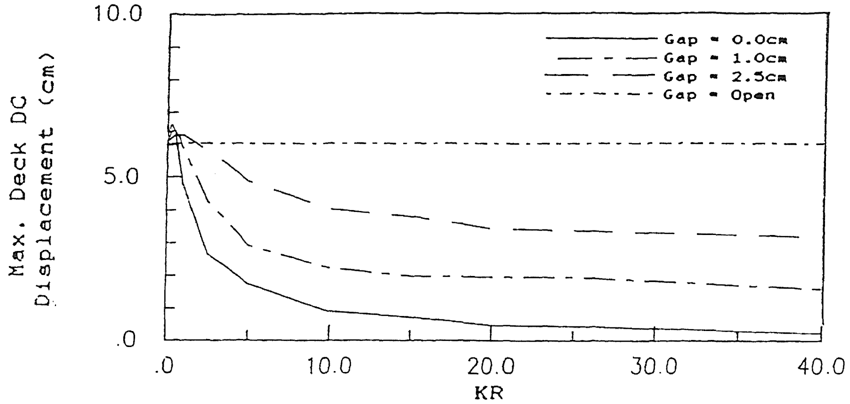

Fig. 6 Effects of the Abutment Stiffness on the Response of the Model

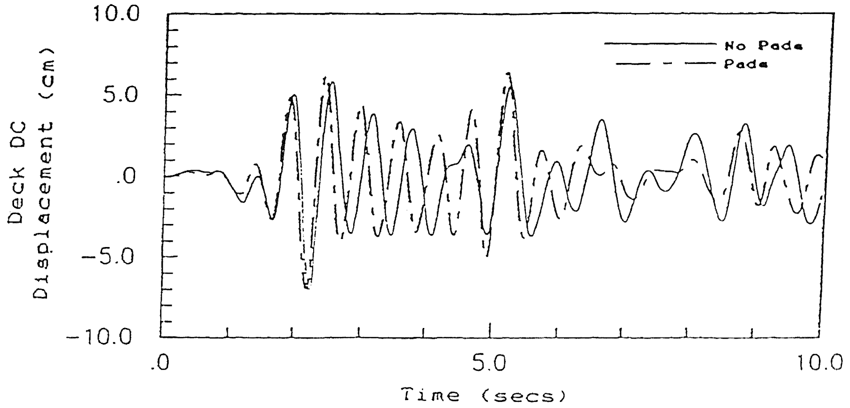

Fig. 7 Effects of the Abutment Bearing Pads on the Time History Displacement Response of the Deck

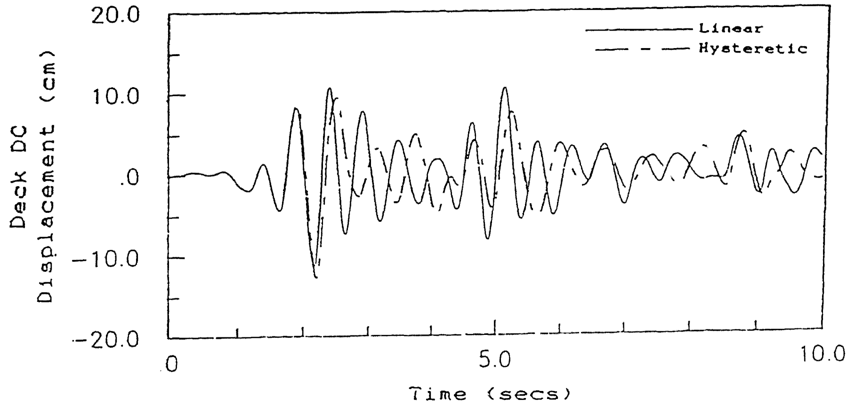

Fig. 8 Effect of the Hysteretic Behavior of the Piers on the Time History Response of the Deck