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Classical formulation of the impact between bridge deck and abutments during strong earthquakes

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ABSTRACT

The impact between bridge decks and abutments has been the source of extensive damage to highway bridges during the 1971 San Fernando and other recent earthquakes. In this paper, a preliminary study related to the effects of impact energy losses on the dynamic response of bridges is presented. The focus of this study is the development of analytical computer models for the formulation of the problem based on the classical impact theory, the performance of some parametric studies to identify the most important parameters, and the exploration of modeling the impact effects by using simpler techniques such as equivalent hysteretic dampers.

INTRODUCTION

The impact between bridge decks and the abutments during strong earthquake shaking, is a phenomenon that has attracted research interest during recent years. This impact affects primarily bridges with seat type abutments, and has been the source of serious damage to both decks and abutments in recent earthquakes. The 1971 San Fernando, California earthquake provides a particularly relevant example.

Many aspects of this interesting phenomenon have been investigated in recent years by several researchers. A short description of these studies and an appropriate reference list are provided by Maragakis et al. (1990). In these studies, the kinematic mechanism of the phenomenon has been analyzed and explained; and several parametric studies have been performed in order to identify the role of the most important parameters associated with this impact.

One aspect that has been neglected in all the previous studies is the

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energy loss associated with the impact between the deck and the abutments. In all the studies related to this phenomenon that have been performed so far, as well as in almost all bridge dynamic analysis programs used by bridge researchers and engineers, the abutments were represented with linear or nonlinear springs, and in some cases with a combination of springs and hysteretic dampers. Although this type of representation for the abutments allows for the modeling of the foundation stiffness as well as for energy losses due to material or radiation soil damping, it does not take into account the energy losses due to the severe collision between the bridge deck and the abutments. The objective of this paper is the presentation of the initial part of a study that has the following major goals: (i) To investigate the effects that energy losses directly related to the collision between a bridge deck and its abutments have on the response of the bridges, and (ii) To develop modeling techniques for these losses that can be incorporated in already existing bridge analysis programs and be used easily by bridge researchers and engineers.

FORMULATION OF THE PROBLEM

In order to investigate the importance that the impact energy losses have on the response of the bridge, two simplified models were developed.

In the first model, hereafter called "model 1", the bridge structure is represented with the system shown in Fig. 1. Based on this figure, one can see that the bridge deck is represented by a rigid mass supported by a translational spring, which accounts for the resistance of the bridge pier. The abutments are represented with translational springs and gaps. An abutment spring is activated after the closure of the corresponding abutment gap, and it is de-activated after the opening of the gap. The stiffness of the abutment springs were evaluated based on a method developed recently for the estimation of the stiffness of longitudinal abutment springs (Maragakis et al. 1990). One should note that this model does not take into account impact energy losses. Its response will be compared with the response of the impact model that will be described next, so that the importance of impact can be investigated. It should also be noted that all the springs are assumed to be linear and that no soil-structure interaction effects are considered. The model is excited at the bottom of the central mass. For the evaluation of its response to a dynamic loading, a computer program was written for the solution of the incremental equations of motion using the Wilson's θ method.

In the second model, hereafter called "model 2", the bridge structure is represented with the system shown in Fig. 2. The major difference between the two models is that in model 2 the abutment masses are included in the representation of the abutment system. After the closure of either one of the abutment gaps, an impact between the bridge deck and the corresponding abutment takes place. Therefore, in this model the effects of energy losses due to impact can be considered. It should be mentioned here, that the abutment springs represent the resistance in the longitudinal direction of the soil masses behind and underneath the abutments. The stiffnesses of these springs should be much higher in compression than in tension. However, for purposes of simplicity in the initial stage of this study, the values of

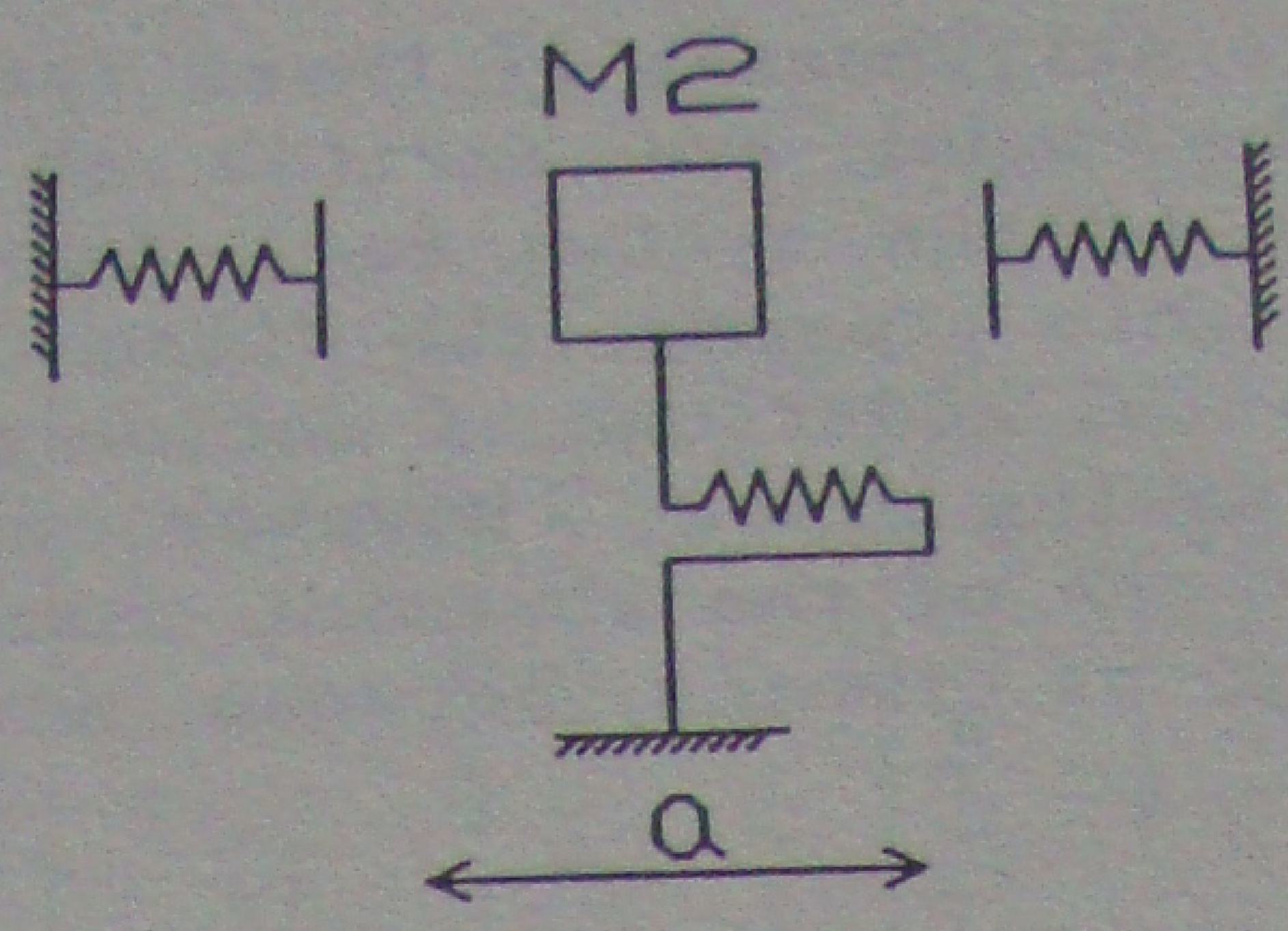

Figure 1. Model 1

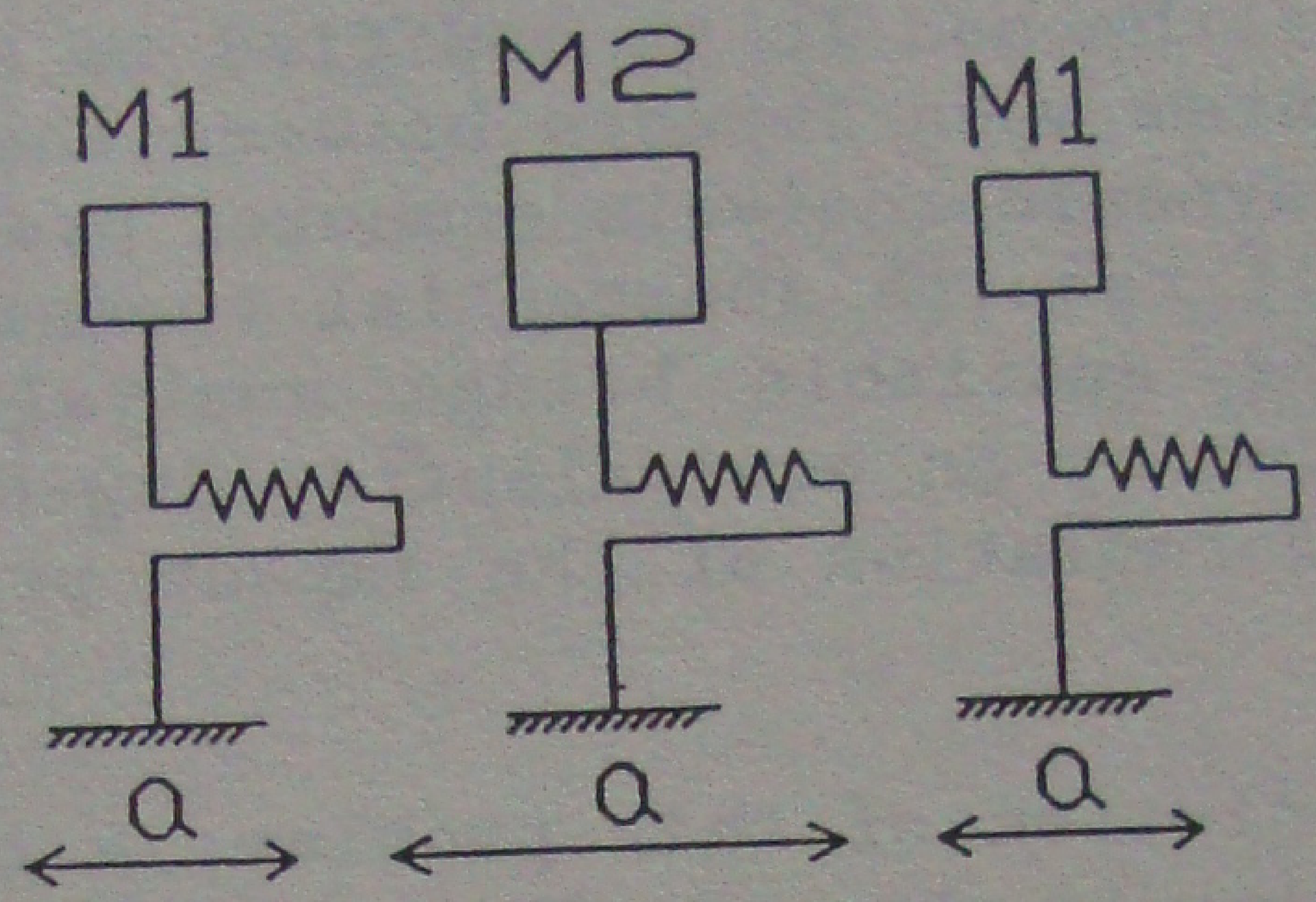

Figure 2. Model 2

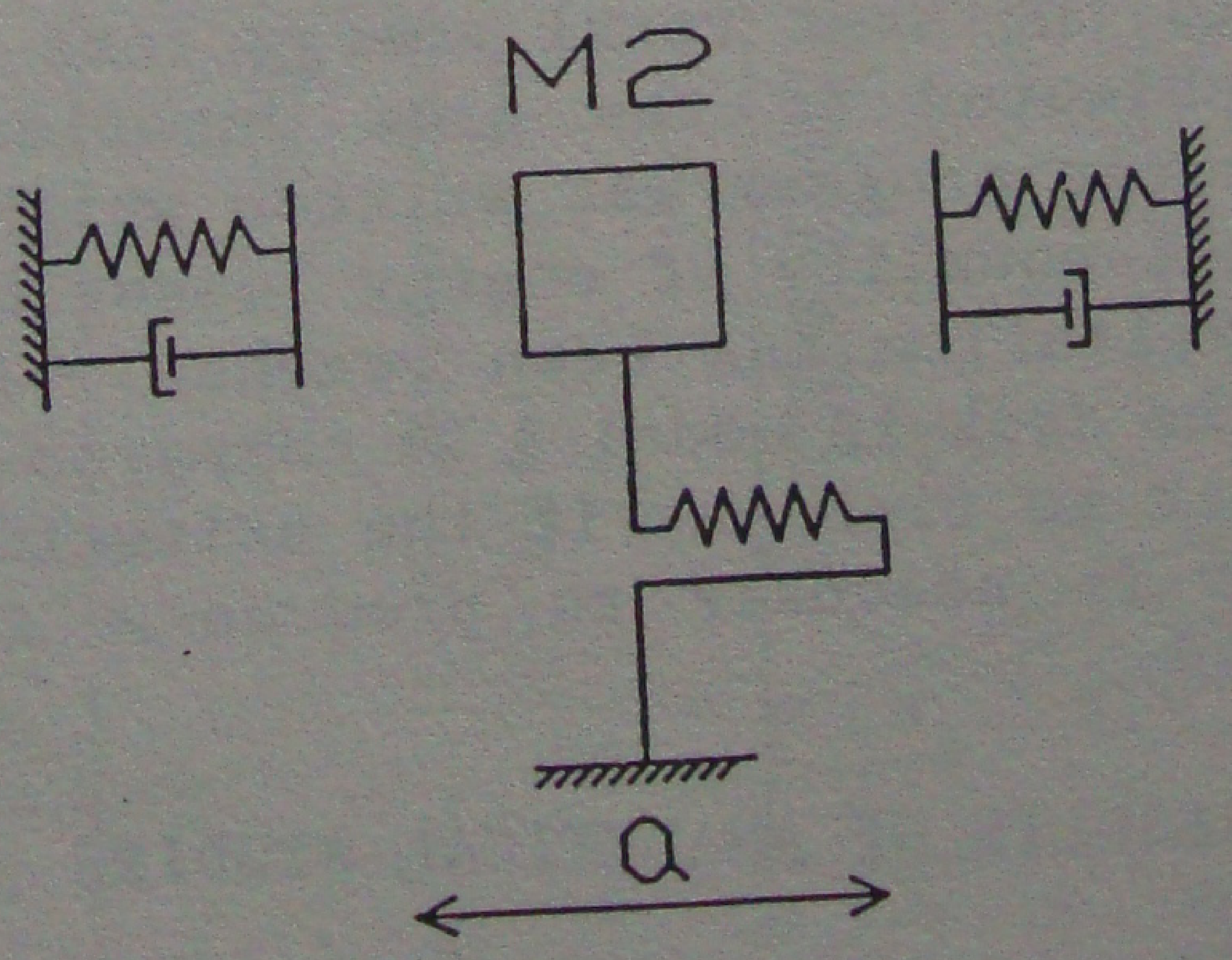

Figure 3. Model 3

the compressive and tensile stiffnesses of these springs were assumed to be equal. The masses of the model are excited at their base. For the evaluation of the response of the system to a dynamic loading a computer program was developed. In this program, the Wilson's θ method was used for the solution of the incremental equations of motion of the three masses when no impact between them is taking place. However, when impacts between the bridge deck mass and either one of the abutment masses occur, the equations from the classical theory of impact between moving masses were used (Maragakis et al. 1990).

A SIMPLER MODEL FOR THE EFFECTS OF THE IMPACT

Using the classical impact theory to evaluate the dynamic response of the bridge when the impact effects between the bridge deck and the abutments are taken into account, required two major modifications: (i) The vibrations of the abutments had to be considered since the abutment mass is an important parameter when the effects of the impact are taken into consideration, and (ii) The solution algorithm had to be modified to evaluate the response of the bridge-abutment system when impacts between the deck and the abutments occur. In the case of dynamic analysis computer programs for large bridges, these modifications will require substantial changes to the whole program. In the majority of the available bridge analysis programs, the bridge abutments are represented by an equivalent spring-damper system. For this reason, the classical formulation of the impact problem cannot be used in these programs.

To simplify the solution of this problem, a third model ("model 3"), was developed. This model is shown in Fig. 3. From this figure, it can be seen that the major difference between this model and model 1 is the representation of the abutment system. In model 3 a viscous damper has been added in the system representing each abutment. The role of this damper is to provide an equivalent representation of the impact between the bridge deck and the corresponding abutment. The value of the damper will be evaluated based on the equality of energy losses of the bridge deck mass between models 2 and 3. For a given base excitation, a value of the damper will be found such that the total energy loss of the bridge deck mass in model 2 due to the impact, will be equal to the same total energy loss in model 3 due to the viscous damper when subjected to the same duration of excitation. To accomplish this, a computer program was written which changes the value of damping in model 3, until equality of energy losses between models 2 and 3 for a certain ground excitation has been reached. After such a value is found, the response of the deck in model 3 is compared to the response of the deck in model 2, in order to find out if the criterion used for evaluating the damping coefficient is adequate to produce a reasonable correlation between the two responses.

RESULTS OF ANALYTICAL STUDIES

To check the validity of the computer programs developed herein, several special cases were analyzed using all three models. Details about these cases are provided by Maragakis et al. (1990).

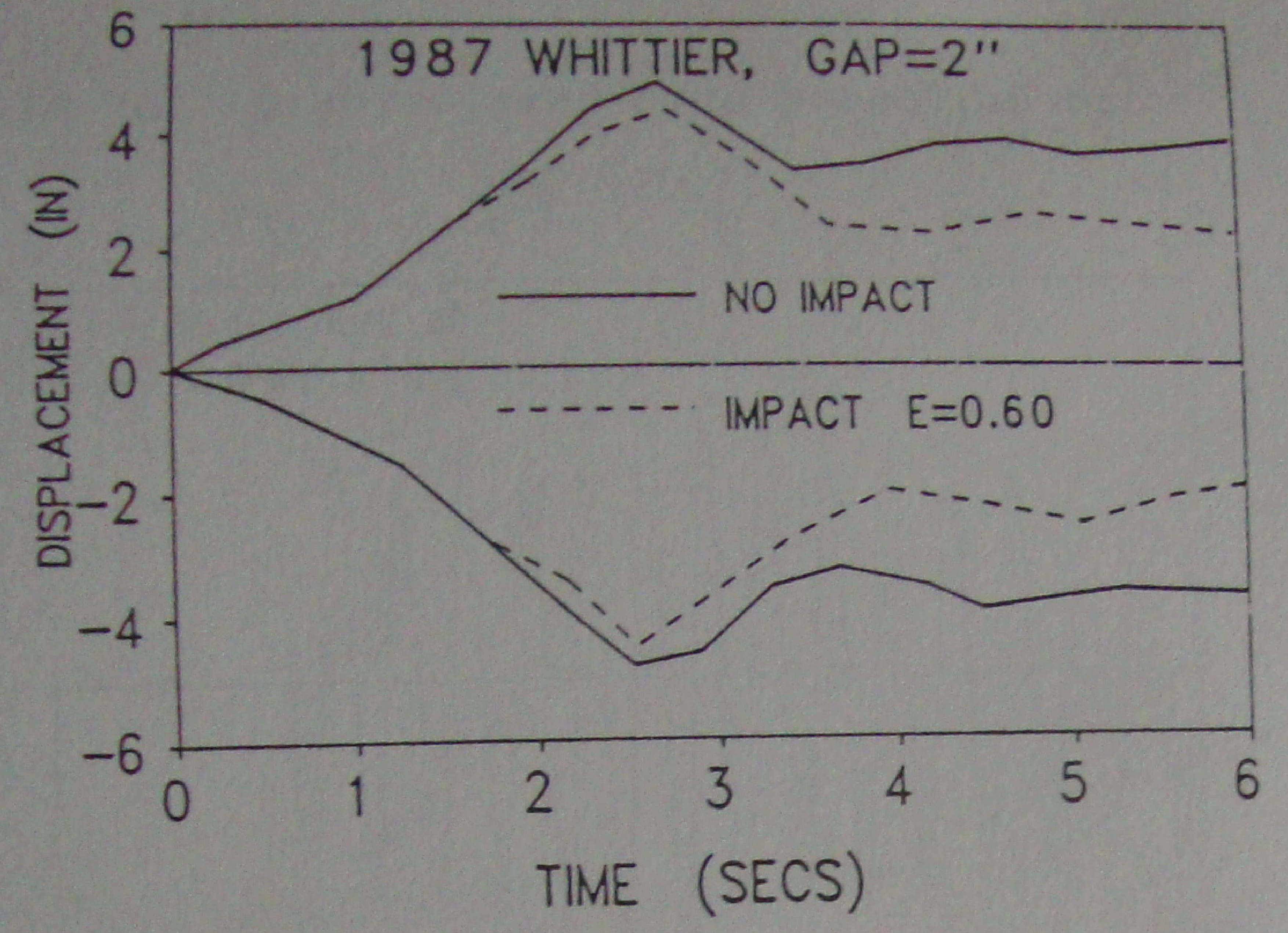

Figure 4. Deck displacement envelopes of models 1 & 2 for soft soil

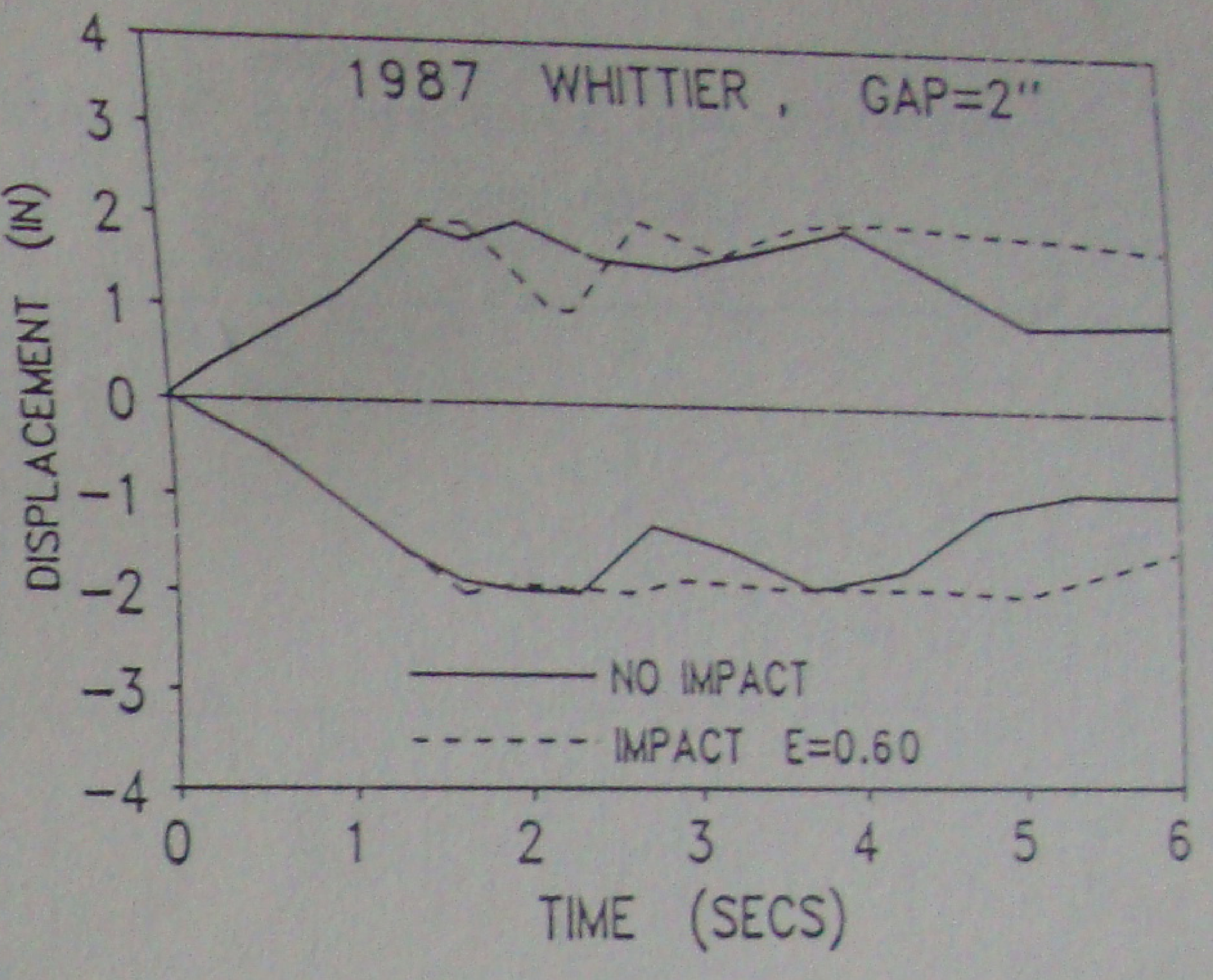

Figure 5. Deck displacement envelopes of models 1 & 2 for stiff soil

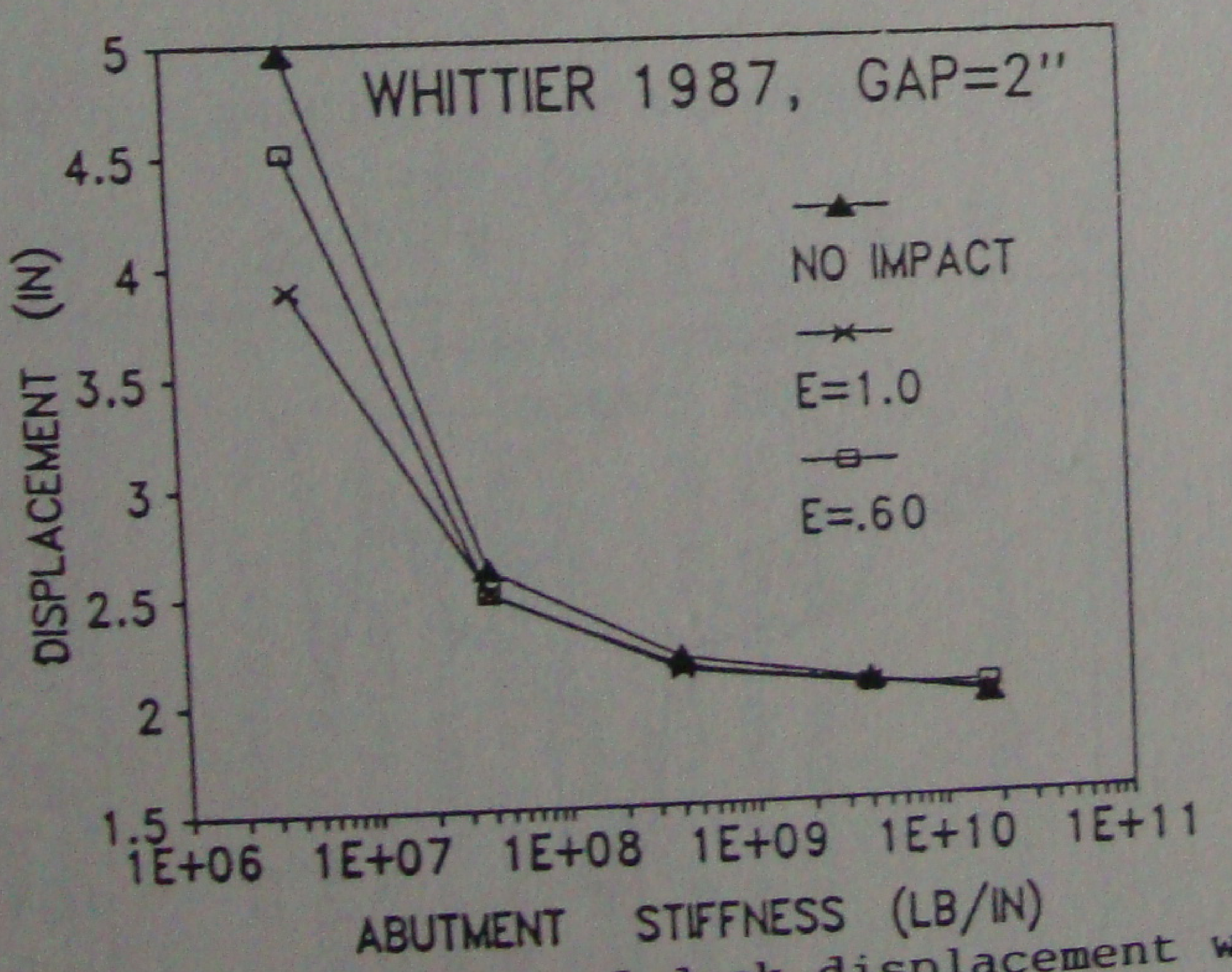

Figure 6. Variation of deck displacement with abutment stiffness for the Whittier earthquake

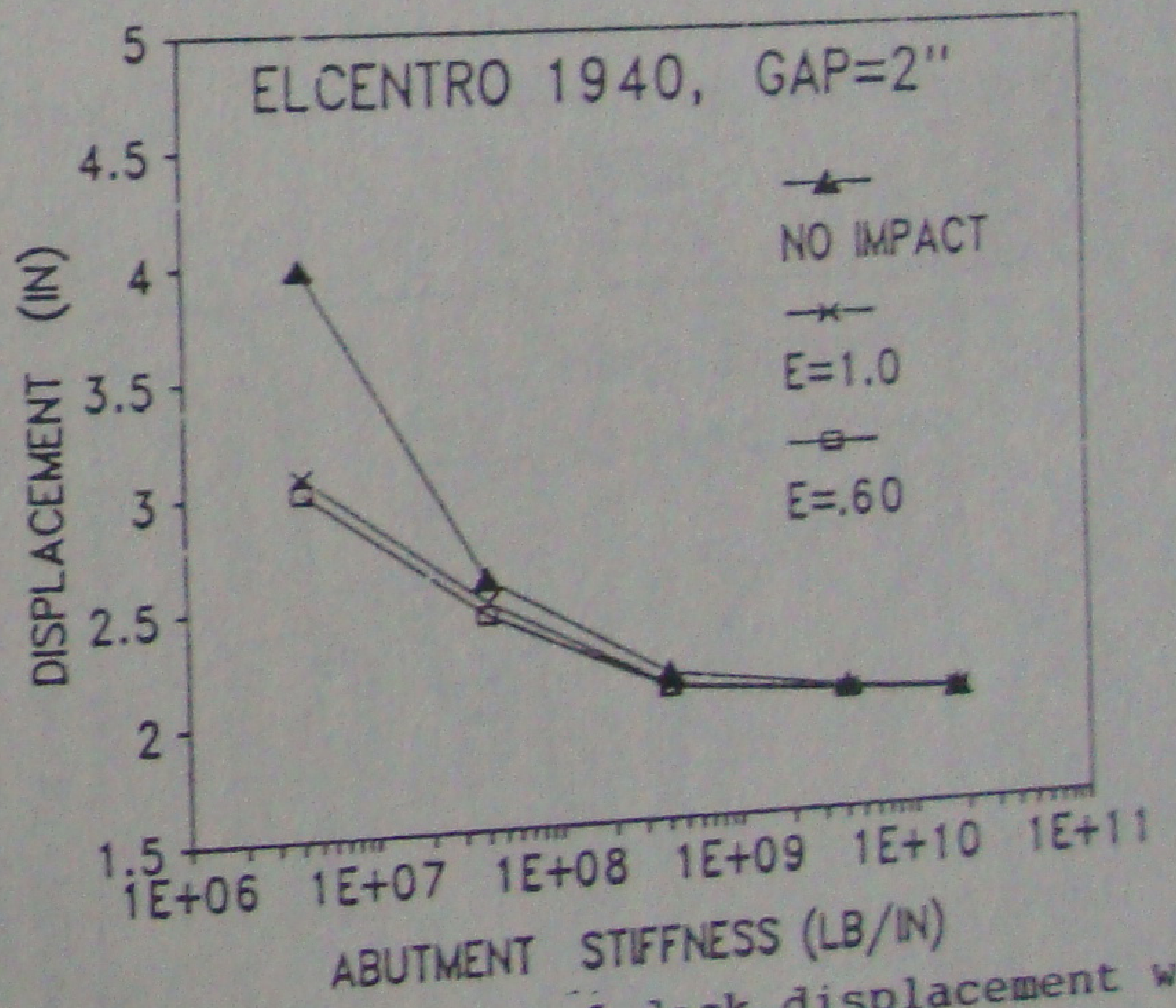

Figure 7. Variation of deck displacement with abutment stiffness for the El Centro earthquake

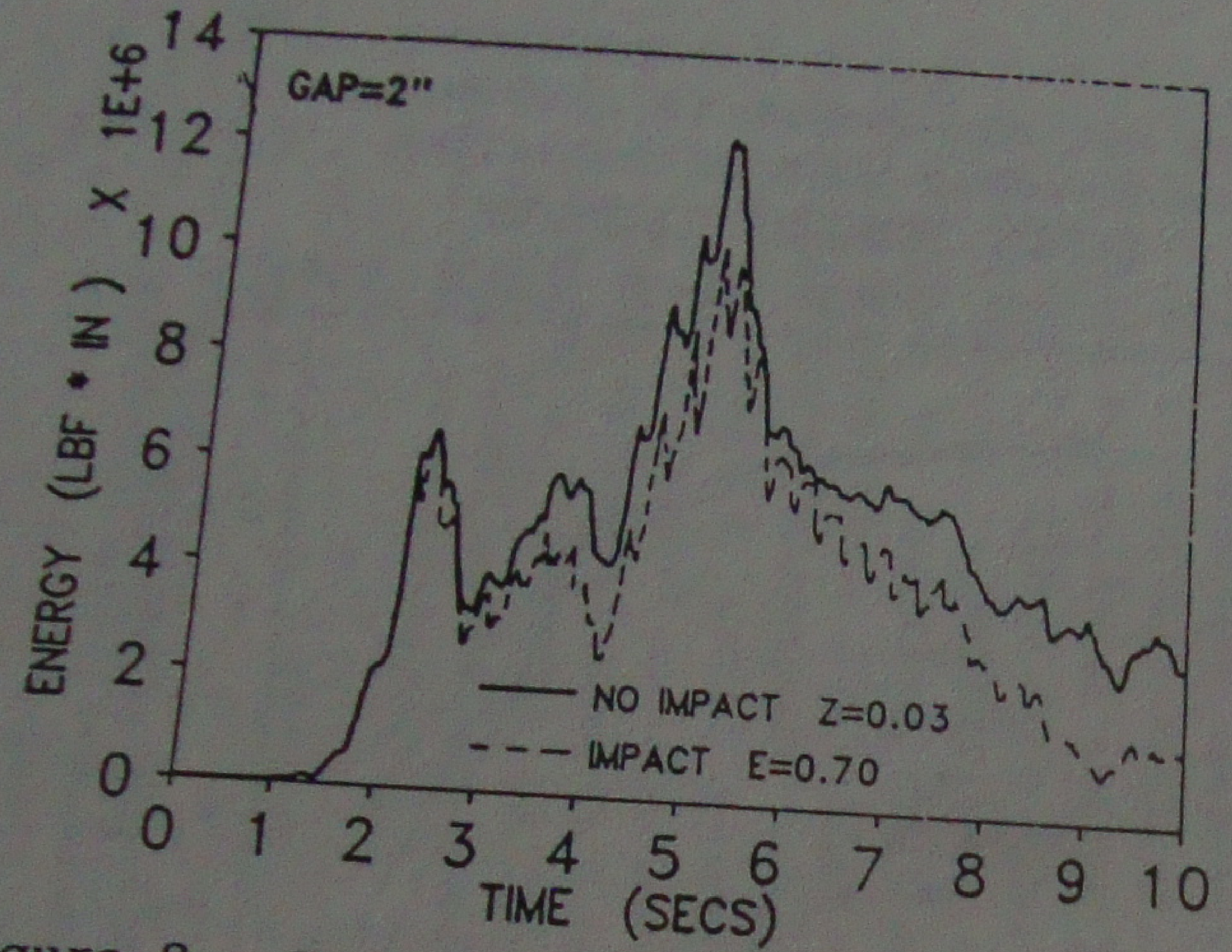

Figure 8. Energy levels of models 2 & 3

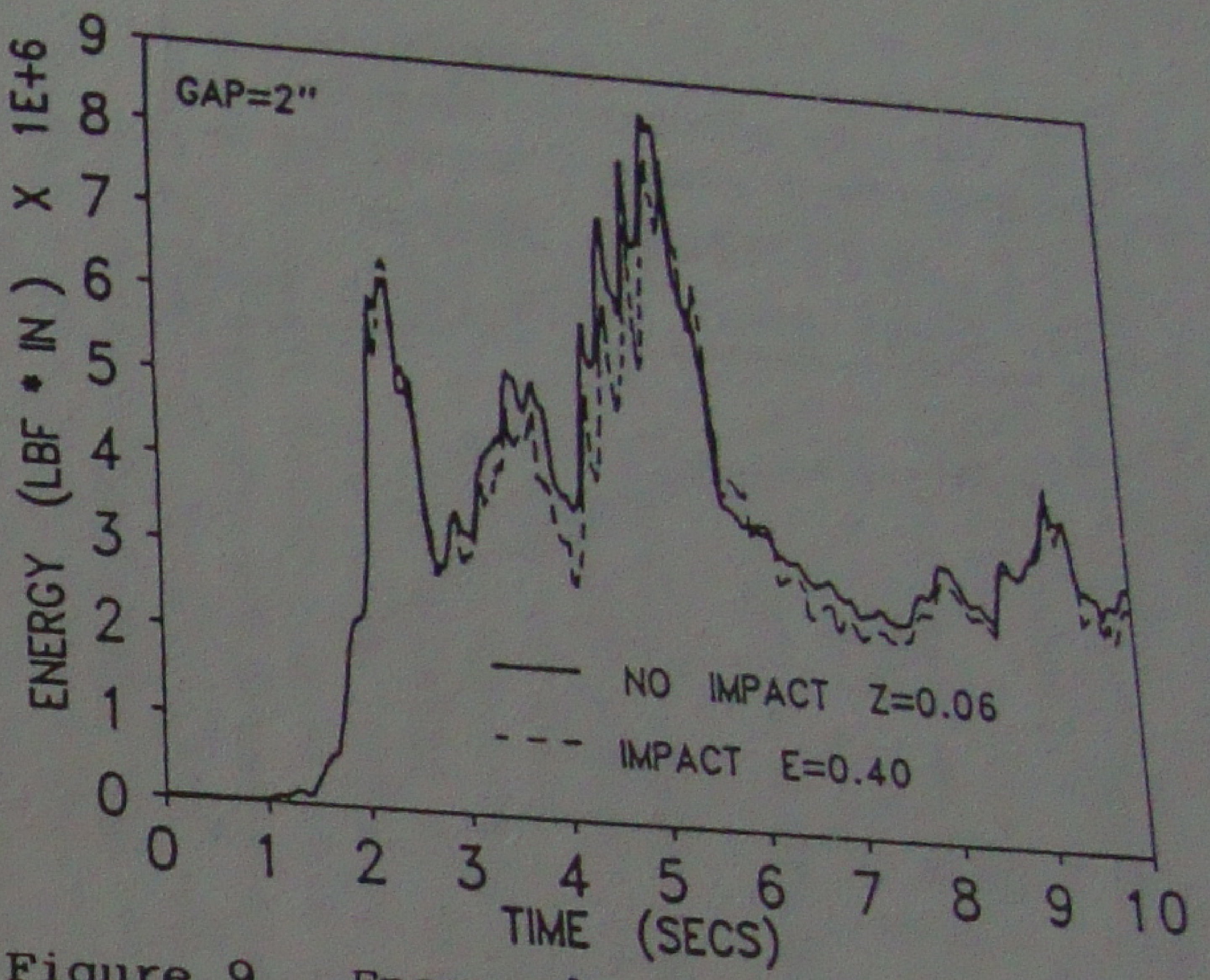

Figure 9. Energy levels of models 2 & 3

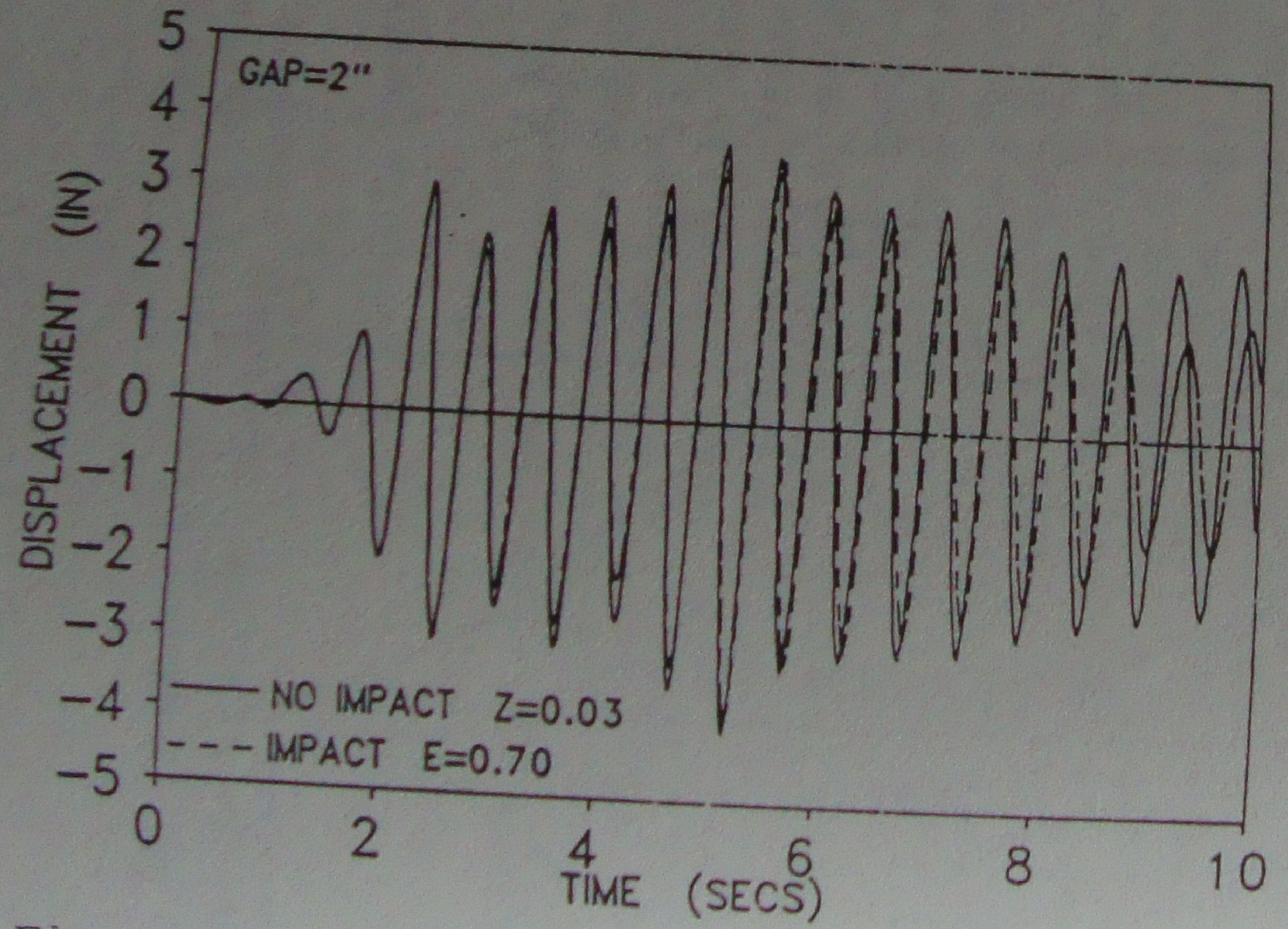

Figure 10. Displacement time histories of models 2 & 3

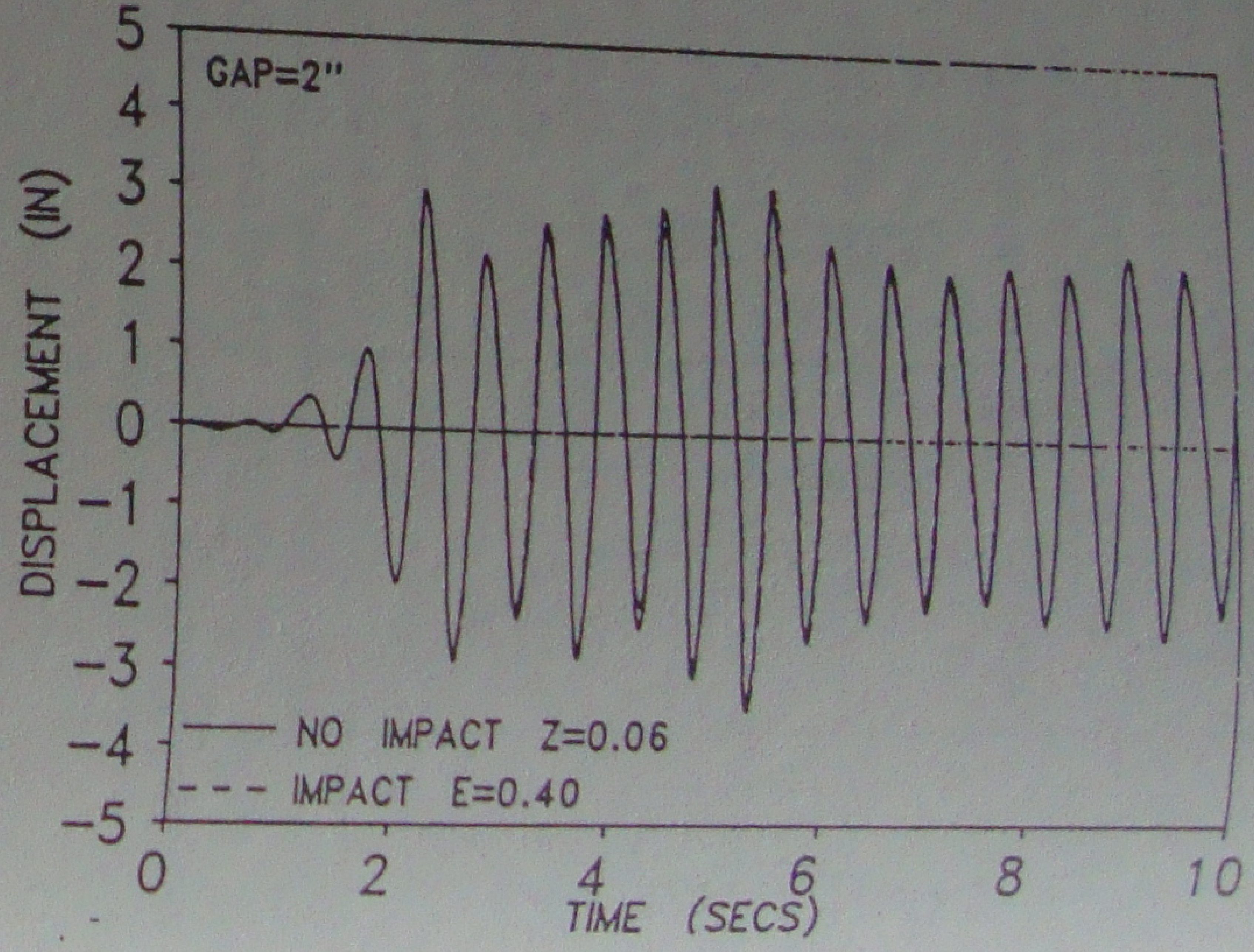

Figure 11. Displacement time histories of models 2 & 3

Figures 4-5 show a comparison of the displacement envelopes of the middle mass for a coefficient of restitution equal to 0.6. In both cases, the models considered have been excited by the 1987 Whittier earthquake. It can be seen that the degree of the impact on the response depends on the stiffness of the abutment soil spring. This is more obvious in Figs. 6-7 that show the maximum displacement of the middle mass for several values of the abutment springs for these different earthquake excitations. One can see that, for softer springs, the effect of the impact on the maximum response is more significant.

Figures 8-11 show the results of a preliminary study related to using model 3 for a simpler representation of the effects of the impact. Figure 8 shows the variation of the energy of the middle mass in the time domain in models 2 and 3. In model 2 the coefficient of restitution, e, was equal to 0.7, while in model 3 the damping, Z, ratio was equal to 3%. The damping coefficient in model 3 was evaluated from the assumed damping ratio based on the mass and stiffness properties of the middle mass. Figure 9 shows the comparison between the displacement time history responses of the middle mass corresponding to the cases described for Fig. 5. Figures 10-11 are similar to Figs. 8-9 with the only exceptions being that the values of the coefficient of restitution and the damping ratio were equal to 0.4 and 6% respectively. From these figures, it is evident that a better correlation between the energy time histories (Fig. 9) results in a better correlation between the displacement time histories (Fig. 11). This is consistent with the criterion used for estimating the equivalent damping ratio, which was described earlier. In all the cases discussed in Figs. 8-11, the models were excited by the first ten seconds of the 1940 El Centro earthquake while the mass properties of the bridge deck and the abutments were evaluated based on the properties of Nichols Road Overcrossing, a two span reinforced concrete bridge located in Riverside, California (Maragakis et al. 1990).

CONCLUSIONS - RECOMMENDATIONS FOR FUTURE RESEARCH

Based on the results of this initial study described above, the following conclusions can be drawn:

i) The energy losses due to impact influences the dynamic response of the bridge deck mass (middle mass), and they should be considered when the dynamic response of bridges with seat type abutments is evaluated.

ii) The degree to which impact influences the response of the bridge depends on the size of the abutment gap, the mass ratio between the bridge deck and the abutments, the stiffness of the abutment springs, and the coefficient of restitution used for calculating the impact energy losses. Extensive parametric studies will be required to accurately determine the sensitivity of the response to these parameters.

iii) The procedures for finding an equivalent viscous damper to allow simple modeling of the effects of impact, based on the criterion of the equality of energy losses between models 2 and 3, produced very promising results. Study of more cases is required in order to perfect the method, identify any limitations or parameter sensitivities that it might have, and improve the efficiency of the computer algorithm.

ACKNOWLEDGEMENTS

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REFERENCES

Maragakis, E., Douglas, B., Vrontinos, S., "Simple Modeling of the Impact Energy Losses Occurring Between the Bridge Deck and Abutments," *Proceedings of the 6th U.S.-Japan Bridge Engineering Workshop*, Lake Tahoe, Nevada, May 1990.