NUMERICAL SIMULATION OF BRIDGES WITH INCLINED DECK UNDER STRONG GROUND MOTION

Nurul Rochmah [1], Tzu-Ying Lee [2]
[1] Double Degree Program
E-mail: Nurulita889@gmail.com
[2] Department of Civil Engineering, National Central University
Jhongda Rd. 300 Jhongli City Taoyuan County Taiwan

ABSTRACT

Pounding between decks was observed on most of the bridges which suffered severe damage even unseating. Although the pounding effect of seismically-excited bridges has been studied by many researchers, only few researchers investigated the bridges with inclined decks on this effect. However, the decks of bridges should be of slopes due to various terrain, route alignment and elevation. Occasionally the slope is up to 10%. Therefore, this research is aimed to study the pounding effect of bridges with inclined decks under strong ground motions. The Vector Form Intrinsic Finite Element (VFIFE) is superior in managing the engineering problems with material nonlinearity, discontinuity, large deformation, large displacement and arbitrary rigid body motions of deformable bodies. In this study, the Vector Form Intrinsic Finite Element (VFIFE) is thus selected to be the analysis method. Two types of bridges, a six-span simply-supported bridge and a continuous bridge are analyzed. Both of bridges are with high damping rubber bearings. This study used different number of element to simulate the decks and the deck slopes are from 0% to 10%. The ground motion scales are from 100% to 300%. From the numerical analysis result, the deck deformations and forces without pounding effect are larger than the cases with pounding effect. And more element number is better to simulate the decks. The deck slope does not influence the number of unseating decks and damage bearings. The dynamic behavior of continuous elevated bridge is better than simply-supported elevated bridge under strong ground motion.

Keywords: *pounding, elevated bridge, vector form intrinsic finite element, high damping rubber bearings.*

INTRODUCTION

Pounding was one of many causes that have made bridges collapse when earthquakes occured. Pounding between adjacent decks or between abutment and deck of bridges can cause damage to decks, bearing failures and even collapse of bridge spans. There were many pounding damage in bridges in the past earthquakes. Such as investigated from earthquake in San Fernando 1971, showed that pounding between bridge deck and abutment could cause damage of seat type abutments. From earthquake in Japan, Hyogo-Ken Nanbu earthquake 1995, showed that pounding as main cause of bearing failure and even contributed to the collapse of bridge spans. From previous research, there were so many researchers that studied about pounding effect of bridges, but only few reasearchers studied about the pounding effect of the bridges with elevated decks. In the fact, there are many elevated bridges in this world. This study is to analyze the effect of elevated bridges to the pounding, bearings on the global response of bridges by using VFIFE.

METHOD

This chapter presents how to design the target bridges in this study, the model of a base-isolated bridge for elevated bridges spesified according the Japan Highway Bridge Design Codes. As can be seen in **Figure 1**, a six single-span isolated bridge and three-span continuous isolated bridge, the bridge consisting superstructures, substuctures, gap for pounding. Twelve rubber bearings are installed for connecting deck (superstructures) and pier (substructures). Seven gaps for pounding are installed for avoiding collisions, two of them between abutment and deck and five of them between adjacent decks.

The superstructure of the target bridges consists of five steel I girders and reinforced-concrete slab are shown in **Figures 4**, two abutments and five reinforced-concrete columns with the height of 10 m are used to support those superstructures.The deck with total length of 6@40m and the width of 12m and with deck slope from 0% to 10%, as can be seen in **Figures 2** and **Figures 3**.

In this study,many cases have been tried in order to know behaviour of elevated bridges. The simply supported bridges and continuous bridges will be analyzed with different number of length element. First, compare equal length elements such as 1 element (case I), 5 equal length elements (case II) and 10 equal length elements (case III). Second, compare 5 unequal length elements such as case IV, case V,case VI and case VII, and also compare 10 unequal length elements such as case VIII, case IX,case X and case XI, those all cases are shown in **Figure 5**, **Figure 6**, **Figure 7**. Next step, by using case IX, try to analyze comparation between bridges are installed compression gap and bridges are not installed compression gap. Then, by using case IX, try to analyze bridges with slope of 0 % to 10. Another cases,by using case IX, try to analyze bridges with slope of 0% to10% by using ground motion scale 100% to 300% at an increment of 10. And the last, by using case IX, try to analyze bridges with slope 0% to10% and ground motion scale 100% to 300% at en increment of 10% for different distance of gap, such as 5 cm, 10 cm, 15 cm, 20 cm, 25 cm and 30 cm.

NUMERICAL RESULTS AND DISCUSSION

1. A Six-Span Simply Supported Bridge with High Damping Rubber Bearings

a. Bridges were analyzed by using equal length element

Shown in **Figures 8** are the comparison for time histories pounding force among 1equal length element, 5 equal length elements and 10 equal length elements. The time of pounding for 1equal length element, 5 equal length elements and 10 equal length elements show the same time.In general, good agreement in pounding time can be seen.

Figures 9 compare among 1equal length element, 5 equal length elements and 10 equal length elements for maximum pounding force each percent. For all the elements, can be seen pounding force for gap 1,2,3 are getting lower, and then continues to increase for the pounding force for gap 4,5,6 and 7 respectively. Generally, pounding forces among those different length elements are found to be slighty different, however the differences are still acceptable.

b. Bridges were analyzed by using unequal length element

Time histories pounding force for 5 unequal elements length cases have the same time for each different element length. In general, good agreement in time can be seen.

The similar observation can also be observed for maximum pounding forces for each percent as depicted in **Figures 10** where the largest pounding force occured in case VII, second largest pounding force occured in case VI.

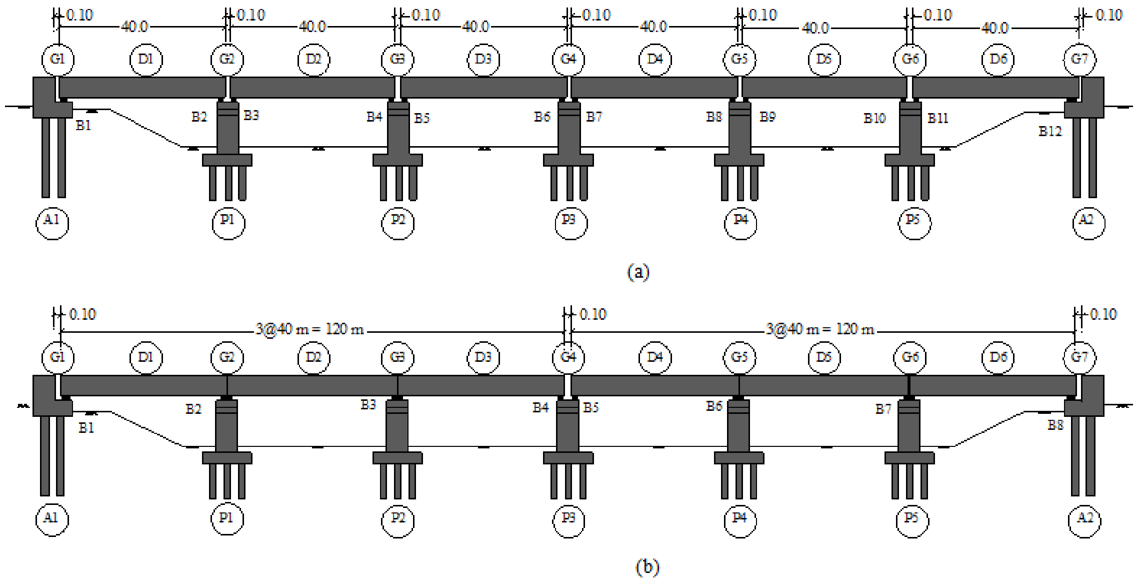

Figure 1. **(a)** Asix Single-Span Isolated Bridge **(b)** A Three-Span Continuous Isolated Bridge

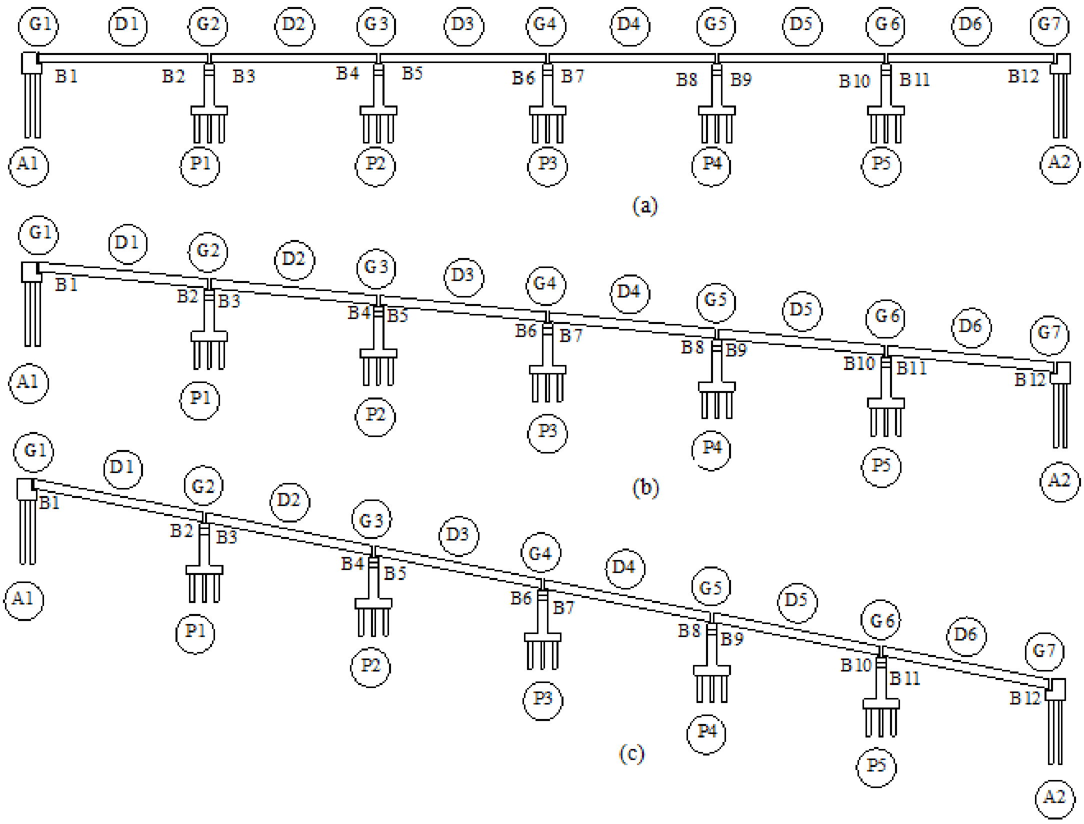

Figure 2. A Six Single-Span Isolated Bridge with Different Slope **(a)** Slope 0%, **(b)** Slope 5% and **(c)** Slope 10%.

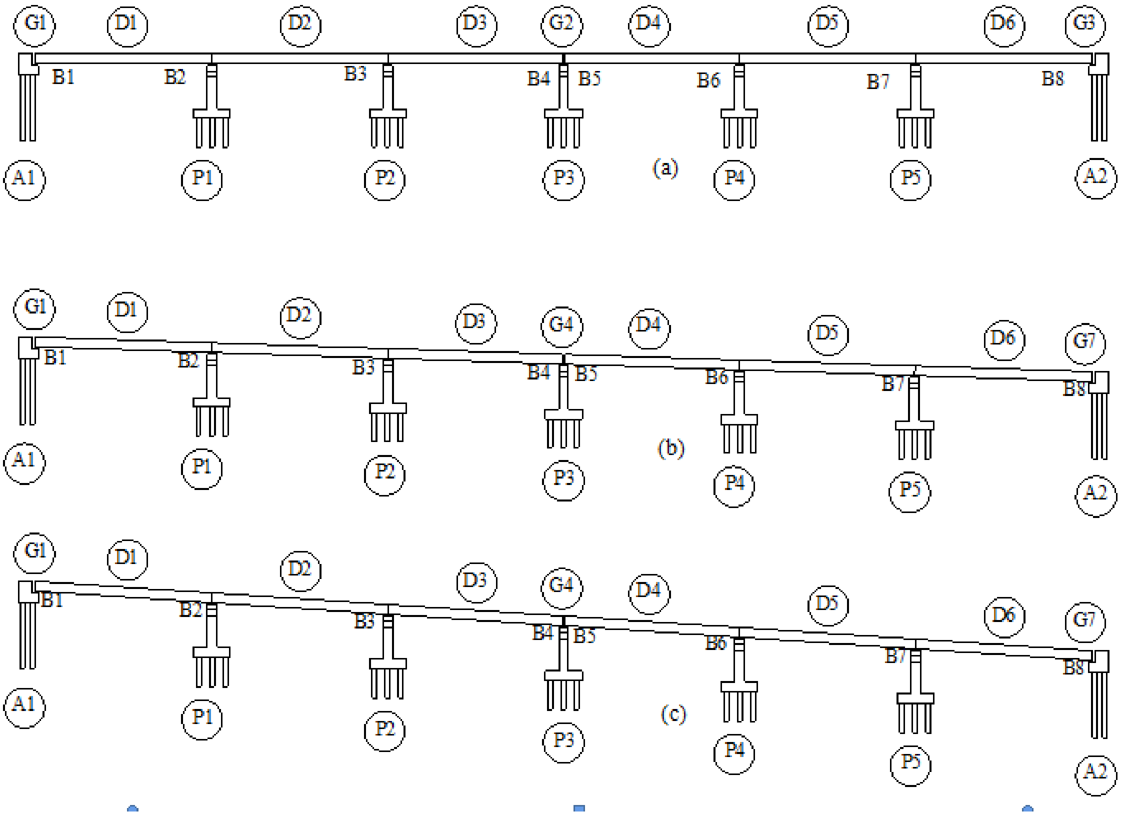

Figure 3. A Three-Span Continuous Isolated Bridge with Different Slope **(a)** Slope0%, **(b)** Slope 5% and **(c)** Slope 10%

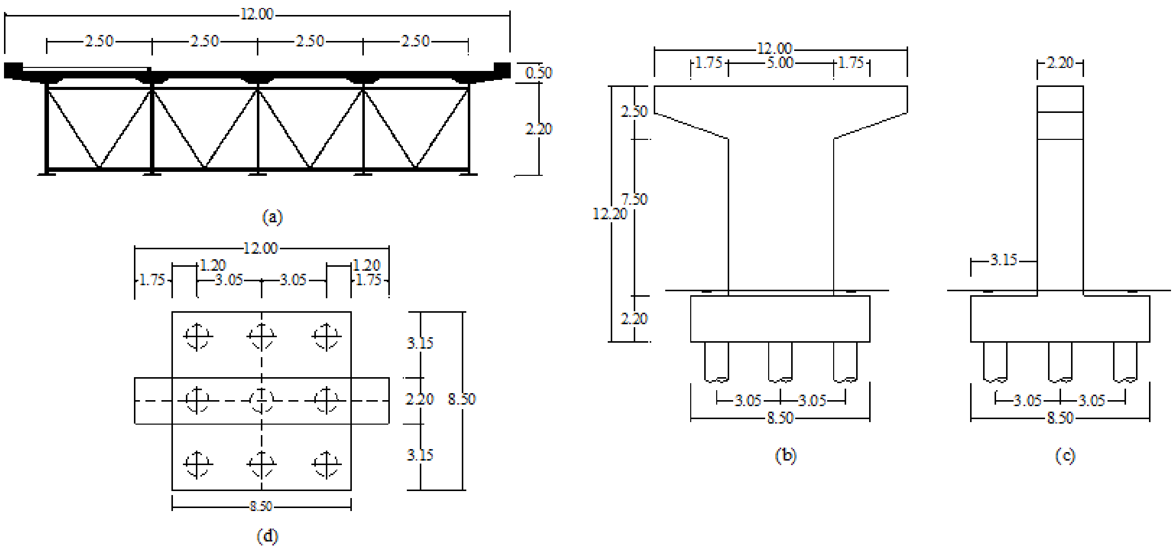

Figure 4. **(a)** Lateral View of Superstructure, **(b)** Lateral View of Column, **(c)** Side View of Column, and **(d)** Pile Configuration

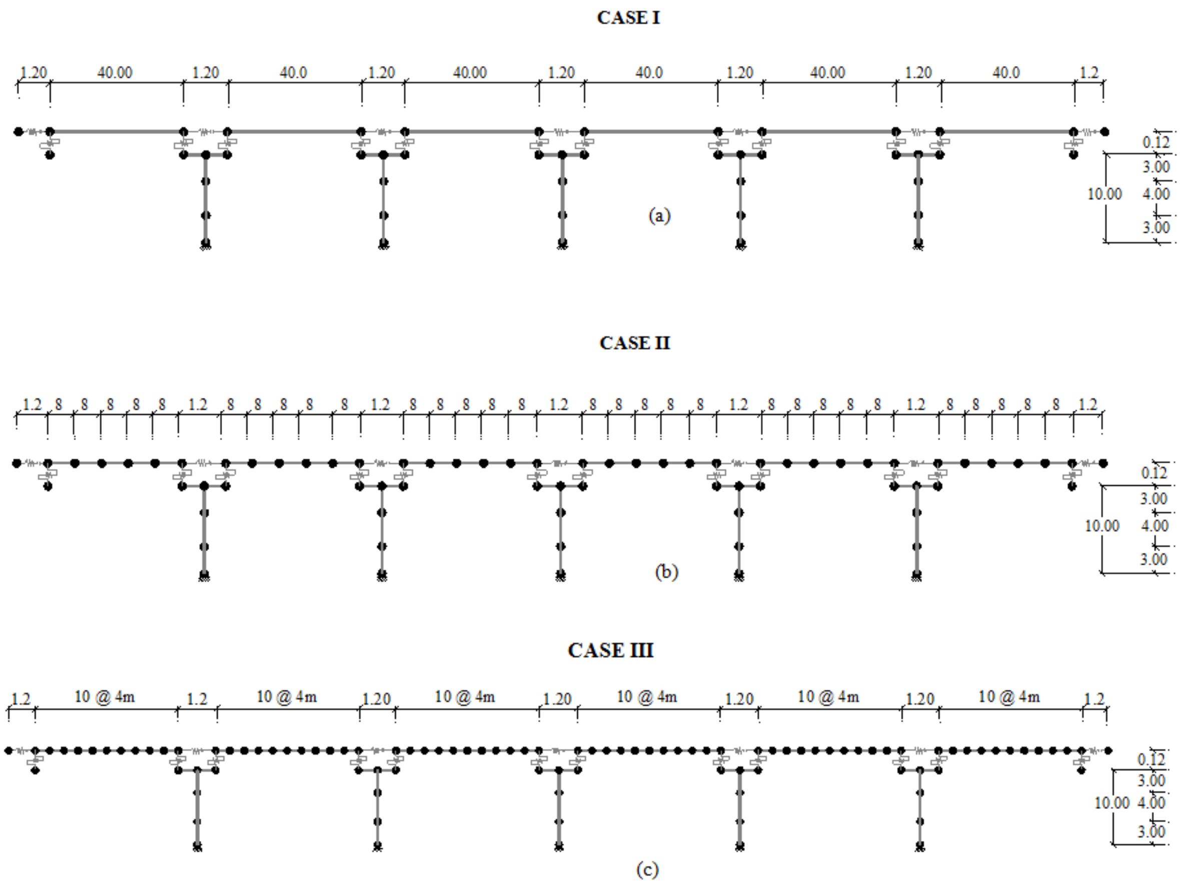

Figure 5. Idealization for Different Length Element of a Six Single-Span Isolated Bridge **(a)** 1 Element for Deck, **(b)** 5 Equal Length Elements for Deck, **(c)** 10 Equal Length Elements for Deck

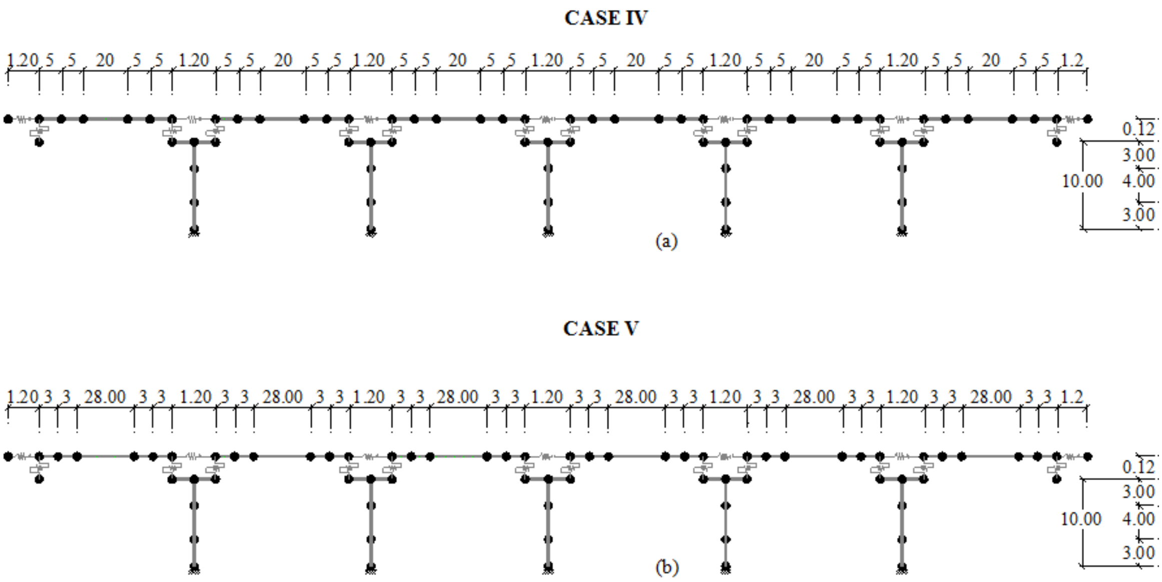

Figure 6. Idealization of 5 Unequal Length Elements for A Six Single-Span Isolated Bridge **(a)** 5m,5m,20m,5m,5m, **(b)** 3m,3m,28m,3m,3m.

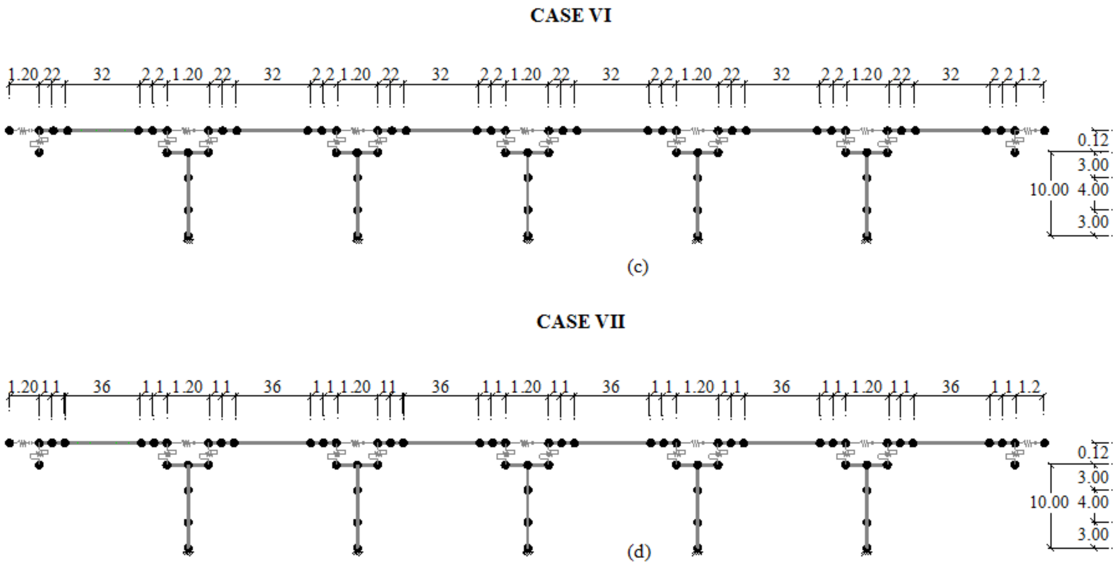

Figure 6. Idealization of 5 Unequal Length Elements for A Six Single-Spanisolated Bridge
(c) 2m,2m,32m,2m,2m, **(d)** 1m,1m,36m,1m,1m

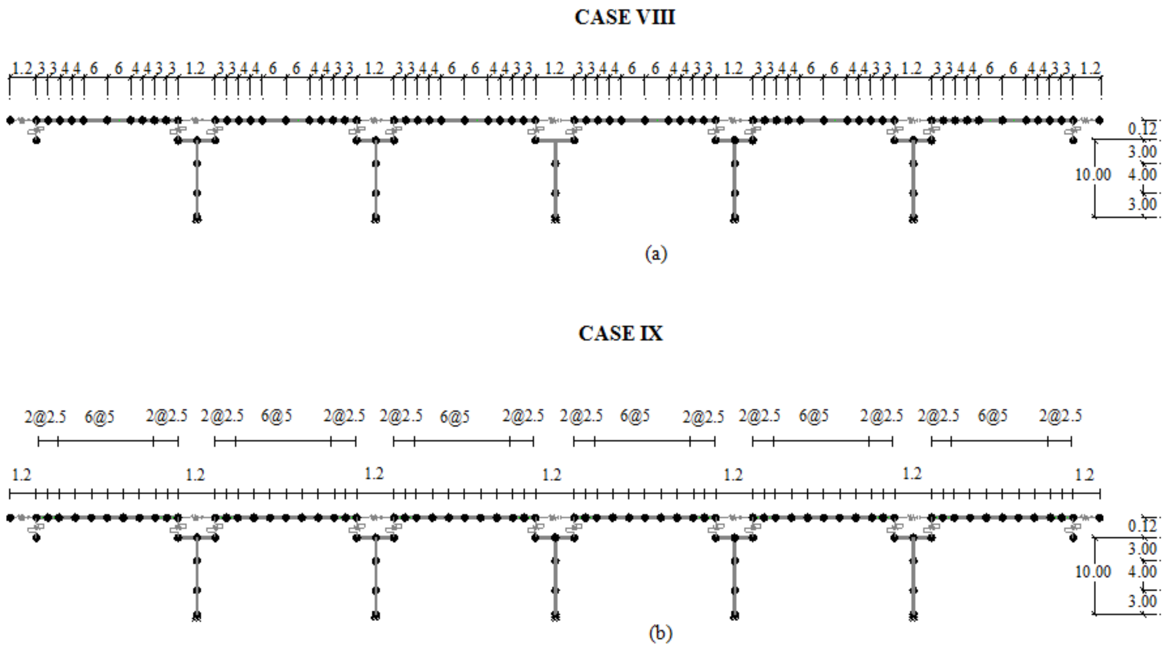

Figure 7. Idealization of 10 Unequal Length Elements for A Six Single-Spanisolated Bridge
(a) 3m,3m, 4m,4m,6m, 6m, 4m,4m, 3m,3m, **(b)** 2.5m, 2.5m, 5m, 5m, 5m, 5m, 5m, 5m, 2.5m, 2.5m.

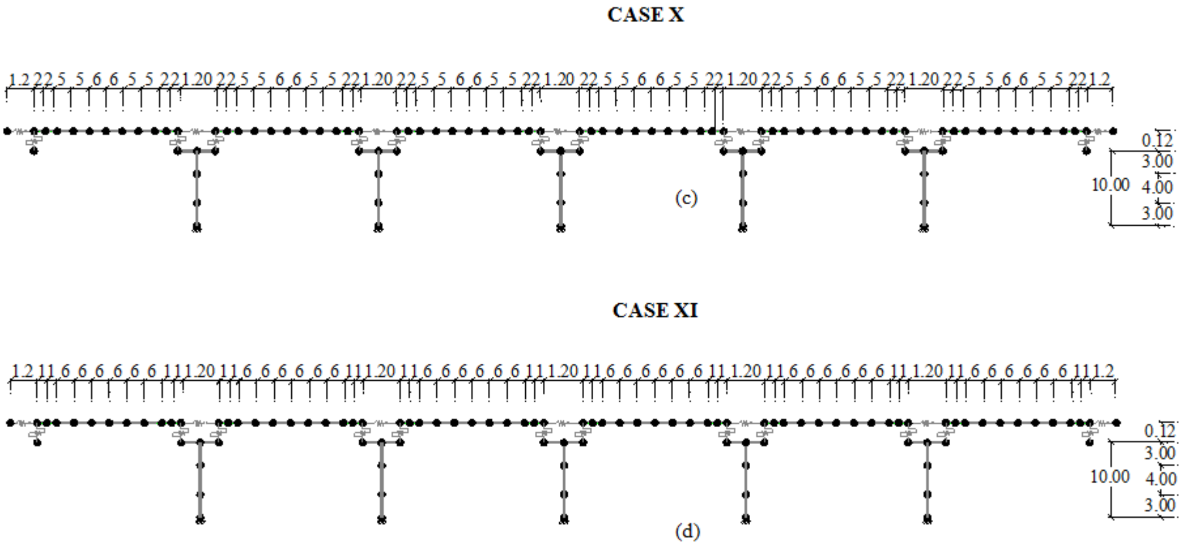

Figure 7. Idealization of 10 Unequal Length Elements for Six Single-Span Isolated Bridge **(c)** 2m,2m, 5m,5m,6m, 6m, 5m,5m, 2m,2m, **(d)** 1m, 1m, 6m, 6m,6m, 6m, 6m, 6m, 1m, 1m.

Third largest pounding force occured in (case V), fourth largest pounding force occured in (case IV), smallest pounding force occured in(case II), for each precent, forces are much different for each case, This because of VFIFE is numerical method, and numerical methods are only approximations to the real actual solution. Every numerical method has some error, so the error in VFIFE depends on the number of element. The more the number of element, the closer the VFIFE solution to the real solution.

The comparison of time histories of pounding force among 10 unequal length elements cases. Those results show for all the cases 10 unequal length elements are almost the same in time. Thus showing time of pounding forces have good agreement among those 10 unequal length elements cases.

As depicted in **Figures 11** for maximum pounding forces for each percentof 10 unequal length elements cases. It can be seen that maximum pounding forces from gap 1 to gap 4 are getting lower and then from gap 4 to gap 7 are getting larger. Those trends occured from deck slope from 0% to 10% and the large of pounding forces for all different element length are almost the same. Thus showing pounding forces have good agreement among those different number of 10 unequal length elements cases.

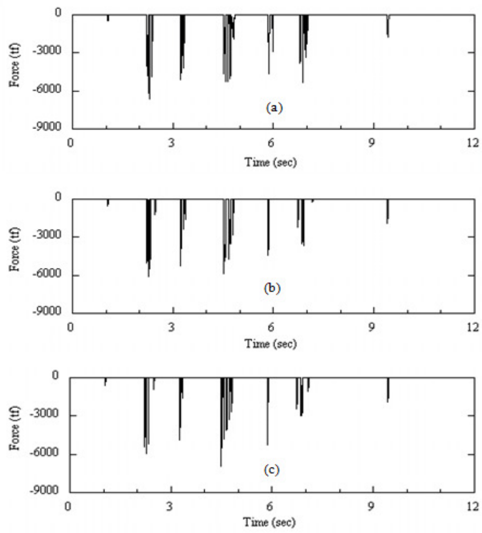

Figure 8. The Pounding Force Time History at The First Gap of Equal Length Element Under JR Takatori Record for Six Single-Span Isolated Bridge and Deck Slope 0% **(a)** 1 Equal Length Element, **(b)** 5 Equal Length Elements, **(c)** 10 Equal Length Elements

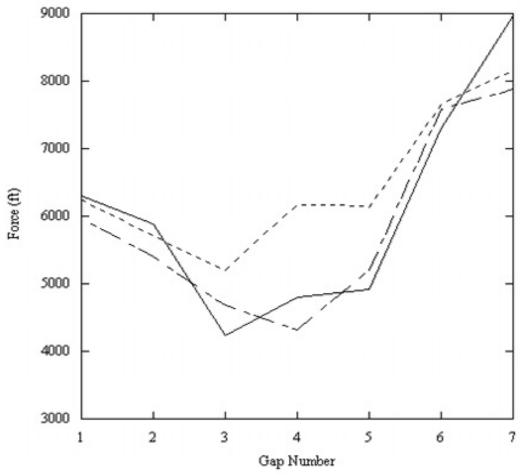

Figure 9. Maximum Pounding Force of Equal Length Element Under JR Takatori Record for Six Single-Span Isolated Bridge and Deck Slope From 0% to 10%(a) 0 %

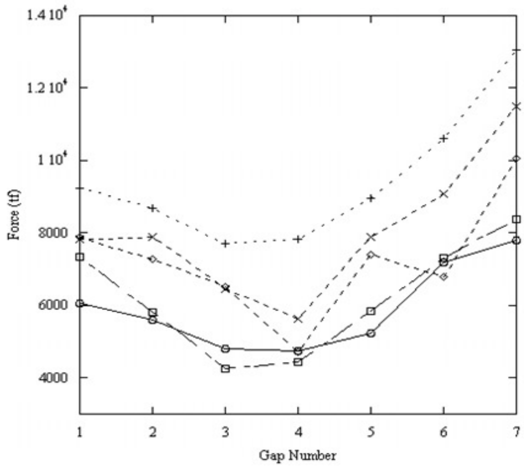

Figure 10. Maximum Pounding Force of 5 Unequal Length Elements Under JR Takatori Record Six Single-Span Isolated Bridge and deck slope from 0% to 10% (a) 0%.

c. Behaviour of elevated bridges

Shown in **Figures 12** are analysis of 2 types of graphs. First one, the result of horizontal deformation of bearing. By comparing bridge is installed compresion gap with the deck slope 0% and bridge is not installed compresion gap with the deck slope 0%, it can be seen that horizontal deformation bearing that is not installed compression gap is larger than that is installed; it is due to the fact that the deformation without pounding grows easier than that with pounding. This is because deformation with pounding has been resisted by pounding force. Second one, the result of horizontal force bearing. By comparing bridge is installed compresion gap with the deck slope 0% and bridge is not installed compresion gap with the deck slope 0%, it can also be seen horizontal force bearing that is not installed compression gap is larger than that is installed. This is because the fact that the relationship between deformation and force is linear which means if the bigger deformation make the bigger force. And after 5 seconds, the horizontal force bearing is not installed compresion gap has different shape to that is installed; it is due to the fact that the bearing of bridge which is not installedcompresion gap is failure so that the force only depend on friction force.

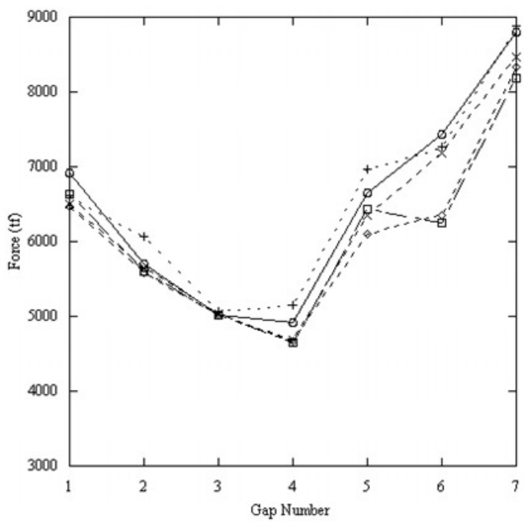

Figure 11. Maximum Pounding Force of 5 Unequal Length Elements Under JR Takatori Record Six Single-Span Isolated Bridge and Deck Slope From 0% to 10% (a) 0%

Figure 13 depicts maximum vertical forces of bearing from deck slope from 0% to 10%. It can be seen that the bigger slope can generate the larger maximum vertical force. It is because the fact that the deck which is installed by compressing gap with slope can generate moment. So that the bigger slope can generate the larger moment. And then the larger moment can result the largervertical force.

The number of bearings failure and unseating decks from deck slope from 0% to 10% and from ground motion scale 100 to ground motion 300. It can be seen that the bigger ground motion scale have more number of bearings failures. On the other hand, for the bigger slope, the number of bearings failure remain the same. It is because the fact that this bridge use high damping rubber bearing which is very stiff in the vertical direction and with low horizontal stiffness. It means the failure is caused by horizontal force only, because for the vertical force is very stiff. As can be seen, the bigger slope can generate larger vertical force and remain the same for horizontal force. So that, number of bearing failures from deck slope from 0% to 10% remain the same.

The bigger gap distance, the more failures occured. It is caused by deformation of bridges which are installed compresion gap has been resisted by pounding force. The shorter gap distance, the more often pounding force occured and that means the more deformation has been resisted by pounding force, and then the more deformation has been resisted, the less bearing failures occured. So that for the shortest gap, has the smallest number of bearing failures.

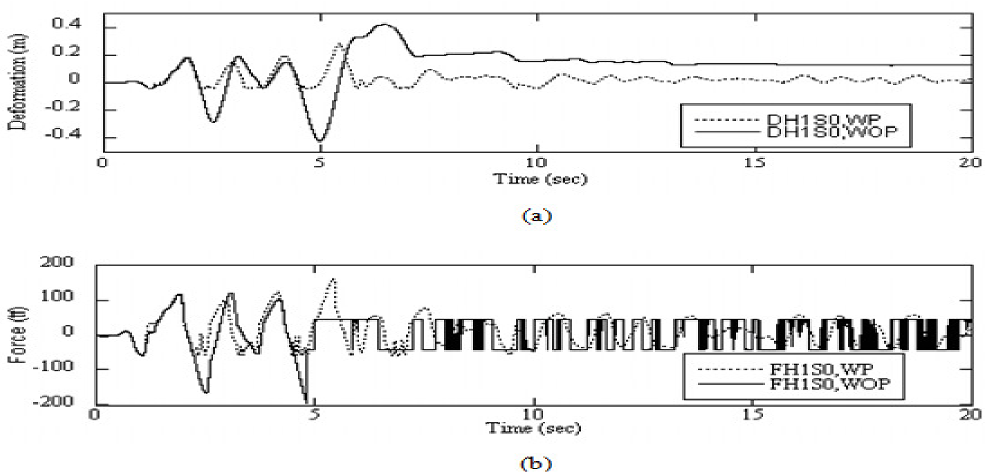

Figure 12. Comparison The Bearing Time History between Six Sngle-Span Isolated Bridge that is Installed Compression Gap and that is not Installed Compression Gap for Deck Slope 0% **(a)** Horizontal Deformation **(b)** Horizontal Force

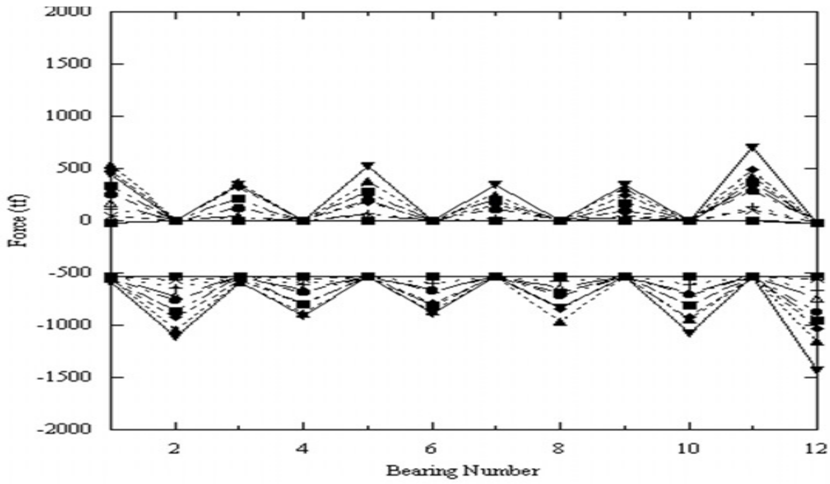

Figure 13. Maximum Vertical Force of Case IX under JR Takatori Record for Six Single-Span Isolated Bridge and Deck Slope From 0% to 10%.

CONCLUSIONS

From the analysis results,several conclusions and recomendations are listed as follow: The more the number of elements, the better of the results of VFIFE, Deformation and force of the case without pounding is larger to grow than those of the case with pounding, The vertical forces of bearings increases as the deck slope increases, Stronger ground motion results in more unseating decks and damage bearings, Bigger slope does not influence the number of unseating decks and damage bearings and The bigger size of the gap, the more failures occure.

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