The Influence of Isolation Location on the Seismic Response of the Bridge

Agim Seranaj
M.Sc. Civil Engineer
Polytechnic University of Tirana, Faculty of Civil Engineering, Tirana, Albania

Forcim Softa
Prof. Assoc. Civil Engineer
Polytechnic University of Tirana, Faculty of Civil Engineering, Tirana, Albania

Abstract:- **The base isolation methodology decreases the external energy coming into the structure, which means that the structure itself will not necessarily behave in the nonlinear range and as a result, there will be no cracks or damages to the structural elements. Most of the deformations are related to the isolation devices and not the structural elements as in the case of the fixed-base structures. Nowadays there are many types of isolators and a number of isolated structures worldwide. In order to analyze the influence of the location of isolators to the seismic response of the bridge we will analyze one bridge structure with rubber bearing isolators in three different conditions: the first model of the bridge with isolators on top of piers, the second model of the bridge with isolators on the bottom of piers and third model of the bridge with isolators on the middle of piers. The same isolators are used for each model of the bridge. The dynamic properties and seismic behaviour of three models are provided by three dimensional finite element nonlinear time history analysis, using the SAP2000 computer program. Rubber bearing isolators are modelled as bi-linear elements. The analysis show the influence of isolators location on the dynamic properties of bridge structure and its influence on the displacement and internal forces of structural elements. Based on the analysis results, it has been concluded that the best location of isolators is on the middle of piers.**

Keywords- Base isolation, bridge structure, rubber bearing, bi-linear elements, time history,

1. INTRODUCTION

Base isolation, is a seismic resistant design concept in which flexible and dissipative elements are inserted at the interface between the foundation and the base of the structure or between the substructure and superstructure of the bridge structure to reduce the seismic force transmitted from the soil to the structure. Base isolation attempts to isolate a structure from the external ground excitations, not by trying to dissipate the energy of the earthquake within the structure, rather by not allowing this energy to even enter the structure. Many years of experience with the bearings used in these earlier engineering applications, particularly with bridge bearings, have demonstrated the reliability, durability and resistance of bearings to many environmental damages. In the past three decades, the number of applications of innovative technologies in earthquake-resistant construction has increased dramatically. Seismic isolation is also used in rehabilitation of existing buildings and retrofitting of generally weak and brittle structures that do not have sufficient ductility in lateral direction (Kelly, 1997). Particularly, base isolation is commonly accepted in strengthening of the structures located in high seismic regions that have not been designed to resist severe earthquakes. In case of bridges the isolation devices are located on top of the piers, between the substructure and superstructure. On this study we try to find the benefits in case of installing the isolators on the middle height of piers.

1.1 General Characteristics of Seismic Isolated Structures

Flexibility- A properly designed base isolated structure has the required flexibility at the isolation level, where large displacements are concentrated in the isolation elements, for the reduction of accelerations and has the required rigidity of the structure elements.

Period Shift- The base isolation system should have high lateral flexibility so that the period of the isolated structure can be much longer than its corresponding fixed base period and the predominant period of many severe earthquake. So, by shifting the period, the structure, suffers two consequences: lower seismic acceleration response, and increase the relative displacement of the isolated system. In the case of base isolated structures, these relative displacements are related to the isolation devices and not the structural elements as in the case of the fixed-base structures.

Damping- The relative displacement of the isolated system can be controlled if additional damping is introduced into the structure at the isolation level. Additional damping further reduces the forces transmitted to the isolated structure.

1.2 Effectiveness of Seismic Isolation of bridges

It is sometimes difficult to define the ideal values for the stiffness and damping of the isolated system, which satisfy particular design requirements. Moreover, further limitations arise from the range of features available from the existing market, particularly with regard to simultaneously satisfying both longitudinal and transversal requirements. The implementation of seismic isolation may be beneficial when several of the following conditions are achieved:

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- The foundations mostly have a low ductility. This may present problems in case of damages, as they are usually difficult to inspect. Using base isolation, the ductility demand is decreased as the behaviour factor q is lower.
- Most of the bridges require little modifications to accommodate an isolation system, because their superstructure has a provision for free movements due to temperature or other factors.
- Isolated bridge superstructures may lead to more integrated and balanced structures with a better distribution of seismic loads between the vulnerable support substructures.
- In case of brittle structures with high stiffness and low damping, the hysteretic isolators may be used to increase the effective ductility without large increase in structural deformations.

The concept of isolation of bridges is fundamentally different than that for building structures. This is because of some features of bridges as below:

- Most of the weight is concentrated in the superstructure, in a single horizontal plane.
- The superstructure is robust in terms of resistance to seismic loads but the substructures (piers and abutments) are vulnerable.
- The seismic resistance is often different in the two orthogonal horizontal directions, longitudinal and transversal.

1.3 The location of Seismic Devices on Bridges

The objective of isolating the bridge is usually to protect the piers and their foundations and sometimes to protect the abutments also by reducing the inertia force coming from the superstructure. The isolation systems are designed to reduce the overall seismic loads, and to distribute them better in relation to the strengths of the piers and abutments and their foundations. In case of installing the isolators on top of piers only the superstructure is isolated, the piers and the abutments are not isolated from the ground motions, but their response is varied from the total response of the structure. This case is presented schematically in Figure 1a. Although it is the most practical location of isolation, there are a number of variations; the isolators may be placed at the bottom of piers which tends to isolate overall the structure as shown in Figure 1b. This case can be more helpful to the foundations but is not preferable mostly because of difficulties due to riverbed conditions. In order to overpass these difficulties the isolators may be placed around the middle of piers as shown in Figure 1c. The decision is to be taken based on the specific situation of the bridge regarding the influence of isolator locations to the behavior of the structure, to the deformations and internal forces of each structural elements.

2. DYNAMIC ANALYSIS OF BASE ISOLATED BRIDGE STRUCTURE

In order to compare the behaviour of the bridges we will analyse the structure in three different conditions: the first model is isolated bridge with isolators installed on top of piers, the second model is isolated bridge with isolators installed on bottom of piers and third model is base isolated bridge with isolators installed on the middle of piers.

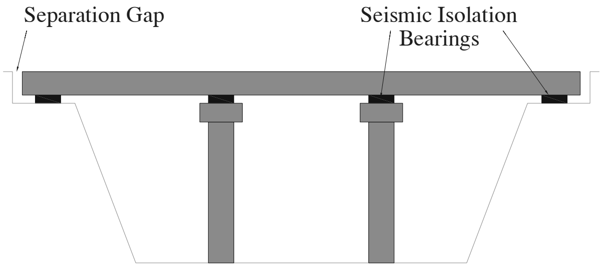


Fig. 1.a. The isolators located on top of piers

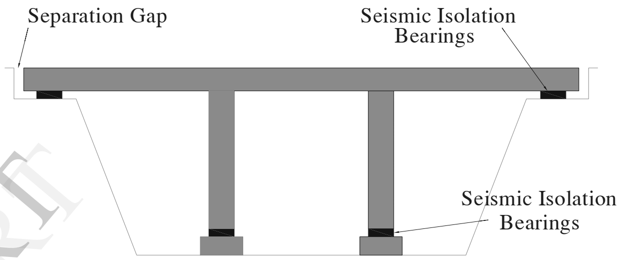


Fig. 1.b. The isolators located on bottom of piers

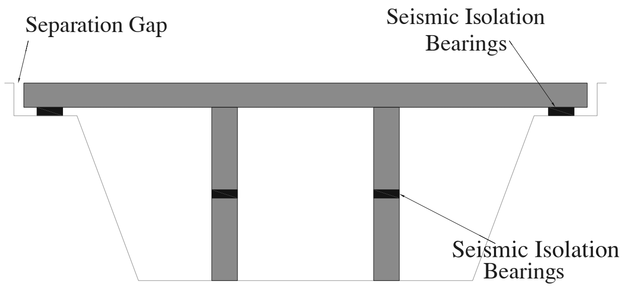


Fig. 1.c. The isolators located around the middle of piers

For each model is used only one type of rubber bearing isolator. The dynamic properties and seismic behaviour of three models are provided by three dimensional finite element nonlinear time history analysis, using the SAP2000 computer program. The seismic responses for the three models of bridges are provided under the real acceleration record of earthquake El Centro 1940. The rubber bearing isolators are modelled as bi-linear elements.

2.1 *Bridge* Structure and Input Data

Structural elements geometry- The analyzed bridge is a multi-continuous reinforce concrete structure with a total length of 360 m, supported by 10 piers and two abutments with a distance of 33 m between them. The geometry of the structure elements of the bridge is shown in Figure 2a and

2b. The superstructure consists of four reinforce concrete beams and a slab. The piers have a rectangular cross section 1m by 2m.

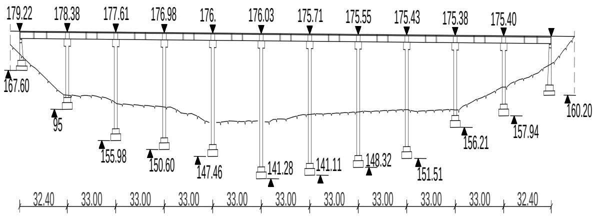


Fig. 2a. Longitudinal section of the bridge

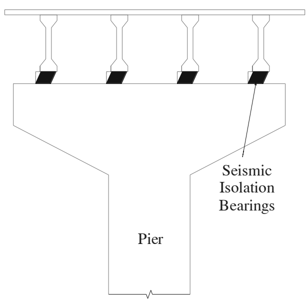


Fig. 2b. Cross section of the bridge

The characteristics of isolators- The type of isolators is selected to be rubber bearings with be-linear diagram as shown in Figure 3 and their characteristics presented in Table I.

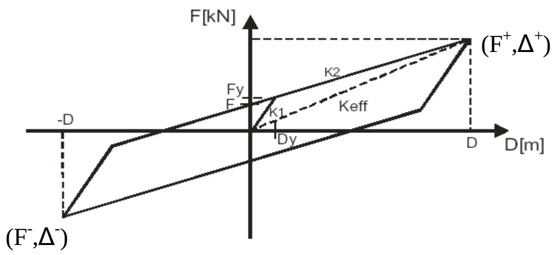


Figure 3. Bi-linear Link isolator

TABLE I. THE ISOLATOR'S CHARACTERISTICS

K_{eff} [kN/m]	F [kN]	K_1 [kN/m]	K_2 [kN/m]	D_y [m]	F_y [kN]	K_{eff} [kN/m]
746	23.43	2830	629	0.0106	30.12	74600

Applied loads and seismic action- Three types of loads are applied to the models: Dead loads, Live loads and Earthquake loads. The selected seismic inputs for the dynamic time history analysis is the acceleration record of El Centro earthquake with peak ground acceleration of PGA = 0.349g which is scaled for the selected site conditions to the peak ground acceleration of Amax= 0.4g. The input acceleration time history of El Centro is shown in Figure 4. These excitations are induced in both, X and Y, direction.

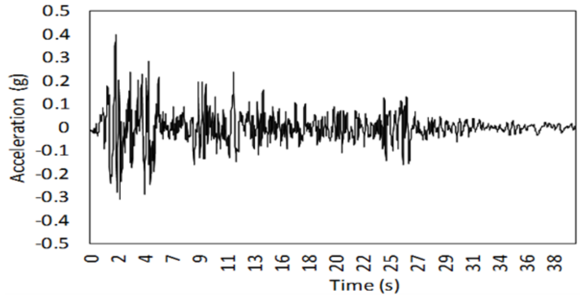


Fig. 4. The El Centro acceleration record

2.2 Modeling of Bridge Structure

The bridge structure is modelled in space using frame finite elements for the superstructure and the substructure. The labels of nodal points and frame elements are shown in Figure 5. The results from the bridge analysis will report the nodal displacements and frame element internal forces and deformations. The selected typical nodes and elements are marked with circle on these figures.

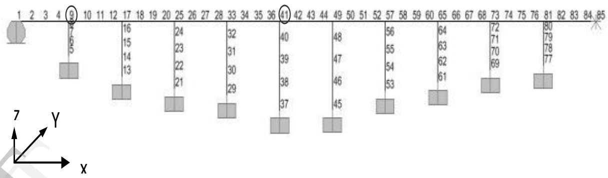


Fig. 5a. The nodal element labels

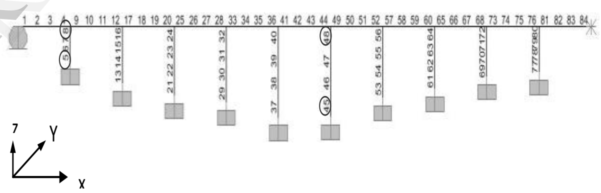


Fig. 5b. The frame element labels

Using the features of SAP2000 program the base isolated bridge will be modelled with "Link" elements for the bearings. So, the dynamic analysis will be linear for the structural elements and non-linear for the bearing elements. The connections between piers or ground and the superstructure or between piers and ground are different for each model of bridges:

Bridge Model-1: The isolators are on top of piers and the connections between piers or abutments and superstructure are modelled with "Link" element. The connections between piers and the ground are fixed.

Bridge Model-2: The isolators are on bottom of piers and the connections between piers and superstructure are rigid. The connections between piers and the ground or between abutments and the superstructure are "Link" element.

Bridge Model-3: The isolators are on the middle of piers and connections between piers and the superstructure or piers and the ground are rigid. The connections between abutments and the superstructure are modelled with "Link" element. With the "Link" elements are modelled the connections between two elements on the middle nodes of piers as well. The deformed shape of the piers for the three models are given schematically in Figure 6.

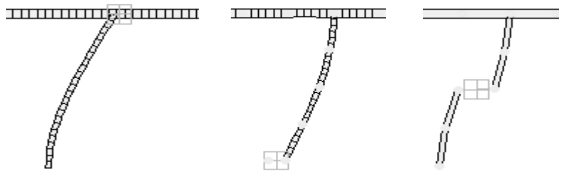


Fig. 6. The schematic deformation of piers of three Models

3. RESULTS OF ANALYSIS

All the interesting results from the dynamic and seismic analysis of three Models of structure are presented.

3.1 Dynamic Properties of Structure

The first four periods of vibrations for three models of structure are presented in Table II, below:

TABLE II. THE PERIODS OF VIBRATIONS

Mode	Model-1	Model -2	Model -3	Direction
1	3.45	3.80	3.10	x
2	2.70	3.26	2.90	y
3	2.36	2.69	2.50	y
4	1.94	2.16	2.04	y

Based on these periods the Model 2 is more flexible than other Models. As it is seen to this figure the first mode is in X direction (longitudinal), while the second, third and forth are in Y direction (transversal) for each Model. The first , second and third mode shapes of Model 3 are shown in Figure 7.

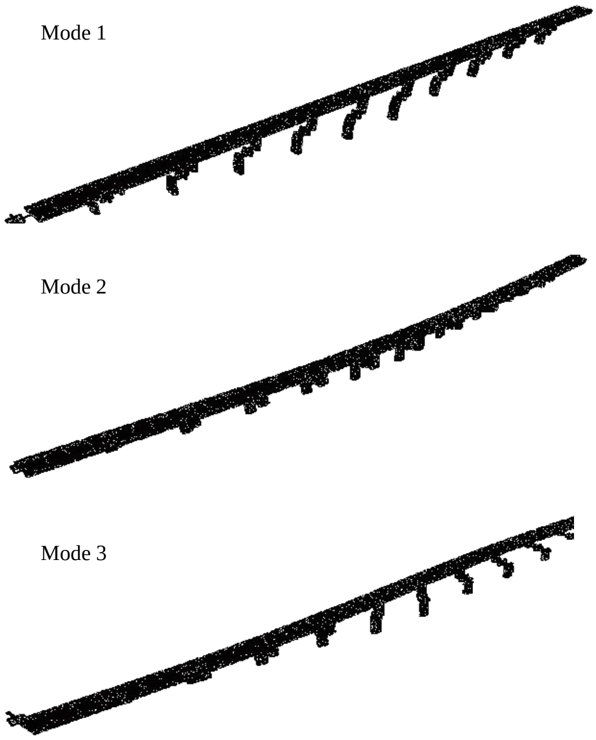


Fig. 7. First three mode shapes of Model 3

3.2 Seismic Response Results:

The seismic behaviour of three models of bridges under earthquake excitations is presented numerically in Table III and Table IV. The parameters selected are the maximum values in x and y directions of superstructure displacements (MaxUx, MaxUy), the piers deformations (MaxDx, MaxDy), isolator deformations (Dx, Dy), shear forces on top and bottom of short piers and long piers (QX, QY). bending moments on top and bottom of short piers and long piers (MX, MY), the base shears (BShear-x, BShear-y).

TABLE III. STRUCTURES RESPONSE IN "X" DIRECTION

Parameter		Model 1		Model 2		Model 3	
		Short pier	Long pier	Short pier	Long pier	Short pier	Long pier
MaxUx (m)		24.3	24.3	19.1	19.1	21.2	21.2
MaxDx (m)		4.43	23.0	3.7	11.7	1.20	9.50
MaxDx (m)		19.9	1.3	15.4	7.4	20.0	11.7
Qx (kN)	Top	590	130	400	140	560	450
	Bott	590	260	450	145	590	540
My (kNm)	Top	0	0	5750	3530	3760	6600
	Bott	7920	6880	0	0	4050	7900
BShear-x (kN)							

TABLE IV. STRUCTURES RESPONSE IN "Y" DIRECTION

Parameter		Model 1		Model 2		Model 3	
		Short pier	Long pier	Short pier	Long pier	Short pier	Long pier
MaxUy (m)		13.0	23.0	10.8	27.8	11.5	23.0
MaxDy (m)		0.2	4.7	0.2	4.6	0.1	1.8
MaxDy (m)		12.8	28.3	10.6	23.2	11.4	21.2
Qy (kN)	Top	370	560	280	370	310	500
	Bott	380	580	308	470	340	580
Mx (kNm)	Top	0	0	3800	17600	2100	9500
	Bott	5070	19750	0	0	2320	11385
BShear-y (kN)							

The diagrams of bending moments on piers for each model in both directions are presented in Figure 8. It is very visible that in case of the Model 3, the maximum bending moments on piers are almost half the moments of the other models. This is confirmed numerically by the analysis results on tables III and IV, although the shear forces are almost the same.

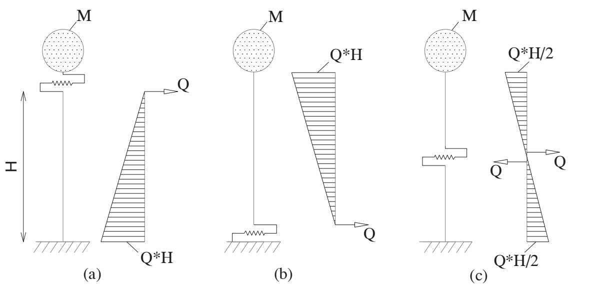
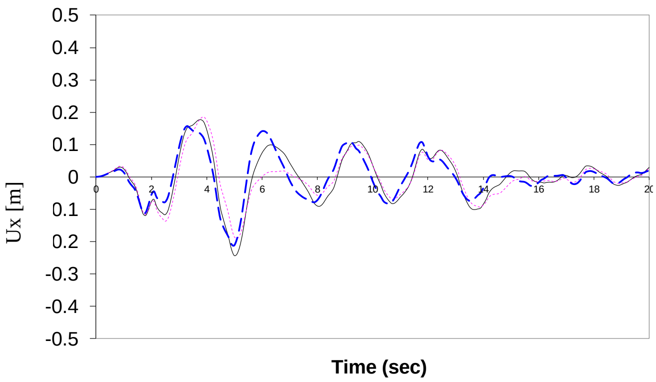


Fig. 8. Bending moments diagrams

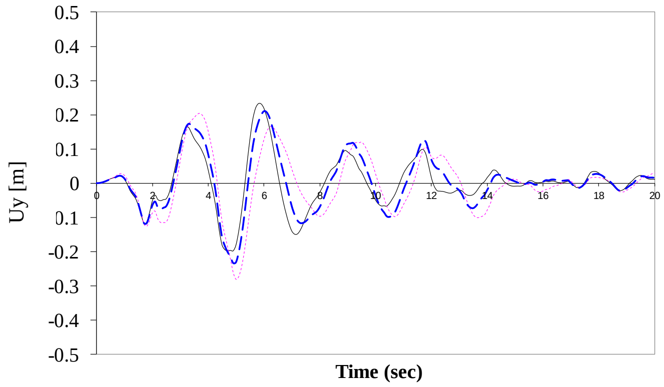
The comparative time history responses between three models of structures are plotted in the Figure 9 to 11. In the Fig. 9a and 9b are shown the comparative time history response of the superstructure displacements in X and Y directions respectively. In the Fig. 10a and 10b are shown the comparative time history response of the shear force of the Short Pier (frame EL-5) in the X and Y directions respectively. In the Fig. 10c and 10d are shown the comparative time history response of the shear force of the Long Pier (frame EL-45) in the X and Y directions respectively. In the Fig. 11a and 11b are shown the comparative time history response of the bending moment of the Short Pier (frame EL-5) in the Y and X directions respectively. In the Fig. 11c and 11d are shown the comparative time history response of the bending moment of the Long Pier (frame EL-45) in the Y and X directions respectively.

The line types of all the graphics selected for three models are presented below:

Structure Model 1
Structure Model 2
Structure Model 3

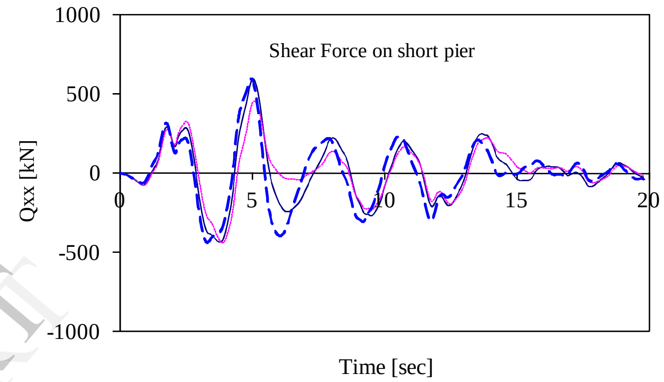


a)

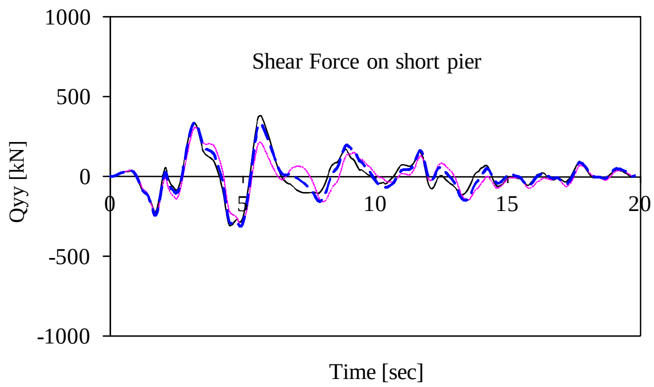


b)

Fig. 9. Time history of superstructure displacement: a) displacement in X ; b) displacement in Y.



a)



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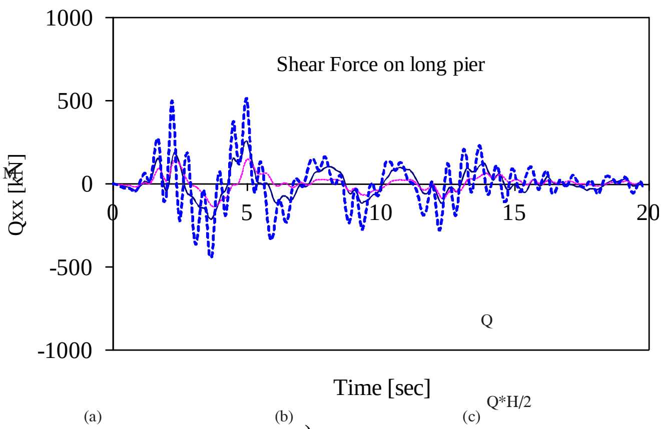
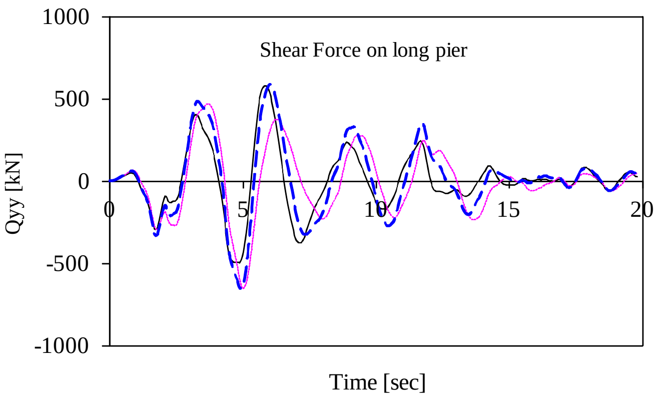
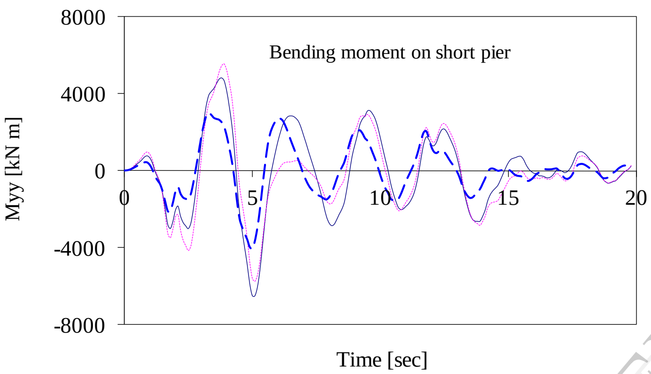


c)

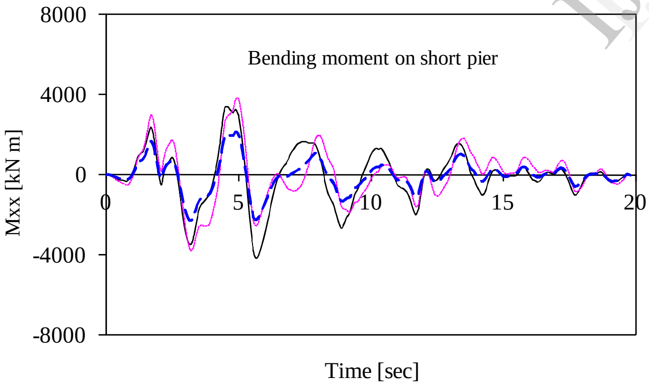


d)

Fig. 10. Time history of shear forces on piers: a) shear force on short pier, in X ; b) shear force on short pier, in Y; c) shear force on long pier, in X; d) shear force on long pier, in Y.



a)



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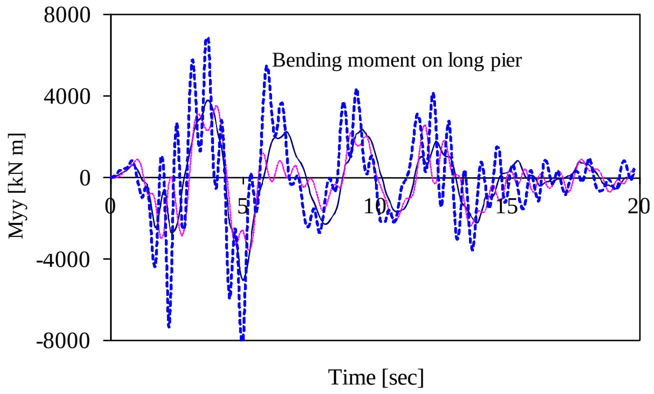

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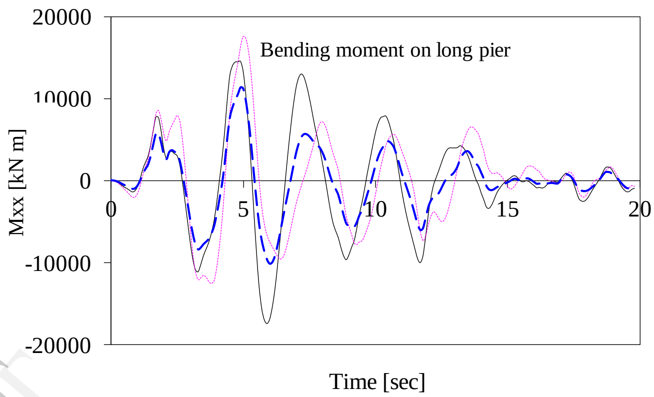

d)

Fig. 11. Time history of bending moments on piers: a) bending moment on short pier, in Y; b) bending moment on short pier, in X; c) bending moment on long pier, in Y; d) s bending moment on long pier, in X.

4. CONCLUSION

Based on the above analyses and results the following conclusions can be derived:

1. The displacements of the superstructure in X direction are smaller on Models 2 and 3 compared to Model 1.
2. On all piers, in X direction, the deformations are smaller on Model 3.
3. On short piers, in X direction, the deformations of isolators are almost the same for each model.
4. On long piers, in X direction, the deformations of isolators are smaller on Model 3.
5. On short piers, in X direction, the shear forces are almost the same for each model, but the bending moments are almost half on Model 3 compared to the other models.
6. On long piers, in X direction, the shear forces and the bending moments are lower on Model 2.
7. The displacements of the superstructure in Y direction are smaller on Models 1 and 3 compared to Model 2.
8. On all piers, in Y direction, the deformations on Model 3 are almost half the deformations on the other models.
9. On all piers, in Y direction, the deformations of isolators on Model 3 are smaller than the other models.
10. On all piers, in Y direction, the shear forces are almost the same for each model, but the bending moments are very low on Model 3.

11. Based on all analysis results and the above conclusions, we can suggest that the best location for the isolator is near the middle of the pier.
12. Having in mind the forces transmitted from piers to foundations, we conclude that placing the isolator as near to the bottom as possible will reduce the bending moment acting on the foundation.

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