Investigating The Seismic Response Of The Base Isolated Bridges With Respect To Soil-Structure Interaction

Mehri.Boozarjmehr, M.Reza.Emami

ABSTRACT - Soil conditions have a great deal to do with damage to structures during earthquakes. This paper attempts to assess the influence of static soil–structure interaction (SSI) on the behavior of seismically isolated simply supported deck bridge. This paper attempts to access the influence of nonlinear soil structure interaction (SSI)on the behavior of seismically isolated deck bridges which is most current type anywhere. The modeled bridge is supported on two piles passing through moderately deep layered soil overlying a rigid bedrock. The piles are supposed as a single equivalent upright beam. The soil–pile interaction is idealized as a beam on nonlinear Winkler foundation using contiguously distributed hysteretic springs. The deck bridge is isolated by using lead-rubber bearings and the effects of SSI are investigated by performing pushover analysis method on it. The seismic response of the isolated deck bridge with SSI was discussed under bi-directional earthquake excitations (i.e. two horizontal components of the earthquake acting simultaneously) under different soil conditions and it is found that in this type of bridges with ordinary span length, one dimensional modeling of the bridge would be sufficient. It is observed that the soil surrounding the piles has significant effects on the response of the isolated bridge specifically when the soil condition is soft to medium. Furthermore, it is found that the linear soil model does not lead to accurate prediction of base shear response and nonlinear soil modelizing is essential to reflect accurate behavior of the soil–pile system properly.

Keywords— Soil–structure interaction(SSI), deck bridge, Nonlinear springs base isolation

I. INTRODUCTION

One of the significant problems in designing the structures is designing them for lateral loads, specially sudden lateral loads as earthquakes. so Many methods have been innovated for strengthening the structures against earthquakes so far, the bridges would have significant share on attention meanwhile[2], [4].Because in the nature point of view they are categorized in the important structures range and also they are essentially needed in the critical conditions. the 1990 Manjil earthquake(Iran-1369),the 2003 Bam earthquake(Iran-1382), the 1995 Kobe earthquake,the,1994 Northridge earthquake, have demonstrated that the strength alone would not be enough for the safety of bridges during the earthquake[1], [6]. In the past several years, the research has been taken place on finding more rational solutions for protection of bridges from severe earthquake attack. Seismic isolation is a strategy which in addition to reducing the responses but displacements, attempts to reduce the seismic forces to or near the elastic capacity of the member[14]. The main concept in isolation is to reduce the fundamental frequency of structure vibration to a value lower than the predominant energy-containing frequencies of earthquake. The other purpose of the isolation is to provide means of energy dissipation, which reduces the seismic energy transmitted to the system during earthquakes thereby significantly reducing the deck acceleration and consequently the brake and thermal forces transmitted to the piers[10].Though the technique of seismic isolation has been so common even before confirmation of it's performance sufficiency. and in this study we have shown that the soil-structure interaction as an act of nature is essential to be considered in some cases.

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THE DECK BRIDGE MODEL

The bridge model used in this study, is the Jananlu bridge, crossing the Kaleibar river in East-Azarbaijan ,northwest side of Iran. This river is extended in south east-north west side and finally meets the Aras river in frontiers. The bridge consists of concrete deck section and the same material for piers. The detailed description of the bridge deck is given in Fig.1. The relevant properties of the bridge deck is given in Table 1. Since the target of this study is to investigate only the analysis results and seismic responses of the bridge in different situations, the simple one-span bridge is chosen for study, for not to be involved too much with the design problems. The modeled single spanned bridge can be seen in Fig.2.

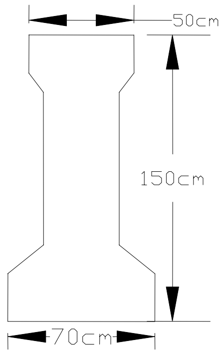

Fig 1.The section of the deck of the bridge

Fig 2. The modeled single spanned deck bridge

The mentioned bridge is modeled by SAP2000 NonlinearV.11.0.0 and the numerical study has been used for it's analyzing. The method of analysis is the Push-over analysis to follow the system to it's collapse capacity .In this study the lead-rubber pad bearings 'behavior has been supposed linear –as it leads to an accurate model of them-and the behavior of the soil has been taken nonlinear. Because linear modelizing of the soil would not lead to an accurate prediction of the structure's behavior [5].The modeled bridge is loaded gravitally and seismically according to the Code For Bridge Loading-Publication No.139 and the Code For Designing Highways and Railways Against Earthquake-Publication No.235respectively [6].

After investigation the bridge's behavior in three and two dimensional conditions and performing the non-linear analysis in both situations we found that the two dimensional Modelizing of the bridge is adequate in this type of the bridge. Thereby the deck and the piers and the piles have been modeled ideally as the linearly elements and the seismic isolators have been modeled as the link elements and the soil stiffness have been modeled as the nonlinear springs which are demonstrated in the Fig 5.It's worth to mention that the chosen isolator is one of a type with very low horizontal stiffness and a high vertical stiffness which it's stiffness has come from the equations below. The vertical stiffness of a bearing pad depends on it's modulus of elasticity. This equation, which is come from the strength of materials, is used for determining the vertical stiffness:

Table 1.
Properties of the materials of deck the bridge

Part of the structure	cross sectional area(m2)	young's modulus (kg/m2)	mass density(kg/m3)	Poisson's ratio
Deck	0.53	2.19E+9	250	0.2
Pier	1.53	2.19E+9	250	0.2
Pier	1.53	2.19E+9	250	0.2

Ec: The modulus of elasticity
A: The area facing the force
t: The ultimate thickness of the rubber pad

$$k_V = \frac{E_c A}{t} \qquad (1)$$

Although the vertical stiffness is important in investigation of the rubber pad's stability and it's vertical force bearing operation, but the response of the structure in the vibration of an earthquake depends on the horizontal stiffness of the rubber pads to some extent. as we know:

$$\omega_n = \sqrt{\frac{k}{m}} \qquad (2)$$

It can be seen that the natural frequency and so the response of the system is a function of the horizontal stiffness. The shear strain γ for the little
displacements can be determined as:

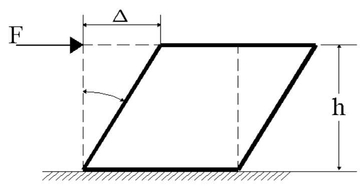

FIG 3.The rubber pads under shear force.

$$\gamma = \frac{\Delta}{h} \qquad (3)$$

$G = \frac{\tau}{\gamma}$ The Hook's low for shear modulus is the equation below:

(4)

In which $\tau = \frac{F}{A}$ and A is the lateral section area of the rubber pad. with substituting these relations in the Eq.4 we will have:

$$G = \frac{Fh}{A\Delta} \qquad (5)$$

We can say: F=k.Δ.so k_H can be obtained from:

$$k_H = \frac{AG}{h} \qquad (6)$$

Then the horizontal stiffness of the rubber pads can be related to it's natural frequency with (7).

$$\frac{k}{m} = \omega_n^2 \qquad (7)$$

Some of the rubber pad's important parameters are:

Table 2.

Rubber pad's type (shore)	modulus of elasticity kg/cm2	shear modulus kg/cm2
10	10.91	3.71
20	13.11	4.55
30	20.51	6.69
40	28.08	9.36
50	30.11	10.37
60	34.12	12.37

It can be observed that the elasticity modulus and the shear modulus are increasing (from type 10 to 60).The rubber pad chosen for this study is 30shore A which is illustrated in the Fig 4.

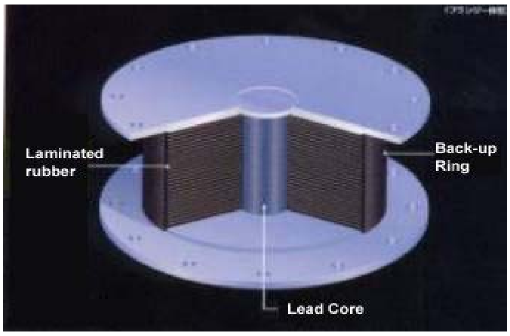

Fig 4. Schematic view of the rubber pads.

III.NUMERICAL STUDY

The soil surrounding the piles has been modeled nonlinearly for getting more accuracy, although some approximations are made about the parameter, but in general the stiffness of the equivalent spring of the soil has come from the formulas of the API code, which is no leisure to be discussed here. The soil strata is demonstrated in detail in table 3.

Table 3.Properties of the soil strata

PI	γ	Φ	C	Depth	Type of soil
15	16.20	17.00	5.00	1.75	Made soil and sand with plum
-	17.50	28.50	12.50	5.25	Silty sand with clay
-	-	-	-	11.00	Water level
-	19.60	22.00	45.00	14.00	Silty clay with saturated sand

IV.CONCLUSIONS AND RECOMMENDATIONS

The observed results of this study can be summarized here.

1.The results of the Pushover analysis for the simple bridge-no base isolation, no SSI -The period of the vibration exertion of the earthquake in the X direction _the direction of the span of the bridge is normally 0.28sec, the ultimate shear force carried by the deck till collapse is around 8.6 ton , the resulting displacement in the same direction is 10.4cm and the ultimate bending moment carried by deck is 25.3 t.m.

2.In the second case-with seismic isolation- the main period of the system has rised to 1.28sec, the ultimate shear force carried by the deck till collapse is around6.51ton and the resulting displacement in the same direction becomes 18.10cm and the ultimate bending moment carried by deck is 18.12 t.m.

3.In the third case of study -with seismic isolation and the nonlinear SSI- the main period of the system has rised to 1.31sec, the ultimate shear force carried by the deck till collapse is around5.73 ton and the resulting displacement in the same direction would be 19.80cm and the ultimate bending moment carried by deck is 17.67 t.m.

4.In the forth case of study-with seismic isolation and the nonlinear SSI with a relatively more soft soil- the main period of the system has raised to 1.43sec, the ultimate shear force carried by the deck till collapse is around5.50 ton and the resulting displacement in the same direction would be 22.72cm and the ultimate bending moment carried by deck is 19.81 t.m.

5.Assuming the linear behavior for the soil in analyzing the Model including piles would not lead to an accurate prediction of the system responses and nonlinear modeling of the soil is recommended for getting near to investigate the real behavior of the soil-pile system.

6.The SSI is mainly observed in comparison between the soft-Medium to firm soil conditions. So it's recommended to include SSI effects in designing

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process of bridges in moderately soft soil conditions. Comparing the results of the second case with the forth one and again the second case with the third one ,it's observed that for the soft soil condition the SSI plays a significant role in the seismic responses of the system.

7.Since the used model was a bridge with medium span, we found that it is no need to use the 3D model for analysis and the lateral directions responses are not that significant to be mentioned, but this doesn't mean that two directional modeling is adequate for getting the right response in the seismic analysis of base isolated bridges with respect to soil-structure interaction, and so we are working on 3D models of bridges with different spans, and of different types. the two model we are working on now are a three spanned deck bridge and an arch bridge which different assumptive spans in the range of 20m to 120m. The results will come in the next coming papers.

V.ACKNOWLEDGMENTS

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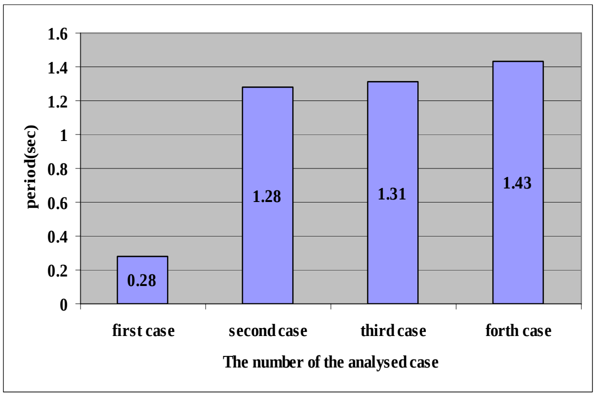

Fig 5.Comparison of the natural period in the four cases of the bridge's study

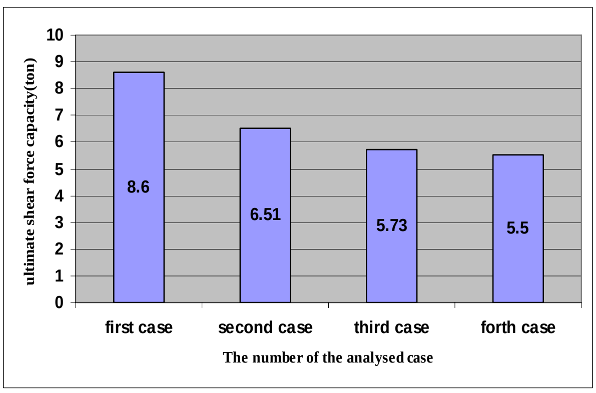

Fig 6.Comparison of the ultimate shear capacity in the four cases of the bridge's study

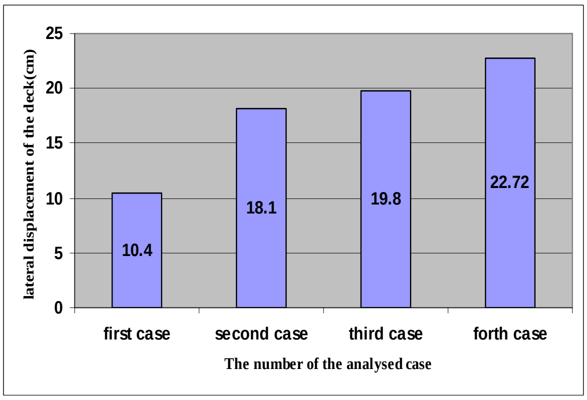

Fig7.Comparison the ultimate lateral displacement of the bridge deck in the four cases of the bridge's study

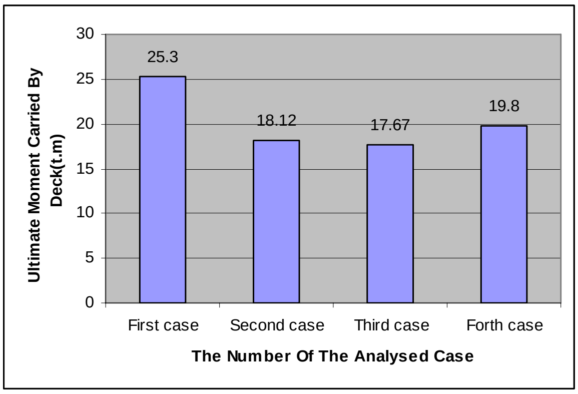

Fig8. Comparison the ultimate bending moment, carried by deck in the four cases of the bridge's study

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