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Seismic Vulnerability Assessment Arched Bridges Retrofit of Reinforced Concrete Box Canyon Deck Using Fiber Reinforced Polymer

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ABSTRACT

Seismic strengthening is the only solution minimize the risk of existing bridges against damage during an earthquake vulnerable. This study, unlike many of the case studies, investigates the vulnerability of arched bridges with a box section frame in the construction and retrofitting of probabilistic deals. As well as Viaduct, because of the way that it needs to pass the Curved horizontal with a radius and height of uniform and non-uniform as well. In such a case, although it may be relatively uniform response of deck structures, required ductility of columns, each column will vary. The effect of the curvature radius with a base height difference of the curved geometry of horizontal bridges adds to the complexity of horizontal seismic behavior of Curved Box bridges. Evaluation of the seismic vulnerability of bridges that span concrete Curve with a deck box strengthening of reinforced concrete is evaluated in this study. In order to prepare the necessary tools for designing, planning, and reducing the vulnerability of bridges in strategic routes and maximum use of resources in the retrofit of bridges, providing a context for the evaluation of the seismic vulnerability of bridges has been presented. Therefore, seismic demand models for multi-span Curved bridge deck box with the same base and altitude circular base of a column and various height are produced. The main parameters of the model require different radius and height difference Curved bridge deck is horizontal. Thus, a class-arch bridge in California constructed after 1970, selected three-dimensional finite element analysis models of bridges, the nonlinear time history analysis is created. The other five bridges with the radius of curvature of the half, one and a half times, twice, three times and ten times of the original sample is modeled. While job engagement had a negative and causal correlation with intention to quit (r = -0.32).

Keywords: concrete arch bridge, unequal piers, the radius of curvature of the arched bridge, bridge strengthening, cfrp

INTRODUCTION

Bridges are one of the most important civil engineering structures in the arterial thoroughfares of each country. Earthquakes that have taken place in recent decades have shown bridges are one of the most vulnerable elements in transportation system. Bridge failures have led to the disconnection of a significant part of highway network which causes significant financial losses and precludes the possibility of post-

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earthquake emergency response (Dukes, 2013). In the meantime, arch bridges have become one of the most popular types of bridges in a plan, especially urban areas. This can be attributed to the geometric capability of arch bridges to meet transportation needs and geometric design of roads. Among the common uses of arch bridges in the plan, one can be referred to outbound routes of highways and connecting parts of non-axial routes. Seismic retrofitting is a solution to minimize the risk on existing bridges that are vulnerable to serious damage during an earthquake. Most earthquake prone countries in the world have devoted a budget to reinforce and reduce the vulnerability of existing bridges in their strategic routes and crisis management. However, due to the large number of bridges and various methods of reinforcement, the limited allocated budget and also high cost of most retrofitting methods, the provision of a set of information to determine firstly the degree of vulnerability of each bridges in the earthquake, and secondly the impact of each of the common methods of retrofitting on their seismic performance seems to have become more necessary than ever (FHWA, 1995). Recently, studies have been conducted on the effect of different retrofitting methods on direct bridges (Padgett, 2008). However, there are no specific and consistent studies on arch bridge. Therefore, due to the specific geometric conditions and the different behaviors that these bridges display in relation to direct bridges during the earthquake, it is necessary to examine and determine the extent of efficiency of common retrofitting methods on reducing their vulnerability.

The experiences acquired through past decades earthquakes in countries such as Japan and the United States, and the collapse of several bridges in these earthquakes, as well as extensive research on the seismic behavior of existing bridges in the last two decades have all shown that bridges constructed based on the old regulations in earthquake prone countries including Iran are not strong enough to withstand moderate to strong earthquakes. Hence, the rehabilitation of bridges built over the past decades is considered the most urgent issues of retrofitting in seismic regions of the country. However, due to the complexity and high costs of existing bridge rehabilitation, the main objective of retrofitting is to prevent unacceptable and catastrophic failures in the event of strong earthquakes otherwise the problem may be economically unjustifiable and renovation is another option to solve the problem.

This study investigates the seismic vulnerability of concrete (skew) arch box girder bridges, considering the effect of retrofitting and changes in the radius of the bridge. The purpose of this study is to investigate the seismic behavior of bridges reinforced by steel jacket method. The main parameter of the analysis in this study was the investigation of the values of column drifts with different curvature radius before and after retrofitting. Because the columns are one of the most important components of the arch bridges, a column failure can lead to a full collapse of the bridge.

PRESENTING THE BRIDGES UNDER STUDY

The investigation of data collected from existing bridges in California shows that the bulk of highway bridges are concrete box girder bridges in the state of California, and these bridges are generally used for taller spans.

The original bridge model is based on bridge made in California and its specification is adopted from (Ramanathan, 2012). The class of bridges in this study is concrete multi-span arch bridge (Four spans) with a box deck with multi-column piers. Also, an intermediate joint is located at a distance of about 20% of the initial length of the third span.

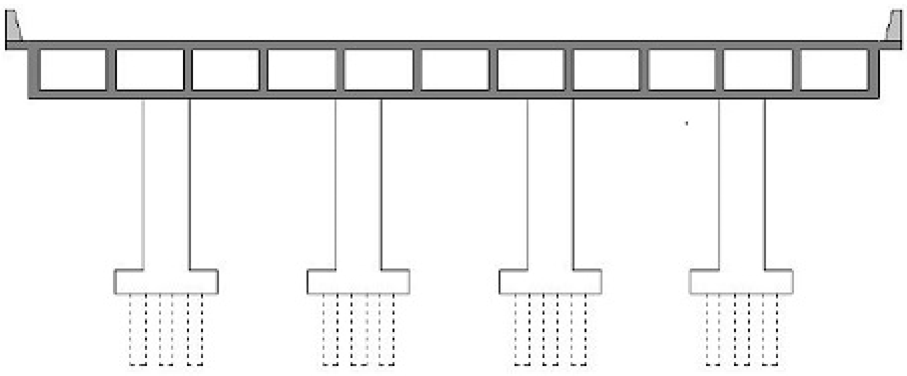


Figure 1. Cross section of the studied bridge

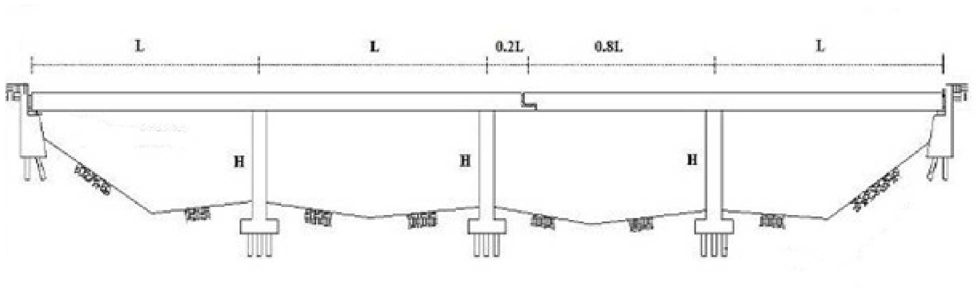


Figure 2. Bridge with constant height difference

As mentioned valley bridges include height difference and curvature radiuse. So in this study 5 bridges, a bridge with height equal to the columns and 4 bridge with varying radius of curvature and height considered which is shown in the figure.

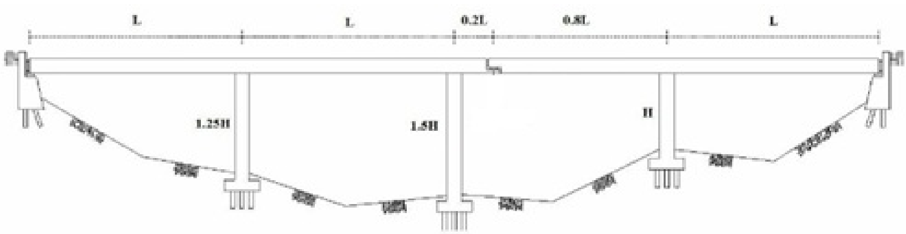


Figure 3. Bridge with columns difference (1.25-1.5-1)H and a radius of curvature of 66 meters

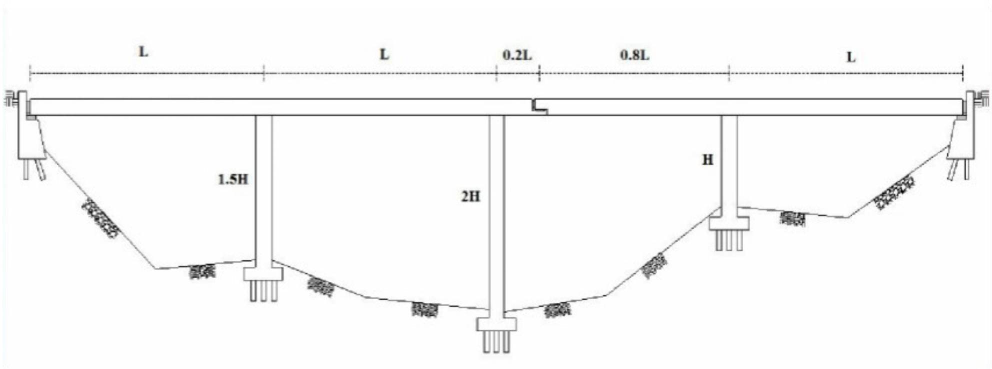


Figure 4. Bridge with columns difference (1.5-2-1)H and a radius of curvature of 200 meters

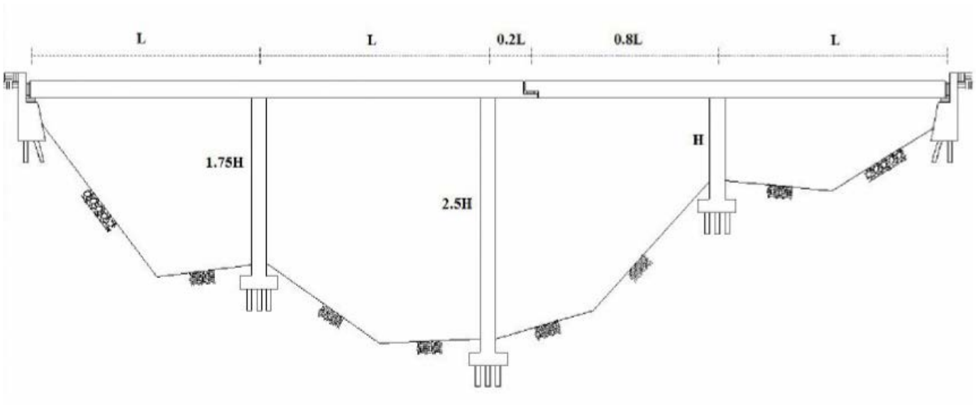


Figure 5. Bridge with columns difference (1.75-2.5-1)H and a radius of curvature of 265 meters

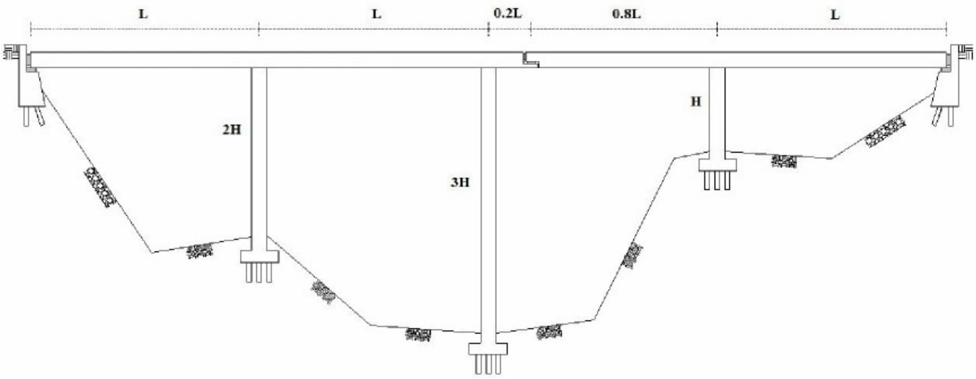


Figure 6. Bridge with columns difference (2-3-1)H and a radius of curvature of 1324 meters

Geometric parameters describing the bridge model applied for nonlinear dynamical analysis are presented in **Table 1**.

Table 1. Geometric Parameters Describing the Bridge Model (Ramanathan, 2012)

Bridge profile	**unit**	**Q.T.Y**
Number of columns in the frame	numeral	4
Column height	m	6
Church column	m	2
Number of longitudinal reinfocement (Φ11)	numeral	42
Distance between the stirrup (Φ4)	m	0
Span length	m	33
Deck width	m	34
Number of deck cross sections	m	11
Total superstructure depth	m	1
Top flange depth	m	0
Thickness of the lower wings of the deck	m	0
Thickness of the cross section of the deck	m	0
Center distance to deck center	m	3
Translational spring stiffnesses	KN/mm	7
Rotational spring stiffnesses	KN/mm	0

Also, the dimensions of the box girder, the size of the columns and the details of the reinforcement are presented. Concrete box girder bridges generally use circular columns, and their diameter and reinforcement depend on the number of columns in each frame. Also, the number of longitudinal reinforcements, as well as the distance between the stir-ups used to reinforce the columns, are listed in the table. The average height of the rolls is about 1.8 meters and is placed on concrete piles of grade 7, which were carried out at 2.1 meters. The average compressive strength of concrete is about 34.5 Mega-Pascal and moderate resistance to the steel delivery limit is 414 mega-Pascal. The main parameters in this study are the change in the radius of the horizontal arch bridge as well as the reinforcement of the columns. The original radius is 132.4 meters. To investigate the effect of changes in the radius of the bridge, as well as the effect of column reinforcement on the steel jacket, 4 other kinds of bridge with different radius were modeled as follows:

66 meters (Approximately half the radius of the original sample)

200 meters (Approximately one and a half times the radius of the original sample)

265 (Approximately twice the radius of the original sample)

1324 (Ten times the radius of the original sample and the same as the straight bridge)

All specifications of materials that were used and geometric parameters other than radius of bridges are similar to the original sample. The length of all samples is 132.4 meters. The modeling is carried out by CSiBridge 2015. The selected longitudinal and transverse directions are shown in **Figure 3**.

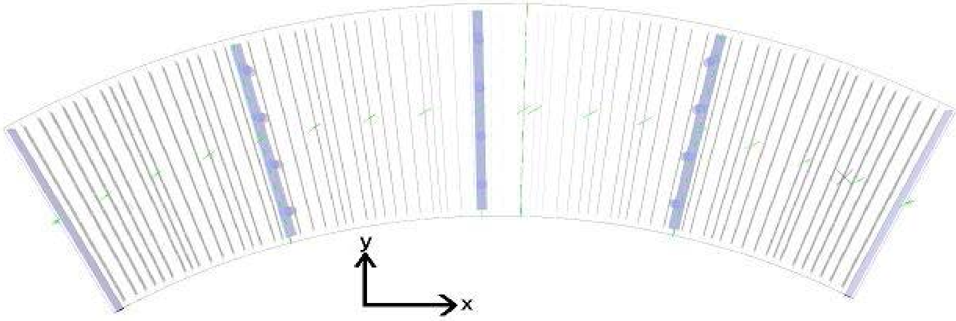


Figure 7. View the longitudinal and transverse directions of the bridge

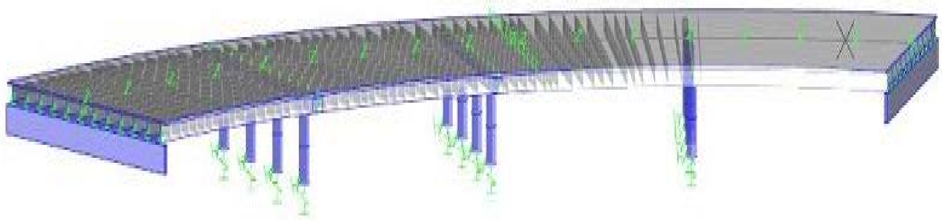


Figure 8. Bridge model in software csi bridge 2015

REINFORCEMENT BY WRAPPING UP THE FIBER-REINFORCED PLASTIC

One of the new methods considered by industrialists in recent years is to retrofit or refurbish existing buildings by fiber-reinforced polymers. A plethora of researches have been conducted in this field and preliminary guidelines have been developed to use them. Due to their high tensile strength, these materials are suitable tools for increasing the capacity of concrete members. Nowadays, a high volume of refinement and reinforcement of concrete structures is being carried out using these materials. The technology of using sheets of fiber-reinforced polymer in civil engineering was first tested by Professor Meyer in Switzerland in 1984, in which carbon sheets of reinforced polymer fibers were tested for the reinforcement of concrete beams (Wright et al., 2011). The biggest advantage of fiber-reinforced polymers over steel is its high resistance ratio. Katsumata et al. (1987) presented the use of fiber-reinforced polymer to reinforce concrete columns (Priestley et al., 1996).

Introduction of Fiber-reinforced Plastic

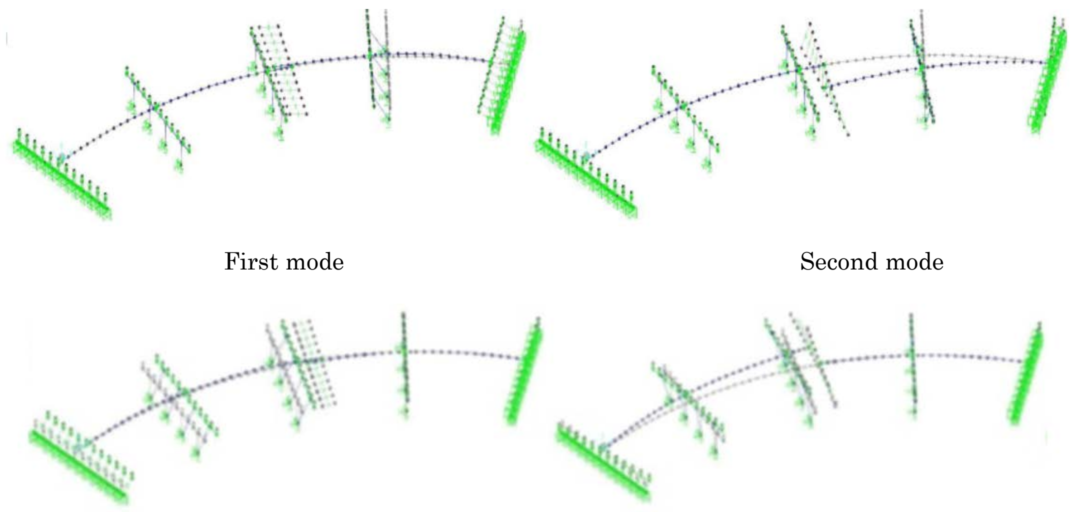
Fiber-reinforced polymers are referred composite materials that are composed of reinforcing fibers and materials consisting of (matrix) or polymer-based resin. Fiber-reinforced polymers are composite and composite materials that are composed of reinforcing fibers and materials consisting of (matrix) or polymer-based resin. Fiber-reinforced polymer sheets typically have at least twice and can even ten times as much strength as steel sheets while their weight is only 20% of that of steel sheets (Chai et al., 1991). These sheets have been being used for many years in various industries and the features of these materials are well-known (FHWA, 2006).

Properties of Fiber

The most common types of fiber used in the manufacturing the composites are carbon fibers, glass and aramid. These fibers have a very strong tensile strength and their stress-strain behavior is linear. Carbon fibers are able to be produced in a wide range of hardness and their most important properties are high strength and hardness, excellent resistance to chemicals and moisture, high resistance to fatigue and failure in the effect. In the method of wrapping up the columns by fiber-reinforced polymers, in order to perform a reinforcement process, a fiber with a better compressive strength should be selected. Since carbon fiber has a higher compressive strength than glass and aramid fibers, its durability is more than glass and aramid fibers in the long run, and is therefore economically feasible, so the carbon fiber is used for reinforcement (far.

MODAL ANALYSIS AND MODAL FORMS

Modal analysis is carried out by CSiBridge 2015. The first period of bridge vibrations is shown in **Tables 2** and **3**. As shown in **Tables 2** and **3**, the first period of the bridge vibrations is approximately the same, and the change in the radius of the bridges does not have much effect on their period of rotation. It is also evident that the steel jacket retrofitting has caused a slight decrease in the period of time. The various modal forms from the first to the fourth modes of the bridge before being retrofitted to a radius of 132.4 meters are shown in **Figure 6**. It should be noted that the modal forms of other bridges (before and after retrofitting) with different radii are similar to those of the same example of the bridge.



First mode Second mode

Third mode Fourth mode

Figure 9. Moody Shapes

Typically, in most bridges, especially direct bridges, the primary mode is in the longitudinal direction, the second mode is along the transverse and third mode is torsional. Generally, in most cases, the second and higher modes are based on the transverse and torsional behavior and responses of the bridge. However, in the case of the proposed bridge, according to the modal forms, it is evident that in the first and second modes, the twisting in n the third and fourth modes, the twist around the central axis of the bridge is the dominant response.

NONLINEAR TIME HISTORY ANALYSIS

It is important to collect earthquake sets to carry out the analysis, which indicates the risk of an earthquake in the entire area under study, but it is also very difficult.

The main idea is to provide a timeline for earthquakes with a wide range of different intensities expected in the geographical range based on earthquake risk analysis, such as magnitude and focal length.

For this historical timeline analysis was performed with 100 records. All earthquakes in this collection, from land databases seismicity of the west American Earthquakes studies Center,

Which is related to shallow earthquakes with a magnitude of 4.3 to 7.9.

Among 100 earthquakes in the Krawinkler complex, 20 of them relate to earthquakes with high velocity pulse characteristics at near fault points

Sub category 1: includes earthquakes related to the site soft soil this subset contains 30 unscalled earthquakes so that their response spectrum is compatible with the predicted logarithmic mean and standard deviation for a 7 magnitude earthquake at 10 km intervals

Sub category 2: includes earthquakes related to a soft soil site this subset contain 30 unscalled earthquakes, so that their response spectrum is compatible with the predicted logarithmic mean and standard deviation for 6 magnitude earthquake at 25 km distance

Sub category 3: includes earthquakes related to the rocky site this subset contains 20 unplanned earthquakes, so that their response spectrum is compatible with the predicted logarithmic mean and standard deviation for a 7 magnitude earthquake at a distance 10 km.

Sub category 4: includes earthquakes near the fault this subset contains 20 unplanned earthquakes for high speed pulse earthquakes.this subset is used to obtain earthquake condition near the fault (Krawinkler, 2000).

Time History Analysis

Nonlinear time histories' analysis is done taking into account the 5% downtrend ratio on the bridge model under a pair of ground motion records.

Analytical results

Analysis of time histories was done by applying on hundred record quake records in two orthogonal directions to one hundred samples from each radius.

Each bridge has 12 columns. After the analysis a total of 1200 outputs from each bridge radiuse were taken from the columns in two directions, longitudinal and transverse.

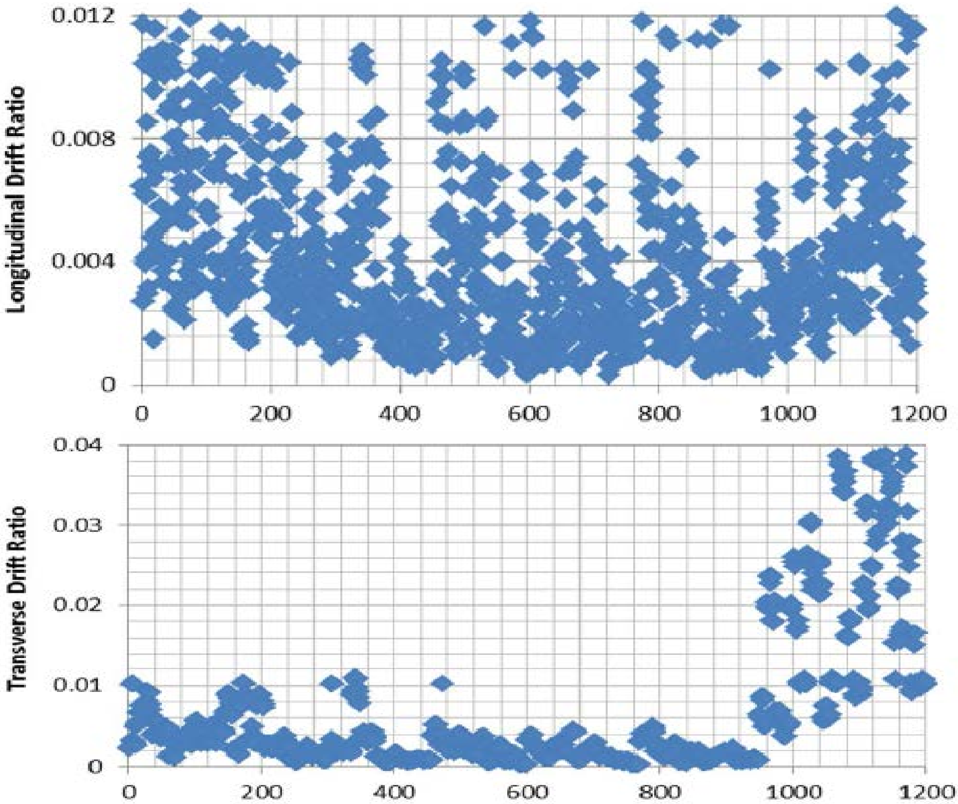


Figure 10. Longitudinal drift (up) and transverse drift (down) of bridge columns with a radius of 132.4 m before retrofitting

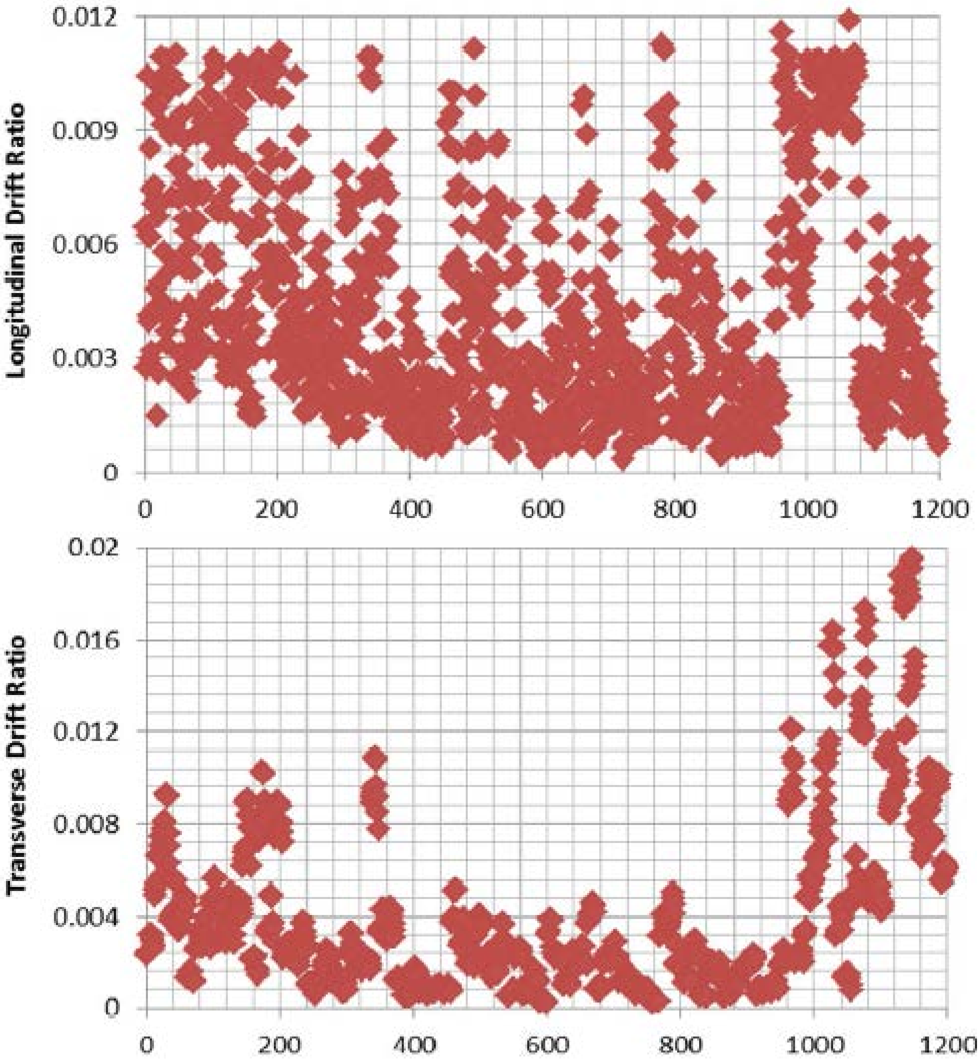


Figure 11. Longitudinal drift (up) and transverse drift (down) of bridge columns with a radius of 132.4 m retrofitting

Table 2. Compare amount Longitudinal and transverse before and after retrofitting

Radius	column height	maximum Longitudinal drift length in bridges before retrofitting	maximum Longitudinal drift length in bridges retrofitting	maximum transverse drift in bridges retrofitting	maximum transverse drift in bridges before retrofitting
66	(1.25h-1.5h-h)	0.01917	0.01239	0.04140	0.02169
132.4	(h-h-h)	0.01198	0.01186	0.03880	0.01958
200	(1.5h-2h-h)	0.01467	0.01393	0.03359	0.01900
265	(1.75h-2.5h-h)	0.01249	0.01455	0.03222	0.01888
1324	(2h-3h-h)	0.00937	0.01641	0.03157	0.01832

In tables the results of the analysis of nonlinear time history output on 10 sample bridges (5 samples before resisting and 5 samples after resisting) are shown. According the tables above, longitude drift of the samples changes irregularly and the latitude drift decreases as the radius increases.

CONCLUSION

After the modal analysis, it's observed that as the radius changes, the main frequency time of the arch bridg doesn't change and remains almost fixed.

- It's also observed frequency time of the bridges retrofitted by CFRP doesn't change as the radius curvature of the bridge increases, but the time is a little bit shorter than the frequency time of non-resistant samples.
- After conducting the nonlinear time history analysis, it's observed that the longitude drift of the bridge columns increases and decreases irregularly as the beam increases and doesn't follow a certain procedure.

This disorder is also observed in retrofitted samples.

- It's observed that the bridge column latitude radius increases as the beam increases. In retrofitted samples it's also the same.

Disclosure statement

No potential conflict of interest was reported by the authors.

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