# EFFECT OF ELASTOMERIC BEARING MODELING PARAMETERS ON THE SEISMIS DESIGN OF RC HIGHWAY BRIDGES WITH PRECAST CONCRETE GIRDERS

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**ABSTRACT :**
Parameters affecting the seismic design and behavior of reinforced concrete (RC) highway bridges with precast prestressed concrete girders are numerically investigated. I-girders of these bridges are often supported at the ends by elastomeric bearing pads. The bearing pad-bridge girder interface defines support boundary conditions and may affect the seismic performance of the bridge. AASHTO design principles are followed throughout this work. A previously designed and constructed real bridge example (the Akcaova Bridge) which is located on the third earthquake zone in Turkey is considered for the analysis. SAP2000 is used to model the bridge. Although numerical investigations reveal that elastomeric pads may positively affect the seismic response of such bridges, this effect highly depends on geometry of bridge, especially the pier rigidities. Other conclusions include that elastomeric bearings may add extra stiffness to the system when tall and flexible piers are used.

**KEYWORDS:**
AASHTO, Seismic behavior, Elastomeric bearing, Precast girder, Simple bridges.

## 1. INTRODUCTION

Reinforced concrete (RC) bridges with precast prestressed concrete girders are commonly used bridge configurations in highway bridges in Turkey. The application possibilities of these bridges are even increasing because of their simplicity in design and construction as well as ease of maintanence (Akogul, 2007). Also, an economical comparison between other alternatives and bridges with precast prestressed concrete girders usually results in favor of such bridge systems for almost all bridges having short-span to medium spans in Turkey. Both simplified and 3D sophisticated analysis methods following AASHTO principles (AASHTO, 2002) are used in the analysis and design. In some cases when required, ATC and/or Caltrans principles are also used (ATC-6, 1981, Caltrans, 1994).

Numerous studies have been achieved on modeling, analysis, and design of bridge superstructures (Yazdani et al., 2000, Jangid, 2002, Dai et al., 2005, Dicleli and Buddaram, 2006). These studies have contributed to the subject in various ways. Mostly, effect of modeling parameters are investigated and discussed. Both linear and nonlinear analysis procedures are covered. In this respect, Kikuchi and Aiken (1996) presented an analytical hysteresis model for elastomeric seismic isolation bearings. However, limited studies have focused on the behavior of regular elastomeric pads which are not recognized as isolation bearings. I-girders of such bridges are often supported at the ends by elastomeric bearing pads. The bearing pad-bridge girder interface defines support boundary conditions and may affect the seismic performance of the bridge. This study mainly focuses on this effect. Depending on mechanical properties of the selected bearings, fundamental period shifts and changes in internal forces in the bridge members are compared with the results obtained from simplified analysis models.

## 2. MODELING ASSUMPTIONS

Mechanical properties of elastomeric pads were used in the computer model. Elastomeric bearings are represented by the link elements in a bridge model where their properties are defined as hard spring under compression and weak spring under shear. The bridge is longitudinally free up to the maximum elastomer flexibility and blocked transversely by concrete shear keys. Both multi-mode and simplified (using an equivalent SDOF system) analyses can be performed. Results from both analyses would be worthy to compare the particular cases of considering and ignoring the elastomeric bearing properties in modeling. Fundamental period shifts and variations in internal force distribution in the bridge members are expected. Also, to show the effect of substructure's rigidity on seismic response, the same bridge with shorter and thus stiffer piers is analyzed. Further issues on modeling are discussed later in the bridge example section.

## 3. BRIDGE EXAMPLE

A previously designed and constructed real bridge (the Akcaova Bridge) which is located on the third earthquake zone in Turkey is considered as an example in this work. Structural analyses are carried out considering and ignoring the elastomeric bearings, and the numerical results are compared. Thereby, the impact of elastomeric bearings on seismic response can be quantified.

Three dimensional multi-mode model of the bridge and a simplified model as a SDOF-system are developed. These computer models and simplified model (using bridge's rigidity and mass) are then studied under seismic effects. In the last phase, internal forces and displacements obtained from computer analyses are compared with the results from simple analysis. Same processes are repeated on the bridge with shorter and thus stiffer piers to show the behavioral changes by changing the bridge geometry.

### *3.1. Seismic Input*

The prescribed acceleration for the bridge is 0.23g. Soil profile type is assumed as II according to AASHTO. Depending on local soil conditions, the site coefficient is taken as 1.2. Elastic seismic response coefficient (C) is computed as follows:

$$C_s = \frac{1.2AS}{T^{\frac{2}{3}}} = \frac{1.2x0.23gx1.2}{T^{\frac{2}{3}}} \qquad (3.1)$$

A spectrum curve can be constructed by using Eqn. 3.1 (Akogul, 2007).

### *3.2. Elastomeric Bearings*

A typical elastomeric bearing is illustrated in Figure 1 and has a shear modulus of G=0.68MPa. Elastomeric bearings are considered as link elements in the structural analysis. Stiffness of the link element is computed in Eqn. 3.2, 3.3 and 3.4 with given properties in Table 3.1 and an assumed shear modulus.

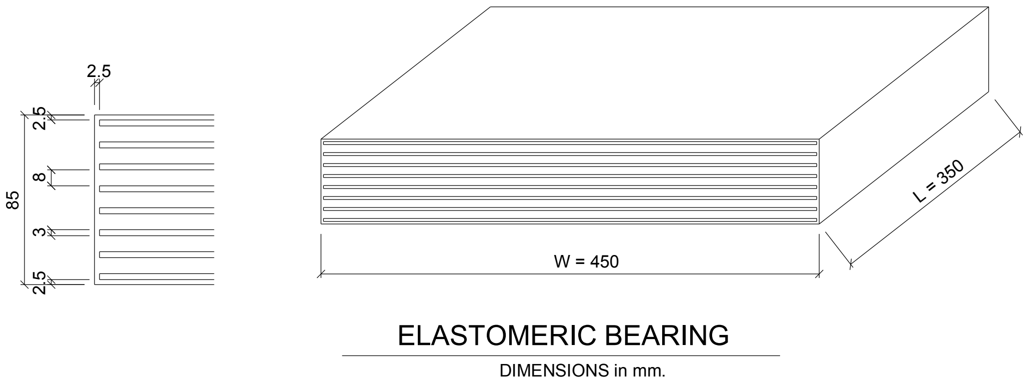

Figure 1 Elastomeric bearing

$$K_H = k_{eff} = \frac{G_{eff} A}{H_r} = \frac{680x0.1575}{0.061} = 1755 kN/m \tag{3.2}$$

$$K_V = \frac{E_c A}{H} = \frac{617263x0.1575}{0.085} = 1143752 kN/m \tag{3.3}$$

$$K_\theta = \frac{EI}{H_r} = \frac{617263x0.0016}{0.061} = 16270 kNm/m \tag{3.4}$$

where $K_H$, $K_V$, and $K_\theta$ denote the lateral, vertical, and rotational stiffnesses of the elastomeric pads used in this bridge (HITEC 98-11, 1998). A link element shown in Figure 2, is composed of lateral, vertical, and rotational stiffness components. Other geometrical and mechanical properties are given in Table 3.1.

Table 3.1 Properties of elastomeric bearing

| | |
|---|---|
| Elastomer Bearing Length L (cm) | 35 |
| Elastomer Bearing Width W (cm) | 45 |
| Elastomer Bearing Height H (cm) | 8.5 |
| Total elastomer thickness $h_r$ (cm) | 6.1 |
| Thickness of one elastomer layer $h_{ri}$ (cm) | 0.8 |
| Thickness of one steel reinforcement layer $h_s$ (cm) | 0.3 |
| Elastomer gross plan area A (cm$^2$) | 1575 |
| Elastomer moment of inertia I (cm$^4$) | 1600 |
| Shape factor S | 12.3 |
| Amount of bearing n (at end of girder) | 10 |

Effective stiffness ($k_{eff}$) is used to consider non-linear behavior of elastomeric bearing (Figure 2). The bridge is longitudinally free up to the maximum elastomer flexibility. The superstructure is blocked transversely by concrete shear keys. In other words, elastomeric pads do not displace in the transverse direction.

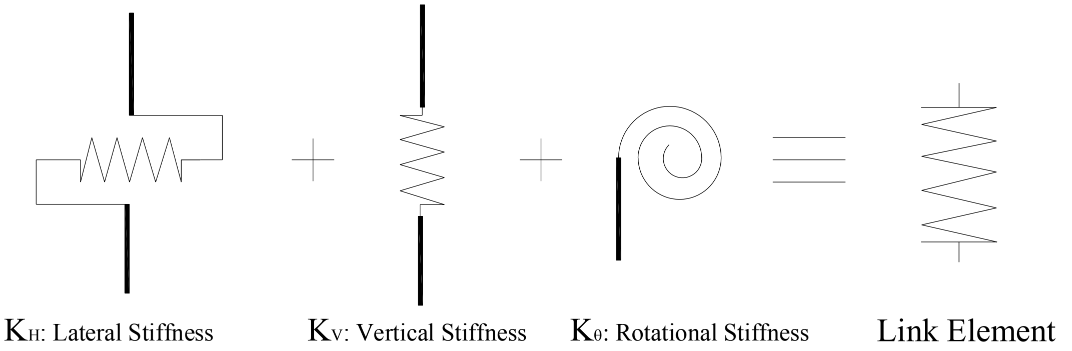

Figure 2 The link element

### 3.3. The Akcaova Bridge

The bridge has three simple spans with 28.7m, 30m and 28.7m. Piers are considered as frame element with a height of 22m. Expansion joints locate only at abutments, therefore the bridge superstructure is considered continuous between two joints (Figures 3a,b,c). As stated before, the bridge is longitudinally free and blocked transversely by shear keys.

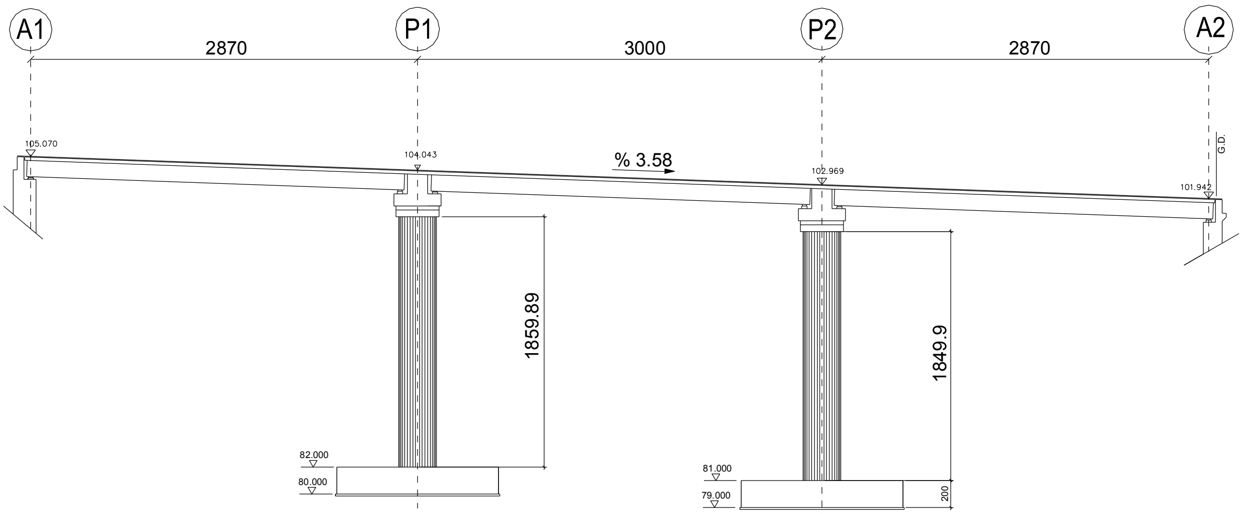

Figure 3a The Akcaova bridge-Elevation

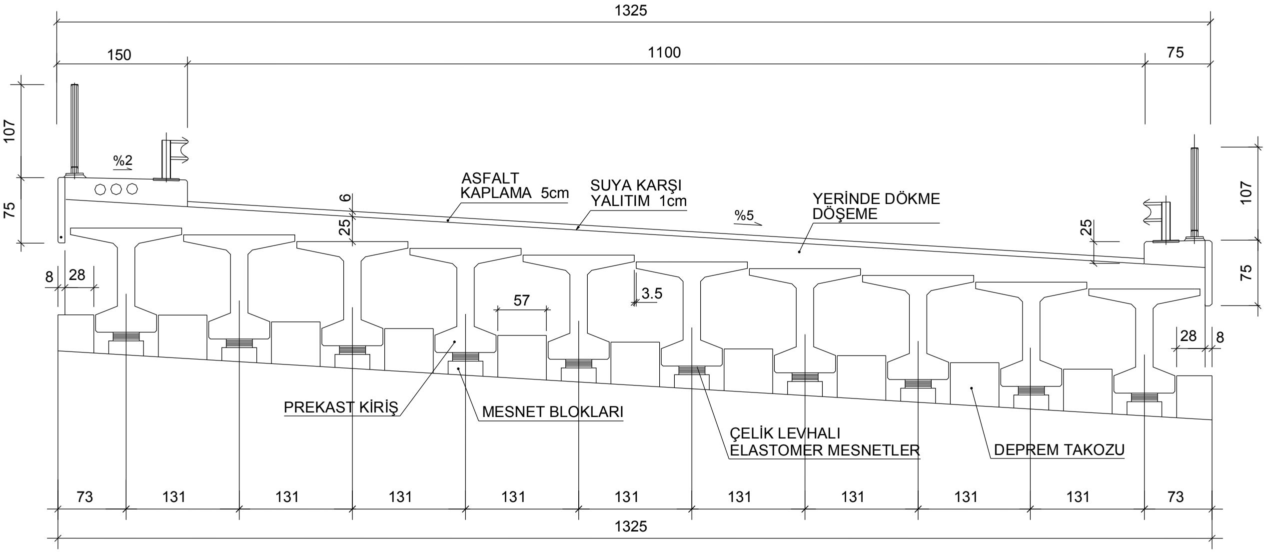

Figure 3b The Akcaova bridge-Cross section of superstructure

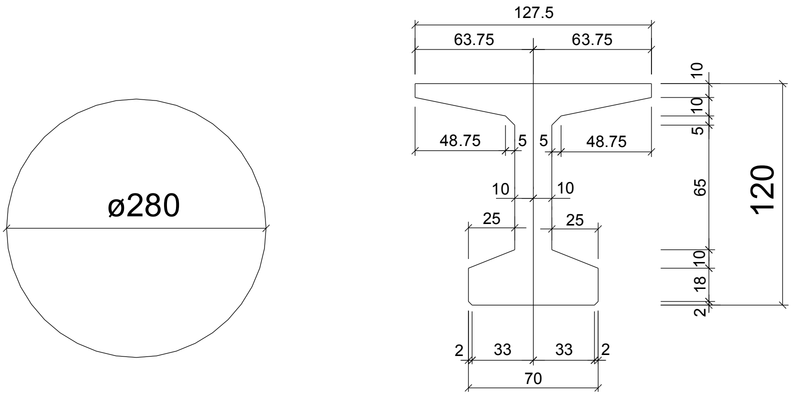

Figure 3c The Akcaova bridge- Cross sections of columns and girders

### *3.3.1 Structural model without elastomeric bearing*

Assuming that elastomers lost their resistance completely at seismic loading which is a common design attitude in Turkey, positive or negative effects of elastomers are ignored (i.e. modeled as simple fixed or sliding hinges) in seismic analysis and design. Connection between substructure and superstructure is free to move at abutments and joint at pier top. Only pier inertia resists longitudinal movement. In this model, abutments carry only vertical loads and they are designed under soil pressures acting on abutment wall.

### *3.3.2 Structural model with elastomeric bearing*

In this case, the bridge superstructure is supported by elastomeric bearings. Stiffnesses of the elastomeric bearings contribute to the overall bridge stiffness. Elastomeric pads are considered in computer analysis (in SAP2000, CSI 2007) with link elements at connections between substructure (abutments, piers) and superstructure (Figure 4). Changes in stiffness could affect the fundamental period of the bridge and earthquake load and consequently the design of the bridge.

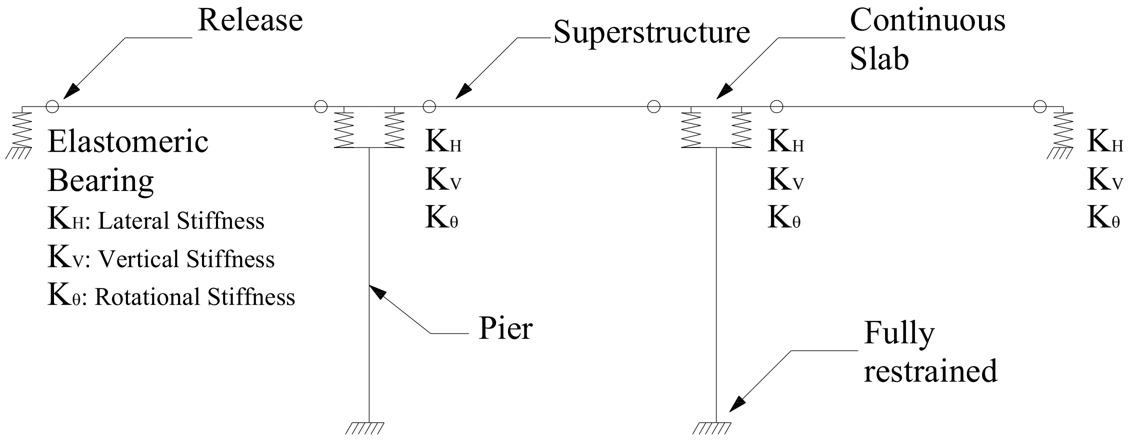

Figure 4 Model with elastomeric bearings

### *3.3.3 Simplified model*

Simplified model is analyzed using an equivalent SDOF system. One frame element and link elements represent piers and elastomers respectively. Significant part of mass participation at seismic case comes from bridge superstructure. Therefore, it is assumed that superstructure mass is summed up at top of the pier. Since the piers have approximately the same height, two piers are modeled into one frame element. Elastomeric bearings on the pier head are considered in the model as a link element where elastomeric pads on the abutment are modeled as springs (Figure 5).

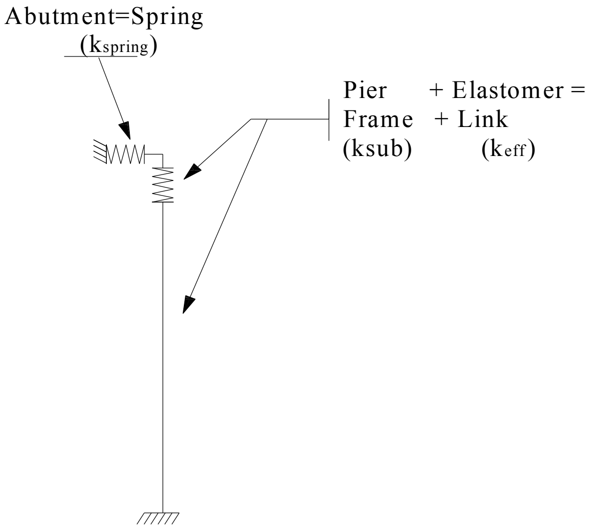

Figure 5 Simplified model representing the bridge substructure and superstructure

*3.3.4 Analysis*

Each of three bridge models (i.e. bridge model without elastomeric bearing, bridge model with elastomeric bearing, and the simplified model) are analyzed with SAP2000. Fundamental periods in the bridge longitudinal direction, internal forces and displacements obtained from each model will be given for comparison purposes. For example, fundamental periods for all three models are found as T=1.72sec, $T_e$ =1.36sec, $T_b$ =1.36sec respectively.

An alternative analysis could be carried out using structure's rigidity and mass with no need a computer model. Pier stiffness and total stiffness of elastomer on pier heads are calculated in Eqn. 3.5 and 3.6:

$$k_{sub} = \frac{3EI}{H^3} = \frac{3x23648850x3.0172}{22^3} = 20103.3kN/m \tag{3.5}$$

$$nxk_{eff} = n\frac{G_{eff}A}{H_r} = 20\frac{680x0.1575}{0.061} = 35100kN/m \tag{3.6}$$

These two stiffness values can be transformed into one singular stiffness value. The effective linear stiffness is computed in Eqn. 3.7.

$$K_{eff} = \frac{k_{sub}k_{eff}}{(k_{sub}+k_{eff})} = \frac{20103.3x35100}{(20103.3+35100)} = 12782.3kN/m \tag{3.7}$$

Lateral stiffness of elastomer bearing on abutments can be calculated easily multiplying one elastomer stiffness with the amount of elastomer (Eqn. 3.8.).

$$k_{yay} = nxk_{eff} = n\frac{G_{eff}A}{H_r} = 10\frac{680x0.1575}{0.061} = 17550kN/m \tag{3.8}$$

Total lateral stiffness is the sum of effective linear stiffness of pier and elastomer stiffness on abutments (Eqn. 3.9).

$$\sum K = \sum(K_{eff} + k_{spring}) = 2(12782.3 + 17550) = 60664.6kN/m \tag{3.9}$$

Participated mass at seismic case is the sum of superstructure mass and half mass of the substructure as follows:

$$M_T = M_{\sup er} + 0.5M_{sub} = 2701.36 + 300.4 = 3001.76t \tag{3.10}$$

Fundamental period of the bridge can thus be determined using the mass and stiffness obtained above:

$$T_k = 2\pi\sqrt{\frac{M_T}{\sum K}} = 2\pi\sqrt{\frac{3001.76}{60664.6}} = 1.398s \tag{3.11}$$

The following observations can be made from these exact and approximate analyses:

- Fundamental period ($T_e$) of bridge model with elastomeric bearings is shorter than the period (T) of bridge model. Possible reasons for this include the followings: Bridge piers are tall and thus have low lateral stiffness, elastomeric bearings are stiffer than the piers, and elastomeric bearings on abutments add extra stiffness to the system in bridge model with elastomers.

- Same period values are obtained from bridge model with elastomers and simplified model.
- Relatively close period values are obtained from control analysis.

### *3.4. Bridge with short piers*

The same bridge with shorter and thus stiffer piers is analyzed to show the effect of substructure's rigidity on seismic response. Analysis stages are equivalent with the previous section. In this case, fundamental periods for all three models are found as T=0.60sec, $T_e$ =1.08sec, $T_b$ =1.08sec respectively.

Further, the followings are observed:

- Fundamental period ($T_e$) of bridge model with elastomeric bearings is longer than the period (T) of bridge model. As expected, elastomeric bearings become more effective in bridges with short and stiff piers.
- Same period values are obtained from bridge model with elastomers and simplified model.
- Close period value are obtained from simple analysis using proposed equations.

## 4. COMPARISON

Results obtained from each bridge analyses are summarized in Table 4.1. In that table, T is the fundamental period, M is moment at pier bottom (R=1), V is shear force at one pier, $V_k$ is lateral force at one abutment, $\Sigma V$ is total base shear force, $d_{sub}$ is displacement of substructure, $d_i$ is displacement of elastomeric bearing, and d is total displacement of bridge. In the first bridge model, elastomers add extra stiffness to the structure. Consequently, base shear force in the model with elastomer is greater ($\Sigma V_e/\Sigma V$=1.16). However base shear force is shared appropriately between the piers and abutments, so shear force and moment in piers reduced by half ($V_e/V$=0.5; $M_e/M$=0.5). Effect of elastomers on seismic response is much obvious in bridge with short and rigid piers. The fundamental period is elongated ($T_e/T$=1.8) and thus internal forces are reduced ($V_e/V$=0.41). Numerical results obtained from simplified system and control analysis are in good agreement with the multi-mode analysis results for regular bridges like this.

Table 4.1 Numerical results

| | Bridge ($H_{pier}$= 22m) | | | Bridge with short pier **(**$H_{pier}$=11m) | | |
|---|---|---|---|---|---|---|
| | Without Elastomer | With Elastomer | Simplified | Without Elastomer | With Elastomer | Simplified |
| T (sec) | 1.72 | 1.36 | 1.36 | 0.60 | 1.08 | 1.08 |
| M (kNm) | 74795 | 37778 | 37720 | 71635 | 29630 | 29615 |
| V (kN) | 3400 | 1712 | 1709 | 6512 | 2675 | 2673 |
| $V_k$ (kN) | - | 2234 | 2234 | - | 1613 | 1613 |
| $\Sigma V$ (kN) | 6800 | 7892 | 7886 | 13024 | 8576 | 8572 |
| $d_{sub}$ (cm) | 17 | 8.6 | 8.6 | 4.2 | 1.7 | 1.7 |
| $d_i$ | - | 4.1 | 4.1 | - | 7.4 | 7.5 |
| d | 17 | 12.7 | 12.7 | 4.2 | 9.1 | 9.2 |

## 5. CONCLUSIONS

Both multi-mode and simplified (using an equivalent SDOF system) analyses are performed for the selected bridge example. Results from both analyses are compared for the particular cases of considering and ignoring the elastomeric bearing properties in modeling. Fundamental period shifts and changes in internal force distribution in the bridge members are discussed. Also, to show the effect of substructure's rigidity on seismic response, the same bridge with shorter and thus stiffer piers is analyzed.

Although numerical investigations reveal that elastomeric pads may positively affect the seismic response of such bridges, this effect highly depends on geometry of bridge, especially the pier rigidities. Other conclusions include that elastomeric bearings may add extra stiffness to the system when tall and flexible piers are used. In this case, shear forces at pier bases decrease by 50% since the lateral loads are more appropriately shared between the piers and abutments. Elastomeric bearings become more effective in bridges with short and rigid columns. For the selected bridge example, the fundamental period is elongated by 80% and thus internal forces are reduced by 60%. For regular bridges, numerical results obtained from the simplified SDOF system are in good agreement with the multi-mode analysis results.

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