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AN ANALYTICAL STUDY INTO THE SEISMIC BEHAVIOR OF RC PIER WITH ELASTOMERIC MATERIALS

H. Dabiri[1*] and A. Kheyroddin[1,2]
[1]Department of Civil Engineering, Semnan, Iran
[2]Visiting Scholar, Department of Civil Engineering and Applied Mechanics, University of Texas, Arlington, Texas, USA

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ABSTRACT

Corrosion of reinforcement bars, large base shear due to earthquake load and tensile defect of concrete are the most important failure factors in an RC column. This paper investigates using elastomeric materials in a RC pier to diminish or even eliminate above-mentioned factors. For this purpose, totally seven numerical piers under Kobe earthquake load and constant axial load were modeled in nonlinear finite element software. Elastomeric material was used in plastic hinge zone of RC pier in different heights and thicknesses. Base shear and ductility of piers were evaluated. Results generally showed that, using elastomeric material in a RC pier reduced ductility but it will decreased base shear force in size of 10.61 percent. The other advantage of using elastomeric material is to eliminate concrete tensile defect in tension surface of pier section and reinforcement bars corrosion due to concrete cover ruin in corrosive environment.

Keywords: Finite element; RC column; elastomeric materials; ductility; base shear force.

1. INTRODUCTION

Following the increase of failure caused by severe earthquakes all over the world, there is an increased interest in the need for an effective seismic strengthening and rehabilitating of reinforced concrete columns [1].

Concrete columns in a structure are critical elements with high importance as their failure can cause partial or even total collapse of the whole structure. Over the years, these members deteriorate due to aging, weathering, overloading, design or construction defects, seismic activity, poor maintenance, corrosive environments, etc. [2 and 3].

Concrete structure failure can be divided in three parts mainly: failure related to mechanical properties of concrete, external factors such as loading and corrosive

*E-mail address of the corresponding author: h.dabiri2010@gmail.com (H. Dabiri)

environment and defects in reinforcement bars.

Despite many advantages characteristics of concrete, there are some unavoidable disadvantages which made researchers improve them using new methods or adding improvement components (e.g. FRP sheet). In some cases researchers try to improve RC elements behavior by replacing concrete with other suitable materials in some place of element such as plastic hinge. One of The most important deterioration factor is corrosion of the reinforcement bars [4]. In particular transverse reinforcement is more vulnerable to corrosion due to its smaller diameter and being closer to the concrete surface, and thus leads to deterioration of confinement due to transverse reinforcement [5 and 6]. It may also adversely affect the structural behavior such as reduction of loading capacity of members due to steel area loss, deterioration of bond between steel bar and concrete and anchorage of steel bar. [5]

One of the other deterioration factors is tensile defect of concrete in a RC element in tension surface when there is cyclic loading (as shown in Fig.1). Researchers have investigated the effect of using steel jacket or replacing concrete with HPFRCCs or ECCs material in tension strength improvement [4, 5, 6, 7 and 8].

RC failure is not limited to the mechanical properties of concrete and reinforcement bar defects. Investigations of bridge failures during the recent earthquakes, such as the Whittier 1987, Loma Prieta 1989, Northridge 1994, and Kobe 1995 show that external factors such as large base shear forces due to earthquake load could Couse failure in a RC column [6, 9 and 10].

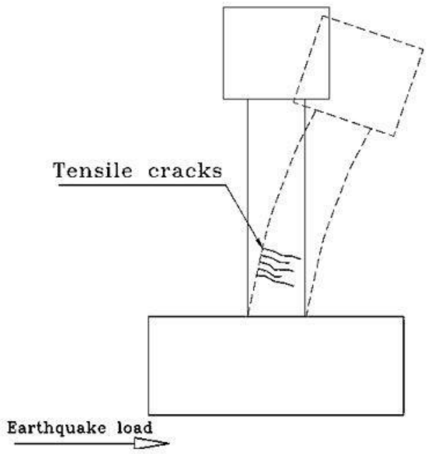

Figure 1. Tensile defect of concrete in a RC column due to cyclic loading

In the past decade, a few researchers have investigated the feasibility of advanced materials and unconventional details that address one or both damage indicators to improve post-earthquake serviceability of bridge structures while preventing collapse, and exploring new approaches to build earthquake-resistant structures. Among these innovative materials and details, elastomeric pads have shown promising results in minimizing damage and residual deformations [11].

Elastomeric materials are capable to undergo large tensile strains without failing. They also have a relatively high damping characteristic. Because of their relatively low stiffness, elastomeric pads have been used in civil engineering structures as base isolators to reduce structural vibration period and take advantage of reduced seismic forces and higher damping. In 2002 a different application of elastomeric pads was explored by incorporating them into the plastic hinge region of concrete bridge columns. The objective in those studies was to eliminate spalling of concrete and to reduce damage in the plastic hinge region. The performance was satisfactory up to moderate levels of lateral displacements. Under large displacements, the rubber did not provide sufficient restraint for the column longitudinal bars and the bars buckled and failed due to low cycle fatigue. As part of an investigation on the performance of post-tensioned, precast bridge columns with energy dissipating joints, Motaref et al. studied the response of a column with an elastomeric bearing pad in the lower part and RC in the upper part. The base was connected to the footing by steel dowels. The elastomeric pad was incorporated into the column to minimize the damage at the plastic hinge and the post-tensioned tendon provided recentering capacity to minimize residual displacements. The elastomeric pad was designed by controlling the failure of the rubber when subjected to combination of axial compression and bending moments. A similar design was discussed by Hillis and Saiidi. Unlike the bearing pads used by Kawashima and Nagai, the new pad incorporated steel shims to prevent bar buckling and the pad was relatively thick to allow for large rotation. The pad was vulcanized to steel plates at the top and bottom, and a central steel pipe was used to prevent shear deformations and to serve as a duct for a post-tensioning rod. The column longitudinal bars passed through drilled holes through the elastomeric pad and the plates. Other holes were drilled only in the end steel plates for the attachment of headed steel dowels to anchor the pad in concrete. Fig. 1 shows the elastomeric pad used in Hillis and Saiidi study. The results obtained in the column with the elastomeric pad showed larger energy dissipation, larger lateral load and drift capacity, and lower overall damage than a benchmark column made with conventional RC [11].

This paper investigates the use of elastomeric materials in seismic behavior of a RC column. The novel goal of this paper is to diminish and even eliminate the three mentioned factors in a RC column failure. In other words long time durability and non-corrosive elastomeric material protect reinforcement bars against corrosion even in corrosive environments. Also large elasticity of elastomeric material make it a good case for replacing it with concrete in tensile surface of column section to eliminate tensile cracks in cyclic loading which affect the ductility and RC column base shear force.

2. NUMERICAL MODELING

To evaluate the seismic behavior of RC bridge pier with elastomeric material, ABAQUS, a software for nonlinear finite element analysis was used. Totally seven RC piers were modeled.

2.1 Model details

Seven reinforced concrete piers with a diameter of 410 mm and a height of 1570 mm were modeled. Eight 4 mm diameter bars provided the longitudinal reinforcement and 3 mm diameter bars at 50 mm provided transverse reinforcement. A foundation with the dimension of 1830*1830*710 was modeled. 4 mm diameter bars at 50 mm were considered as reinforcement in the both longitudinal and transversal directions. A RC cube with the dimensions of 680*580*660 mm was placed in the top of the pier as cap. Eleven 4 mm diameter rectangular bars were modeled as transverse reinforcement [11]. One pier which was considered as control pier, was modeled with RC material completely. Four piers were covered by an elastomeric tube with the height of 700 mm and 500 mm and the thickness of 5, 10 and 15 mm. in models SBR50 and SBR70, concrete was replaced with elastomeric pad entirely. Fig. 2 and Table1 presents the details of the seven models.

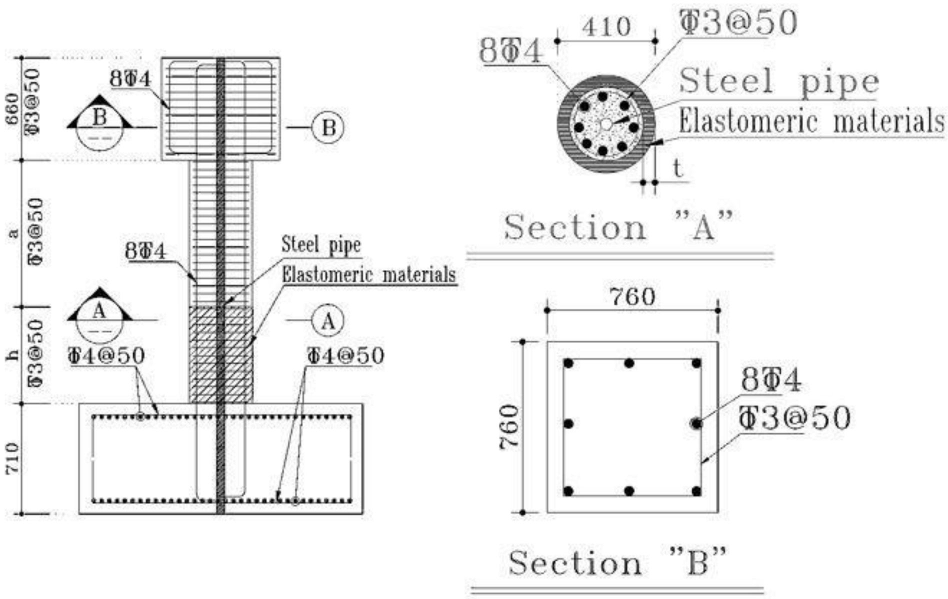

Figure 2. Detail of the models [11]

Table 1: Details of numerical models

Names of models	Characteristic of models	t (mm)	h* (mm)
RC	A pier modeled concrete entirely	0	0
SBR550	A pier with elastomeric tube within 500 mm height and 50 mm thickness	50	500
SBR1050	A pier with elastomeric tube within 500 mm height and 100 mm thickness	100	500
SBR50	A pier with elastomeric pad within 500mm height	205	500
SBR570	A pier with elastomeric tube within 700 mm height and 50 mm thickness	50	700
SBR1070	A pier with elastomeric tube within 700 mm height and 100 mm thickness	100	700
SBR70	A pier with elastomeric pad within 500 mm height	205	700

* for all of the models a+h=1570 mm.

The bottom surface of foundation was fixed while Kobe earthquake (1995) was applied to the top surface of the column. A uniform axial load of 355.8 KN was applied at the top surface of pier cap [11].

The 7 and 28 days strength of concrete were 31.8 MPa and 53.5 MPa while the module of elasticity and the poisons ratio were 20 MPa and 0.2, respectively. The yield strength F_y of 619 MPa and the tensile strength F_u of 670 MPa were considered for reinforcement bars [11].

According to few researches on the mechanical properties of elastomeric materials, elasticity module of an elastomeric pad can be computed using Eq. (1) [12-16]:

$$E = 6GS^2 \tag{1}$$

Researchers have also indicates that existing a hole in the elastomeric pad, could reduce E about 33 percent. Therefore, the E of an elastomeric pad with a hole in it, will be obtained from Eq. (2) [12-16]:

$$E = 4GS^2 \tag{2}$$

As this paper investigates the effect of elastomeric tube on the seismic behavior of RC bridge pier, the elasticity module of elastomeric components used in this study, was calculated using Eq. (2). G is shear module and is considered 3.3 MPa. S is shape factor and is the ratio of "load applied surface" to "none load applied surface". For an elastomeric pad with a hole in it, S is calculated using Eq. (3):

$$S = \frac{\pi(r_o^2 - r_i^2)t}{2\pi rt} = \frac{(r_o^2 - r_i^2)}{2r} \tag{3}$$

where r_o is outer radius of elastomeric tube, r_i is inner radius of elastomeric tube. t is the thickness of elastomeric tube. Considering dimensional characteristic of models and elastomeric tubes, the parameter S is calculated using Eq. (3) and is presented in table 2.

Table 2: Calculated S for models

	$\mathbf{r_o}$	$\mathbf{r_i}$	**h**	**S**	**E**
SBR550	20.5	15.5	50	0.05	**0.03**
SBR1050	20.5	10.5	50	0.1	**0.13**
SBR50	20.5	0	50	0.21	**0.55**
SBR570	20.5	15.5	70	0.04	**0.02**
SBR1070	20.5	10.5	70	0.07	**0.07**
SBR70	20.5	0	70	0.15	**0.28**

According to studies done by researchers, to have a true assumption for elasticity module of elastomeric tube, Eq. (4) must be verified [12-16].

$$6GS^2 < \frac{k}{60G} \tag{4}$$

where K is young module and is equal to 2000 GPa. Using Eq. (4) we will have:

$$S < \sqrt{\frac{K}{360G^2}} \quad (5)$$

As Eq. (5) is verified for all six models including elastomeric material, it can be conducted that the assumed amount for G (3.3 GPa) is correct. Therefore the elasticity module for elastomeric pad with a hole in it, is according to Eq. (2) and Table (1).

It should be mentioned that a steel pipe was placed in the center of the RC piers (parallel to the longitudinal reinforcement) to amend shear defect of elastomeric materials [11].

3. MODEL VALIDATION

To investigate the effect of using elastomeric material on the seismic behavior of RC bridge pier, seven numerical models using nonlinear finite element software ABAQUS were created according to Saiidi et al (2010) experimental research [11]. To verify numerical model according to experimental model, all conditions such as boundary conditions, loading conditions, model dimensions, model reinforcement and model components were exactly the same as experimental specimen.

Fig. 3 compares the results of numerical and experimental specimen envelope load-displacement diagram. As Fig. 3 illustrates, there is a close agreement between the numerical and experimental RC bridge pier.

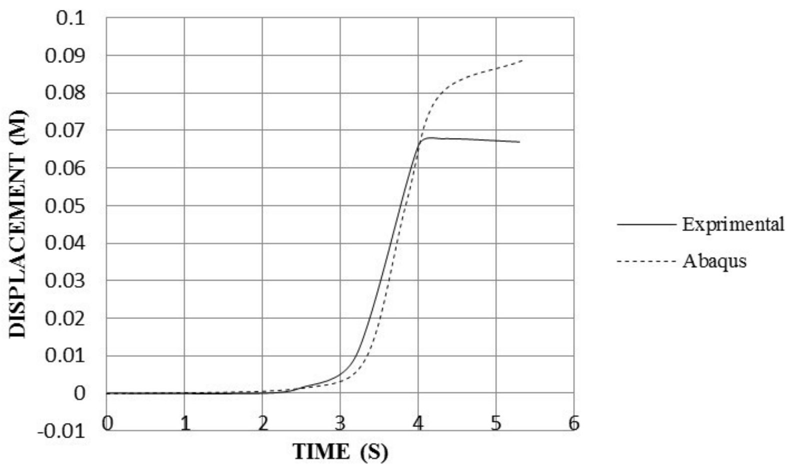

Figure 3. Comparison of numerical and experimental load-displacement diagram of RC pier

4. RESULTS

The total of seven models were analyzed in ABAQUS software and results were obtained in two main parts: time-base shear force and displacement-force of the top of pier.

4.1 Time-base shear force diagram

Fig. 4 shows the time-bas shear force diagram of all seven numerical models under Kobe earthquake.

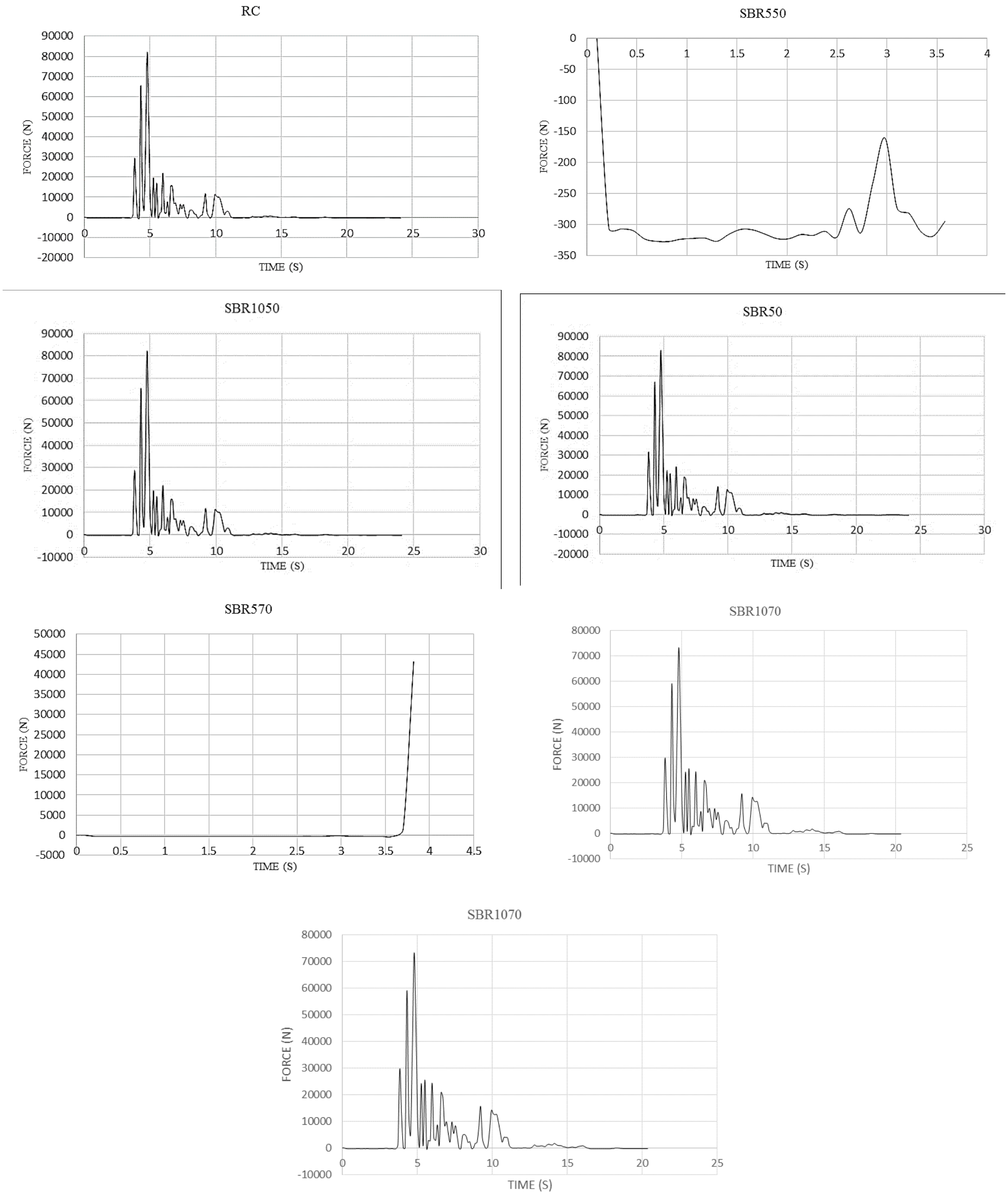

Figure 4. Time-base shear force diagram of seven numerical models

4.2 Force-displacement hysteresis diagrams

Force-displacement hysteresis diagram of five numerical models related to the top of the RC piers are shown in Fig. 5.

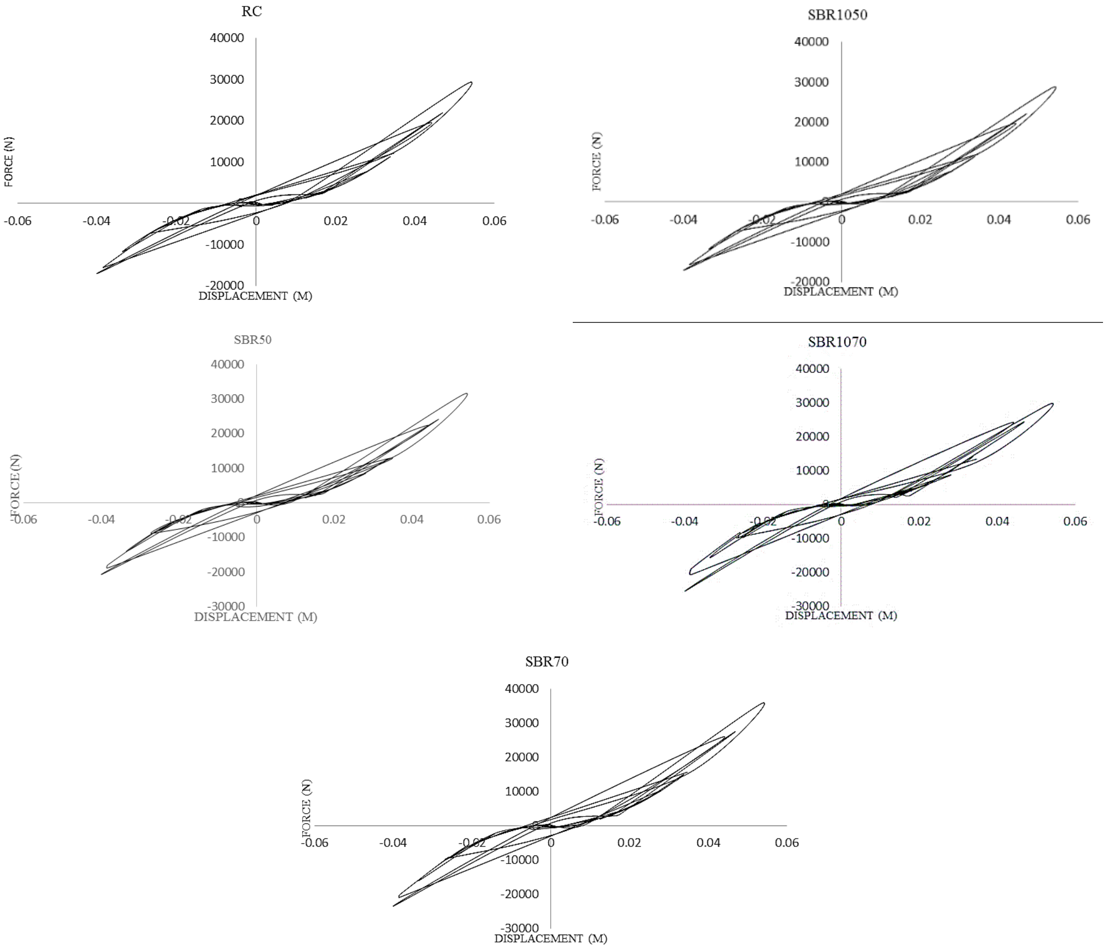

Figure 5. Force-displacement diagrams of seven numerical models

5. DISCUSSIONS

Both SBR550 and SBR570 models failed in the fourth second of loading. It could be due to the small thickness of elastomeric tube that it tears. Other five models containing elastomeric materials, were investigated under Kobe earthquake durability before column failure. Results are discussed in two parts: Time-base shear force diagram and displacement-force hysteresis diagram.

5.1 Time-base shear force diagram

Table 3 provides the maximum base shear force of the piers. Fig. 6 shows envelope curves of time-base shear force of models. From table 3 we can find that the minimum base shear force belongs to the model SBR1070 and is 10.61 percent less than RC model. To compare the RC model with the models containing elastomeric materials, it could be said that the base shear forces of SBR50, SBR1050 and SBR70 are respectively 1.22, 0.15 and 3.56 percent greater than base shear force of RC model.

Table 3: Base shear force of models

Model name	Base shear (N)
RC	81942.42
SBR50	82940.90
SBR1050	82066.40
SBR70	84861.52
SBR1070	73246.34

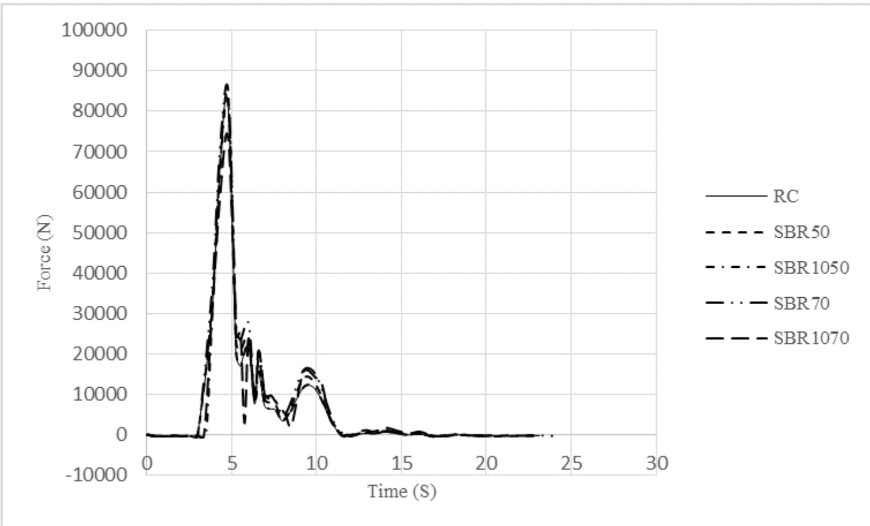

Figure 6. Displacement-time envelope curves of seven numerical models

5.2 Force-displacement hysteresis diagrams

Fig. 7 shows the force-displacement envelope curves of all the seven numerical pier models. From Fig. 7 and with comparing the area under force-displacement envelope curves of models, it can be conducted that the ductility of RC model is 20, 28 ,12 and 16 percent greater than SBR50, SBR1050, SBR70 and SBR1070, respectively.

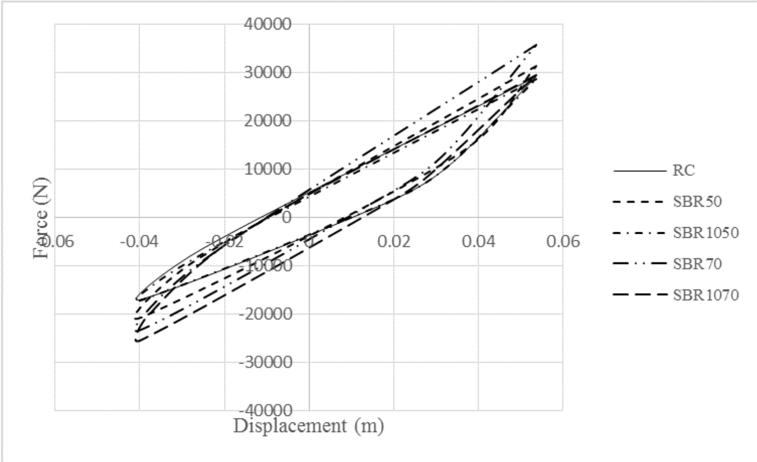

Figure 7. Displacement-force hysteresis envelope curves of seven numerical models

6. CONCLUSION

The effect of using elastomeric material instead of concrete on the seismic behavior of RC column was investigated using finite element software in this study. To evaluate the replacing concrete with elastomeric material, the two parameter of base shear force and absorbed energy were investigated. From obtained results, following conclusions can be drawn:

1. If dimensions of elastomeric pad are chosen correctly, replacing concrete with elastomeric materials could decrease the base shear force.
2. Using elastomeric material in an RC column does not improve ductility of it. in other words, replacing concrete with elastomeric materials has neither positive nor negative effect on RC column ductility.
3. In case of using elastomeric tube, to prevent elastomeric failure, the tube thickness should be larger than 48 percent of pier section radius and 100 mm.
4. One of the main goal of this study was to diminish or even eliminate reinforcement bars corrosion –especially in corrosive environment like bridge pier in sea- which is one of the main factors of structural failure. The results show that, using elastomeric materials has no considerable negative effect on the RC column rather, it reduces the base shear force in the same loading conditions compared with an ordinary concrete column.

Using elastomeric material in plastic hinge of a RC column, eliminates cracks in tensile surface of concrete section. In other words, elastomeric material in plastic hinge zone of a column, improves structural behavior of column in cyclic loads.

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