The Effect of Seismic Isolation on the Dynamic Behavior of Cable-Stayed Bridges

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ABSTRACT

The earthquake effects on cable-stayed bridges isolated by single concave friction pendulum (SCFP) are investigated in this study. Reducing ways of the destructive earthquake effects are getting vital important for researchers and engineers. One of the most accepted ways for reducing the effects of earthquake is using seismic isolation systems. The result obtained from an analytical study on the seismic responses of Manavgat Cable-Stayed Bridge with and without seismic isolation system are compared each other. The selected bridge is the first cable-stayed bridge of Turkey and has 202m length between its side supports. In order to determine the contributions of isolation systems to the bridge dynamic behavior, 3D finite element model (FEM) of the bridge is created in Sap2000 [1]. Time history analysis is performed for 3D FEM. Three different earthquake ground motions having transverse and longitudinal directions are used in analyses. Comparison of dynamic behavior of the bridge with and without the SCFP systems under three different earthquake motions has been conducted. The results obtained from analyses of the bridge are presented by graphics and tables in detail. It is seen that using of isolation system reduces the destructive effects of earthquakes on the bridge.

Keywords: *Seismic isolation, Cable-stayed bridges, finite element model, single concave friction pendulum (SCFP) bearing.*

INTRODUCTION

Earthquake is inevitable natural disaster which occurs unknown time and place. Harmful effects of earthquake on structures and decreasing these effects are most important issues in the engineering world. As a result of studies show that reducing the interaction between structure and soil may decreases the harmful effects of earthquakes. For this purpose seismic isolators which are partially separate structure and soil are employed. Using of isolators raise the periods of structures so transferred acceleration due to the earthquake decrease. In this way internal forces of structure decrease. Furthermore displacements especially occur on isolators hence superstructure remains relatively rigid. Accurate design and application of seismic isolation ensure structure to remain in elastic zone and display rigid behavior under earthquake loads. Seismic isolation method is one of the best solutions for earthquake effects [2].

There are two types of isolation systems in terms of behavior which are elastomeric bearing and bearing based on sliding. The elastomeric bearing systems included lead use rubber for restoring force and hysteretic damping of lead for energy dissipation. Another type of isolation system is friction pendulum bearing. Important feature of this bearing is energy dissipation based on sliding between stainless steel plates. Energy dissipation related with velocity of sliding. Sliding bearings use their curvature surfaces to generate the restoring forces from weight of structure on isolation systems. Zayas introduced one of the most effective isolation systems, namely single concave friction pendulum (SCFP) bearing offer developments in strength, life span, resistance of severe earthquake and easy to installation. All concave friction pendulum system based on the SCFP bearing system. This friction pendulum system and following friction pendulum systems are sliding devices that take advantage of spherical surface to provide a restoring force and friction to dissipate energy [3]. Friction pendulum systems are widely used to strengthen existing structures and new buildings, bridges, offshore platform, and industrial factories [4]. Tsopelas at all carried out an experimental study on seismically isolated bridge with friction pendulum bearing and non-isolated bridge to compare seismic excitation. The bridge deck was supported four friction pendulum bearings with friction coefficient in the range 0.07 and 0.12. The results of the experimental study demonstrated a considerable gain in the capability of seismically isolated bridge with friction pendulum bearing to sustain all levels seismic excitation subjected to elastic conditions [5]. The seismic responses of the isolated and non isolated cable-stayed bridge are compared by Soneji and Jangid [6]. They use three different type of isolator, namely, high damping rubber bearings (HDRB), lead rubber bearings (LRB) and friction pendulum system (FPS) on cable-stayed bridge to achieving seismic isolation system. Time history analysis is performed for the isolated and non-isolated bridge. Four different earthquake ground motions are used in analysis and applied in the longitudinal direction using Newmark's method. The study shows effectiveness of isolation system. It reduces acceleration of the deck and base shear of the tower. Ateş and Constantinou examined on a curved bridge isolated with friction pendulum bearings are placed between the deck and the piers [7]. The mentioned bridge is selected to exhibit the application for seismic isolation. As a result, using of isolation systems on bridge provide advantages for the internal forces of the deck for the mentioned compared to non-isolated curve bridge.

2. Description of Manavgat Cable-Stayed Bridge

In this study, Manavgat Cable-Stayed Bridge is preferred for a numerical application. The bridge is first cable-stayed bridge of Turkey. The bridge, shown in Figure 1, is 202 m long and 13.7 m in width, with equal spans of 101 m; and designed for two lanes of road traffic. The bridge have approximately 42 m λ shape steel tower. The Tower has a hollow hexagonal cross-section. The deck of bridge is composite and consists of 25 cm thick concrete, 10 cm thick asphalt and steel profiles. The main I cross section steel profiles which is used in the deck extends continuously from one end to the other end of the bridge [8].

Figure 1 Manavgat Cable-Stayed Bridge

The schematic form of Manavgat Cable-Stayed Bridge is shown in Figure 2. Deck of the bridge is supported with 28 steel cables which is a link to tower. The distance between the tower and the closest cable to the tower is 19.6 m while the distance between cables is 12 m. Distance between supports which are on shore and last cable connection point on the deck is 9.4 m, as well. Following assumption are made for the analysis of isolated bridge.

The effect of soil-structure interaction not takes into consideration. The bridge deck is assumed to be continuous from one end to another end. Stiffness contribution of non-structural elements such as parapet walls and kerbs and their mass is neglected. Shear force and bending moment not occur on the cables. They are only subjected to axial force.

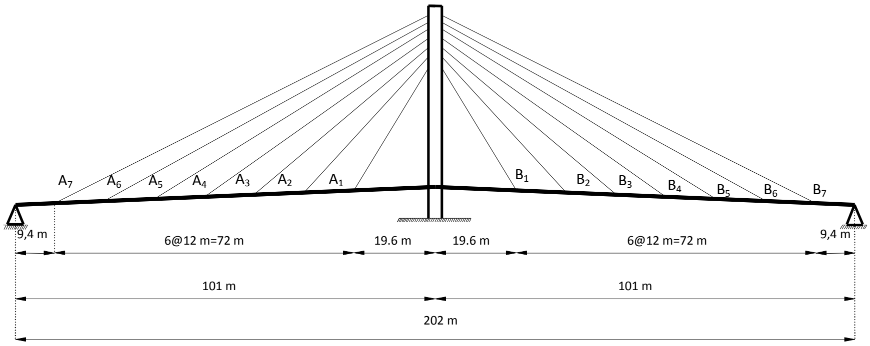


Figure 2. The schematic form of Manavgat Cable-Stayed Bridge

The non-isolated bridge model consist of 3652 nodal points,1130 frame, 32 links, 832 solid and 1980 area elements. The deck and tower are represented with beam elements while cables are described by using truss elements.

3. NUMERICAL COMPUTATIONS

Nonlinear time history analysis of the isolated and non-isolated cable bridge is performed in SAP2000 in order to determine the dynamic behavior of Manavgat Cable-Stayed Bridge. Three dimensional FEM is given in Figure 3. Damping ratio is specified as 5%. SCFP bearing selected as an isolation system. Effective radius of curvature, R_{eff} =1.4m, frictional coefficients, μ =0.09, and displacement capacities, d=0.40m.

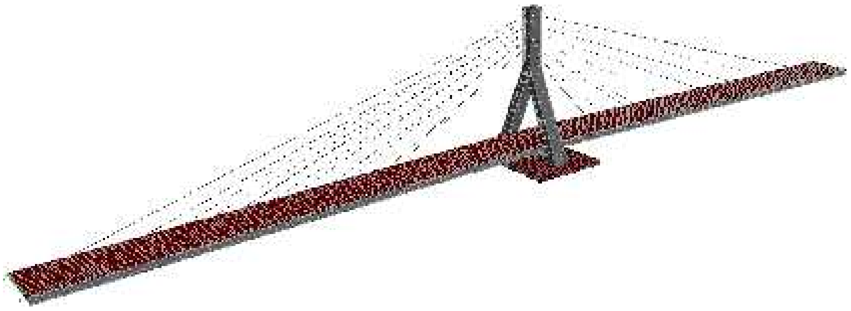


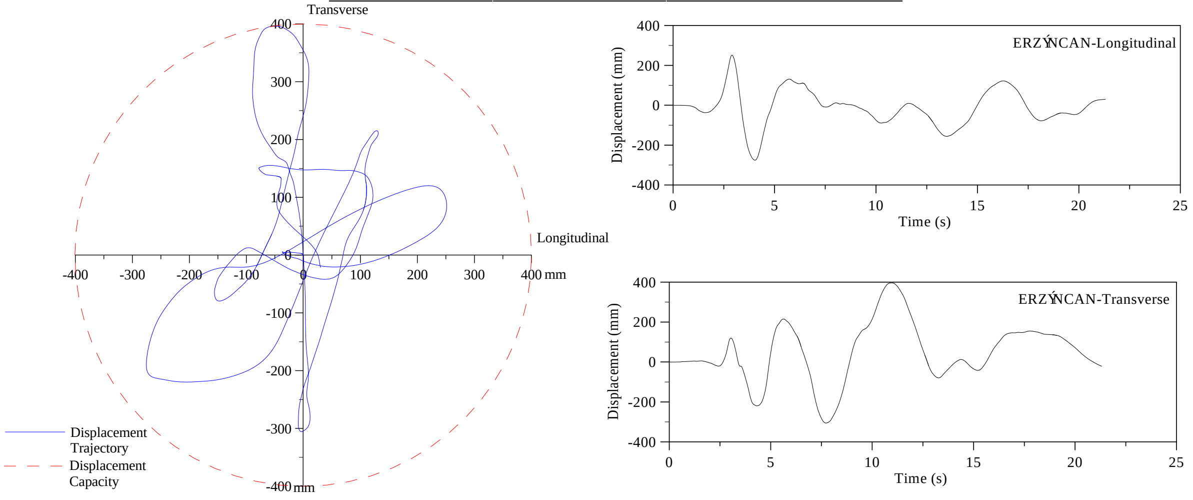
Figure 3. Finite Element Model of Manavgat Cable-Stayed Bridge

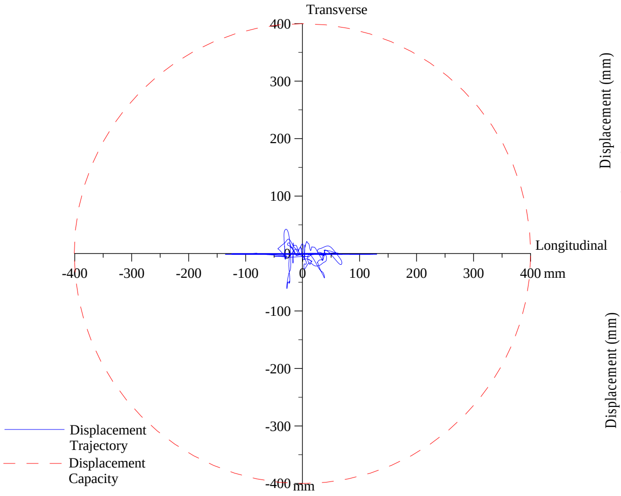
BOL-000 and BOL-090 components of 11 December 1999 Düzce, ERCİŞ-EW and ERCİŞ-NS components of 23 November 2011 Van-Erciş, and ERZ-EW and ERZ-NS components of 13 March 1992 Erzincan earthquake ground motions are used in dynamic analysis to determine dynamic responses of the bridge [9]. ERZ-NS, BOL-090, and ERCİIS-EW components are applied to the bridge at the longitudinal directions and ERZ-EW, BOL-000, and ERCİŞ-NS components are applied to the bridge at the transverse directions. The acceleration of gravity is also included in the vertical component by using a ramp function in the beginning of the time history in order to take into account the effect of the dead load on the behaviour of the of the SCFP bearings.

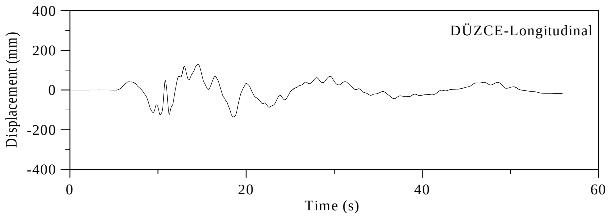
The peak accelerations of the ground motions are 0.496g and 0.515g for Erzincan, 0.728g and 0.822g for Düzce earthquake, and 0.172g and 0.182g for Van-Erciş earthquake. The first five periods of vibration of the isolated and the non- isolated bridge obtained from the analysis are given in Table 1. Comparisons of isolator displacement trajectory and histories of longitudinal and transverse displacements of SCFP from earthquakes are given in Figure 4. Base shear forces for the isolated and non-isolated bridge are also given in Figure 5. Top of the bridge tower accelerations for three earthquakes are given in Figure 6.

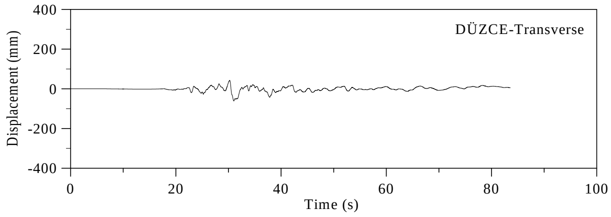
Table 1. Periods for the isolated and non-isolated bridge

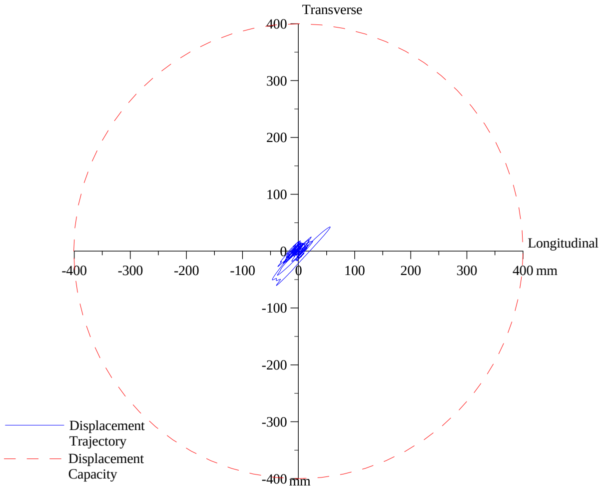
Mode Number	Period (sec)	
	Isolated	Non-Isolated
1	5.517	1.735
2	2.673	0.825
3	2.108	0.536
4	1.713	0.452
5	1.171	0.435

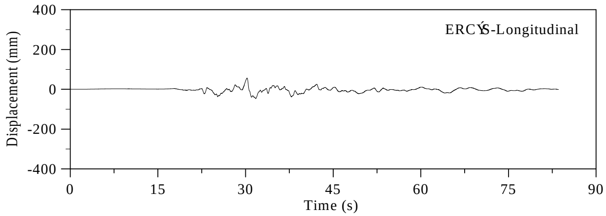


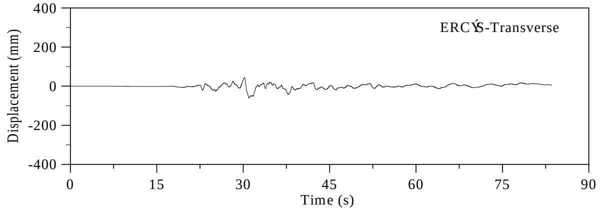

Transverse
Longitudinal
400
300
200
100
0
-100
-200
-300
-400 mm
-400
-300
-200
-100
100
200
300
400 mm
Displacement Trajectory
Displacement Capacity

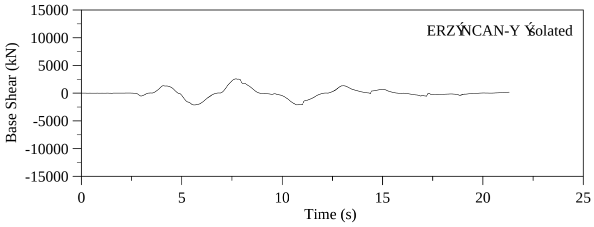

DÜZCE-Longitudinal
Displacement (mm)
400
200
0
-200
-400
0
20
40
60
Time (s)

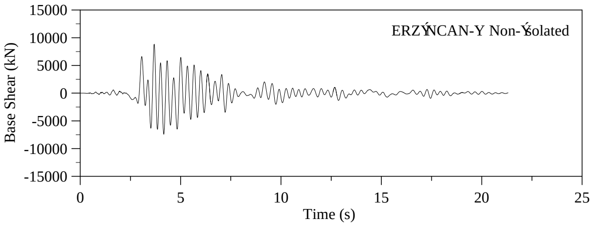

DÜZCE-Transverse
Displacement (mm)
400
200
0
-200
-400
0
20
40
60
80
100
Time (s)

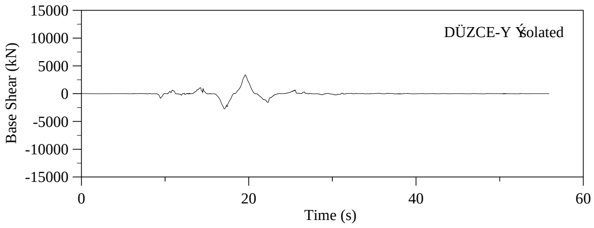

Transverse
Longitudinal
400
300
200
100
0
-100
-200
-300
-400 mm
-400
-300
-200
-100
100
200
300
400 mm
Displacement Trajectory
Displacement Capacity

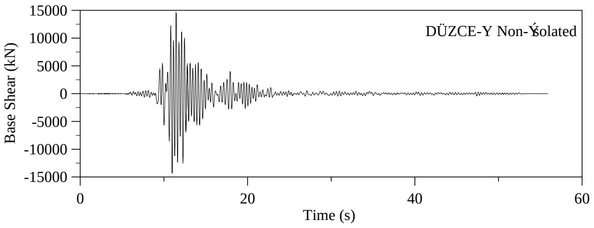

ERCÝS-Longitudinal
Displacement (mm)
400
200
0
-200
-400
0
15
30
45
60
75
90
Time (s)

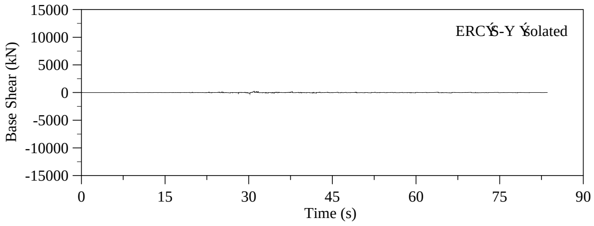

ERCÝS-Transverse
Displacement (mm)
400
200
0
-200
-400
0
15
30
45
60
75
90
Time (s)


ERZÝNCAN-Y Ýsolated
Base Shear (kN)
15000
10000
5000
0
-5000
-10000
-15000
0
5
10
15
20
25
Time (s)


ERZÝNCAN-Y Non-Ýsolated
Base Shear (kN)
15000
10000
5000
0
-5000
-10000
-15000
0
5
10
15
20
25
Time (s)


DÜZCE-Y Ýsolated
Base Shear (kN)
15000
10000
5000
0
-5000
-10000
-15000
0
20
40
60
Time (s)


DÜZCE-Y Non-Ýsolated
Base Shear (kN)
15000
10000
5000
0
-5000
-10000
-15000
0
20
40
60
Time (s)


ERCÝS-Y Ýsolated
Base Shear (kN)
15000
10000
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-5000
-10000
-15000
0
15
30
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60
75
90
Time (s)

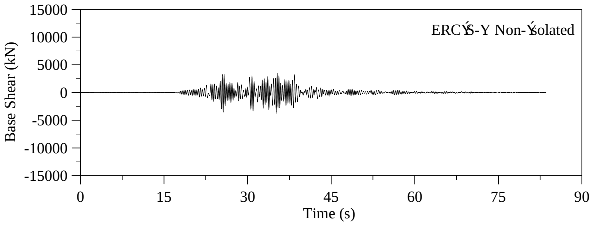
ERCÝS-Y Non-Ýsolated
Base Shear (kN)
15000
10000
5000
0
-5000
-10000
-15000
0
15
30
45
60
75
90
Time (s)

Figure 5. Base shear forces for the isolated and non-isolated bridge for three earthquakes

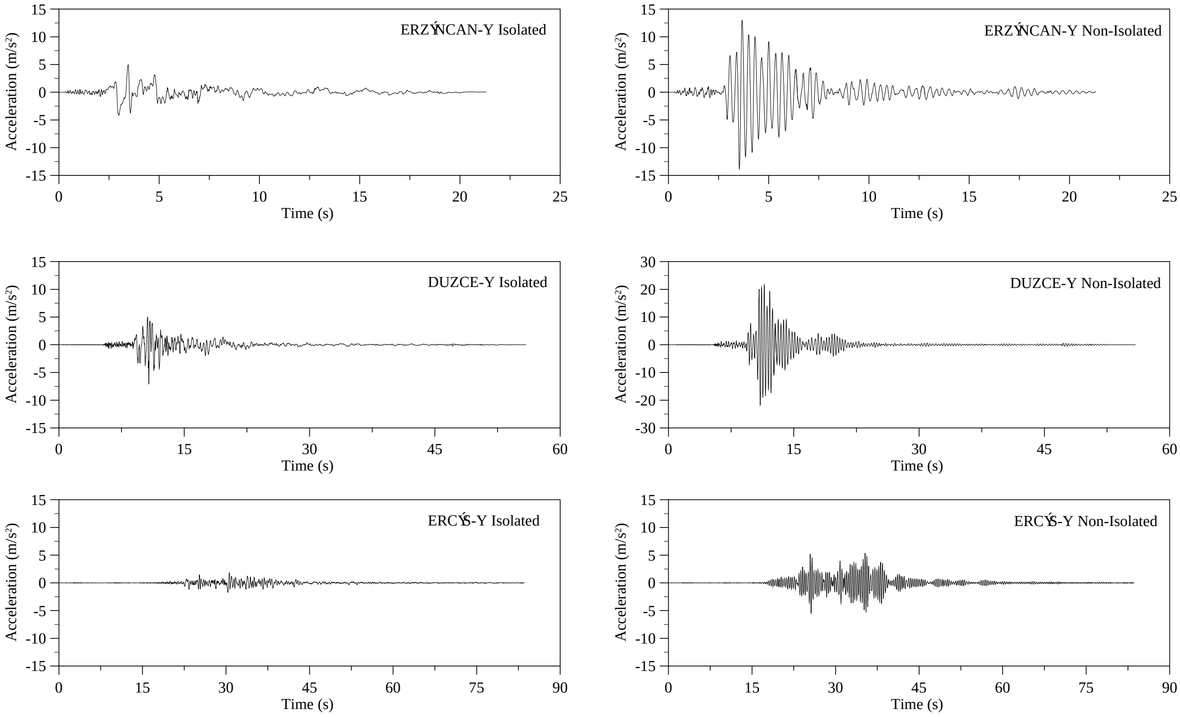

Figure 6. Top of bridge tower accelerations for three earthquakes

CONCLUSION

Manavgat Bridge isolated by SCFP bearing and non-isolated bridge is compared in this study. Nonlinear time history analysis in order to investigate of effectiveness of the seismic isolation systems on the bridge is performed. Erzincan, Düzce, and Van-Erciş earthquakes are used to analyses of the isolated and the non-isolated bridge.

Isolation system significantly changes the bridge periods. Seismic isolation system increases the dominant periods of the bridge so transferred acceleration due to the earthquake decrease. It reduces acceleration of the tower and base shear of the bridge too. Peak acceleration reduction on isolated bridge is approximately 65% at the top of the tower for three different ground motions. The results show that the isolation system significantly reduces the base shear forces. The maximum base shear force of the isolated bridge at the bearing level is approximately obtained as 0.035W, 0.046W and 0.0034W for the Erzincan, the Düzce and the Erciş earthquakes, respectively. For non-isolated bridge are 0.120W, 0.198W and 0.048W for Erzincan, Düzce and Erciş earthquakes, respectively. Base shear reduction of isolated bridge ranging from 70% to 93% in case of the usage of the three earthquake records. The displacements of the SCFP bearing for three ground motions are obtained. Maximum displacements of SCFP reach to 396.32 mm, 60.82 mm and 60.47 mm in case of Erzincan, Düzce and Erciş earthquakes, respectively.

Finally, it should be noted that isolation system is more effective when the bridges are subjected to earthquake.

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