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Dynamic behaviour of cables of cable-stayed bridge isolated with SCFP placed under pylon

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ABSTRACT

This paper presents earthquake response of cables of cable-stayed bridge isolated by single concave friction pendulum (SCFP) bearing installed under pylon. Generally isolation devices are placed under the deck and abutment of cable-stayed bridges whereas in this study isolation devices are placed under pylon and abutment. Manavgat Cable-Stayed Bridge is selected as a numerical application. Three dimensional finite element model (FEM) of the base isolated and non-isolated bridge are constituted using SAP2000 in order to determine the contributions of isolation systems to dynamic responses of the bridge. Analytical model of the bridges are analysed using 11 December 1999 Duzce, 23 November 2011 Van-Ercis and 13 March 1992 Erzincan earthquake records to determine the seismic behaviour. BOL-090 and BOL-000; ERCIS-EW and ERCIS-NS; ERZ-NS and ERZ-EW components of ground motions are applied to the bridges at the longitudinal and transverse directions, respectively. Nonlinear time history analysis is executed to determine the dynamic responses of the bridge. Comparison of cables dynamic behaviour of isolated and non-isolated bridge under three different earthquake motions has been conducted. The results obtained from analyses of the bridges are presented by graphics and tables in detail. Effect of isolation system installed under pylon on axial force of cable depends on ground motion and location of cable.

Keywords: Base isolation, cable-stayed bridges, finite element model, seismic isolation, single concave friction pendulum bearing.

1 INTRODUCTION

Usability of bridges after severe earthquake is very important issue because of high cost and logical importance of these structures. Previous major earthquakes show up strength alone would not be adequate for safety of bridges. Seismic isolation system may be an alternative protection way for bridges exposed severe earthquakes. Seismic isolation is a method that attempts to decrease the seismic forces or keep in members

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in elastic zone, thereby eliminating or reducing inelastic deformations. The main concept in isolation is to increase the period of structural vibration. If the fundamental period of structure is lengthened or energy dissipating of structure is increased, the seismic forces on bridge can be reduced. In typical application, isolation devices are connected end spans to substructures and deck to pylon. This paper focus on issues related to isolating the bridge with isolation devices provided connecting the end spans to the substructure and the pylon base to the foundation.

Seismic isolation systems have been successfully applied on new and existing structures. The most comprehensive literature researches about base isolation and base isolation systems are carried out Buckle and Mayes (1990), Jangid and Data (1995), Kunde and Jangid (2003), Mostagnal and Tanbakuchi (1983), Lin and Tadjbakhsh (1986), Kelly (1999), Tsai et al. (2003), Morgan and Mahin (2008), Panchal et al. (2010), Khoshnoudian and Rabiei (2010).

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 system (Zayas et al. 1987). In the literature, there are some studies related to structural performance evaluation of base isolated long span highway bridges. Tsopelas et al. (1996a) carried out an experimental study on seismically isolated bridge with friction pendulum bearing and non-isolated bridge to compare seismic excitation. Tsopelas et al. (1996b) carried out an experimental study on seismically isolated and non-isolated bridge to demonstrate effectiveness of sliding bearings and rubber restoring force devices. Chadwell et al (2004) explores isolation for protecting cable-stayed bridge due to severe earthquake, near source seismic events. They used isolation system devices under the central pylon and end span connections. Thus the complete system can be isolated and superstructure can be protected against destructive effect of earthquake. The seismic responses of the isolated and non-isolated cable-stayed bridge are compared by Soneji and Jangid (2006). Numerical investigations have been carried out on the base isolation effect of the DCFP bearings by Kim and Yun (2007). Tsai et all. (2010) conducted experimental and numerical studies for structures having sliding type isolators. Yurdakul and Ates (2011) studied on a two dimensional-and eight-story of a building with and without isolation system to investigate of the effectiveness of the seismic isolation system on the buildings. Soni et al. (2011) described a mathematical model and force-displacement relationships of double variable frequency pendulum isolator. Behavior of this isolator is examined by varying its geometry and coefficient of friction of the sliding surfaces. Ates and Constantinou (2011) examined on a curved bridge isolated with friction pendulum bearings are placed between the deck and the piers.

The aim of this study is to introduce the advantages of seismic isolation systems on cable supported bridges subjected to three different earthquake ground motions. For this purpose, a cable stayed bridge built in Manavgat is chosen as a numerical example. Finite element analyses are performed to non-isolated and single friction pendulums bearings conditions. The dynamic characteristics and axial forces of cables are compared with each other to extract the base isolation system effect on cables.

2 DESCRIPTION OF MANAVGAT CABLE-STAYED BRIDGE

Manavgat Cable-Stayed Bridge is the first cable-stayed bridge constructed in Turkey. The bridge is 202 m long and 13,7 m in width, with equal spans of 101 m; and designed for two lanes of road traffic shown in Fig. 1. The bridge have approximately 42 m λ (upside down of Y) shape steel tower. The pylon is placed on 1 m thick concrete base. The pylon 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 profile which is used in the deck extends continuously from one end to the other end of the bridge. For more details about bridge, the reader is referred to Atmaca and Ateş (2012).

The schematic form of Manavgat Cable-Stayed Bridge and location of SCFP bearings at the pylon-foundation connection is shown in Fig. 2 and 3, respectively. Following assumption are made for the analysis of isolated bridge.

- The effect of soil-structure interaction is not taking 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 do not occur on the cables. They are only subjected to axial force.

Fig. 1 Manavgat Cable-Stayed Bridge (Google Earth2013)

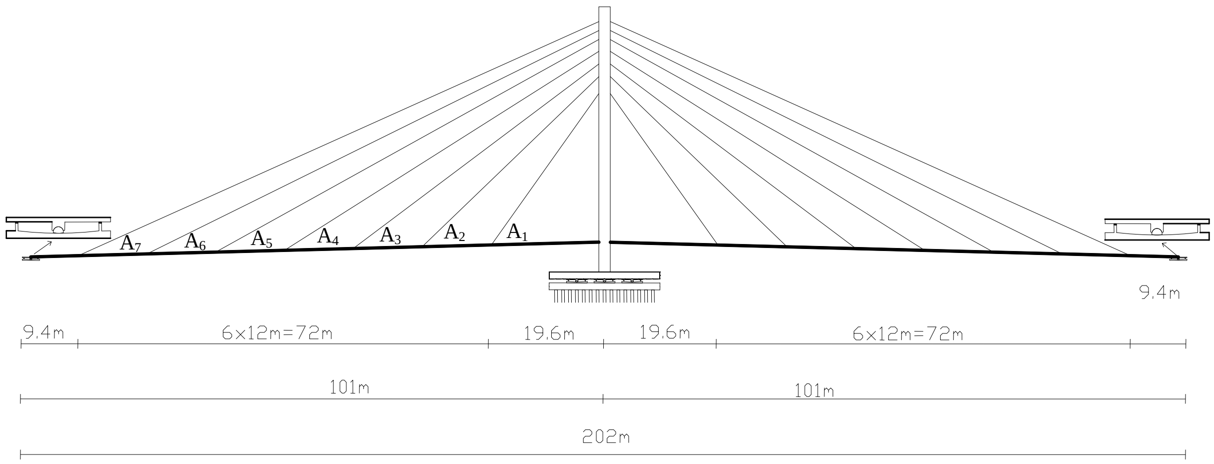

Fig 2 The schematic form of Manavgat Cable-Stayed Bridge

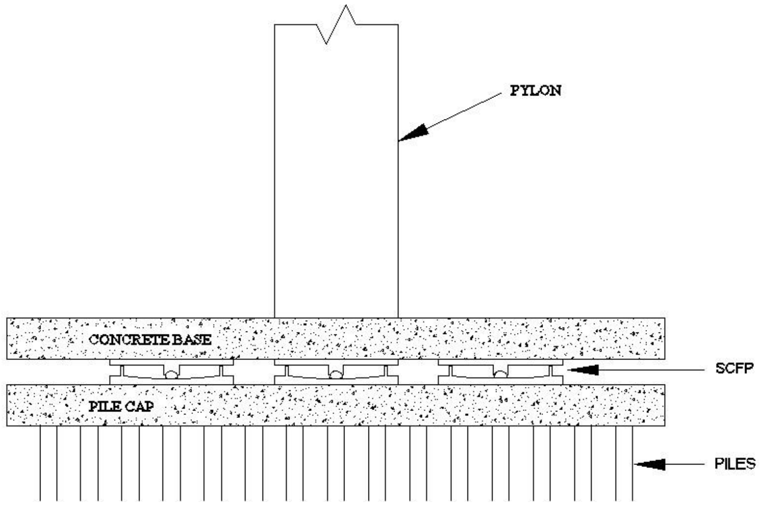

Fig 3 Location of SCFP bearings at the pylon-foundation connection

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. Stay cable data and strands properties is given Table1 and Table2, respectively.

Whereas the non-isolated bridge model consist of 3652 nodal points, 1130 frame, 32 links, 832 solid and 1980 area elements, the isolated bridge model consist of 3663 nodal points, 1130 frame, 42 links, 832 solid and 1980 area elements The steel parts of deck, tower and pylon, cables, slab of deck and concrete base are represented with beam, truss, area and solid elements, respectively.

Table 1. Stay cable data

Stay Cable Data		
Cable No	No. of Strands	Approximate angle to horizontal
A_1	15	56
A_2	16	45
A_3	19	37
A_4	19	33
A_5	22	29
A_6	19	26
A_7	24	24

Table 2. Strands properties

Strands Properties	
Nominal Diameter	15.2 mm
Area	150 mm^2
Ultimate Strength	1860 MPa
Elastic Modulus	$1{,}97 \times 10^5$ kN/m^2

3. NUMERICAL COMPUTATIONS

Nonlinear time history analysis of the isolated and non-isolated bridge is performed in SAP2000 (Computer and Structures 2007) in order to determine the dynamic behavior of Manavgat Cable-Stayed Bridge. Three dimensional FEM of non-isolated bridge is given in Fig. 4. Four isolators among them are connected end spans to substructure and the other six isolators are connected concrete base to pile cap (Fig. 3). Damping ratio is specified as 5%. SCFP bearing selected as an isolation device. The properties of SCFP is determined as; effective radius of curvature, Reff =1,4m, frictional coefficients, μ=0,09, and displacement capacities, d=0,40m for numerical analyses.

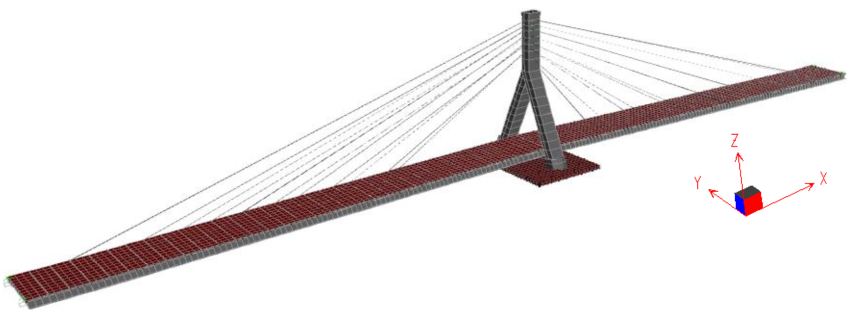

Fig. 4 Finite Element Model of Manavgat Cable-Stayed Bridge

BOL-000 and BOL-090 components of 11 December 1999 Duzce, ERCIS-EW and ERCIS-NS components of 23 November 2011 Van-Ercis, 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. ERZ-NS, BOL-090, and ERCIS-EW components are applied to the bridge at the longitudinal directions and ERZ-EW, BOL-000, and ERCIS-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 behavior of the of the SCFP bearings.

The peak accelerations of the ground motions are 0,496g and 0,515g for Erzincan earthquake, 0,728g and 0,822g for Duzce earthquake, and 0,173g and 0,182g for Van-Ercis earthquake.

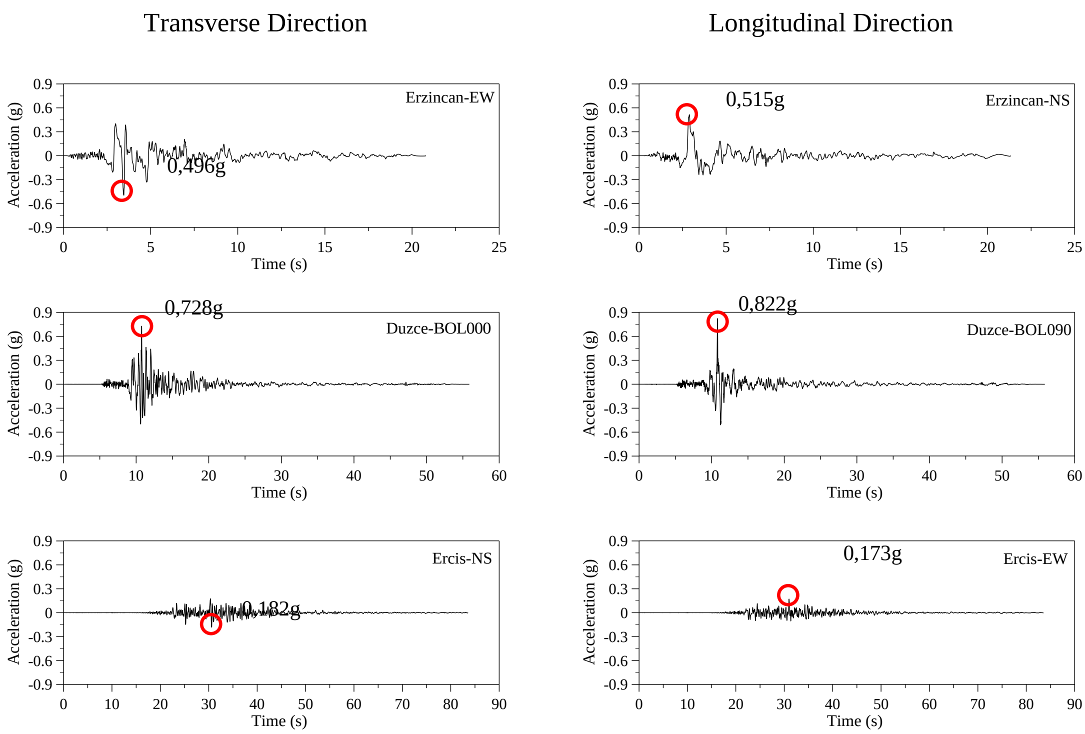

Fig. 5 Earthquake ground motions.

4 NUMERICAL RESULTS

4.1 Cable response

The axial forces of cable no A_1 of isolated bridge are compared to those of non-isolated bridge for Erzincan, Duzce and Van-Ercis earthquakes in Fig.6. Axial forces of cables increase on Erzincan and Duzce earthquakes however decrease on Van-Ercis earthquake when isolators were used. Increasing percentage of axial forces on Erzincan and Duzce earthquakes are 150% and 237% respectively. Decreasing percentage of axial forces on Van-Ercis earthquake is 6%.

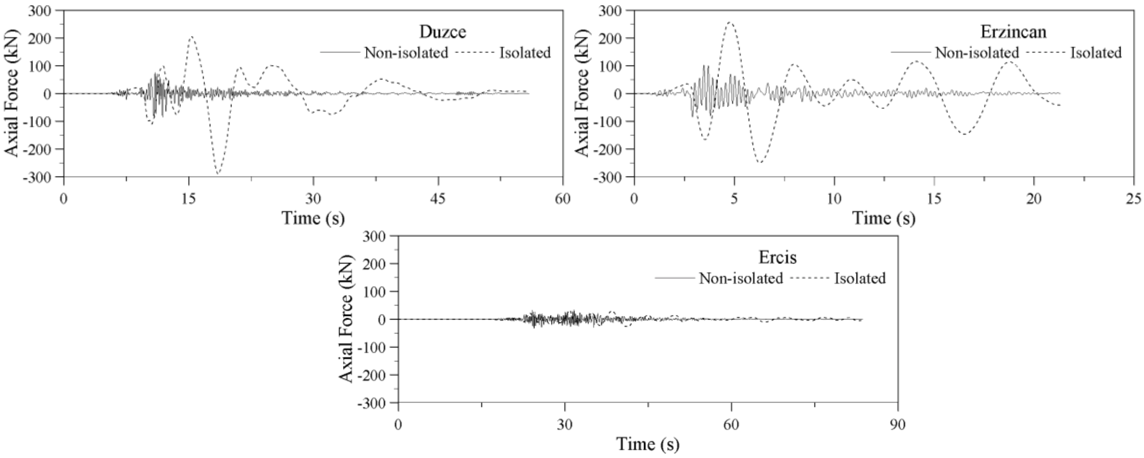

Fig. 6. Maximum axial force of cable A_1.

The axial forces of cable no A_2 of isolated bridge are compared to those of non-isolated bridge for Erzincan, Duzce and Van-Ercis earthquakes in Fig.7. Axial forces of cables increase on Erzincan and Duzce earthquakes however decrease on Van-Ercis earthquake when isolators were used. Increasing percentage of axial forces on Erzincan and Duzce earthquakes are 50% and 85% respectively. Decreasing percentage of axial forces on Van-Ercis earthquake is 33%.

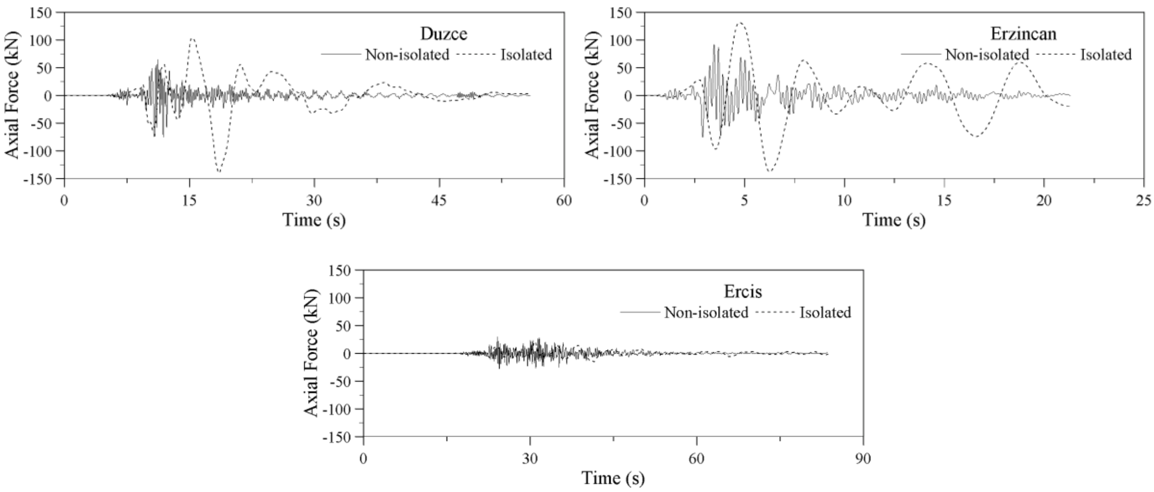

Fig. 7. Maximum axial force of cable A_2.

The axial forces of cable no A_3 of isolated bridge are compared to those of non-isolated bridge for Erzincan, Duzce and Van-Ercis earthquakes in Fig.8. Axial forces of cables increase on Erzincan earthquake however decrease on Duzce and Van-Ercis earthquakes when isolators were used. Increasing percentage of axial forces on Erzincan earthquakes is 4,7%. Decreasing percentage of axial forces on Duzce and Van-Ercis earthquake are 5% and 44% respectively.

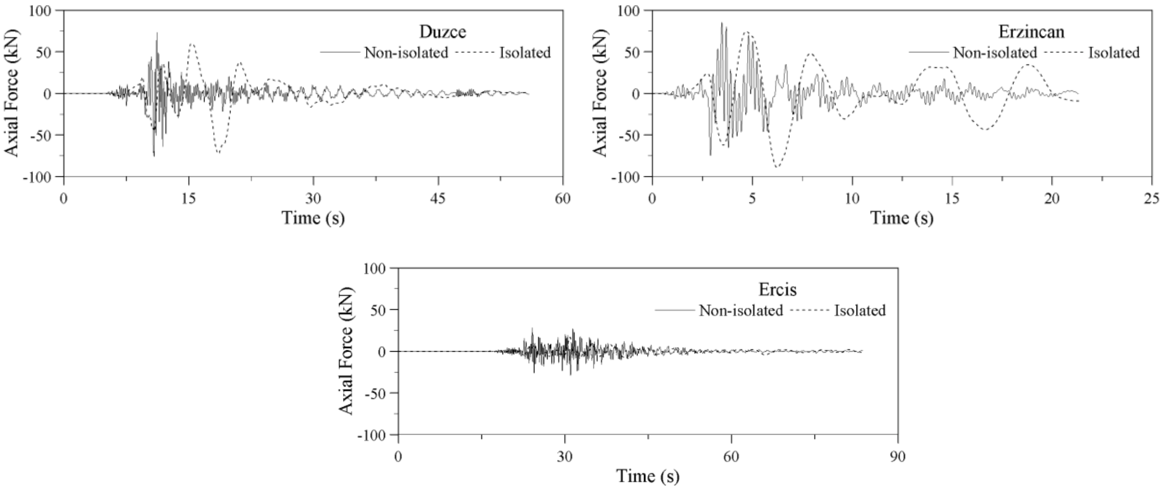

Fig. 8. Maximum axial force of cable A_3.

The axial forces of cable no A_4 of isolated bridge are compared to those of non-isolated bridge for Erzincan, Duzce and Van-Ercis earthquakes in Fig.9. Axial forces of this cable decrease for all selected earquakes when isolators were used. Decreasing percentage of axial forces on Erzincan, Duzce and Van-Ercis earthquakes are 44%, 56% and 60% respectively.

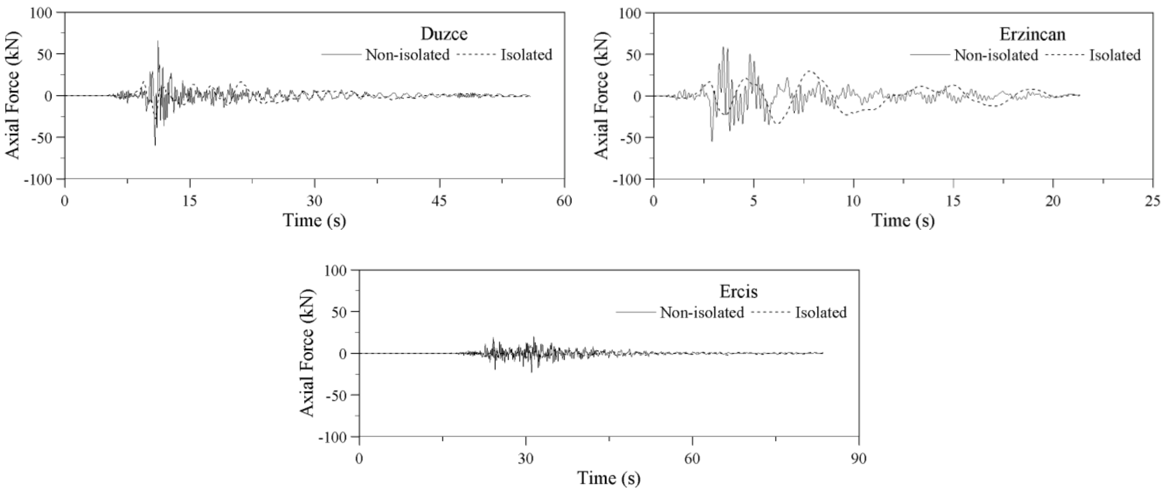

Fig. 9. Maximum axial force of cable A_4.

The axial forces of cable no A_5 of isolated bridge are compared to those of non-isolated bridge for Erzincan, Duzce and Van-Ercis earthquakes in Fig.10. Axial forces of cables increase on Duzce earthquake however decrease on Erzincan and Van-Ercis earthquakes when isolators were used. Increasing percentage of axial forces on Duzce earthquake is 6%. Decreasing percentage of axial forces on Erzincan and Van-Ercis earthquakes are 29% and 58% respectively.

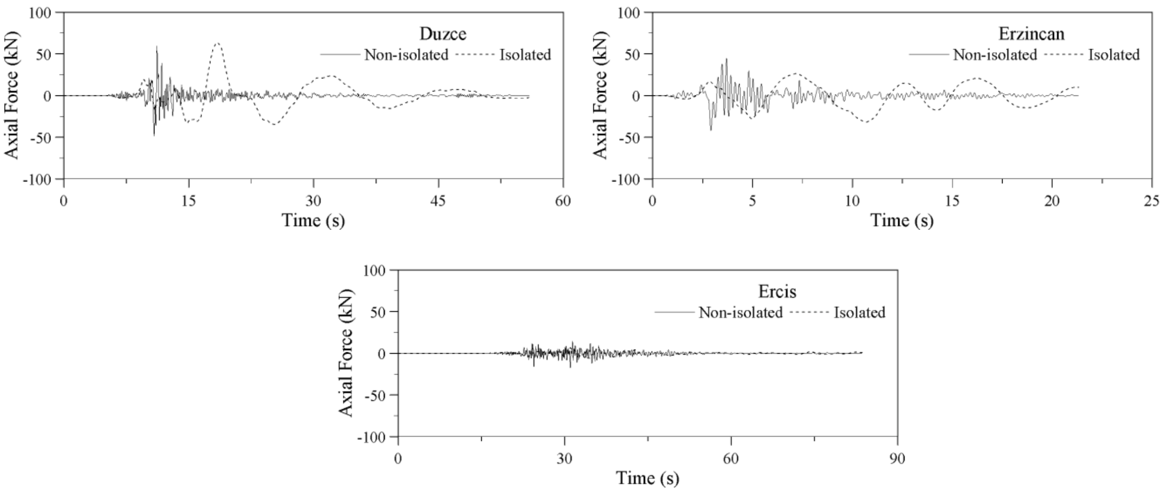

Fig. 10. Maximum axial force of cable A_5.

The axial forces of cable no A_6 of isolated bridge are compared to those of non-isolated bridge for Erzincan, Duzce and Van-Ercis earthquakes in Fig.11. Axial forces of cables increase on Erzincan and Duzce earthquakes however decrease on Van-Ercis earthquakes when isolators were used. Increasing percentage of axial forces on Erzincan, Duzce and Van-Ercis earthquakes are 5%, 150%. Decreasing percentage of axial forces on Van-Ercis earthquake is 30%.

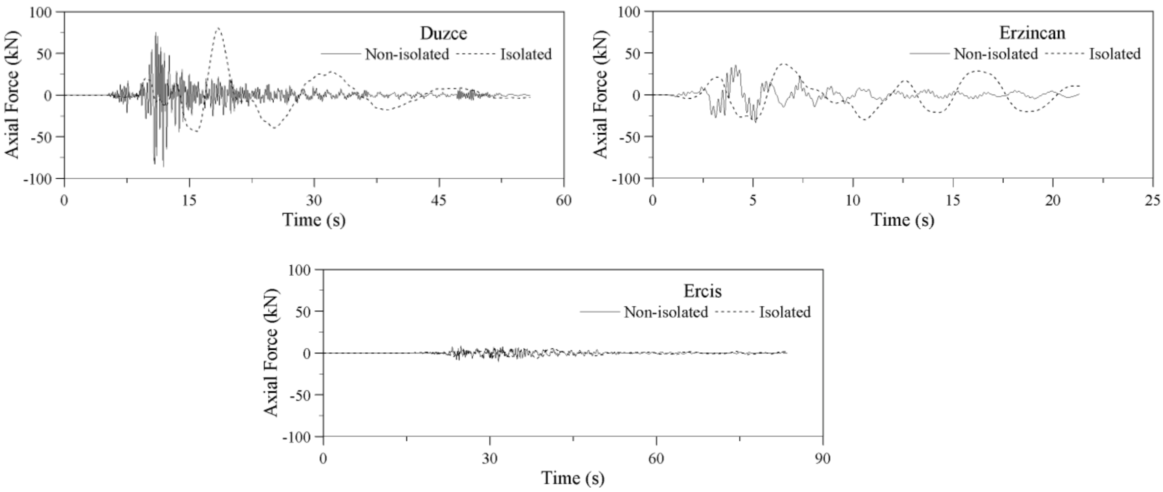

Fig. 11. Maximum axial force of cable A_6.

The axial forces of cable no A_7 of isolated bridge are compared to those of non-isolated bridge for Erzincan, Duzce and Van-Ercis earthquakes in Fig.12. Axial forces of cables increase on Duzce earthquake however decrease on Erzincan and Van-Ercis earthquakes when isolators were used. Increasing percentage of axial forces on Duzce earthquake is 285%. Decreasing percentage of axial forces on Erzincan and Van-Ercis earthquakes are 8% and 35% respectively.

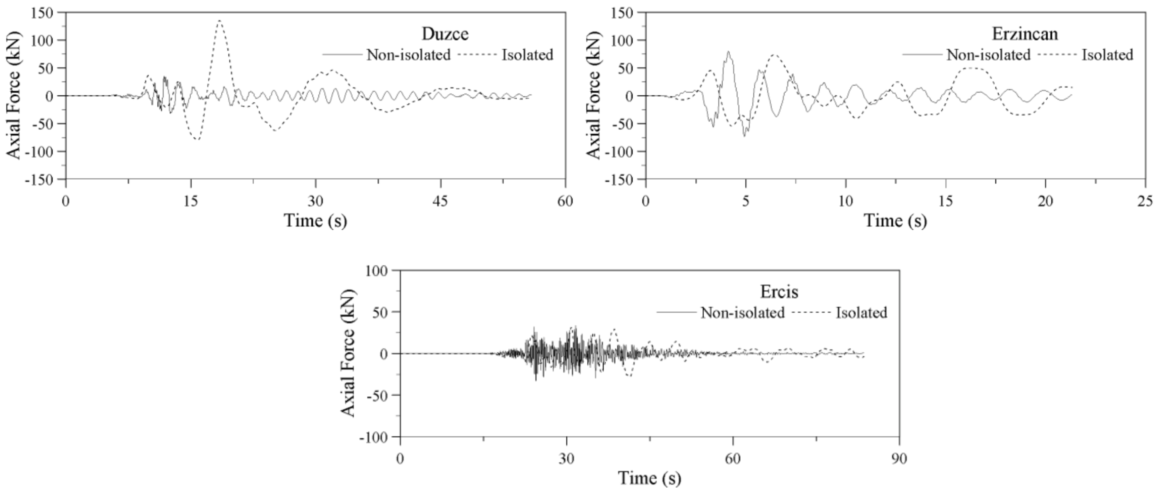

Fig. 12. Maximum axial force of cable A_7.

5. CONCLUSION

This study is compared Manavgat Bridge isolated by SCFP bearing with non-isolated bridge. Finite element model of the isolated and non-isolated bridges are created with SAP2000. Nonlinear time history analysis is performed in order to investigate effectiveness of the seismic isolation systems on cables of the bridge. Transverse and longitudinal directions of Erzincan, Duzce, and Van- Ercis earthquakes are used for dynamic analysis. As a result of analysis, variations of axial forces of cables of bridge models are obtained. The main conclusions of this study can be summarized as;

- The maximum axial forces occurred on cable A1 is closest to the bridge tower.
- Isolators decreased the axial force of the all bridge cables on Van-Ercis earthquake. Approximate decreasing percentage of axial force is 6%, 33%, 44%, 60%, 58%, %30 and %35 on A1, A2, A3, A4, A5, A6 and A7 cables, respectively.
- The axial forces of cable A4 decreased on all selected earthquake ground motions when isolators were used. Approximate decreasing percentage of axial force is 44%, 56% and 60% for Erzincan, Duzce and Ercis earthquake ground motions, respectively.

The results show that variation of cable axial forces depend on ground motions and location of cables. It is not clear to say that using of isolator decrease or increase the axial forces of cable.

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