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Performance Assessment of the Roll-N-Cage (RNC) Isolators impacts on Progressive Collapse Behavior in Cable-Stayed Bridges

Mohammad E. Omran[1,*] , Abbas H. Karani[2]

[1] Civil Engineering Department, Kurdistan University, Kurdistan, Iran
[2] Civil Engineering Department, Kurdistan University, Kurdistan, Iran

ABSTRACT: Structural safety can be threatened by the failure of one member of the structure if it fails other members of the structure. This phenomenon, which has recently attracted the attention of designers and engineers, is known as progressive collapse. Progressive collapse, especially during a severe earthquake, could threaten the general stability of structures and lead to their collapse. This research has been aimed to investigate the performance of the isolated cable-stayed bridges with modern Rolled-N-Cage (RNC) isolators under near-fault seismic loads and after losing a cable. In this regard, Bill Emerson isolated Cable-Stayed Bridge is implemented under three near-fault seismic events and assessed the results of the cable loss. Then, the buffer mechanism of the RNC isolator and its effects against preventing the progressive collapse is evaluated on preventing progressive collapse of the bridge. The results indicate that the RNC isolator with an activated buffer mechanism appropriately decreases the permanent displacement under near-fault seismic loads. While, not using the RNC isolator and buffer mechanism, causes the damage propagation and progressive collapse of the bridge.

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1. INTRODUCTION

Progressive collapse is among the issues that have received a great deal of attention in the fields of structural engineering analysis and construction design of the infrastructures. Progressive collapse event initially occurs with local damage in a relatively small part of the structure and then expands to the other parts of the structure [1]. Most common regulations which are considered and discussed the progressive collapse, only have general recommendations to reduce the progressive collapse effects on the structures in which experienced overload more than their design loads. Therefore, the necessity to evaluate different structures against the progressive collapse of additional loads is also felt more[2]. This research has been tried to investigate the damages caused by progressive collapse through dynamic loads on the cable-stayed bridges.

2. STRUCTURAL MODEL

Bill Emerson Memorial Cable-Stayed Bridge is located on the Mississippi River and connects Missouri and Illinois states. The bridge has a total length of 1.2 Km, a width of 29 m, a height of 150 m, and also has 3 main spans. The bridge model has been validated and verified based on Ismail et al. [3]. Bill Emerson Memorial Cable-Stayed Bridge geometric specifications are illustrated in Fig. 1. Three-dimensional finite element model has been modeled with Opensees Software and nonlinear dynamic analysis has been applied under real earthquake events. An isolated cable-stayed bridge has been studied under three seismic events of San-Fernando, Northridge, and Imperial Valley in two cases considering (1) intact bridge model (2) bridge model with removed cable.

The bridge has been isolated with eight Roll-N-Cage (RNC) isolators considering two bearings at each bridge end, one at each side, and two bearings at each tower. 128 cables are modeled considering the truss element with pre-stressed tensile material behavior connecting the deck to the towers. The cables number is shown in Fig. 2.

3. ROLL-N-CAGE (RNC) SEISMIC ISOLATOR

RNC isolator has three basic features: (1) buffer mechanism in severe seismic excitations caused by considering the unique configuration of the rolling core and the inner faces of the upper and lower bearing plates. This feature leads the system to limit the isolator displacement and provides the stored stiffness at both sides of the force–displacement relationship curve of the RNC isolator. (2) The linear recentering mechanism, which is based on the gravity loads. This feature leads the system to prevent residual displacement after seismic excitations. (3) Hysteretic mechanism caused by the metallic curved shape dampers arranged around the rolling core.

To model the three features of the RNC isolator simultaneously in Opensees Software, three parallel elements with uniaxial material have been used. The hysteretic

*Corresponding author's email: m.esmaeilnia@uok.ac.ir

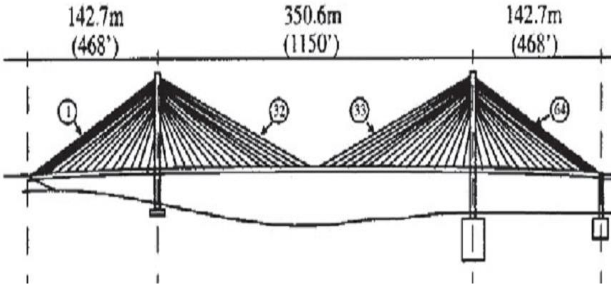


Fig. 1. Cable-stayed bridge geometry dimensions [4]

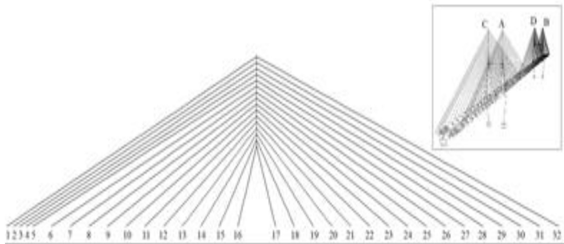


Fig. 2. Assigned cable numbers

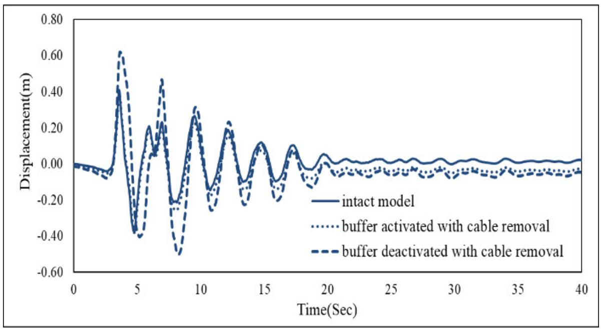


Fig. 3. Displacement history of the isolated cable-stayed bridge considering cable 32 removal under seismic records

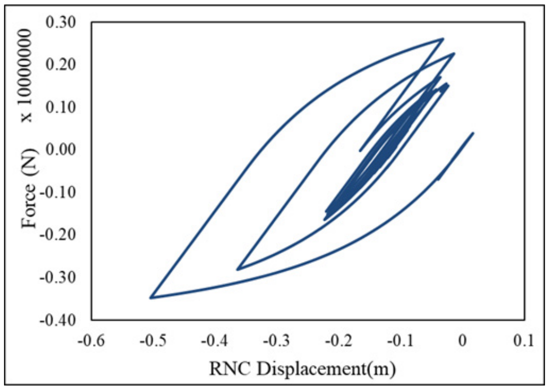
component of the RNC isolator is modeled by using of Bouc-Wen hysteretic material by setting dimensionless parameters as A = 1 and β = γ = 0.5. In this approach, parameter A controls the tangent stiffness, and parameters β & γ control the shape of the hysteresis loop.

4. RESULTS AND DISCUSSION

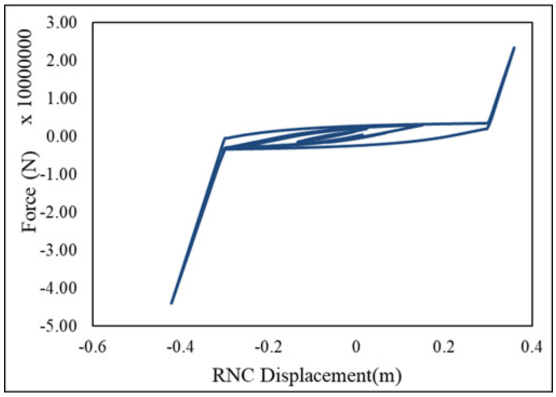
Roll-N-Cage (RNC) isolator performance considering progressive collapse condition has been investigated during the ground seismic motions. For this purpose, according to the previous section, the cable-stayed bridge model has been analyzed considering five scenarios with three seismic records. As indicated in fig.3 losses the cable which connects the middle part of the deck to the towers, leads to occur the permanent displacement with the significant increase of the axial force in adjacent cables.

Force-displacement history response of the Roll-N-Cage (RNC) isolators is represented in Fig. 4 with considering the activated and deactivated buffer mechanism.

RNC isolator with buffer mechanism function provides Better performance after the failure of the critical cable 32.



(a)Deactivated buffer mechanism under San Fernando



(b)Activated buffer mechanism under San Fernando

Fig. 4. Force-displacement history response of the Roll-N-Cage (RNC) isolators considering cable 32 removal under seismic records

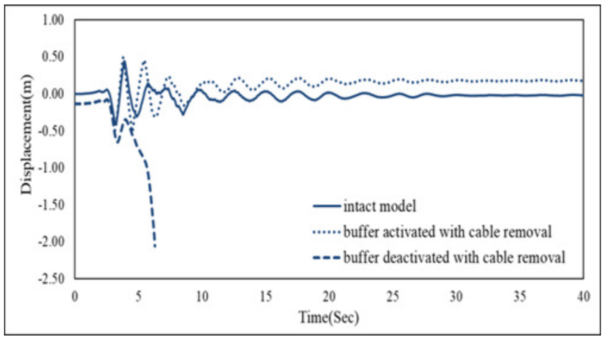


Fig. 5. Displacement history of the isolated cable-stayed bridge considering cable 1 removal under seismic records

In the following, Roll-N-Cage (RNC) isolator performance is evaluated considering the cable 1 removal condition which connects the end side of the deck to the towers. Displacement history of the isolated cable-stayed bridge is indicated in Fig. 5.

As it can be seen, losses the cable 1 leads to occur the permanent displacement at the bridge deck. Activating buffer mechanism in time history analysis leads to a reduction in permanent displacement and in the maximum displacement of the deck and also makes a significant decrease in cables axial forces. However, the deactivated buffer mechanism leads to occur extraordinary intense displacement and cables axial forces which indicate the progressive collapse occurrence.

5. CONCLUSIONS

In this research, the isolated Cable-stayed Bridge is modeled by considering cable removing effects during the ground motion. Nonlinear dynamic analysis are conducted in two cases like (1) intact bridge model (2) bridge model with removed cable. Results show that the activated buffer mechanism provides complete hysteretic cycles with proper energy dissipation by limiting the RNC inner displacement and especially prevents progressive collapse in end cable losses condition.

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