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Seismic Analysis and Retrofitting of Bridges

Hafsa Farooq[1], Danish Jeelani[2] and Abdul Haseeb Wani[3]

[1,2]Department of Civil Engineering, NIT Srinagar
[3]Department of Civil Engineering, IIT Jammu
E-mail: [1]hafsafarooq@nitsri.net, [2]jeelanidanish9@gmail.com, [3]abdulhaseeb.445@gmail.com

Abstract—*All over the world, a new interest has developed among engineers and researchers which include retrofitting of old bridges and seismic design of new bridges and this has been most challenging work. Since the development of modern codes, it has become easier and much better. Before, the bridges were designed for nominal seismic force without provision of ductility which has lead to much more failure of bridges during an earthquake. In India, many bridges exist and since being constructed a long time ago, they need to be made resistant to any kind of disaster that can lead them to failure. And those which have already undergone failure and those which can fail during any kind of circumstances are to be retrofitted and some are to be analyzed seismically. Several retrofitting techniques have been developed which means the already existing structures can be made resistant to any upcoming disaster. Many bridges have been retrofitted and many are under process. Once retrofitted, the risk of failure becomes less. In this paper, a three span bridge is taken and is checked for structural deficiencies which are overcome by use of a certain restrainers as retrofitting technique. Restrainers have been used to connect piers with the deck slab. Seismic non-linear analysis viz. Pushover analysis have been carried out prior and after retrofitting using SAP2000 and the results have been compared. The evaluation of the result shows certain difference in the displacement and base shear.*

1. INTRODUCTION

Extensive damage to structures due to earthquakes has been a very common problem in the recent years. India itself being a developing country has been vulnerable to earthquakes as well. The major 2001 Gujarat earthquake and 2005 Kashmir earthquake keen interest was given towards safety and stability of structures. Today engineers and builders are more concerned about the safety. A lot of effort has been put in order to make the various structures seismically safe and resistant. The main steps include developing of the seismic design building code i.e. IS1893 (part I) which was later revised in 2002 providing the necessary guidelines for design of safe structures. In this whole process, the main emphasis was given to buildings and less attention has been given to bridges.

Bridges form an important role in our day to day life. In terms of disaster, these are the major mode for transportation. Therefore these also need to designed in such a manner such that they are seismically resistant. Before 1970, bridges were not designed for seismic resistance such as ductility making them more vulnerable to failure. Since the revision of the codes, making our bridges seismically sound is necessary and for that the earthquake resistant design and retrofitting of the old bridges has been carried out accordingly.

2. METHODOLOGY

In this study, nonlinear seismic analysis has been performed on the three span bridge. The nonlinear static analysis also known as the Pushover Analysis came into practice in 1970’s but has been recognized only since past 10-15 years. This method is typically used to determine the strength and drift capacity of the existing structure and the seismic demand for the structure subjected to a selected earthquake. The seismic guidelines for this analysis are given in ATC 40 and FEMA 356 and the design codes Euro code 8 and PCM 3274.

In the Pushover analysis, a mathematical model incorporates nonlinear load- deformation characteristics, where each element is subjected to monotonically increasing load till target displacement is exceeded. It tells us about the structural performance by estimating the force, the deformation capacity and seismic demand at any reference point. Pushover Analysis therefore gives us in a structure: (i) Force and displacement capacities (ii) Force demands on any brittle or ductile elements (iii) Damages on any element, global displacement demand under an earthquake (iv) Overall stability and sequence how the elements will fail (v) identification of critical regions.

The Pushover procedure involves monotonically increasing the magnitude of the lateral load. Structure is displaced till the ‘control node’ reaches the target displacement or it collapses. The sequence of cracking, plastic hinging and failure of structural components throughout the procedure is observed. The relation between base shear and control node displacement is plotted for pushover analysis. The curve is called the **Pushover curve or capacity curve**.

The pushover curve in an Acceleration displacement response spectrum (ADRS) format is termed a ‘capacity spectrum’ for the structure. The seismic ground motion is represented by a response spectrum in the same ADRS format and it is termed as demand spectrum.

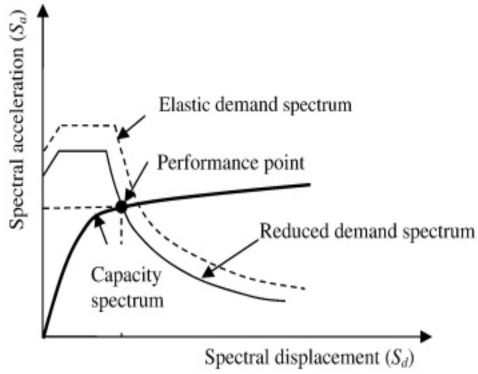

Figure 1 Capacity Spectrum Method (ATC 40)

After the implementation of Pushover analysis, the model accounts for nonlinear behavior of structural elements. Point-plasticity concept is utilized which leads to formation of hinges at specific points under consideration.

Piers in this study were modeled with flexure (P-M2-M3) hinges at possible plastic regions under lateral load (i.e., both ends of the beams and columns). Properties of flexure hinges must simulate the actual response of reinforced concrete components subjected to lateral load.

3. STRUCTURAL MODEL

The RC bridge including the piers and girders are modeled by 3D frame elements. The girder- pier joints are modeled by giving end offsets to frame elements, to obtain the bending moments and forces at beam and column faces. The piers of the bridge are circular and the bridge deck is trapezoidal. The pier cap is rectangular and at the both ends are the abutments. The bridge model has three spans. The pier ends at foundations are fixed. The deck is not modeled physically; however the weight of the bridge deck is applied on the beam as dead load. Also, mass of the deck is considered for modal analysis.

4. BRIDGE MODEL

The bridge model is actually a bridge existing in reality. In the state of J&K, the bridge has been constructed in Srinagar at Dalgate. The project is actually based on "widening of via-duct". The total span of the bridge is 250m. For this research, three spans of length 12.5m, 12.4m and 12.69m have been taken up. The piers of the bridge are circular in shape with a diameter of 1m, which are located at a distance of 1.35m, 3.7m and 6.05m from one end of the pier cap, with height of 8m each. The length of the pier cap is 7.5m.

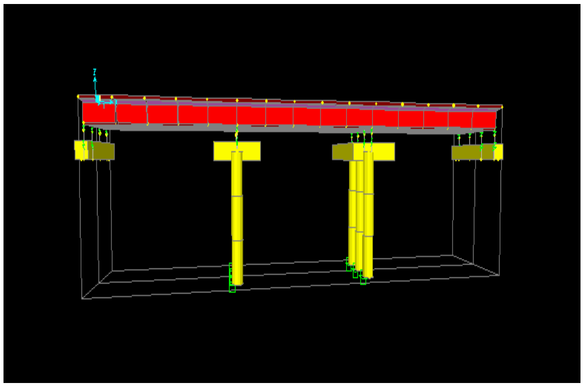

Figure 2 Model of the Bridge

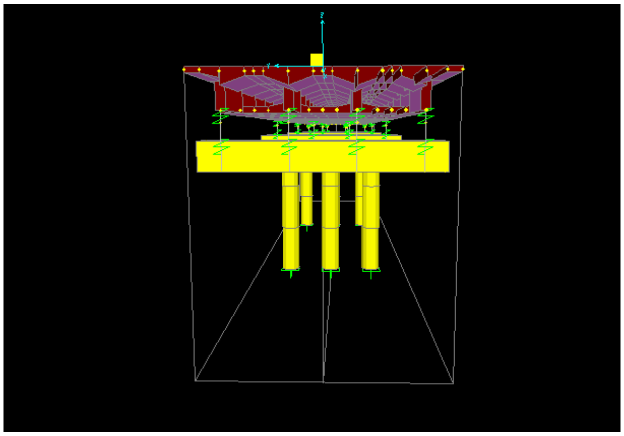

Figure 3 Front elevation

4.2 Retrofitted Model

The retrofitted fitted model is same as the model without retrofitting except it consists of additional elements called as restrainers. As discussed earlier, restrainers are connected from the deck slabs to the pier cap or columns or at the abutments. The restrainers used have a length of 0.696m. The area of the restrainers is 6.452 E-04, and the slack length provided is 0.19m.

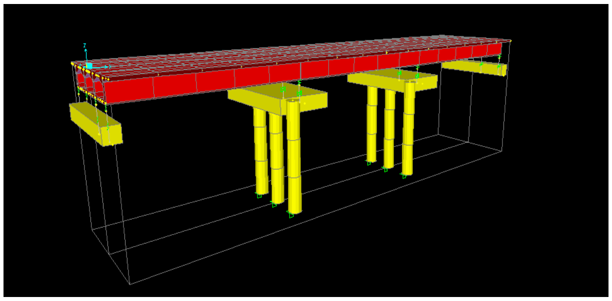

Figure 4 Model with restrainers

5. RESULTS AND DISCUSSION

The nonlinear Pushover analysis has been carried out in SAP2000 using FEMA 356 displacement coefficient method. The gravity loads that are the dead and live loads have been used for analysis. The target displacement has been calculated with the base reactions and the moment. The damping ratio used is 5%. Pushover analysis has been carried out in both directions i.e. x and y as PUSH X and PUSH Y. The displacement for the first case which is RC bridge without restrainers is 0.012 m in x-direction and 0.003m in y-direction. For RC bridge with restrainers, the displacement is 0.011m and 0.003m in x and y direction respectively. The capacity spectrum curves for both cases are shown below with the performance point.

Table1 Base reaction & moment for RC bridge without retrofitting

S.No	Load case	Base reaction (KN)	Moment (KN-m)
1	PUSH X	31141.015	16.73
2	PUSH Y	47457.626	13.18

Table2 Base reaction and moment for RC bridge with retrofitting.

S.No	Load Case	Base reaction (KN)	Moment (KN-m)
1	PUSH X	31140.005	16.24
2	PUSH Y	46210.745	0.7838

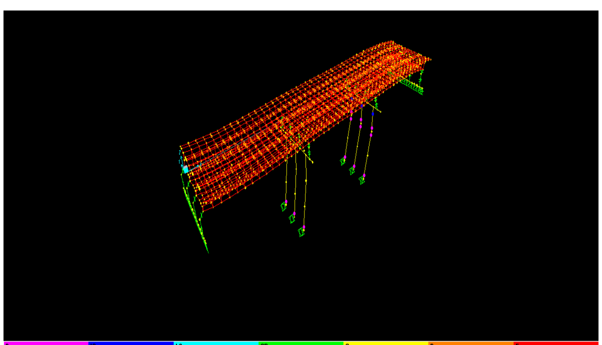

Figure 5 RC bridge without retrofitting at final step PUSH X

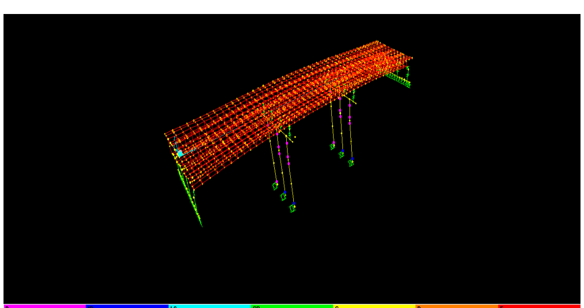

Figure 6 RC bridge without retrofitting at final step PUSH Y

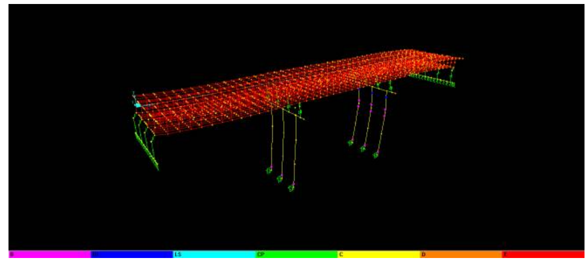

Figure 7 RC bridge with retrofitting at final step PUSH X

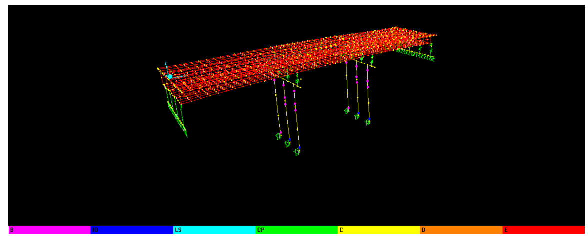

Figure 8 RC bridge with retrofitting at final step PUSH Y

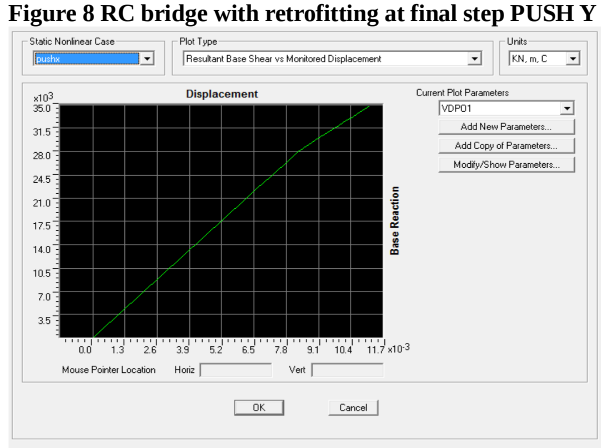

Figure 9Pushover curve for RC bridge without retrofitting at final step PUSH X

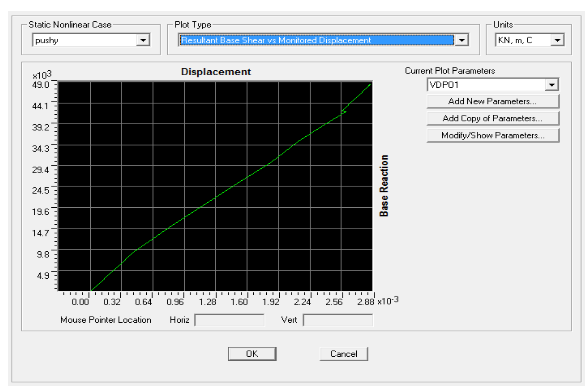

Figure 10Pushover curve for RC bridge without retrofitting at final step PUSH Y

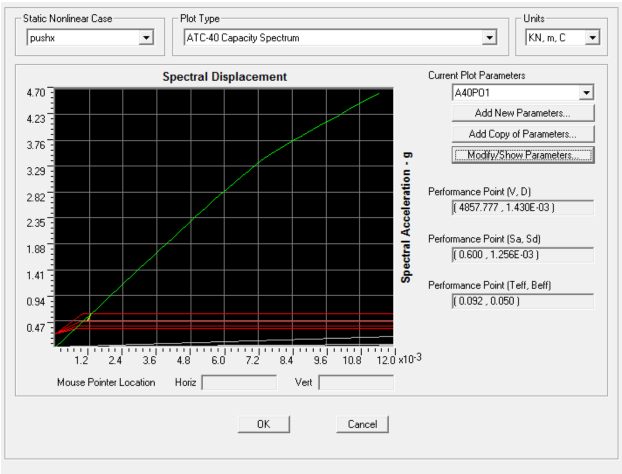

Figure 11Capacity spectrum curve ATC-40 for RC bridge without retrofitting at final step PUSH X

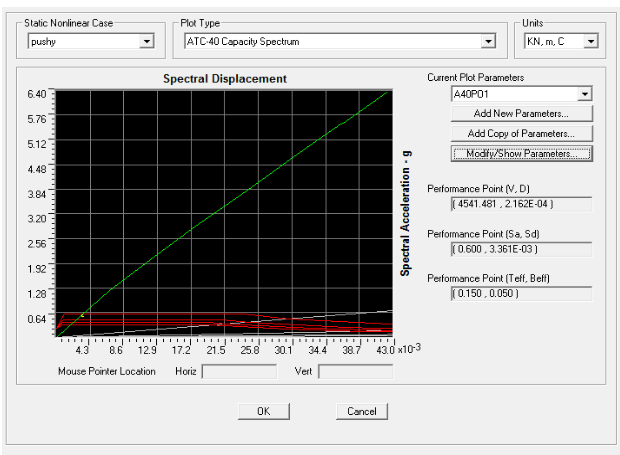

Figure 11Capacity spectrum curve ATC-40 for RC bridge without retrofitting at final step PUSH Y

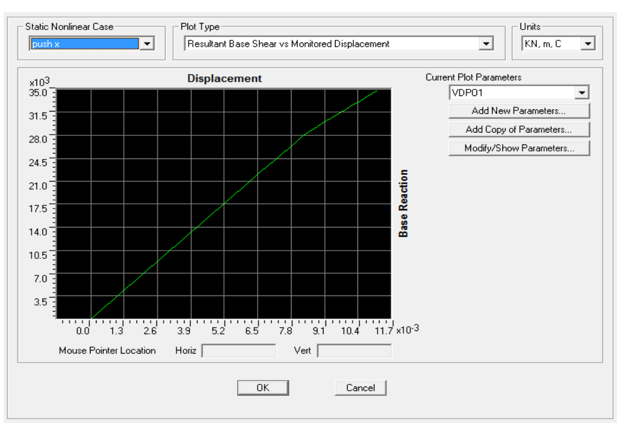

Figure 12Pushover curve for RC bridge with retrofitting at final step PUSH X

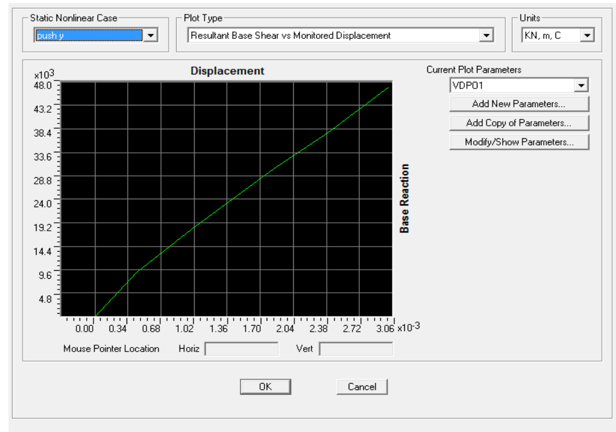

Figure 13Pushover curve for RC bridge with retrofitting at final step PUSH Y

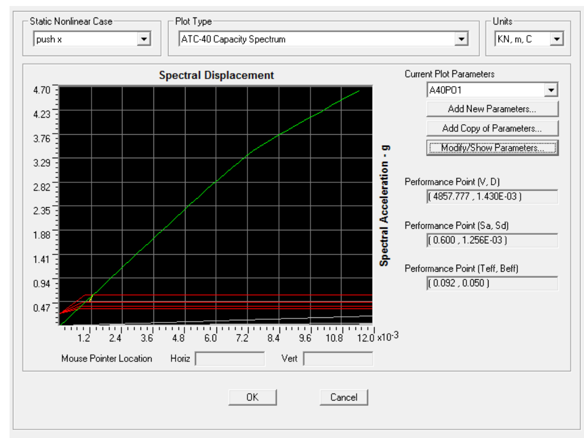

Figure 14Capacity spectrum curve ATC-40 for RC bridge with retrofitting at final step PUSH X

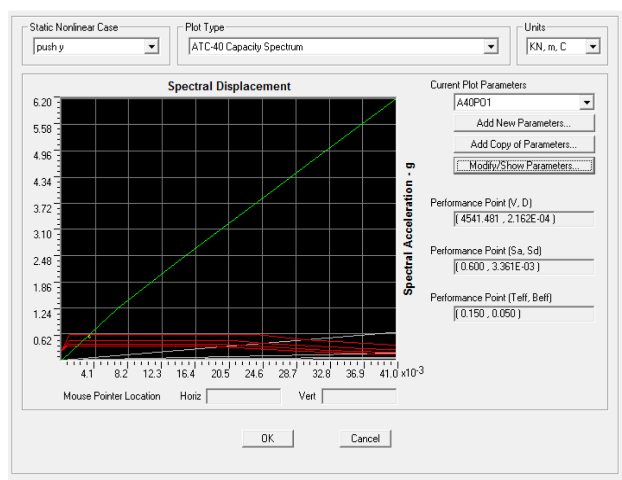

Figure 15Capacity spectrum curve ATC-40 for RC bridge with retrofitting at final step PUSH Y

From the above analysis i.e. Pushover Analysis we conclude that there is not much difference between the base reaction and the displacement after retrofitting of the model. The performance point which is the intersection of the capacity spectrum and the demand spectrum obtained is (4857.777, 1.43 x10^{-3}) for X-direction and (4541.481, 2.612 x10^{-3}) for y- direction. After the analysis, hinges are formed on the piers of the RC bridge. The hinges are formed at various steps of the analysis and they accordingly change the deformation of the structure. Figure 5,6,7 and 8 show the location of hinges at various positions on the pier of the bridge.

6. CONCLUSION

Bridge is a structure that extends horizontally and is restrained at both ends. This is what makes it different from the buildings. In this report, the two cases of RC bridge with and without retrofitting have been analysed using Pushover Analysis on SAP2000. We conclude that the pushover analysis results hardly change after retrofitting. The hinges are formed on the pier columns. The implementation of restrainers has shown promising results. The estimation process is a rigorous analytical study and takes into account more structural elements rather than displacement ductility alone. The bridges need retrofitting primarily because of two reasons (i) these were designed for smaller forces than that occur (ii) these may lack in ductility in the absence of ductile detailing of reinforcement.

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