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Effect of CFRP Retrofitting on Seismic Vulnerability of Reinforced Concrete Frame Structures in Pakistan

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Abstract

The objective of this research work is to study the effect of CFRF retrofitting on the seismic vulnerability of typical reinforced concrete structures in Pakistan. Pakistan is located in high seismicity zone as it lies on seismic fault line which divides the area in such a way that half of it lies in Eurasian plate and other half lies in Indian plate. After the massive earthquake of Kashmir 2005 most of the structures failed because of the high seismic vulnerability of existing structures. After 2005 event, earthquake zones were also changed to a higher hazard level, hence increasing the seismic demand on the existing structures that were constructed prior to the earthquake 2005. This research accounts for the seismic vulnerability assessment of reinforced concrete frame structures in Pakistan and the effect of retrofitting on these structures. After carrying out a detailed survey of Pakistan a hypothetical reinforced concrete frame structure, typologically similar in construction practices in Pakistan is designed and modelled in Perform 3D to study the effect of lateral forces on these structures. Seismic vulnerability curves are computed using Capacity Spectrum Method and the effect of seismic forces on existing structure is studied. In order to improve the seismic performance the joints of RC frame structure are retrofitted using CFRP which are the critical elements for structural performance. By using the confined properties of concrete through CFRP, an analytical curve is developed again using the same procedure. These curves are compared and the effect of retrofitting is studied.

Keywords: Seismic Vulnerability; Hazard; Nonlinear Analysis; Reinforced Concrete Frame Structures; Risk; Retrofitting; Response Spectrum; Capacity Spectrum.

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1. Introduction

Pakistan is located in a region of high hazard [1] but almost all the structures that were constructed prior to the Kashmir earthquake 2005, were designed under the gravity loads only and lateral loads were neglected [2]. Furthermore code provisions before earthquake 2005 were not satisfactory to provide expected level of life safety. Non-engineering practices in construction industry makes the situation worse. The design and construction standards are also not properly being followed [3].

Damage due to earthquake is comparatively much larger in Pakistan. Past earthquakes in Pakistan resulted in great loss of lives and property as well. The 2005 Kashmir earthquake has taken 100,000 lives and 400,153 buildings were destroyed. The total economic loss was approximately $5.2 billion. Building Code of Pakistan provide the seismic provisions on the design of the new buildings but still there is no or very till work done on the assessment of seismic vulnerability of existing buildings in Pakistan [4].

Retrofitting is a technique to improve existing structures to make them more resistant to expected hazard. Retrofitting can be done by using fiber-reinforced polymers, fiber reinforced concrete and high strength steel, FRP jacketing, Base isolators and Slosh tank etc. For this research work carbon fiber-reinforced polymers used to improve the performance of the beam-column joints, hence improving the overall seismic performance of a structure.

2. Literature Review

In moment resisting frames, beam to column joint is assumed to be rigid. In normal design practice for gravity loads, the design check for joints is not critical. However by studying failure of a structure because of earthquakes, joints were found to be the critical elements [5].

Reinforced concrete (RC) beam-column connections have been identified as potentially one of the weakest components when a reinforced concrete moment frame is the main Seismic Force Resisting System. The joints therefore should have adequate strength and stiffness to resist the internal forces induced by the framing members [5].

In National University of Sciences and Technology [6] the stress strain behavior of CFRP confined specimens was studied. The effect of column shape on confinement effectiveness, bond slip behavior and an improvement in bond strength due to CFRP wrapping was explained. Nine cylindrical specimens were tested under compression, three of which were unconfined and six were confined with single and double layers of CFRP wrap. The existing stress strain models for FRP confined concrete were discussed and their performance was checked with the experimental results of this work.

Author in [7] began his research work with vulnerability curves developed for the island of Cyprus. He claimed that these curves are highly unreliable because they were developed on limited available data. Author in [7] also got the data regarding PGA from Earthquake Rehabilitation service, after analyzing the data author developed PGA attenuation curves for Cyprus. Damage data of various events along with these curves were used to develop vulnerability curves for RCC and Masonry structures. These curves range between 0.11g to 0.17g while the only set of data was available for 0.25g. Therefore analytical procedures were used to investigate the characteristics of buildings at PGA of more than 0.25g. For analytical procedures he began using finite element software Drain 3D to observe building's behavior.

3. Design of Proposed Building

Except few major capital cities the general practice of designing a 3-4 story building was to design the building under gravity loads only and there was no such practice to cater for the lateral loads before the adaptation of building code of Pakistan 2005 [9]. Therefore, we also designed the building of similar configuration only under the gravity loads, in order to make it similar to existing buildings. Buildings that are designed under gravity loads only are more prone to damage if there would be any lateral load. No strict provision was available before the 2005 Kashmir earthquake but after the event BCP added special provisions to cater the lateral loads for earthquake resistant design criteria.

The purposes is to calculate seismic vulnerability of gravity load designed hypothetical reinforced concrete structure to any earthquake event which would represent all the buildings with similar typology which already exists and were designed for gravity loads only.

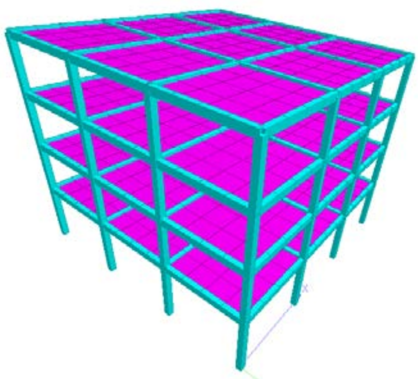

Figure 2: RC building model using STAAD. Pro 2007

4. Basic Structural Modeling and Non-Linear Analysis

Analytical model of the designed structure was developed in the Perform 3D to study its nonlinear behavior. After modelling a hypothetical structure similar to the local conditions of Pakistan, analysis was run and hysteresis loop was generated. This hysteresis loop was generated again after CFRP retrofitted of beam to column connections modeling and results were compared.

Nonlinear cyclic pushover analysis was run to get the capacity curve which is the plot of the base shear at Y-axis and the displacement at X-axis. For pushover analysis triangular distribution of lateral loads calculated from UBC 97 was used [10].

A displacement controlled cyclic pushover analysis was run in the perform 3D to generate hysteresis loop. Gravity load case and fifty static pushover load cases were defined in analysis phase. Each static pushover load case has a triangular distribution of loads which comes from UBC 97 or Building Code of Pakistan BCP 2007.

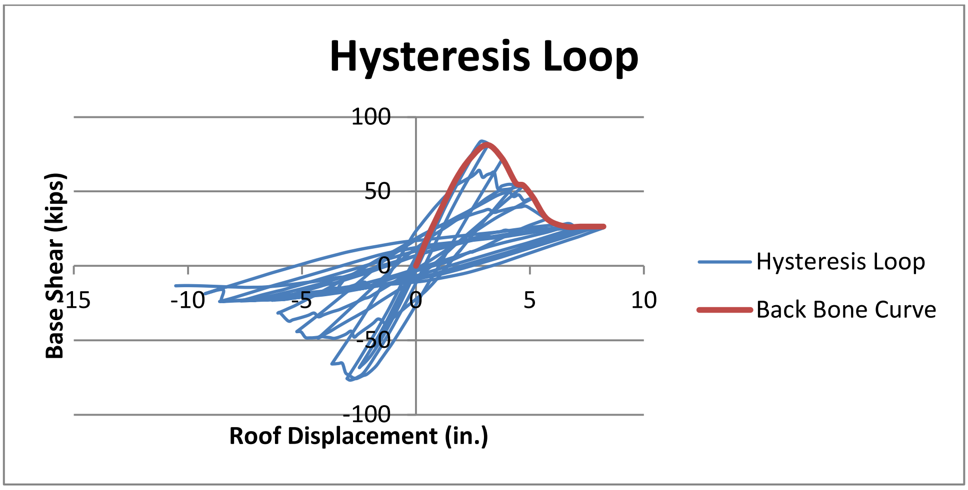

Figure 3: Hysteresis Loop and Back Bone Curve

5. Seismic Vulnerability Assessment

Capacity spectrum method presented in FEMA 440 [11] was used to generate seismic vulnerability curve which shows damage index for a particular hazard level.

Back bone curve of a structure was extracted from the hysteresis loop of a structure and was transformed to capacity curve for the development of seismic vulnerability curve.

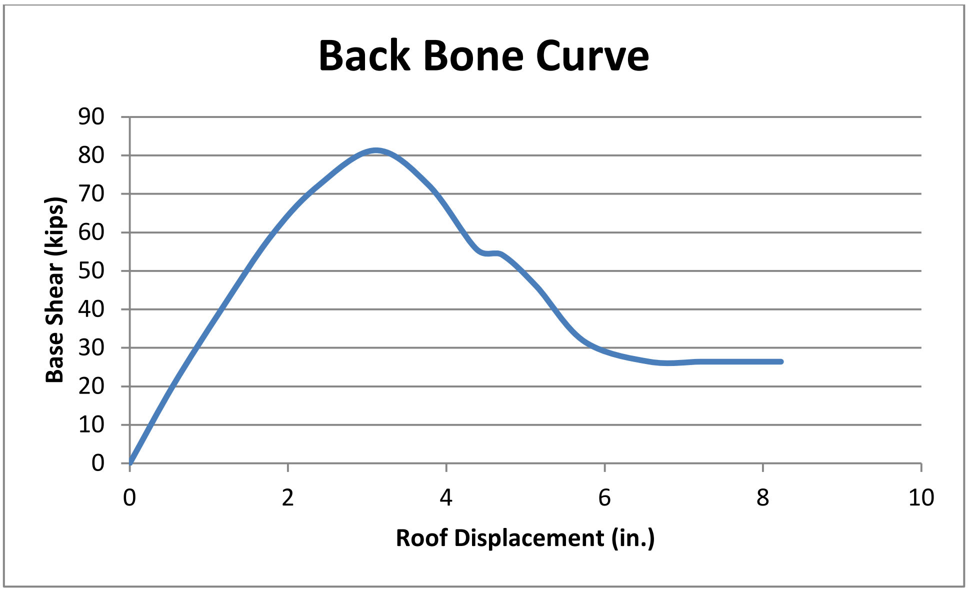

Figure 4: Back Bone Curve

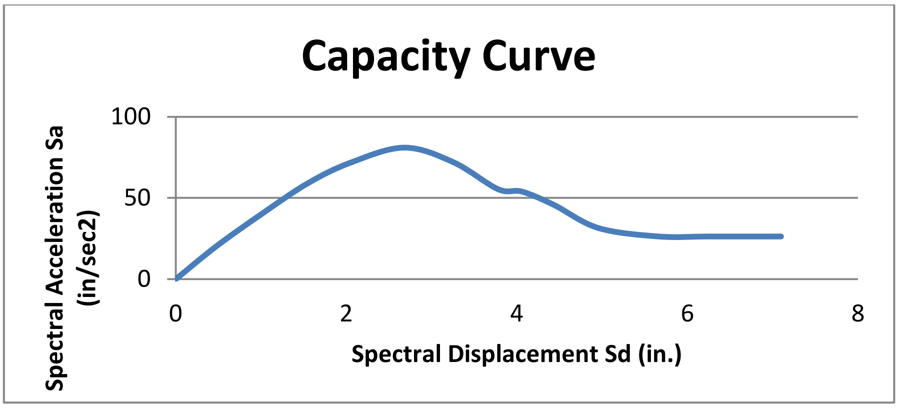

Figure 5: Capacity Curve

Response spectrum which uses the maximum response (acceleration, velocity, displacement) with a particular damping effect and time period, is a function of various parameters like earthquake zone, soil type, PGA's and the distance of site from the nearest fault line. Euro code (EC8) [12] response spectrum was used for the determining the response of a structure

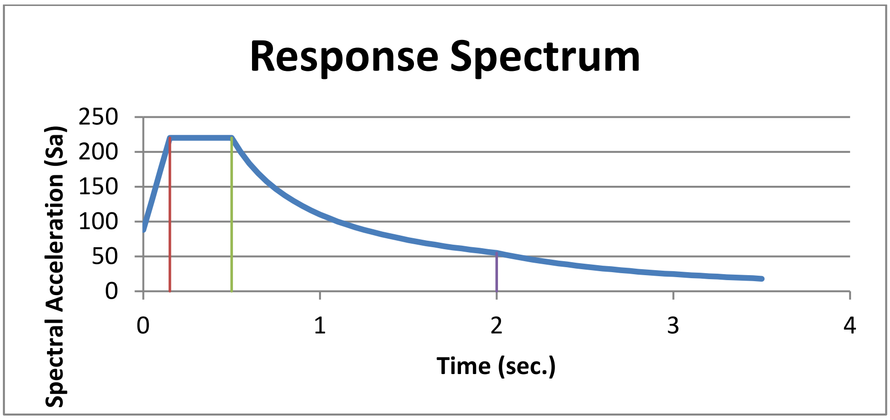

Figure 6: Response Spectrum

In order to generate performance points the elastic response spectrum was converted from (SA-T) to (SA-SD).

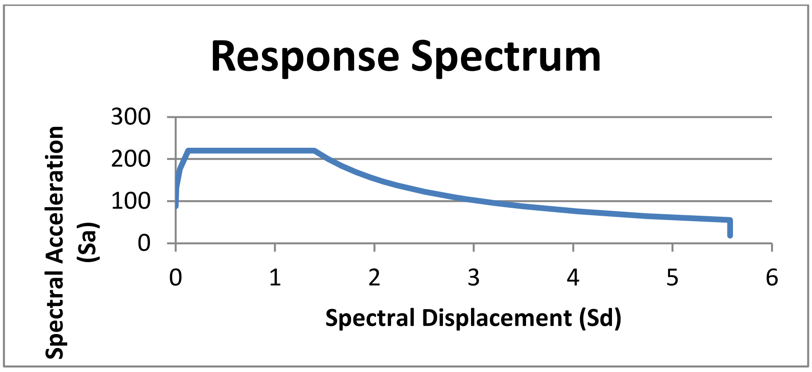

Figure 7: Response Spectrum in (Sa-Sd) format

Spectral acceleration (Sa) was modified by a factor 'M' and MADRS was generated using FEMA 440 [11] vulnerability assessment approach.

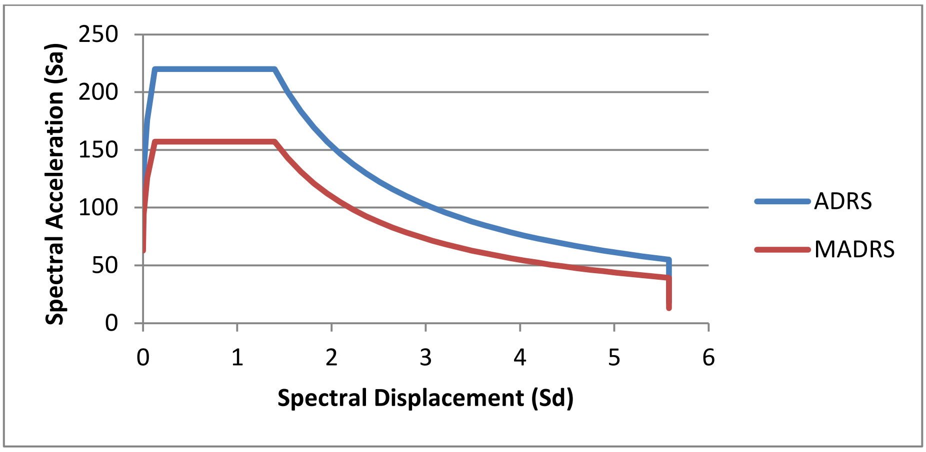

Figure 8: The MADRS

The capacity curve was idealized according ATC 40 [11] .

Therefore bilinear idealized capacity curve was generated using equal energy principle [13].

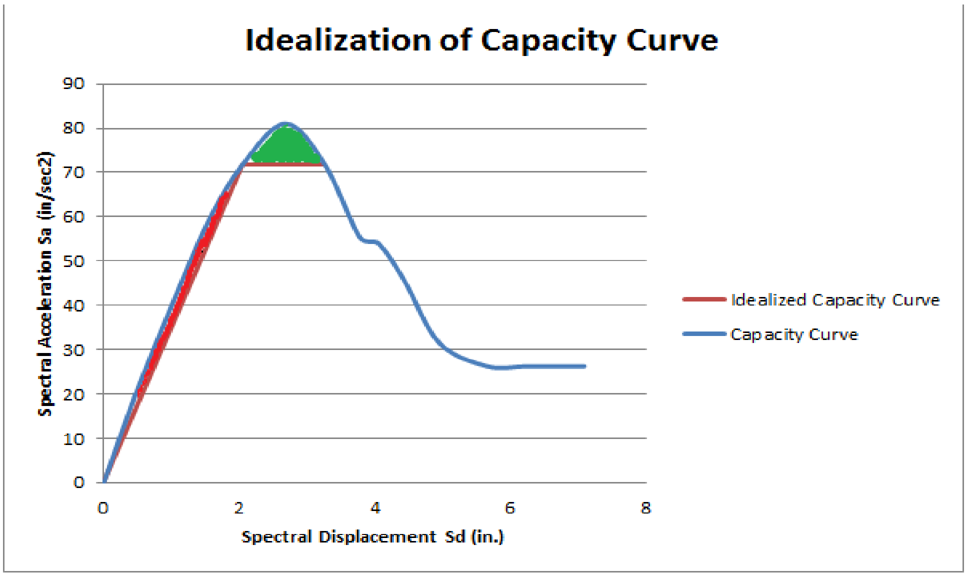

Figure 9: Idealization of Capacity Curve

The above figure shows the Elastic Spectrum approximation for the assumed performance point. The blue curve represents the capacity curve and red curve is the bi-linear elastic perfectly plastic curve. Red area is the positive area while the green area is the negative area. Both are so balanced that the net would be zero.

As a result of idealization of curve, for every assumed performance point a corresponding yield point is obtained on the curve and hence ductility is calculated by dividing the spectral displacement of performance point to the spectral displacement of the yield point

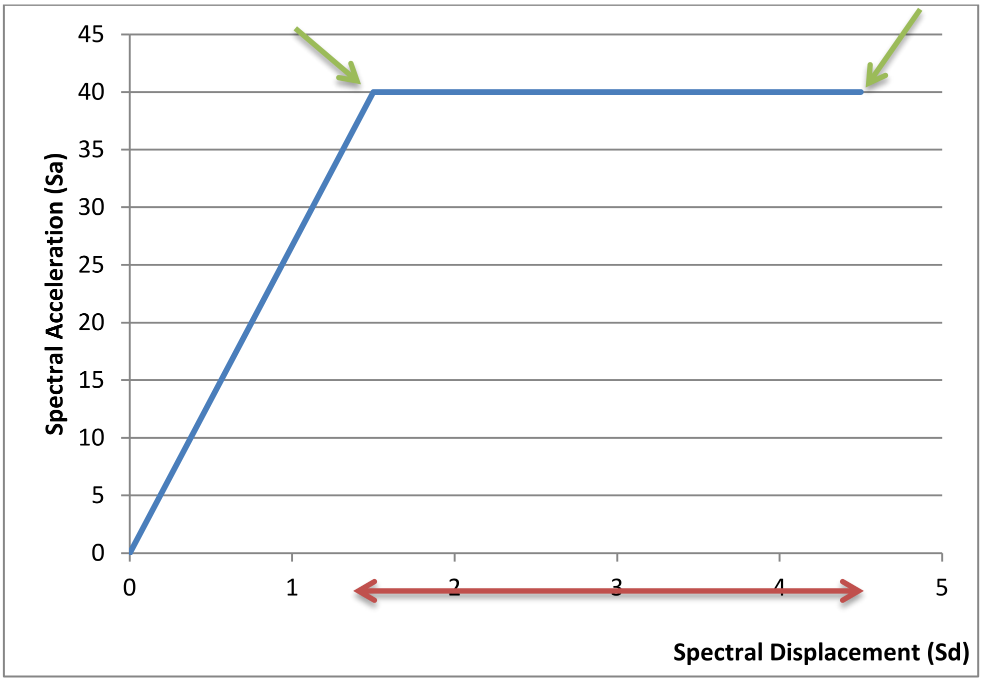

Figure 10: Ductility of Assumed Performance Point

For every assumed performance point, there would be a damage index against the hazard level.

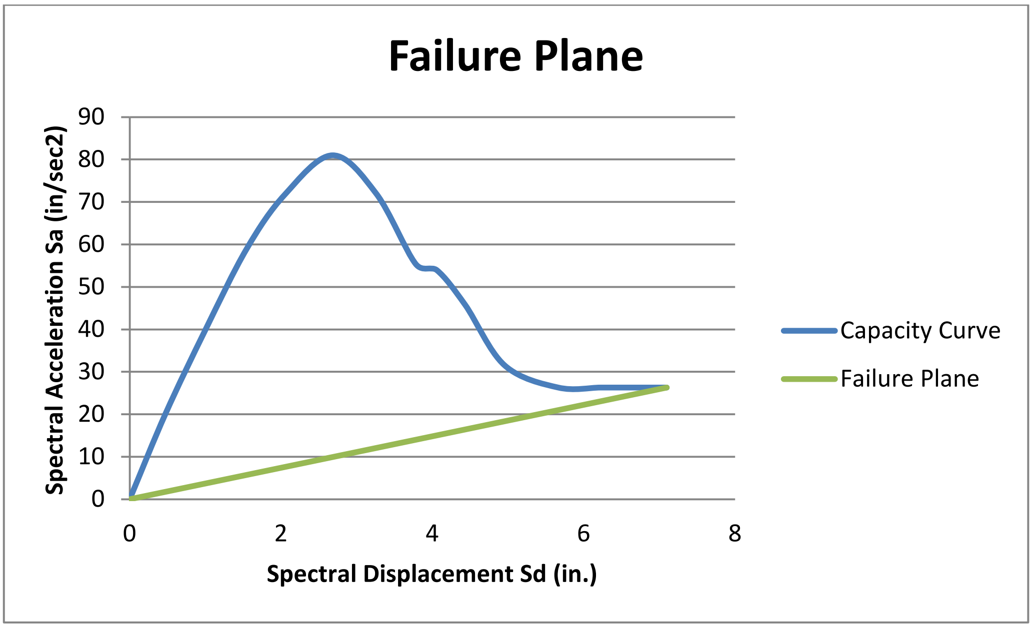

Figure 11: The Failure Plane

Varying the PGA's by applying the reverse Kyriakides approach, performance point was calculated by intersecting the point of the idealized capacity spectrum to the MADRS.

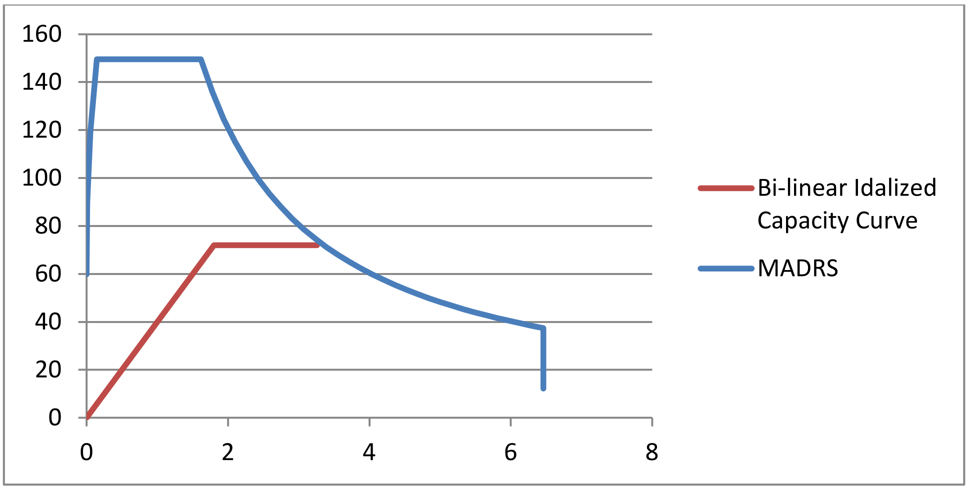

Figure 12: Evaluating the Performance Point

The procedure was repeated by varying the performance point and PGA's and hence a vulnerability curve was generated.

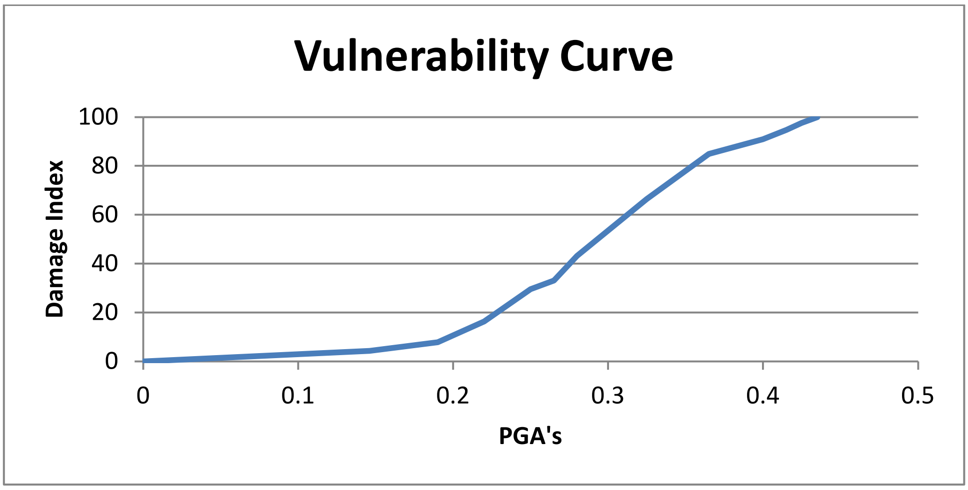

Figure 13: The Vulnerability Curve

In order to generate vulnerability curve for a retrofitted frame using CFRP's, same analytical approach was used.

The material properties of both the concrete and steel got modified when these were wrapped by carbon fibers reinforced polymers known as CFRP's. The stress to strain relationship, the bar pull out model, the compressive strength of concrete, the tensile strength of steel all got modified.

Mr. Hammad Salahuddin [14], M.Sc Scholar did a very valuable research in the lab over the retrofitting using CFRP's. He studied the behavior of concrete under various conditions using single and double wrap of the fibers and compare the result with ordinary concrete.

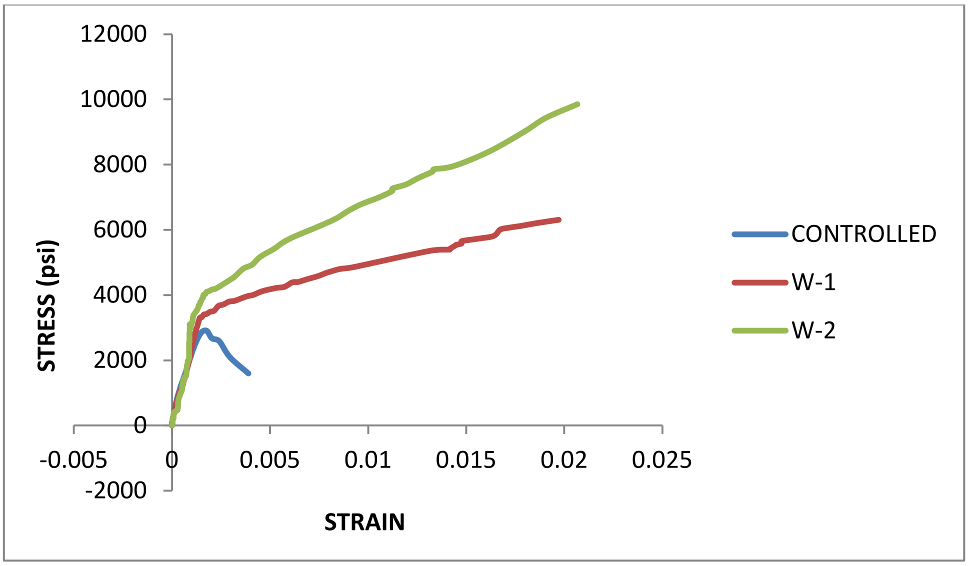

Figure 14: Average Compressive Strength for Confined Concrete

The blue curve shows the specimen under controlled condition (normal specimen), the red curve shows the specimen with a single layer of CFRP's whereas the green curve shows the specimen with a double layer of CFRP's. By wrapping the concrete column or beam with a certain type of material enhances its strength and improves the behavior of structure.

Similarly, the CEB-FIP [15] Model was also modified. In this research work bar pull out model was used in the joints, as joints are the most critical regions in lateral loadings. Slippage of steel bars may occur at the joints.

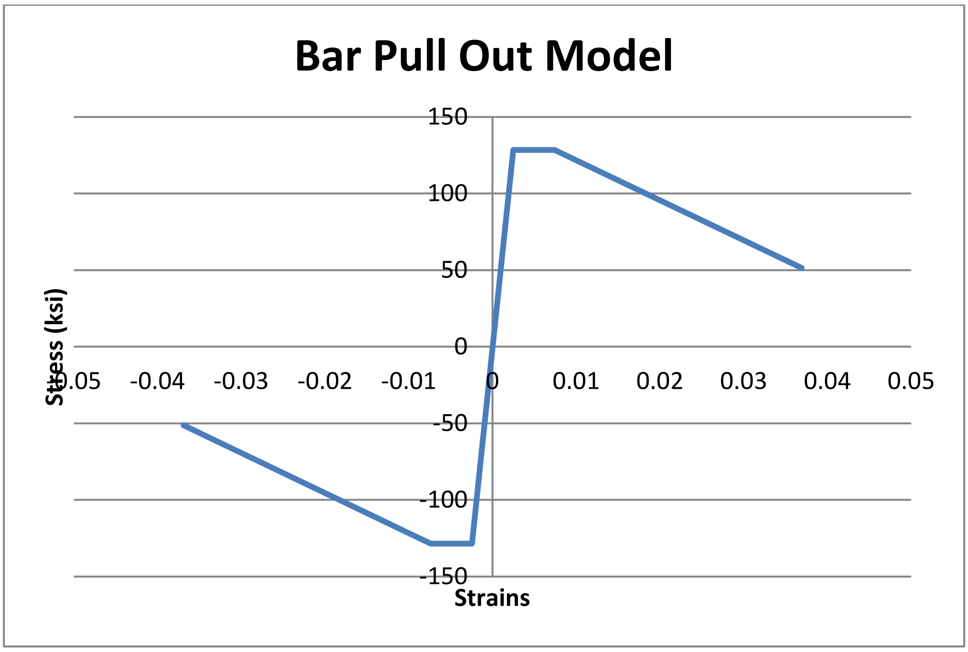

Figure 15: Bar Pull out Model

The hysteresis loop of a retrofitted reinforced concrete frame structure was generated by using PERFORM 3D.

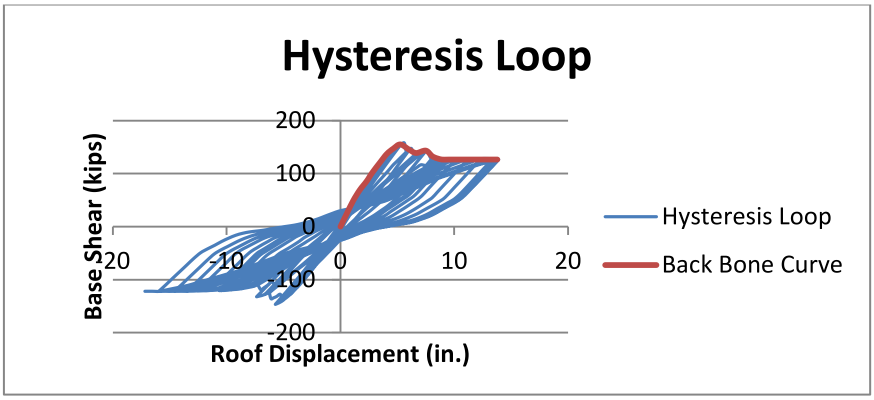

Figure 16: Hysteresis Loop

Similarly back bone curve of retrofitted frame was converted into the capacity curve using capacity spectrum method.

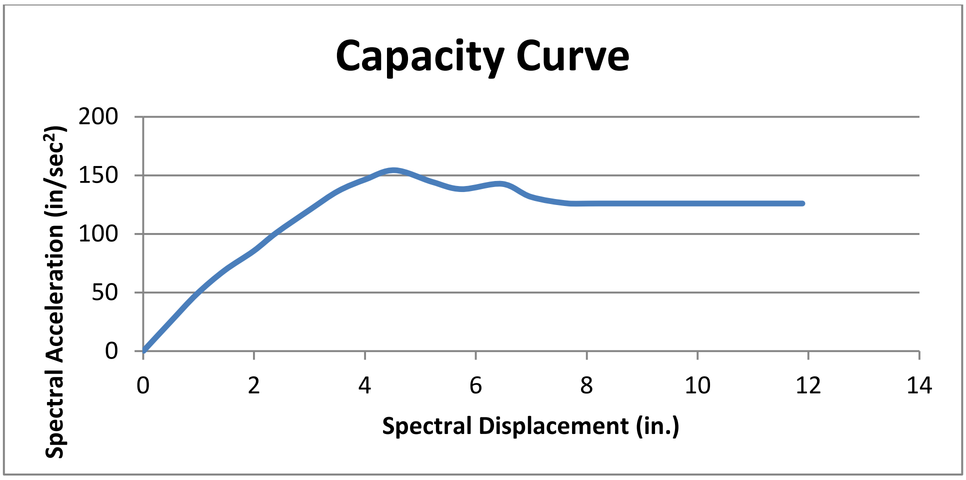

Figure 17: Conversion of Backbone Curve into Capacity Curve

Similar procedure was followed to generate the response spectrum.

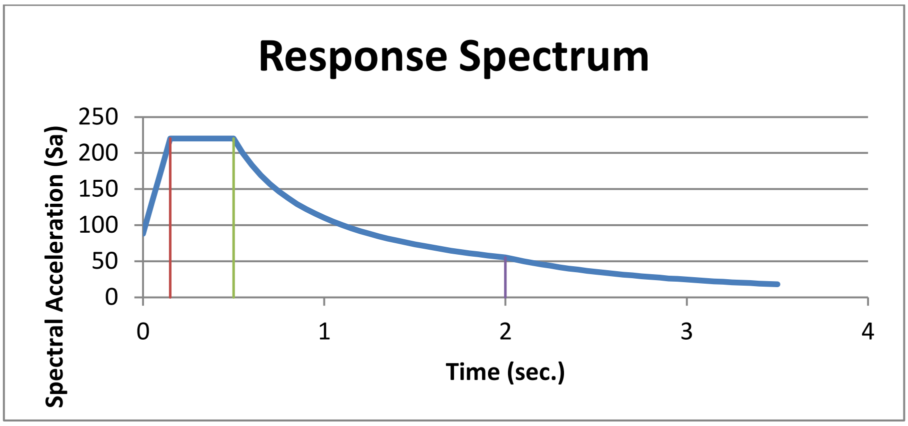

Figure 18: Response Spectrum

Similar transformation was done to generate elastic response spectrum.

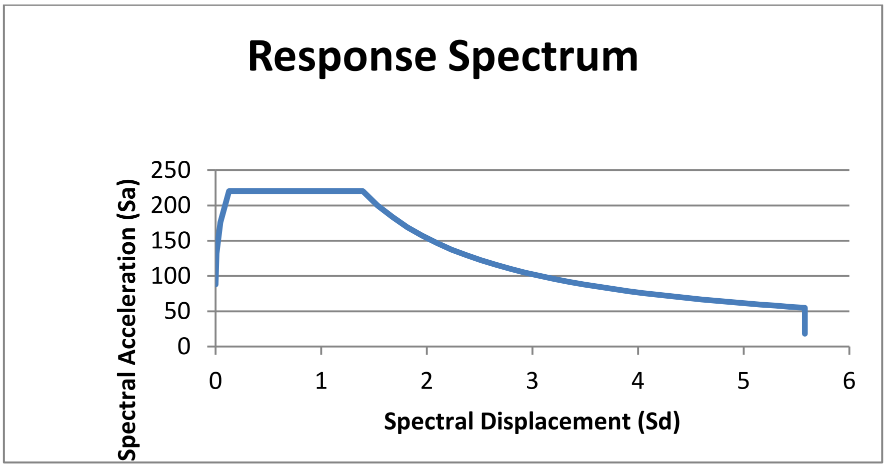

Figure 19: Response Spectrum (Sa-Sd)

The MADRS was formulated from ADRS as per FEMA 440 [11].

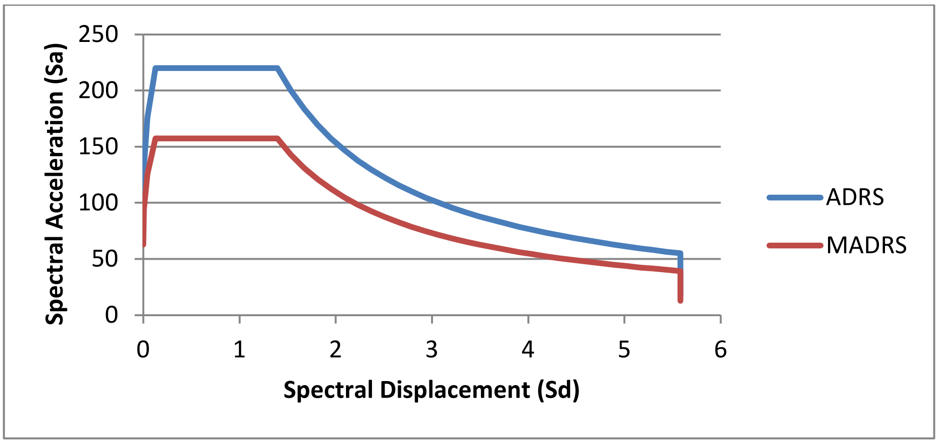

Figure 20: MADRS

The capacity curve of a retrofitted frame was idealized using equal energy rule.

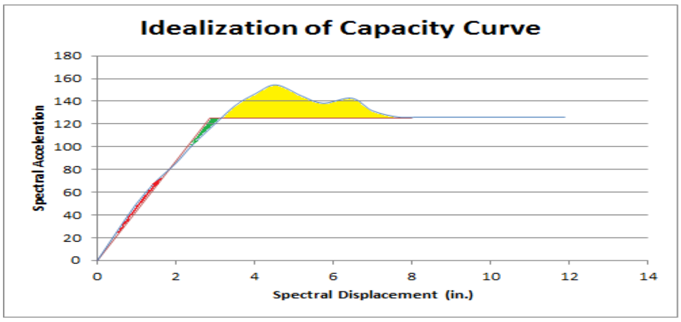

Figure 21: Idealization of Capacity Curve

The above figure shows the Elastic Spectrum approximation for the assumed performance point. The blue curve represents the capacity curve and red curve is the bi-linear elastic perfectly plastic curve. Red area is the positive area while the green area is the negative area whereas the yellow area is neglected area representing the dissipating in energy.

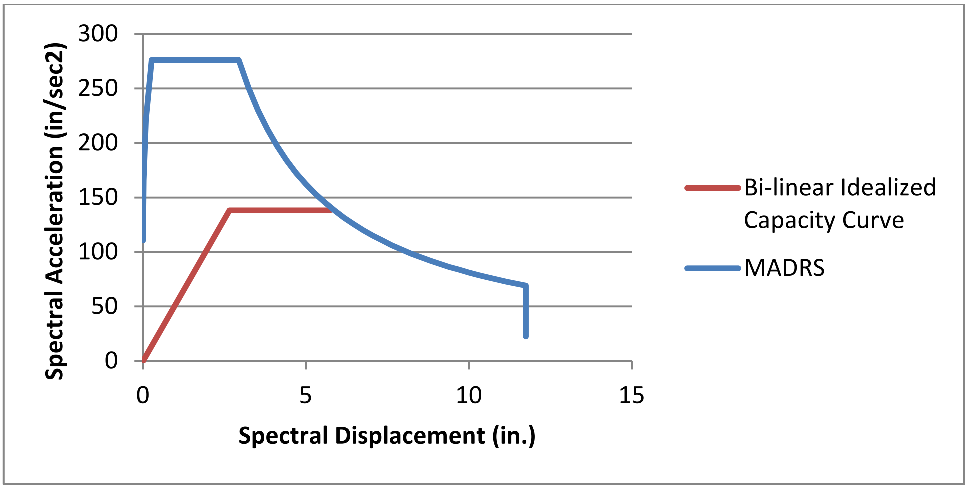

Figure 22: Evaluating Performance Point

The procedure was repeated by varying the performance point and PGA's and hence a vulnerability curve of a retrofitted reinforced concrete frame structure was plotted.

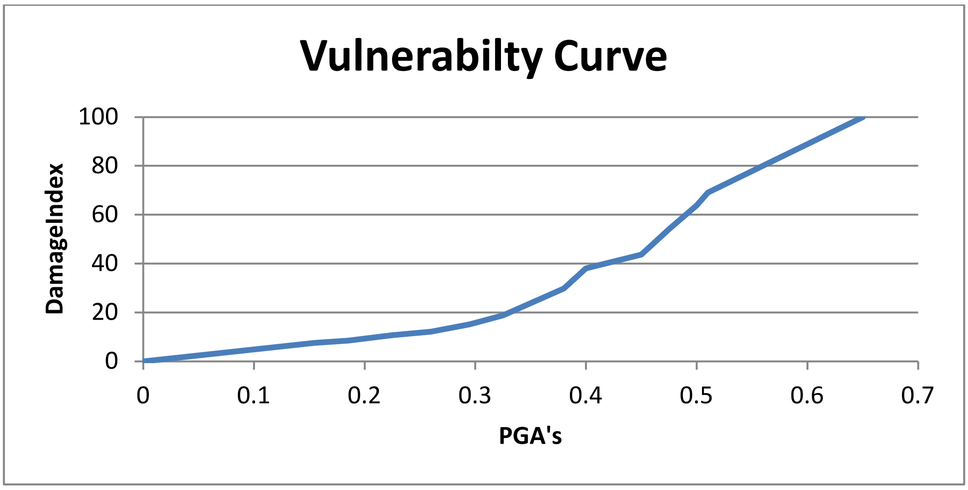

Figure 23: Vulnerability Curve for Confined Model

Comparison between Retrofitted and Un-Retrofitted Structure:

Both the curves were studied thoroughly and the behavior of the structure was studied effectively. It was concluded that by confining the concrete near the joints by using double wrap of CFRP, can improve the stability and behavior of structure effectively.

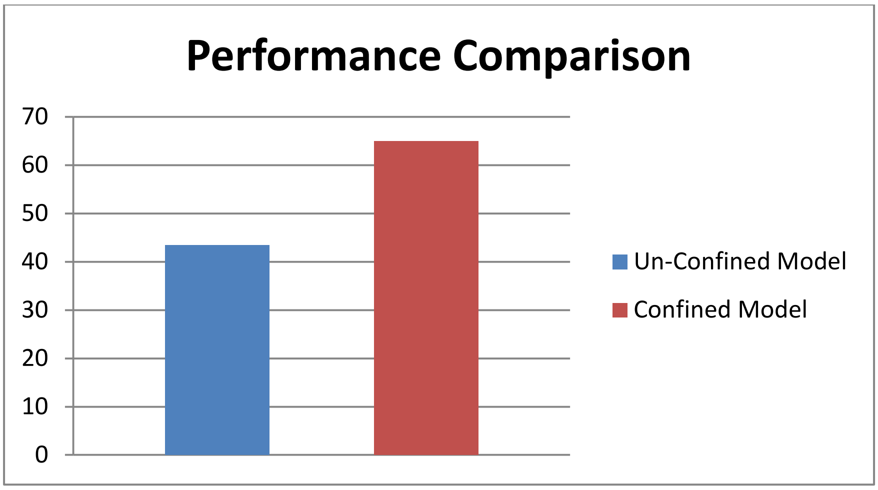

Figure 24: Performance Comparison of the Two Structures

6. Conclusions

Structural collapse was observed at approximately 0.65g after retrofitting beam to column joints with CFRP's instead of 0.43g for a typical reinforced concrete Structure constructed in Pakistan. It is therefore concluded that by applying CFRP's at joints, the performance of the structure may increase up to 150% i.e Retrofitted buildings undergo 100% damage at greater PGA nearly 0.6g as compare to the buildings not retrofitted which will fail nearly at 0.4g-0.5g. At low Hazard level up to 0.2g there is no significance of retrofitting.

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