“Effects of surface preparation on the performance of Reinforced Concrete Columns retrofitted using RC jacketing.”

FINAL YEAR PROJECT UG-2017

By

Faizan Ahmad Nadeem (Group Leader)	**215873**
Muhammad Nashit Bhatti	**212276**
Muhammad Husnain Ali	**208872**
Badar Ul Hunain Khan	**208996**

NUST Institute of Civil Engineering (NICE)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST), Islamabad, Pakistan

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This is to certify that the

Final Year Project Titled

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Muhammad Nashit Bhatti	**212276**
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Has been accepted as the requirement

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Engineer Arslan Mushtaq

Lecturer-Department of Structural Engineering,

NUST Institute of Civil Engineering (NICE)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology, Islamabad, Pakistan

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In this global crisis of COVID19-Pandemic, despite the psychological, social, and economic pressure and our detachment from a regular academic and practical environment, we not only completed our final year project but also got very useful and reliable data as a result of our research, which is surely the blessing of Allah Almighty.

We admire the efforts, guidance, support, and constant motivation given by our Supervisor, Engineer Arslan Mushtaq, Lecturer at Structural Engineering Department of NUST Institute of Civil Engineering (NICE), Pakistan, to make our Project as much effective as possible for the advancement of retrofitting techniques and structural engineering. This Project could also have not been possible without the cooperation and supportive attitude of the Laboratory Engineers and Technicians of the Structure Lab at NICE.

Table of Contents

Effects of surface preparation on the performance of Reinforced Concrete Columns retrofitted using RC Jacketing

Abstract

Retrofitting techniques become a very important structural strengthening method when we encounter variations in the design loading type due to client requirements, in case of poor construction practices due to the absence of skilled engineer's supervision, when the owner wants vertical expansion above old construction or structural strengthening against seismic forces. In the developing world, the most widely used retrofitting technique is Reinforced concrete Jacketing and columns are the structural component that is mostly retrofitted against gravity loads. In this study, Physical modeling and testing were performed to enhance the axial strength and performance of the prevailing conventional technique of RC Jacketing. A new approach for RC Jacketing of square columns was introduced. For better performance, we tested the RC retrofitted technique with the surface being prepared (Removal of cover) of the base specimen and compared the axial strength of the specialized RC retrofitted column with the conventional RC Jacketed column and got 12% more axial strength for our surface prepared Retrofitted column.

Background and Introduction

Retrofitting-A Gateway to the Sustainable future of modern Infrastructure

It is the famous saying of Chares Darwin that, "**It is not the strongest that survive, nor the most intelligent, but the ones most responsive to change.**" and

Retrofitting is everything about the adaptation to the variations in human development. Retrofitting is the Re-strengthening of our existing structures or different structural components. So, in the uncertainty of the forces acting on the structure, different retrofitting techniques help us:

- To reduce or eliminate the vulnerability of any kind of damage from, high winds, earthquakes, or other hazards.
- To Enhance resistivity for a governing action.
- To improve the performance of the structure.
- To Enhance the life span of a building.
- To make buildings more energy efficient.
- And most importantly for the transition of traditional infrastructure to a sustainable one.

And that is a more convincing motivation that we must have to make our existing an infrastructure capable enough to deal with the evolution of human development and constant variations in humanity's infrastructural demands because these demands change the scope of the built environment. So, improvement of construction methodologies and materials due to academic efforts and with that the Improved knowledge about a hazard, its impacts, and causes triggers the need for retrofitting. Because engineers can never afford to degrade the already collapsing environmental balance of our home Planet due to the growing technological revolutions and can play their role to save us from global catastrophes by the Conservation of natural resources and by reducing the overall carbon footprint of the construction industry by using retrofitting instead of constructing new infrastructure.

Introduction

In our Final Year Project, we have used a research-oriented approach to investigate the *effects of surface preparation on the performance of reinforced concrete Columns retrofitted using RC jacketing.* The universal significance of retrofitting in the engineering world compelled us to utilize the opportunity of our final year's project to do some work on the topic.

Problem Statement

The problems we are addressing through our research are:

- Variations in design loading type due to client requirements.
- Poor construction practices due to the absence of skilled engineer's supervision.
- Owner wants vertical expansion above old construction.
- Old construction (without seismic provisions) and the owner wants structural strengthening by introducing seismic retrofitting strategies.

Objectives

- To study the effects of surface preparation on axial strength of Reinforced Concrete Columns retrofitted using RC jacketing.
- To draw the comparison of Surface Prepared RC Jacketing With normal RC Jacketing technique (Conventional vs. specialized).

Literature Review

In our research, we have worked for the advancement of traditional retrofitting techniques which are used in developing countries, and for repairing and strengthening damaged or defective RC columns the most effective and common technique is Reinforced Concrete Jacketing (Ahed Habib1, 2020). In earthquake-prone countries, this technique is a practical solution to improve and recover the load-bearing capacity and strength of reinforced concrete columns. The basic principle of this technique involves the enveloping of existing structural elements in a layer of concrete having transverse and longitudinal steel bars (Ahed Habib1, 2020). In the case of square or rectangular columns, this technique can be applied as one-sided, two-sided, three-sided, or four-sided (Ahed Habib1, 2020). RC Jacketing is usually done by tying the longitudinal bars to the adjacent slabs or footings so that the shear and flexural behavior and the confinement of column can be improved, when confinement and shear capacity is the only concern in the designing phase, the longitudinal bars are stopped at both ends of the columns. To improve the bonding between existing and new concrete, interface roughness improvement is done which is increasing the roughness of existing concrete by techniques like sandblasting (Ahed Habib1, 2020).

One of the most effective techniques for retrofitting square columns is by wrapping the column by using Fiber Reinforced Polymer (FRP) however for rectangular columns several complexities are associated (Osama Youssf, 2017). Debonding of layers usually occurs which can be improved by using mechanically fastened FRP that uses steel anchors to connect FRP to the concrete substrate (N. Mahdavi, 2018). The shape of the column also affects the performance of the FRP.

FRP is a very effective technique for the retrofitting of circular columns but in rectangular columns, the sharp corners of the column affect FRP performance due to the irregular confinement pressure (Osama Youssf, 2017). Cross-section modifiers (to convert a sharp corner into circular ones) can be used to improve the performance of FRP. Crumb rubber concrete (CRC) having different rubber quantities in place of sand can be used to make modifiers because it has high energy dissipation, durability, impact resistance, and rigidity but it has low compressive and tensile strength. The modulus of elasticity is also lower than conventional concrete, but it is only useful when an existing square column is retrofitted using the circularization approach (Osama Youssf, 2017). Two-part epoxy resin is also used to attach the concrete shape modifiers to the square column that is retrofitted, and during the FRP confinement process. The circularized approach shows the highest modulus of toughness among other columns (Osama Youssf, 2017).

In the case of columns replacement of damaged member is too risky and it seems better to strengthen the existing member itself (Saim Raza, 2019). And to strengthen the damaged portion of a column retrofitting is the most useful technique worldwide which can be global or local depends on the extent of damage or scope of its application (G E Thermou, 2005). And jacketing is the most preferred method to do so. In the case of traditional jacketing by reinforced concrete is most cost-effective in comparison to Confinement with Ferrocement. I.e., Wire meshes Mortar Jacketing or Wrapping the sheets of fiber-reinforced polymers such as carbon fiber and glass fiber reinforced polymers. The performance of the Reinforced Concrete jacketing has a very great influence on the bond formed between the original column and the outer jacket and we can achieve this by the increase in the roughness of the linked surface with a hammer or chisel and then by using an agent such as epoxy or using shear connectors or dowel rebars. (Tabish Rasool Sheikh1, 2017) Contrary to all other techniques, the existing research in the field have shown that the traditional Reinforced Concrete jacketing can bring a uniform and gradual distribution of increased strength and stiffness in the columns, and sometimes, the RC Jacketing can allow the member or structural component to accommodate large seismic loads. Moreover, the durability and performance of the original column can also be improved (Tabish Rasool Sheikh1, 2017). With the increasing reliability and trust of structural engineers on retrofitting or rehabilitation, the conventional RC jacketing will continue to be improved and investigated as an economic and dependent retrofitting technique, in the future too. So, we have investigated the impact of cover removal (reinforcement of original column exposed) on the axial strength of the reinforced concrete jacketed column to further advance the conventional RC Jacketing Technique.

Methodology

We started our research with physical modeling of columns of standard dimension followed by retrofitting of the cured specimens. After the casting and curing were completed, we did the reaction frame testing to get the compressive strength of each specimen, which was followed by the extraction of load-deformation data, modeling of our 3 types of columns, and pushover analysis in ETABS. In the end, the analysis of the results was done for each type.

Physical Modeling

We did the casting of our columns in two phases; the first phase was the initial casting of specimens and 2nd phase was two types of retrofitting techniques use on the standard specimens previously cast.

Phase-1:

For initial casting, the cross-section of the mold was 7.5 by 7.5 inches, Length was 2.5 feet, as shown in figure 1.3, 4 #3 steel bars were used as longitudinal reinforcement, and confinement was done using #2 steel bars with 3” center to center distance. we used normal-weight concrete with cement to sand to aggregate ratio 1:2:4.

Two types of specimens were casted in phase 1. One type of our specimens was base specimen, and the other type was casted to be retrofitted later in the phase-2 of our physical modeling. Figure 1 shows one of our base specimens and the figure 2, is of type-2 specimen having holes in it using PVC pipes so that we can add transverse reinforcement, for retrofitting in phase 2.

Figure 1 Base Specimen

Figure 2 Specimen to be Retrofitted

Figure 1mold used for initial casting.

Phase-2:

For retrofitting of standard specimens, in phase-2 of physical modeling, we made a mold of cross-section 11 by 11 inches, with the length or height of 2.5 feet as shown in figure-4. To retrofit, we used longitudinal reinforcement having 4 steel bars of #3, and for transverse reinforcement, 8 steel bars of #3 were used while confinement was made of #2 bars with 3” center to center distance.

Two types of specimens were casted in phase two, one of them was retrofitting the specimen without surface preparation and the 2nd one was retrofitting the specimen with surface preparation. Figure 5 is showing the prepared surface of the standard specimen in which the cover was removed to expose the steel bars to get better slippage resistance and thus better axial strength, figure-6 and figure-7 are showing the additional reinforcement around the specimen with surface prepared and without surface prepared, respectively.

Figure 4 Mold used for Retrofitting (Phase-2 of Casting)

Figure 5 Prepared Surface (Removed Cover)

Figure 6 Cage around surface prepared specimen ***Figure 7 Cage around the specimen with surface not prepared.***

Testing

We casted three types of specimens and for testing each specimen we used a reaction frame testing machine. The Maximum Capacity of the reaction frame testing machine was 30 Ton. We observed the load-deformation effect occurring on each specimen by using a 50mm LVDT sensor. LVDT or Linear Variable Differential Transformer is an electromechanical sensor that is used to convert mechanical motions and vibrations into electric signals.

Results and Analysis

In figure-8 there is a base specimen in the reaction frame testing machine, and we can see that the LVDT is applied to the column in the direction perpendicular to the neutral axis. The loading was applied to the column using a frame testing machine and diagonal cracks were observed in our column in a shear plane and crushing was observed as we can see in figure 9.

Figure 8 Base Specimen Testing

Figure 9 Base Specimen Failure

In figure-10 there is a retrofitted column without the surface preparation. The LVDT is applied in the same manner as the base column for efficient results. The loading was also applied in the same manner and significant cracking was observed as we can observe in figure-11 but as the capacity of the testing machine was limited to 66.14 kips so we couldn't observe full failure.

Figure-10 Retrofitted Specimen without surface preparation Testing

Figure-11 Retrofitted Specimen without surface preparation Cracking.

In figure-12 is a retrofitted column with the surface preparation. The surface preparation is the removal of a cover of the standard specimen to expose the reinforcement for better slippage resistance and thus better axial strength of the retrofitted column. The column was placed in the same manner with LVDT, and loading was applied which resulted in microcracks in the column as shown in figure-13. Due to the limited capacity of the machine, we could not observe the full failure of this column as well.

Figure 13 Retrofitted Specimen with surface preparation Cracking.

Figure 12 Retrofitted Specimen with surface preparation Testing

Initial Observations-Frame Test:

Table-1 presents the load sustained by each column. Failure of base column was observed at 61.03 kips. In case of retrofitted column without surface preparation when the maximum capacity of our testing machine reached significant cracking was observed but in case of retrofitted column with surface preparation only a micro crack appeared. It can be clearly seen in the Table-1, that at the load of about 61 kips the base specimen experienced a complete crushing failure, while the specimens who were retrofitted experienced a significant cracking and a micro-crack for surface not prepared and surface being prepared respectively. For the column whose surface was not prepared, cracking started to appear at 57.32 kips while in case of the surface prepared retrofitted column, micro crack started to appear at 63.93 Kips. Thus, Cracking of surface prepared column started at 6.61kips more load than the column whose surface was not prepared. This clearly concludes that the surface preparation can make a Reinforced concrete retrofitted column capable enough to bear 12% more axial load than the conventionally retrofitted column before cracking.

Table 1 Initial Observation-Testing

Column Type	Compression Load (KG)	Observation Description
Base Specimen	27683 (61.03 kips)	Complete crushing of the column.
Retrofitted Without Surface Preparation	30000 (66.14 kips)	Significant Cracking. (Cracking Started at 57.32 Kips)
Retrofitted with Surface Preparation	30000 (66.14 kips)	A microcrack appeared. (Cracking Started at 63.93 Kips)

PM-Curves of Specimens

Figure-14 shows our Load moment diagrams and here we can see our 7.5 "column's maximum load-carrying capacity is 89 kips in the absence of any moment and maximum moment carrying capacity is about 6 kips-ft in pure flexural state. But on the other hand, 11" retrofitted column's cross-section has a maximum load-carrying capacity of 179 kips in the absence of any moment and maximum moment carrying capacity is about 18.24 kips-ft in the pure flexural state.

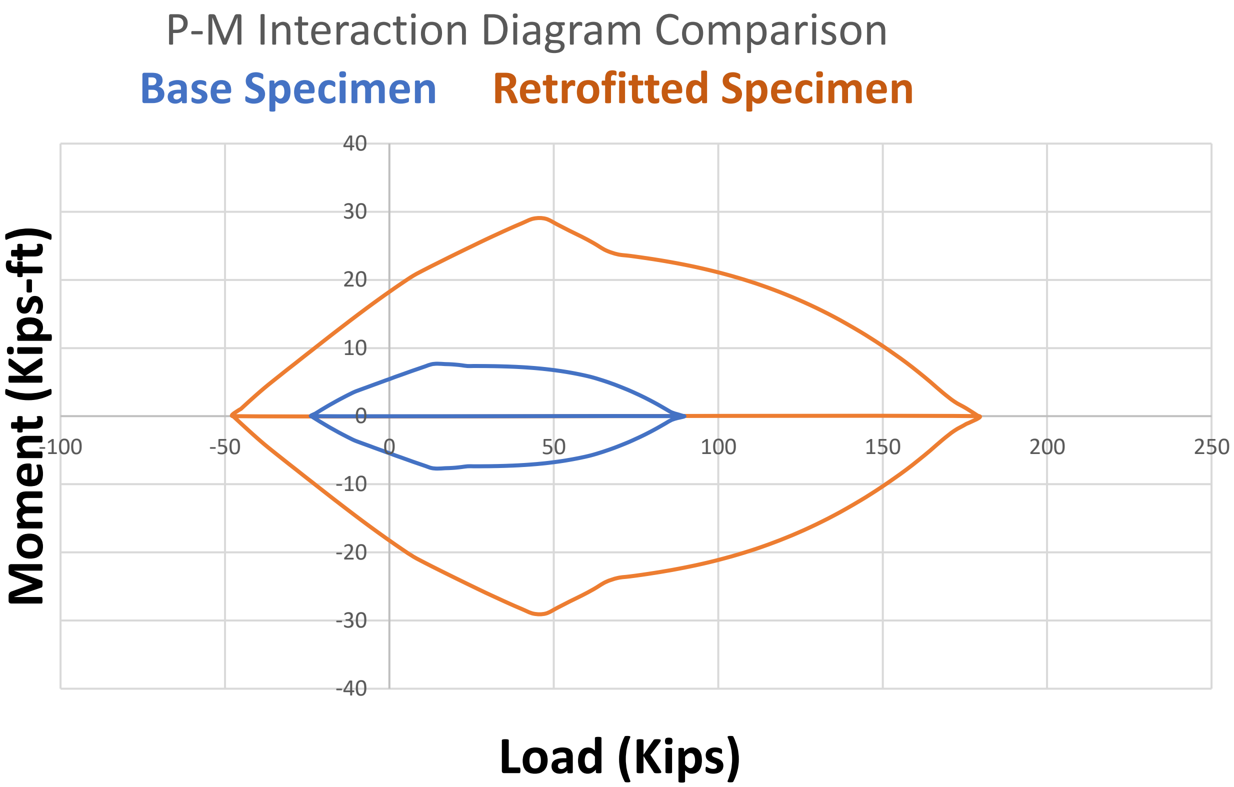
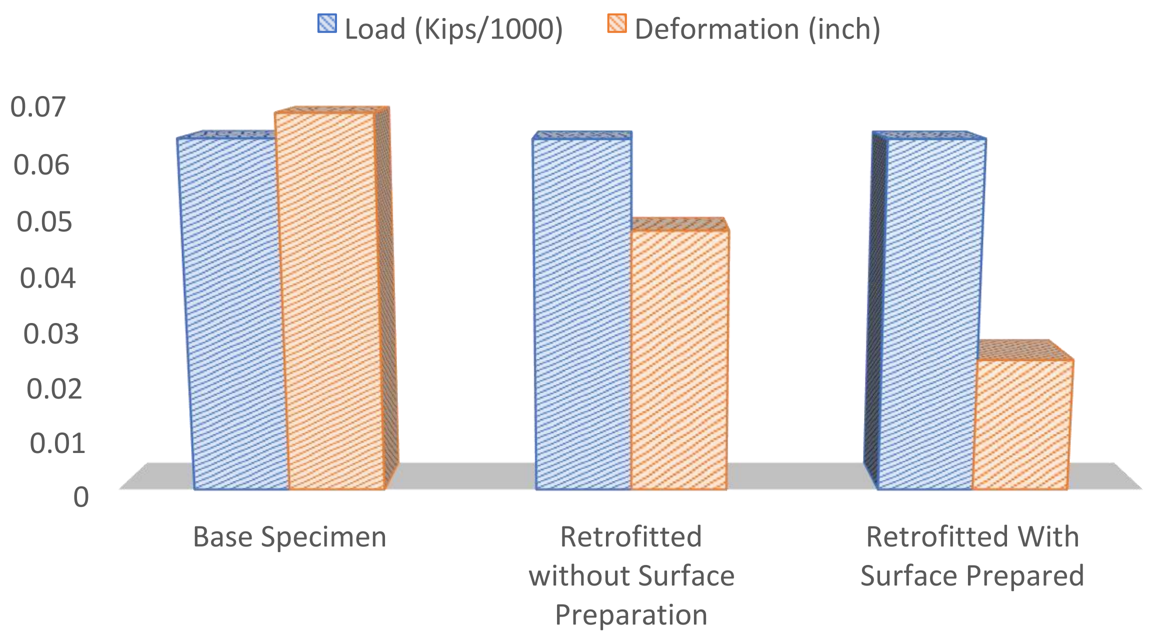


Figure 14. PM Curve Standard cross-section VS Retrofitting's Cross-section

Load Deformation (Comparison)

Table-2 is the comparison of our results of load-deformation data we obtained from the compression test of the frame testing machine. Here you can see that at the load of 61.03 kips, which was the ultimate load-carrying capacity of our base specimen, our base specimen's observed deformation was about 0.068 inch and at the same load our retrofitted column whose surface was not prepared gave deformation of 0.047 inches and our main Retrofitted column with the surface being prepared, we got deformation of 0.024 at the same load. The trend of decreased deformation under the same value of load concludes that our surface prepared retrofitted column's performance was much better than the column without surface treatment with a difference of 0.023 inches. That means for the same load it deformed 50% less as compared to the normally jacketed column.

Table 2 Load/Deformation Comparison

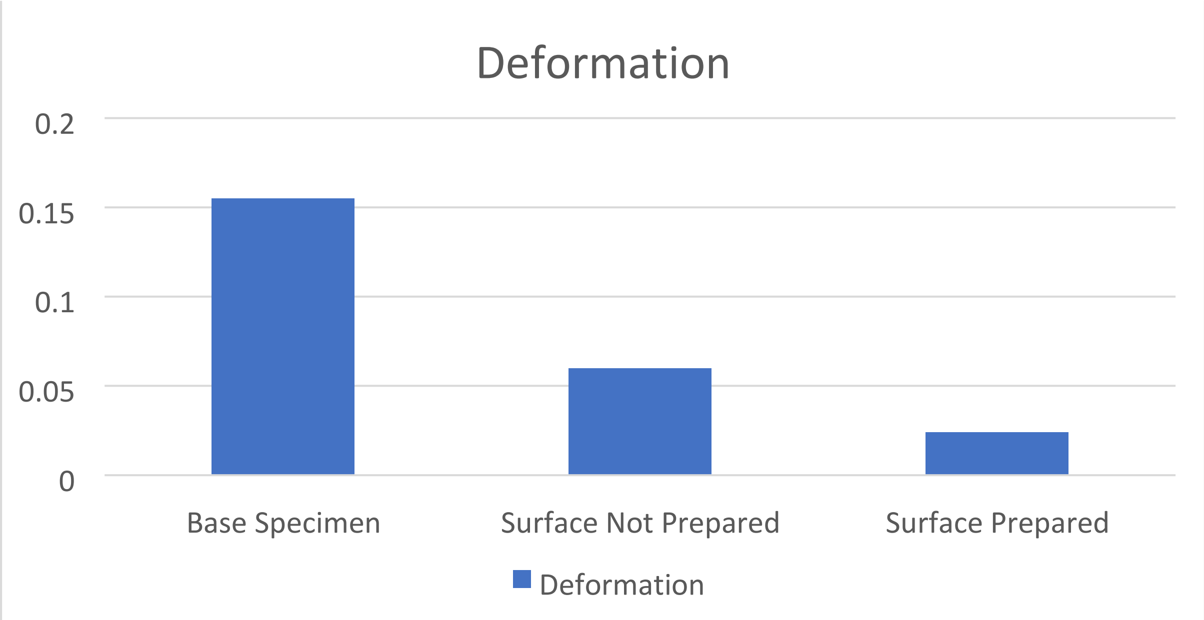


	Base Specimen	Retrofitted without Surface Preparation	Retrofitted With Surface Prepared
Load (Kips/1000)	0.0631	0.06301	0.06301
Deformation (inch)	0.067512438	0.047	0.023845635

Maximum observed Deflection (comparison)

In Table-3 below, we have displayed the graph of total deformation caused in our columns during testing. You can see that our base specimen's deformation value was 0.15 inches and it's 0.06 and 0.025 inches for retrofitted columns with the surface not prepared and the surface being prepared respectively. The greater value of deformation for the base specimen is because it failed before the machines maximum capacity was reached, and the retrofitted columns didn't fail till the maximum capacity of the machine.

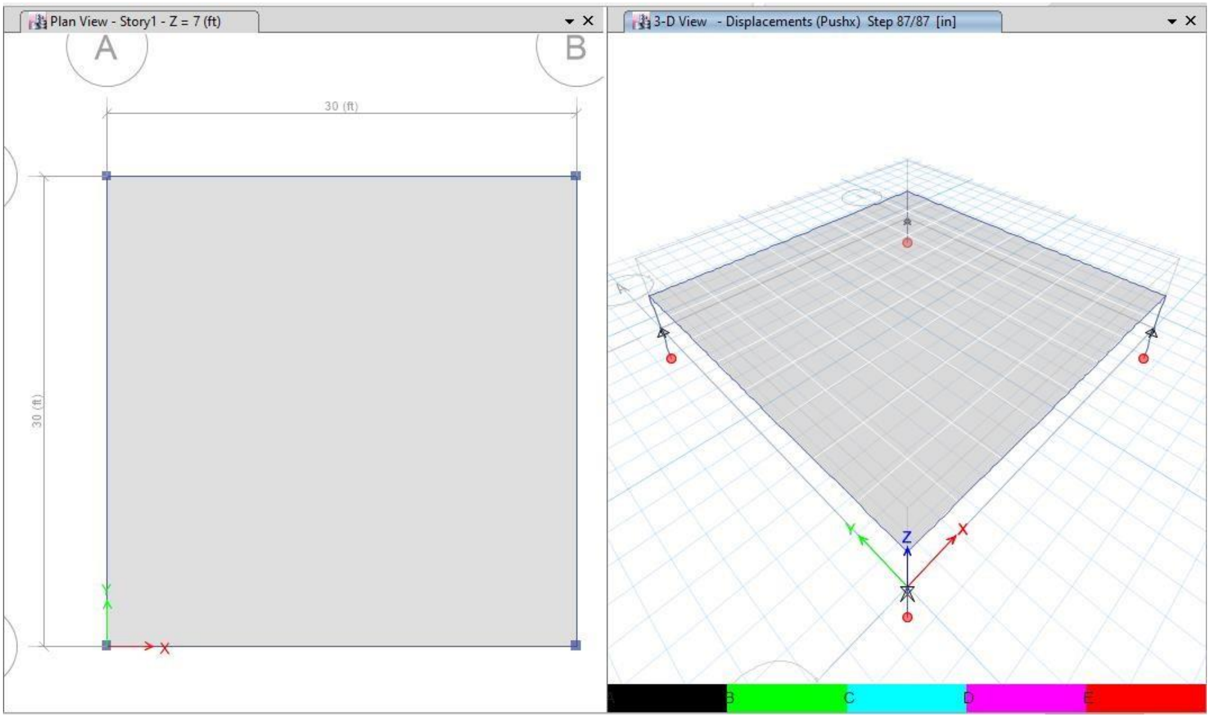
Maximum Deformation Comparison



Pushover Analysis ETABS

Pushover Analysis-Base Specimen

we did a Pushover analysis to further analyze the performance of our columns in ETABS. We modeled a hypothetical simple frame with four corner columns having the same dimension as we casted in the lab, but the length of 7ft. So, for Pushover analysis, we defined our hinges for the columns and a load case name Push-x with horizontal acceleration and the dead load. We tried different scale factors for applied loads and at a scale factor of 4, we got our hinges failed as shown in figure-15 and figure-16, respectively.



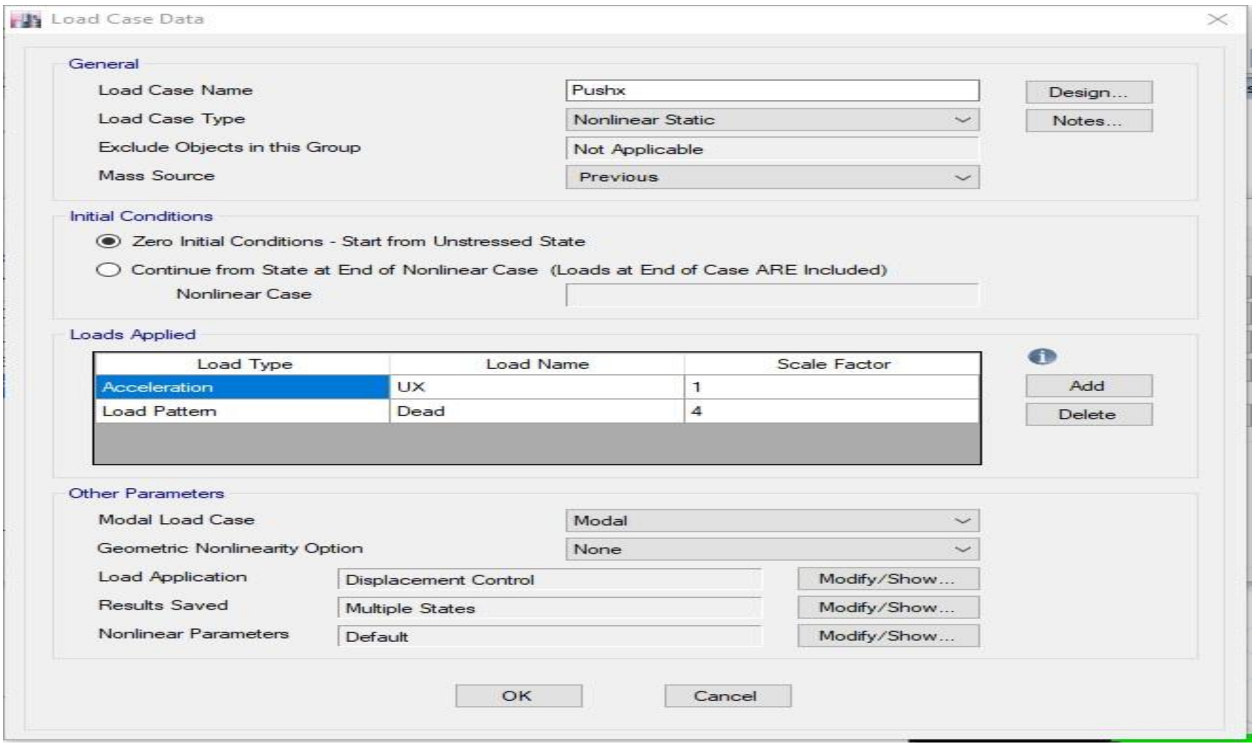


Figure 15 Pushover Analysis Base Specimen

Figure-16 is the base shear vs displacement graph which we extracted from ETABS, after analyzing our model and you can see base specimen faced maximum displacement before hinge failure at less than 90 E+3 kips base shear.

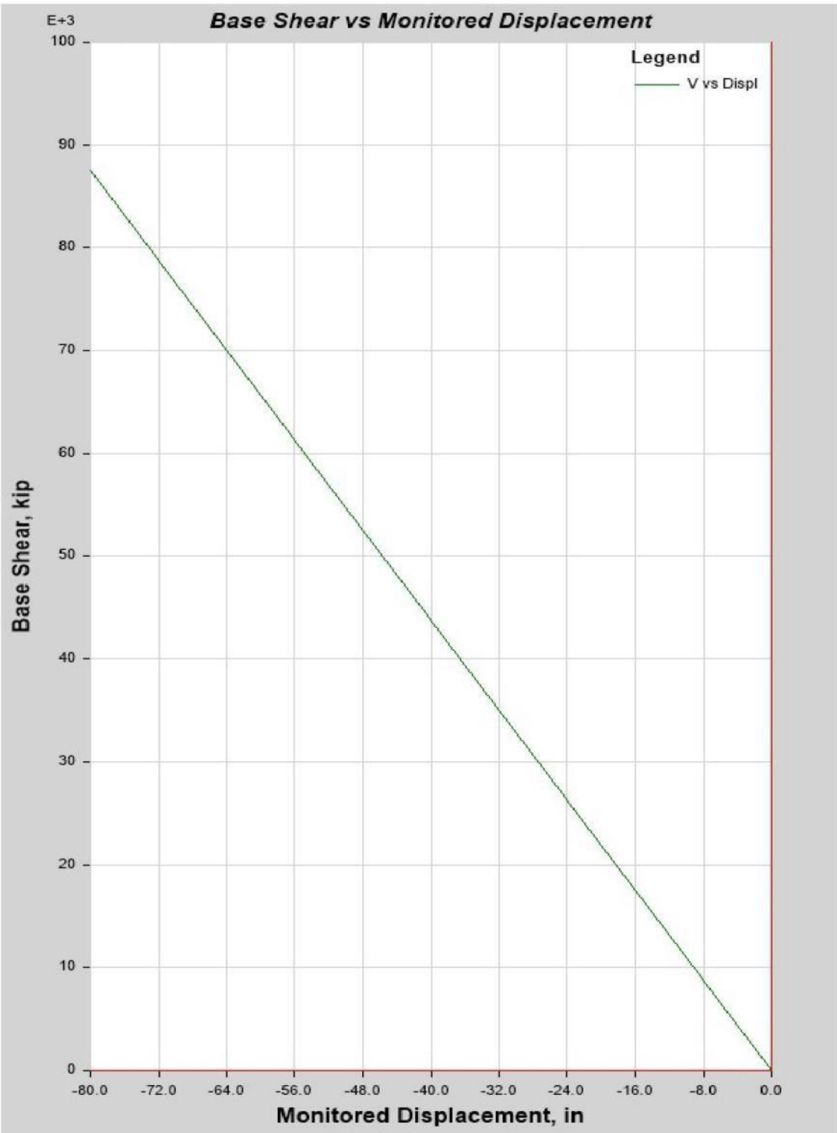


Figure 16 Base Shear VS Monitored Displacement Base Specimen

Pushover Analysis-Retrofitted Columns

We did the same modeling for our retrofitted columns as we did for base specimen, and we got hinges failed at a scale factor of 5 and 7 for dead load in load case push-x for surface not prepared and the surface being prepared column respectively as shown in Figure-17 and Figure-18.

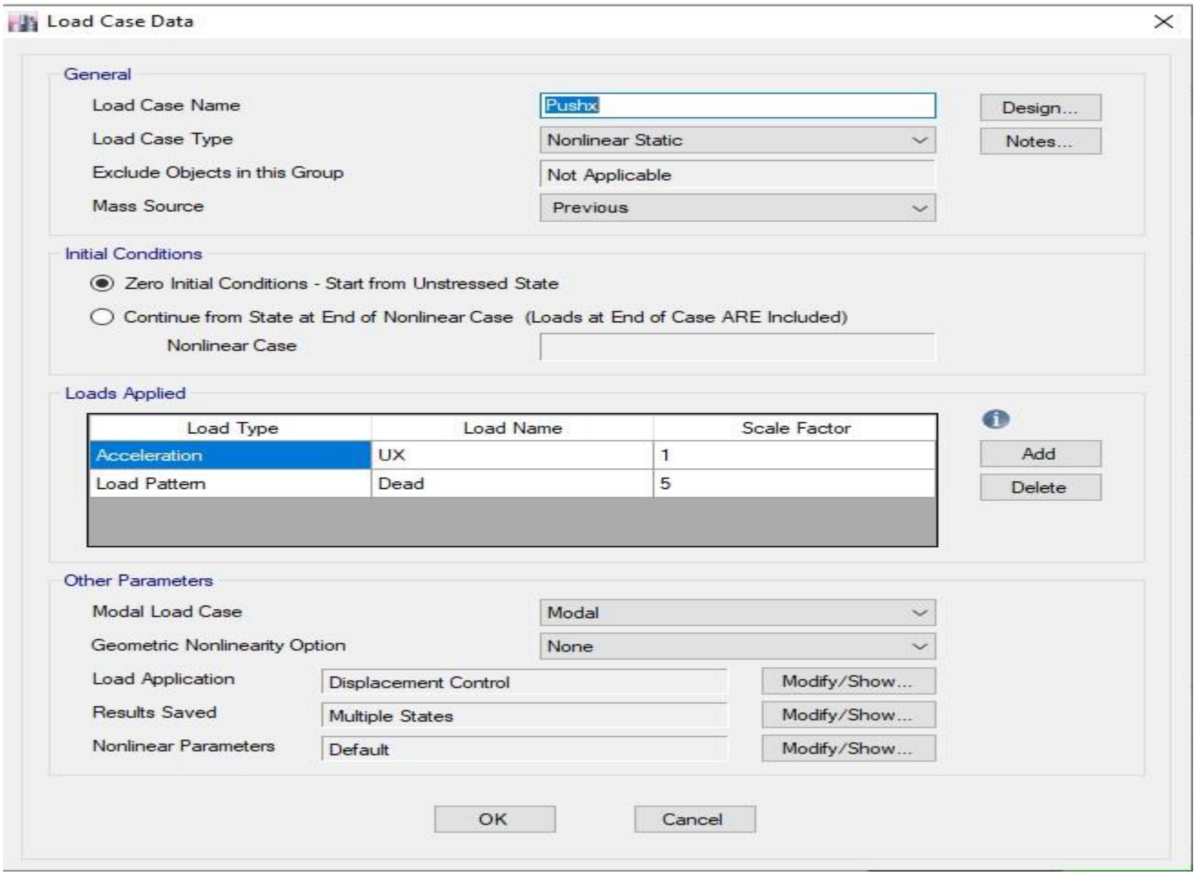


Figure 17 Pushover analysis Surface Not Prepared Retrofitted Column

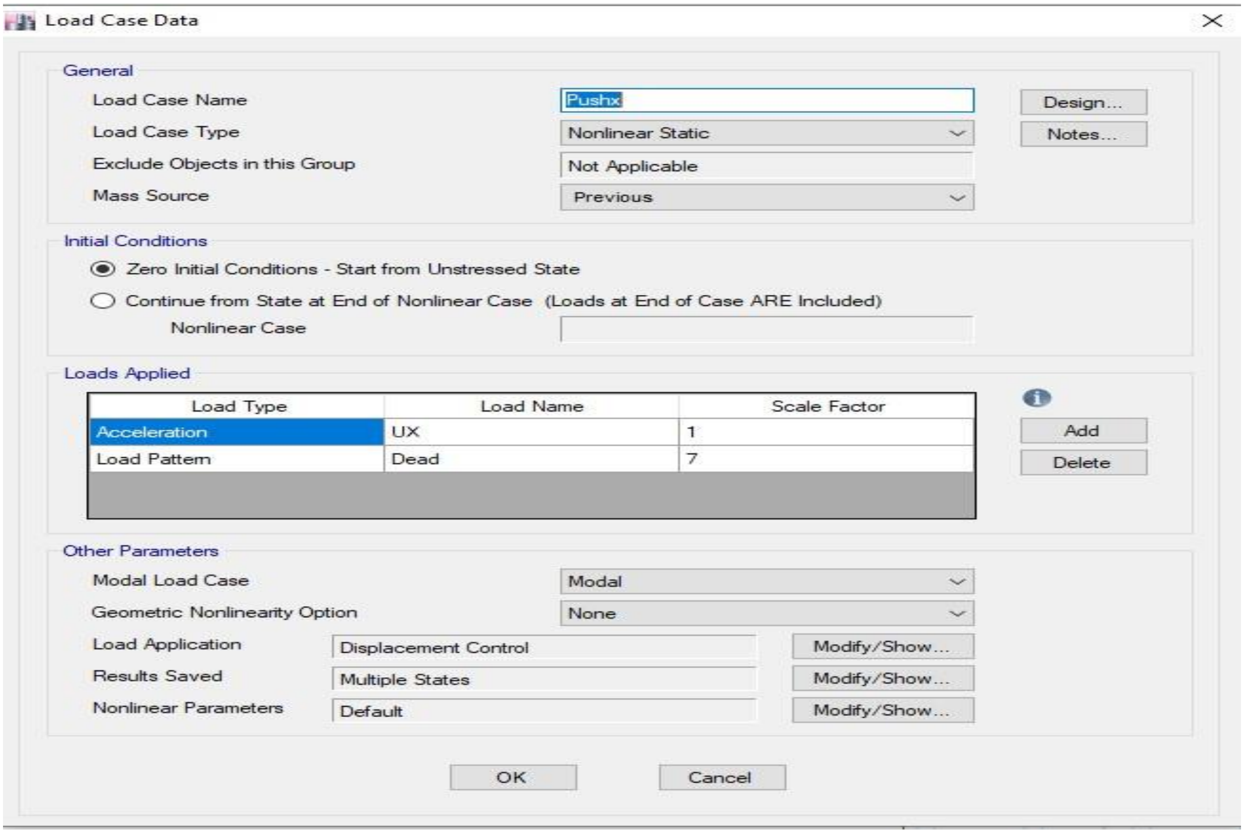


Figure 18 Pushover analysis Surface Prepared retrofitted Column

Graphs shown in figure-19 and 20 shows that for conventional jacket we got maximum displacement at about 1.1 E+6 kips base shear and for specialized jacketing, we got this value as 3.2 E+6.

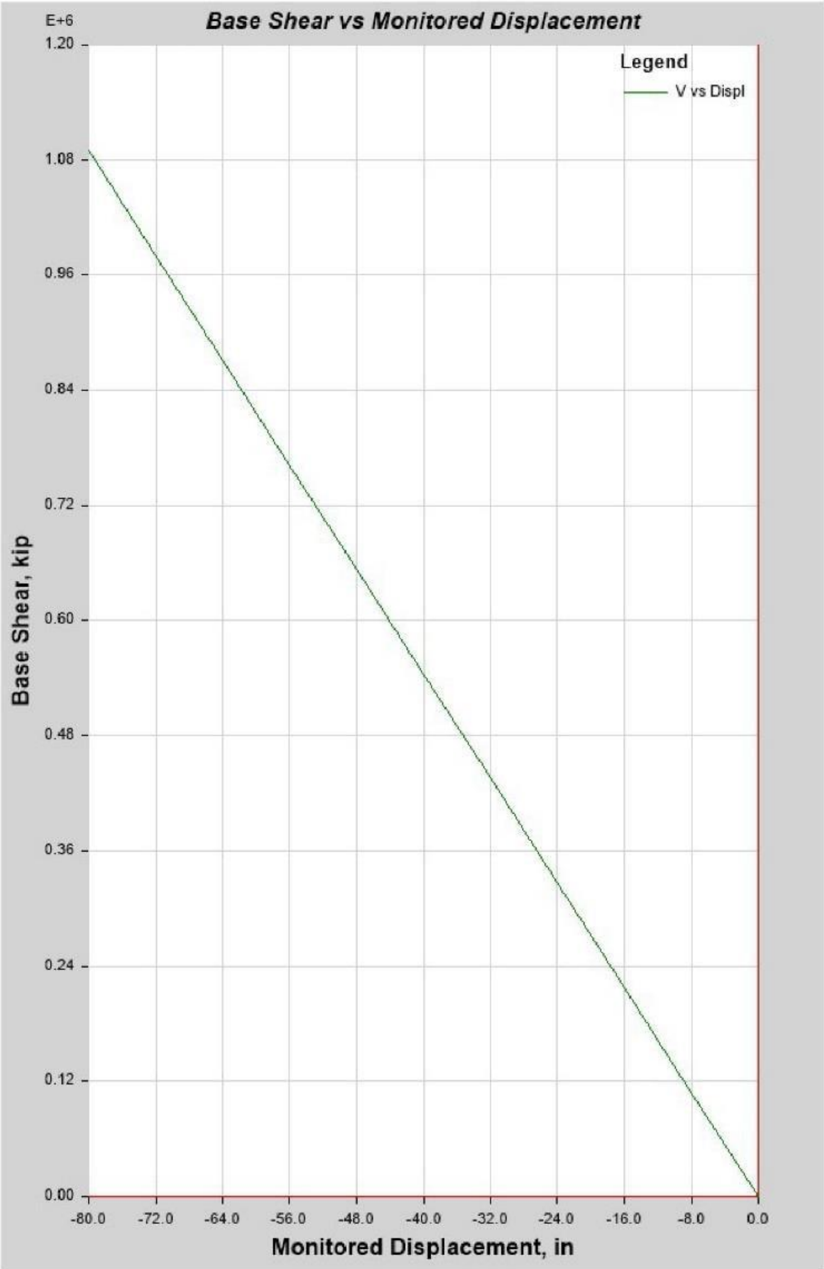


Figure 19 Base Shear VS Monitored Displacement for Surface not Prepared Retrofitted Specimen

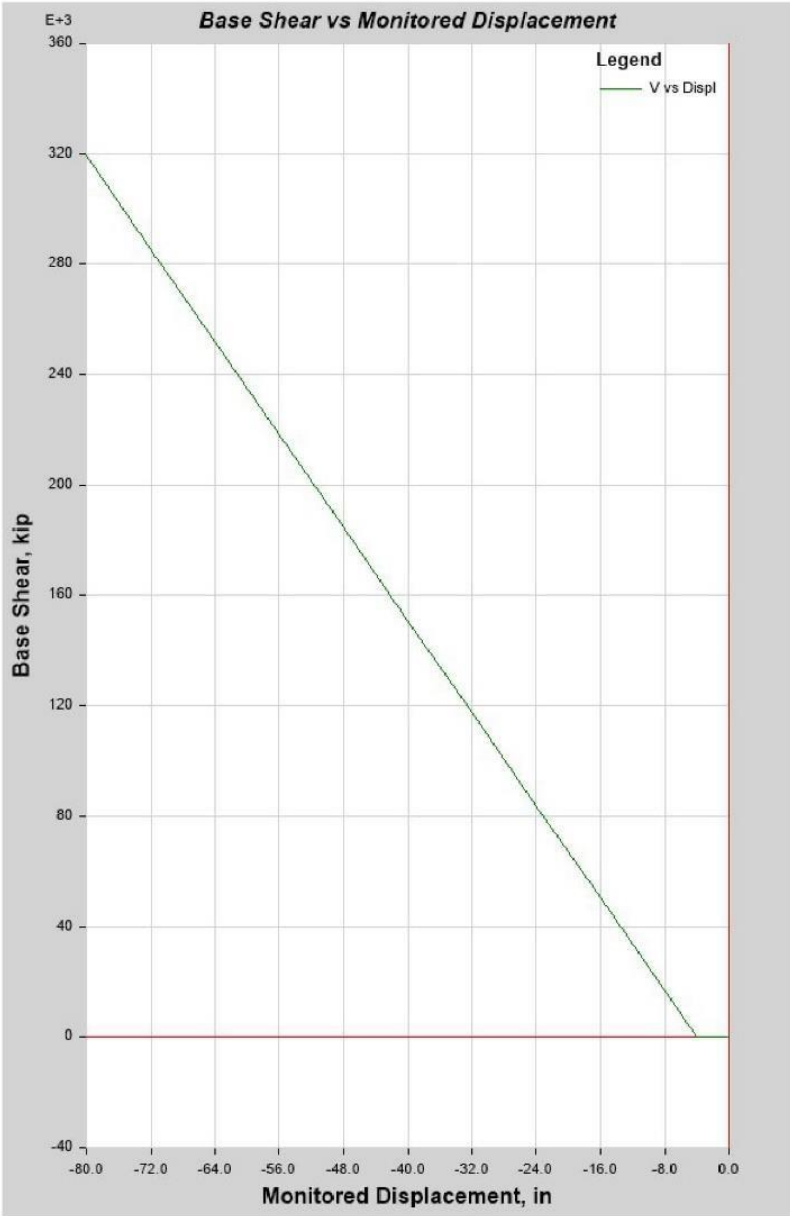


Figure 20 Base Shear VS Monitored Displacement for Surface Prepared Retrofitted Specimen

Conclusion/Future directions

Based on the results of our research and the analysis of data we obtained, we can confidently say that, Surface prepared RC Jacketing can enhance the axial load carrying capacity of a square column by 12% as compared to normal RC Jacketing. And in the future, students can adopt the same methodology to investigate the effects of surface treatment on the flexural strength of beam elements.

Also, by using a frame test machine of more capacity someone can also do research work on post-peak behavior of the discussed types of columns and can extract very useful information about the performance of surface-prepared retrofitted columns.

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