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Study on Strengthening and Rehabilitation of Basement Columns Using Structural Retrofit Methods

Gabriel Jose Posenti GHEWA[1*], Jessica GITOMARSONO[2]

[1,2]Teknik Sipil Soegijapranata Cahtolic University, email: ghewa@unika.ac.id

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Abstract

This study investigates the seismic performance of a reinforced concrete basement column retrofitted using two structural strengthening methods: concrete jacketing and steel jacketing. A single column, modeled with actual dimensions (450 mm × 450 mm, height 4.5 m, fc' = 25 MPa, fy = 240 MPa, 12D16 bars), was analyzed under dynamic loading. The seismic input was developed using a time history record matched to the elastic response spectrum of Semarang City, assuming a soft soil profile (Site Class E). Initial analysis showed that the unretrofitted column experienced a peak displacement of 159.9 mm and remained unstable within the 10-second duration after ground motion. After retrofitting, the maximum displacements were significantly reduced to approximately 41 mm for steel jacketing (20 mm thick, fy = 280 MPa) and 12.7 mm for concrete jacketing (100 mm thick, fc' = 25 MPa). The columns stabilized at 3.2 seconds and 2.0 seconds, respectively, indicating enhanced dynamic performance. The greater effectiveness of the concrete jacket is attributed to its larger contribution to section inertia and damping, while the steel jacket's performance was limited by practical thickness constraints. This research concludes that concrete jacketing provides superior reduction in lateral displacement and faster stabilization under seismic loads. These findings emphasize the importance of stiffness enhancement and jacket geometry in retrofit design and offer a basis for selecting appropriate strengthening strategies for vulnerable basement columns in soft soil seismic zones

Keywords: *retrofitting, jacketing, concrete, steel, column rofitting, jacketing, concrete, steel, column*

1. Introduction

Basement columns serve as critical structural components in buildings, responsible for carrying both vertical loads from the superstructure and resisting lateral forces, particularly in seismic zones or areas with high soil pressures. Over time, due to material degradation, seismic activity, changes in functional requirements, or construction deficiencies, these columns may exhibit signs of distress or fail to meet current design standards. In such cases, strengthening and rehabilitation through structural retrofitting methods become essential to ensure continued safety, functionality, and compliance with modern codes without resorting to complete demolition.

Various retrofit techniques have been developed and applied in practice, including the use of steel jacketing, fiber-reinforced polymer (FRP) wrapping, concrete jacketing, and section enlargement (Nesheli, 2006). Each technique has its advantages and limitations, depending on factors such as the type of structural deficiency, site accessibility, environmental exposure, and cost considerations. For instance, FRP wrapping has gained popularity due to its high strength-to-weight ratio and ease of application (Seible et al., 1997), while concrete jacketing remains widely used for its compatibility with existing concrete and robust performance under axial and lateral loads. Several studies have demonstrated the effectiveness of retrofit methods in improving the axial load capacity, ductility, and seismic performance of reinforced concrete

columns. For example, Sheikh and Yau (2002) highlighted significant improvements in ductility and confinement when using composite jacketing. Meanwhile, Bousias et al. (2007) investigated retrofit strategies under cyclic loading and emphasized the importance of anchorage and confinement detailing. Moreover, the integration of hybrid retrofitting solutions has been explored to optimize performance across multiple loading conditions.

Steel jacketing is a structural strengthening technique used to reinforce concrete columns, particularly square reinforced concrete columns. It involves placing longitudinal steel angles at each corner of the column, connected with transverse steel straps to form a steel frame around the column. This method increases the column's load-bearing capacity, stiffness, and ductility without significantly increasing its size (Rahman, 2024). The steel jacketing process typically involves bonding steel plates or angles to the existing concrete element using structural adhesives or by welding, creating a composite action between the steel jacket and the original column. This reinforcement method is effective in enhancing the strength and stiffness of columns, making it suitable for retrofitting buildings to prevent failures such as soft-story collapse (Resmaindra, 2024).

Despite these advancements, challenges remain in selecting the most suitable retrofitting strategy, especially for basement environments that may be subject to moisture, limited access, and complex load paths (Truong, 2017). Therefore, this study aims to evaluate and compare several structural retrofit methods applied to basement columns, focusing on their effectiveness, constructability, and long-term performance under realistic loading and environmental conditions.

2. Methodology

This study focuses on evaluating the seismic performance of a single reinforced concrete column under dynamic loading, with and without retrofitting. The column is modeled individually using its actual cross-sectional dimensions and reinforcement details, replicating existing field conditions as accurately as possible. The purpose of isolating a single column is to closely examine the displacement behavior and assess the effectiveness of different retrofitting strategies in enhancing seismic resistance.

Seismic loading is applied to the model based on the response spectrum data specific to Semarang City, following the guidelines in SNI 1726:2019. To perform a realistic dynamic analysis, time history ground motion records are developed by matching selected accelerograms to the target response spectrum of Semarang through spectral matching techniques. This ensures that the dynamic characteristics of the applied load closely reflect local seismic conditions. The site is classified as soft soil (Site Class E), indicating relatively low shear wave velocity and high seismic amplification potential.

Once the time history analysis is conducted, the column’s displacement response over time is recorded and analyzed. Key parameters such as peak displacement and overall displacement pattern are used to evaluate structural performance. The analysis is then extended by simulating retrofitting interventions on the same column using two strengthening approaches: concrete jacketing with a thickness of 10 cm, and steel jacketing with a thickness of 2 cm. In both cases, the retrofit materials are assumed to be fully bonded and working integrally with the original section.

The time–displacement responses of the retrofitted models are compared against the original, unretrofitted column. From these results, the performance of each retrofitting method is assessed, with the goal of identifying which technique provides the most effective reduction in displacement and overall enhancement of seismic behavior.

3. Result and Discussion

The modeling process begins by defining a column with the following specifications:

Tabel 1. Perbandingan indikator kinerja utama (KPI)

Parameter	Value
Concrete compressive strength (f'c)	25 MPa
Column cross-section	450 mm × 450 mm
Longitudinal reinforcement	12 bars of D16 (16 mm)
Column height	4.5 m
Steel yield strength (fy)	240 MPa

Table 1 presents the baseline properties used in the numerical model. The column has a square cross-section of 450 mm × 450 mm and a height of 4.5 m, with concrete compressive strength of 25 MPa and 12 longitudinal D16 bars. The original steel yield strength is 240 MPa. These parameters define the initial stiffness and strength of the column and provide a consistent basis for comparing the unretrofitted and retrofitted models. Because the same original column is used for each case, differences in the calculated displacement can be associated with the retrofit configurations and their assigned material properties.

The modeling illustration can be seen in Figure 1.

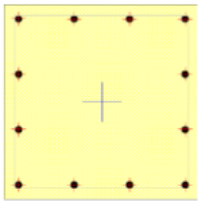


Fig 1. Column Section

Figure 1 illustrates the cross-section of the original reinforced concrete column and the arrangement of its longitudinal reinforcement. The section dimensions and reinforcement layout correspond to the parameters listed in Table 1. Establishing this baseline section is important because the retrofit assessment depends on the change in section geometry and stiffness relative to the original column. The figure therefore serves as the reference configuration for evaluating the additional concrete or steel jacket.

The response spectrum input and the result of the time history–response spectrum matching can be seen in Figures 2 and 3, respectively.

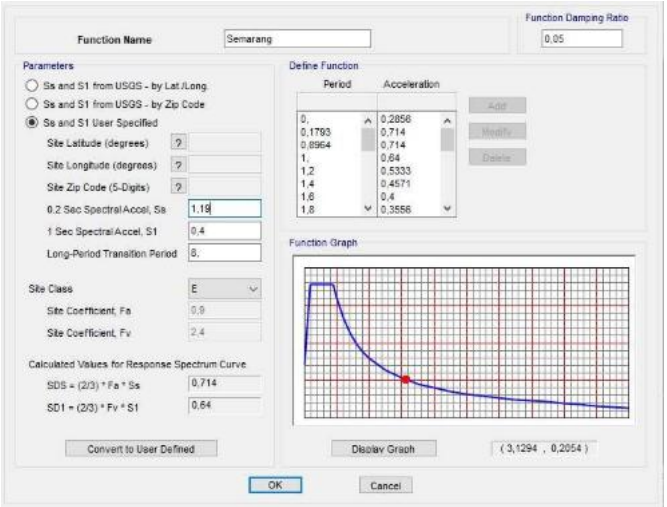


Figure 2. Spectrum Response Input

Figure 2 shows the response-spectrum input used to represent the seismic demand for Semarang City. In the study, this target spectrum follows SNI 1726:2019 and assumes Site Class E, representing soft-soil conditions. The spectrum provides the target dynamic characteristics against which the selected ground-motion record is matched. This step is important because the displacement response of a column depends not only on its structural properties but also on the frequency content and intensity characteristics of the applied seismic input.

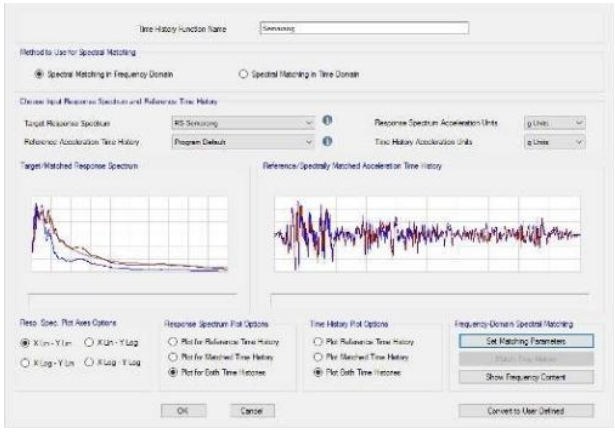


Figure 3. Time History Input

Figure 3 presents the time-history input obtained through matching the selected accelerogram to the target response spectrum. The time-history record supplies a sequence of changing seismic excitation over the analysis duration, allowing the model to capture the column's displacement response as the load varies with time. Using the same seismic input for the original column and both retrofit cases makes the comparison consistent: the observed differences in response are assessed under identical loading conditions rather than different earthquake records.

After the seismic loads are modeled and applied, the next step is to run the analysis. The result is the time–displacement relationship, which is shown in Figure 4.

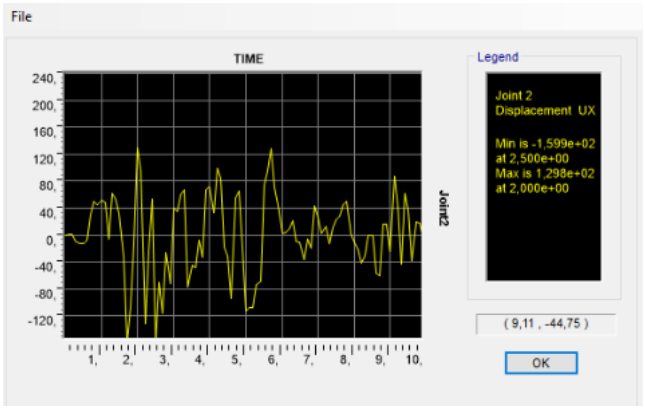


Figure 4. Initial result

Figure 4 presents the time–displacement response of the original column before retrofitting. The peak displacement reaches 159.9 mm, and the response continues to fluctuate through the 10-second analysis window without reaching a stable condition. This large lateral movement indicates that the original model has insufficient stiffness and/or damping to control the imposed seismic response under the modeled conditions. The result establishes the reference value against which the displacement reduction achieved by the two retrofit methods is evaluated.

It can be observed that the maximum displacement reached 159.9 mm, and the joint remained unstable within the 10-second interval after being subjected to the seismic load. The addition of retrofitting measures in the form of concrete jacketing and steel jacketing is expected to reduce the displacement and dampen the vibrations, allowing the joint to return closer to its original position. The modeling illustrations of the column with a 10 cm thick concrete jacket and a 2 cm thick steel jacket are shown in Figures 5 respectively.

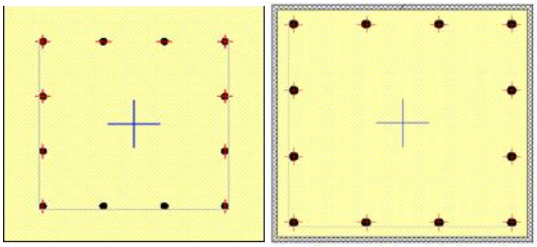


Figure 5. Retrofitted Column Section (Left for Concrete Jacketing and Right for Steel Jacketing)

Figure 5 compares the cross-sections after retrofit: the concrete-jacketed configuration is shown on the left and the steel-jacketed configuration on the right, as stated in the figure caption. Both approaches enlarge or reinforce the original section, but they do so using different materials and thicknesses. The 100 mm concrete jacket produces a larger geometric increase than the 20 mm steel jacket in the modeled configurations. This difference is relevant to the comparison because the amount and distribution of added material influence the section's moment of inertia and, consequently, its lateral stiffness.

The retrofitting material propertian can be seen in table 2.

Table 2. Reftrofitting Material Properties

Retrofitting Type	**Material**	**Thickness**	**Compressive Strength**
Concrete Jacketing	Concrete	100 mm	f'c = 25 MPa

Steel Jacketing	Structural Steel	20 mm	fy = 280 MPa

Table 2 summarizes the material and thickness assumptions for the two retrofit alternatives. The concrete jacket is modeled with a thickness of 100 mm and concrete compressive strength of 25 MPa, while the steel jacket is modeled with a thickness of 20 mm and yield strength of 280 MPa. These properties distinguish the two retrofit configurations from the original column and are the basis for interpreting the different displacement responses. The comparison should be understood as applying to the particular thicknesses and material properties selected in this study, rather than proving that concrete jacketing will outperform every possible steel-jacketing design.

Using the same loading conditions, the following results were obtained.

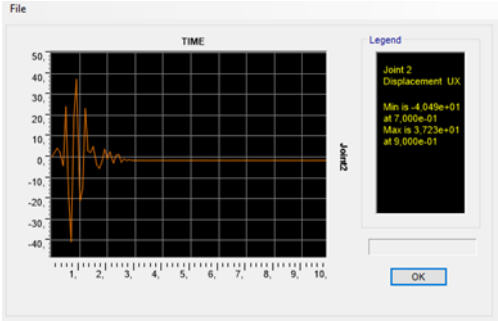


Figure 6. Joint Displacement-Time Result For Steel Jacketing

Figure 6 shows the time–displacement response for the column strengthened with a 20 mm steel jacket. Compared with the original peak displacement of 159.9 mm, the maximum displacement decreases to approximately 41 mm. This corresponds to a reduction of about 74.4%. The response also becomes stable at approximately 3.2 seconds, which indicates that the steel jacket improves the modeled column's ability to limit lateral movement and settle after the seismic excitation. Nevertheless, some displacement remains, and the result reflects the performance of the specified 20 mm jacket under the selected loading record.

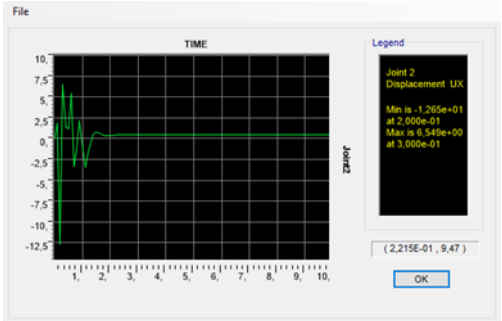


Figure 7. Joint Displacement-Time Result For Concrete Jacketing

Figure 7 shows the time–displacement response for the column strengthened with a 100 mm concrete jacket. The maximum displacement is approximately 12.7 mm, substantially lower than both the original column and the steel-jacketed model. Relative to the original peak of 159.9 mm, this is a reduction of about 92.1%. The response stabilizes at around 2.0 seconds, earlier than the steel-jacketed case. Within the assumptions of the numerical model, this result indicates that the thicker concrete jacket provides the greatest improvement in lateral stiffness and displacement control among the two configurations examined.

From Figures 6 and 7, it can be observed that the maximum displacement for the column retrofitted with steel jacketing is approximately 41 mm, while for the concrete jacketing, it is

around 12.7 mm. In the case of steel jacketing, the joint reaches a stable condition approximately 3.2 seconds after being subjected to the seismic load. For the concrete jacketing, the joint stabilizes earlier, at around 2 seconds after the seismic event.

The seismic response analysis reveals that the original column (without retrofit) reached a peak lateral displacement of 159.9 mm, with residual motion persisting beyond the 10 s analysis window—a clear indication of inadequate stiffness and damping.

Under identical loading, the steel-jacketed column (20 mm thick, fy = 280 MPa) achieved a maximum displacement of ≈ 41 mm, while the concrete-jacketed column (100 mm thick, f'c = 25 MPa) further reduced displacement to ≈ 12.7 mm. Calculating the average reductions:

- Steel jacket: (159.9 – 41) / 159.9 ≈ 74.4%

- Concrete jacket: (159.9 – 12.7) / 159.9 ≈ 92.1%

Thus, concrete jacketing outperformed steel, reducing displacement by an additional

~18% relative to steel.

Mechanical behavior is closely linked to changes in section stiffness: the thicker concrete jacket significantly increases the moment of inertia (I), leading to greater stiffness and lower displacement—consistent with Ishaq & Karim (2024), who emphasized the importance of jacket thickness on flexural strength (Thermou, 2021).

In summary, the quantitative data and literature synthesis indicate that both retrofit methods drastically reduce displacement and improve stability. Concrete jacketing, with its greater thickness, offers superior performance—lower displacement and faster stabilization—compared to steel jackets limited to 20 mm. The steel jacket's potential is hindered by practical thickness constraints; significant performance improvements would require thicker jackets or advanced composite configurations.

Furthermore, the superior performance of concrete jacketing can also be attributed to the stronger bond that develops between the existing structural element and the newly added concrete layer, especially when proper surface roughening and dowel anchorage are applied. This bond ensures monolithic action under loading, which significantly enhances flexural and shear resistance. In contrast, steel jacketing relies heavily on mechanical fastening or welding, which may introduce stress concentrations and reduce overall retrofit efficiency if not carefully executed.

In addition, the long-term durability aspect should be considered. Concrete jacketing not only improves stiffness but also provides additional cover that enhances fire resistance and protects the original structural core against environmental degradation. Steel jackets, while faster to install, are more vulnerable to corrosion and require consistent maintenance or protective coatings. Therefore, in terms of both structural performance and service life, concrete jacketing demonstrates a more sustainable and reliable solution for retrofitting compared to thin steel encasements.These findings suggest that, in the context of soft soil conditions similar to Semarang, concrete jacketing is the more efficient and pragmatic choice for seismic retrofit of basement columns.

4. Conclusion

In conclusion, both retrofitting methods substantially improved the seismic performance of the column compared to the original condition. However, concrete jacketing showed superior results in both displacement reduction and stabilization time, making it a more effective option for seismic strengthening of basement columns in soft soil conditions such as those found in Semarang. While this study compared steel and concrete jacketing individually, future research

could explore hybrid retrofitting systems, such as combining thin steel jackets with fiber-reinforced concrete or incorporating carbon/aramid fiber-reinforced polymers (FRP) to optimize both strength and ductility. Hybrid systems may bridge the gap between stiffness and energy dissipation capacity.

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