Retrofitting of square reinforced concrete column by welded wire mesh jacketing with concentric axial load

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ABSTRACT. Structural failure to carry the earthquake load is due to several factors such as the column design that ignores ductility or restraint, bad column detailing so the column performance decreases than the previous planning, besides the planner ignores the concept of "strong columns weak beams". One way to increase the existing structure column ductility is retrofitting the column by wrapping the column using Welded Wire Mesh (WWM). The research is to determine the effectiveness of WWM as a column restraint material and determine the model of reinforced concrete column stress-strain relationship curves retrofitted by using WWM. The experimental testing used a square column with an initial size of 150x150mm and covered by WWM then there was a casting to make the size became 220 x 220 mm with three types of columns namely RCH, RCHWWM-1 and RCHWWM-2 with column test specimen height = 800 mm. All columns underwent a compressive test with monotonic concentric axial load. Test result indicates that, there is an increase in compressive strength (f’cc), Confined concrete strain (ε’cc) and ultimate concrete strain (ε’cu) on RCHWWM-1 and RCHWWM-2 column. For RCHWWM1 Column, f’cc increase = 0.26%, ε’cc = 87.50%, and ε’cu = 175.71%, RCHWWM2 Column f’cc increase = -1.65%, ε’cc = 85.00%, and ε’cu = 214.24%. f’cc deviation obtained from Experimental and Theoretical validation ranges from -1.50% to -4.429%, ε’cc deviation ranges from -0.333 to -3.51% and ε’cu deviation ranges from 20.79 to 35.66%.

1. Introduction
Earthquake is a threat to humanity and it is not a local, national, or regional issue but a global phenomenon. Even today, there is no technology that can detect when an earthquake will occur. It is impossible to prevent earthquake, but it is possible to alleviate structure destruction, loss of life, loss of property and suffering from earthquakes. Building collapses due to several factors including column planning that does not anticipate ductility or restraint requirement, and bad column casting.
implementation can decrease the concrete quality, less attention to detailing, and many planners ignore the concept of “Strong Columns Weak Beams”. The design of earthquake resistant reinforced concrete column is in accordance with SNI 03-2847-2012 that requires the use of restraint reinforcement to achieve the required ductility. Specific details in the form of restraints are given mainly in the areas that have the potential for plastic joints in accordance with the current design concept of earthquake resistant structures. In addition, at the end of columns and longitudinal reinforcement connection area, it requires tighter restraints to ensure sufficient ductility so that the building does not experience unwanted brittle failure.

One way to strengthen the building existing column structure without dismantling the column is to wrap the column by welded wire mesh (WWM). WWM usage is one of the more economical solutions to be used as a ductile column retrofit material, because WWM price is relatively affordable, it is easy to obtain and it has a high practical value. Besides, WWM has been fabricated in a net, so it gives better precision. The research problem is how WWM as a restraint of reinforced concrete columns compared to reinforced concrete columns BJTP stirrup reinforcement, what is the form of reinforced concrete column behavior of WWM retrofit, how is the reinforced concrete column stress-strain relationship curve of WWM retrofit. This research is expected to be useful for retrofitting the existing buildings, mainly for buildings located in areas prone to medium and strong earthquake.

2. Literature Review

2.1. Concrete Restraint by Welded Wire Mesh (WWM)
Concrete Restraint by WWM will give more confined concrete core area and more distributed bridle pressure compared to the stirrups reinforcement, as in figure 2.1

![Square columns restraint with WWM](image1)

![Restraint by stirrups reinforcement retrofitted by WWM](image2)

If WWM is used as the material of column retrofit on the existing buildings, then WWM can be placed by wrapping WWM on the existing reinforced concrete column perimeter, as in Figure 2.2.

2.2. Reinforcement Transversal Requirements
Rectangular section’s hoop total area for restraint process must not less than the value of 2

\[
A_{sh} = 0.3 \left( s \cdot h_c \times \frac{f'_c}{f_{yh}} \right) \left( \frac{A_B}{A_C} - 1 \right)
\]

\[
A_{sh} = 0.09 \left( s \cdot h_c \times \frac{f'_c}{f_{yh}} \right)
\]
2.3. **Concrete Stress-Strain Curve**

Mander, Priestley and Park (1988) gives a description of stress-strain relationship on concrete, compressive strength and concrete strain will increase due to restraint, as in Figure 2.3 below.

![Stress-Strain Relationship Curve for Unconfined and Confined Concrete Monotonic Loading](image)

Figure 2.3 Stress-Strain Relationship Curve for Unconfined and Confined Concrete Monotonic Loading

Peak press strain of confined concrete is

\[ \varepsilon'_cc = 0,002[1 + 5(f''cc / f'_c - 1)] \]

Ultimate strain of confined concrete is

\[ \varepsilon'_{cu} = 0,004[1 + 1A.\rho_s.\varepsilon_{syh}.\frac{\varepsilon_{sm}}{f'_c}] \]

3. **Research Methodology**

3.1. **Test Objects**

Design parameters used in this study were:

a. Square cross section column with an initial size of 150 x 150 mm
b. Post retrofitting square cross section column of 220 x 220 mm
c. Column height h = 800 mm
d. Compressive strength of concrete \(f'_c\) = 32,12 MPa.
e. Yield Stress of BJTD \(f_y = 525\) MPa
f. Yield Stress of BJTP \(f_y = 380\) MPa
g. Yield Stress of welded wire mesh (WWM) \(f_y = 433\) MPa
h. Longitudinal column reinforcement using BJTD 4D9.8
i. Reinforcement columns using BJTP \(\Phi = 7,8\) mm
j. WWM diameter \(\Phi = 2\) mm grid size of 25 x 25 mm and a grid of 50 x 50 mm
3.2. **Theoretical Analysis**

| Column Type  | $\rho_s$ | $f'_{cc}$ (MPa) | $\varepsilon'_{cc}$ | $\varepsilon_{cu}$ | $P_{max}$ |
|--------------|----------|----------------|---------------------|------------------|----------|
| RCHWWM-1    | 0.00562 + 0.00155 | 33.501 | 0.00243 | 0.00821 | 165,289 |
| RCHWWM-2    | 0.00562 + 0.000776 | 32.698 | 0.00220 | 0.00577 | 159,575 |

4. **Research Result and Discussion**

4.1. Reinforced Concrete Column (RCH) and Reinforced Concrete Column are retrofitted using Welded Wire Mesh (RCWWM)

a. **Collapse Mechanism.**

Figure 4.1 is RCH column collapse and Figure 4.2 is RCHWWM column collapse after pressure loading.
b. Concrete Stress-Strain Curve

![Concrete Stress-Strain Curve](image1.png)

![Concrete Stress-Strain Curve](image2.png)

Figure 4.3. Concrete Press-Strain Curve of Theoretical Column and Experimental Result (RCHWWM-1)

Figure 4.4. Concrete Press-Strain Curve of Theoretical Column and Experimental Result (RCHWWM-2)

Based on the combined curve in Figure 4.3 there is a difference between theoretical and experimental curve. The experimental curve has an increasing in $f'_{cc}$ strength = 0.26%, $\varepsilon'_{cc} = 87.50\%$, $\varepsilon'_{cu} = 175.71\%$, which are greater than the theoretical result. In the experimental result, it can be seen that the column experiences strength increase when approaching the peak load. Nonetheless, there are cracks elongated on the column cross section to P load = 170 tons, of which the column strength reaches $f'_{cc} = 32.202$ Mpa. Column destruction is due to the failure on $\varepsilon'_{cu}$ concrete material = 0.0488 instead of the conventional reinforcement and WWM.

Based on the combined curve in Figure 4.4 there is a difference between theoretical and experimental curve. The experimental curve has an increasing in $f'_{cc}$ strength = -1.65%, $\varepsilon'_{cc} = 85.00\%$, $\varepsilon'_{cu} = 214.24\%$, which are greater than the theoretical result. In the experimental result, it can be seen that the column experiences strength increase when approaching the peak load. Nonetheless, there are cracks elongated on the column cross section to P load = 168.2 tons, of which the column strength reaches $f'_{cc} = 31.589$ Mpa. Column destruction is due to the failure on $\varepsilon'_{cu}$ concrete material = 0.05582 on P = 115 tons instead of the conventional reinforcement and Welded Wire Mesh.

| No | Column type | $\rho_s$ | $f'_{cc}$ (MPa) | $\varepsilon'_c$ | $\varepsilon'_cu$ | Increase(%) |
|----|-------------|---------|----------------|----------------|----------------|-------------|
| 1  | RCH         | 0.00562 | 32,12          | 0.004          | 0.0177        |             |
| 2  | RCHWWM-1    | 0.00717 | 32,202         | 0.0075         | 0.0488        | 0.26        | 87.50       | 175.71     |
| 3  | RCHWWM-2    | 0.006396| 31,589         | 0.0074         | 0.05562       | -1.65       | 85.00       | 214.24     |

In table 4.1, there is an increase on RCHWWM_1 column by $f'_{cc} = 0.26\%$, $\varepsilon'_{cc} = 87.50\%$, $\varepsilon'_{cu} = 175.71\%$ on the RCH column, and there is a decrease on RCHWWM_2 column and the ductility was $f'_{cc} = -1.65\%$, $\varepsilon'_{cc} = 85.00\%$, $\varepsilon'_{cu} = 214.24\%$ on the RCH column.

4.2. Comparison of Theoretical and Experimental Hypothesis Data.

| No. | Column n | $\rho_s$ | Theoretical $f'_{cc}$ | Theoretical $\varepsilon'_{cc}$ | Theoretical $\varepsilon'_{cu}$ | Experimental $f'_{cc}$ | Experimental $\varepsilon'_{cc}$ | Experimental $\varepsilon'_{cu}$ |
|-----|----------|---------|-----------------------|--------------------------------|-------------------------------|------------------------|-------------------------------|-------------------------------|
| 1   | RCHWWM-1 | 0.00717 | 32,725                | 0.00751                        | 0.0404                        | 32,202                 | 0.0075                        | 0.0488                        |
| 2   | RCHWWM-2 | 0.006396| 33,053                | 0.00767                        | 0.0410                        | 31,589                 | 0.0074                        | 0.05562                       |

From the Theoretical and Experimental Hypothesis in Table 4.2 above, it can be seen that:

1. In RCHWWM_1 column, there is a strength deviation of concrete $f'_{cc}$, experimental concrete strain on theoretical analysis that is $f'_{cc} = -1.60\%$, $\varepsilon'_{cc} = -0.133\%$ and $\varepsilon'_{cu} = 175.71\%$.
20.79%.

2. In RCHWWM_2 column, there is a strength deviation of concrete $f'_{cc}$, experimental concrete strain on theoretical analysis that is $f'_{cc} = -4.429\%$, $\varepsilon'_{cc} = -3.52\%$ and $\varepsilon'_{cu} = 35.66\%$.

From the description above, $f'_{cc}$ deviation is ranging from -1.50 to -4.429 %, $\varepsilon'_{cc}$ deviation is ranging from -0.333 to -3.52% and $\varepsilon'_{cu}$ deviation is ranging from 20.79-35.66%.

5. Conclusions
The conclusions are as follow:
1. The experimental results of WWM restrained columns and conventional stirrups RCHWWM which have approximately the same ratio of transverse reinforcement ($\rho_s$) by RCH columns have almost the same characteristics in terms of strength increasing and ductility.
2. From theoretical and experimental analysis there are similar trends in stress-strain concrete curve in RCH, and RCHWWM_1 and RCHWWM_2, column, between theoretical and experimental there is a deviation in the $f'_{cc}$ stress and $\varepsilon_{cc}$ strain < 5% meanwhile on $\varepsilon_{cu}$ there is a huge, that is more than 20-35% on each result column, experimental result indicates that column strength and ductility on restraint column by Welded Wire Mesh is quite effective as retrofit material of reinforced concrete column.
3. From the experimental results, it can be seen that the column concrete compressive strength of ($f'_{cc}$) has decreased slightly but the decrease does not significantly affect the column strength due to the column strength of begins with reinforcement not by concrete. The confined concrete strain ($\varepsilon'_{cc}$) has a relatively similar value, but the ultimate concrete strain value ($\varepsilon'_{cu}$) increases quite large when compared to theoretical analysis, therefore it can be concluded that the experimental result has good ductility and WWM, and quite safe to be used as a restraint for concrete columns.
4. The behavior of reinforced concrete columns by WWM has almost the same behavior with RCH column, began with cracks in the concrete blanket and reaching the peak load and the column is able to carry on a large enough displacement before it collapses.
5. The use of WWM as Retrofitting material by Jacketing has a good indication to reinforce the existing building.

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