Numerical Study on the Behaviour of Reduced Beam Section Presence in Rectangular Concrete Filled Tubes Connection

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Abstract. This paper discusses about the behaviour of two types of RCFT column connections with steel beams due to cyclic loads using software based on finite element method ABAQUS 6.14. This comparison involves modelling RCFT connections with rigid connection that do not allow any deformation and rotation in the joint. There are two types of model to be compared: BB and BRBS which include RCFT connections to ordinary beam without RBS (BB) and to Reduce Beam Section Beam (BRBS). The models behaviour can be discussed in this study are stress value, von misses stress pattern and rotational degree of each model. From the von misses stress pattern value, it found that the highest regions of stress occurs in vicinity of beam flange near column face for connection without RBS (BB). For earthquake resistant building, that behaviour needs to be avoided because sudden collapse often happen in that joint connection. Moreover, the connection with the presence of RBS (BRBS), the highest regions of stress occurs in reduced beam section of the beam, it means that the failure might be happen as proposed plan. The ultimate force that can be restrained by BB model (402 kN) is higher than BRBS model (257,18 kN) because of reducing of flange area. BRBS model has higher rotation angle (0,057 rad) than BB model (0,045 rad). The analysis results also observed that cyclic performances of the moment connection with RBS (BRBS) were more ductile than the connection with ordinary beam (BB).

1. Introduction
Indonesia as Earthquake prone area are always claimed the lives caused by building collapse during the earthquake. The collapse of the current building during the earthquake will hit people around it so it can cause severe injuries. Therefore, the earthquake resistant building are required, so the number of casualties due to the earthquake can be minimized. For example, in the other countries, as in Northridge, California (1994) earthquake and the Kobe, Japan (1995) earthquake showing the collapse of steel structures at that time was caused by failure of the connection. After experiencing the earthquake, several studies on the design of optimal connections for earthquake prone areas began to emerge.
The increasing demand for earthquake resistant building leads to the need for an economical, effective, and efficient earthquake resistant structure design without reducing the stiffness of the building structure components. One of example is using composite structure in building. Concrete-steel composite structures have been widely used for building construction, bridges, and various other constructions. The use of composite steel allows the utilization of all cross-section in accepting the load, due to the interaction between steel structure components and concrete that have basic advantages characteristics of each material can optimally utilized, resulting in better structural performance and more effective in increasing the loading capacity and stiffness of the building.

There are two types of composite columns, the first one is encased steel columns and the second one is concrete filled tubes (CFT). The CFT column as a composite column relies on the interaction between ductile steel tubes with rigidity of core concrete [12]. This collaboration will increase the strength of the column because the compressive strength of the concrete will be increased by the restrain effect of the steel tube and the local buckling of the steel tube will be reduced due to the presence of concrete that helps to hold it. The use of composite structural elements such as CFT columns will provide several advantages, including: Strength per unit area greater than conventional reinforced concrete columns so dimension of columns may be smaller, then it doesn’t need for formwork again for concrete casting, The combination of strengths of two steel and concrete materials makes CFT columns suitable for high-rise buildings [13]. and the complexity of the connection [16].

The connection between steel structure elements or composite structures is an important part of the overall structure other than the element itself. The connection serves to drain the loads from one structural element to another structural element in addition to functioning to unite the components of the structure. Research on steel connections includes the CFT column connections to date, among others [5] [11]. Kimura et al and Cheng et al examined the connection detail and shear strength in the panel area of the CFT-steel column beam joints.

This research will be focused on the behavior and capabilities of the CFT column connection with steel beams. Concrete columns of concrete-based steel used are Rectangular CFT (RCFT), while steel beams are used as well as two common WF blocks and RBS (Reduced Beam Section) blocks. This modeling covers the modeling of WF beam connections - RCFT columns and RBS blocks - RCFT columns. The partial reduction of cross-section of the block beam through RBS aims to rigid the beam junction area - the CFT composite column and weaken the cross section of the WF beam in the plastic joint area so that the structural collapse behavior can behave more ductile [8].

In previous study in 2014, found that cyclic performance of the moment connection with RBS were much superior to the connection without RBS and it still need to be compared to bolted connection for each types [4]. From this study, it is expected that modeling of CFT - steel beam connections that meet the requirements of both strong and ductile buildings for strong earthquake areas can be obtained. In modeling CFT column connection with steel beam in this study will be used software based on finite element method that is ABAQUS software, to make a simple and cheaper model than use experimental test. Using finite element modelling in this numerical study will show the stress value that not only shows possible failure location in each model by stress pattern, but also estimated value.

2. THEORY

2.1. Ductility

Structures in earthquake prone areas have to follow the design concept and standard of earthquake resistant structures. According to SNI 03-1726-2012 [1], earthquake resistant structures have not collapsed at the time of the strong earthquake strike and only suffered minor damage during the earthquake. This behavior can be achieved when the structural components have the ability to absorb and emit seismic energy through the mechanism of plastic joint formation. Therefore, the structural components must have ductility capable of sustaining their capacity or strength after undergoing considerable inelastic deformation before collapse.
2.2. Concrete Filled Tube
Morino and Tsuda [13] said that the advantages of using RCFT as a column are:

1. Local buckling of steel tubes can be delayed, due to the presence of concrete. On the other hand, the strength of concrete increases due to the restraining of steel tubes. Shrinkage and creep on concrete is also smaller when compared to reinforced concrete.
2. The ratio of steel to the CFT cross section is much larger when compared to reinforced concrete. Because of this, the dimensions of the columns used will be much smaller, the weight of the structure will be smaller so as to reduce the load to the foundation.
3. Since steel tubes also serve as formworks for concrete, the use of CFT columns is more practical and can reduce waste from using formwork.
4. In terms of construction costs, and implementation time and workmanship in the field, the use of CFT columns is more effective and efficient.

2.3. Reduce Beam Section
Reduced Beam Section (RBS) is a modified cross-section of the beam by providing a reduction of the extent of a particular wing of the pedestal. This reduction process is done in such a way that all melting and plastic joint processes occur in this RBS section. In addition, the reduction of the area also plays a role in reducing the moment on the column while controlling the occurrence of inelastic deformation in the column [8].

2.4. Experimental Test

2.4.1. Experimental Test of WF – RBS Connection by Jones
Jones [10] did the experimental test to know the behaviour of WF – RBS connection, with boundary condition, experimental setup as known above and SAC loading protocol as seen below:

![Figure 1. Boundary condition on experimental test model](image1)

![Figure 2. Experimental setup](image2)
3. MODELLING
There will be four types of connection to be compared in this study that four type as seen in the table below:

| Name of Model | Types of Beam                      |
|---------------|-----------------------------------|
| BB            | Ordinary Beam without RBS         |
| BRBS          | RBS Beam Section                  |

3.1. Part Modelling
In each type of model, there will be three part to be assign in assembly module in ABAQUS. Firstly, for the RCFT section, there are the concrete core and Rectangular Hollow Tube. And for beam there are two different section to be model, the ordinary WF 600.200.11.17 beam and the RBS beam. As seen in figures below:
3.2. Material Properties
Material of the model divide in two types, they are concrete and steel, concrete that used as a core has $f'_c = 30$ MPa and the steel has $f_y = 250$ MPa. There are some material properties to be filled in the modelling module of material include density, elastic properties and plastic properties. Density of concrete and steel had been written in the Table 2 below. The density values that have to be input to Abaqus have to in t/m$^3$ unit as seen below:

| Name of Material | Density (N/mm$^3$) | Density (t/m$^3$) |
|------------------|--------------------|-------------------|
| Concrete         | $2.4 \times 10^{-5}$ | $2.4 \times 10^{-9}$ |
| Steel            | $7.85 \times 10^{-5}$ | $7.85 \times 10^{-9}$ |

For elasticity, concrete material in finite element model, use the equation of elastic modulus from its $f'_c$ that is stated on SNI 2847-2013 [3]. Then the steel material will use the value from SNI 1729-2015 [2]. Beside of elastic modulus, there are poisson’s ratio that need to be input in material properties of model. The the elastic material properties had been written in the Table 3 below:

| Name of Material | Elastic Modulus E (N/mm$^2$) | Poisson’s Ratio |
|------------------|-----------------------------|----------------|
| Concrete         | 27.691,47                   | 0,2            |
| Steel            | 200.000                     | 0,3            |

Then, for the plastic material properties of steel, stress-strain values obtained through the analysis approach with the formulation of Eurocode 3 as written in Poh [6] [15]. as seen in Figure 7 then had been written in Table 4 and that had been input in ABAQUS.
Table 4. Plastic material properties of Steel

| Stress (N/mm²) | Strain  | Inelastic Strain |
|---------------|---------|------------------|
| 0             | 0       | 0                |
| 0.00125       | 250     | 0                |
| 0.02          | 250     | 0.01875          |
| 0.022         | 266     | 0.02075          |
| 0.024         | 282     | 0.02275          |
| 0.026         | 298     | 0.02475          |
| 0.028         | 314     | 0.02675          |
| 0.03          | 330     | 0.02875          |

| Stress (N/mm²) | Strain  | Inelastic Strain |
|---------------|---------|------------------|
| 0.032         | 346     | 0.03075          |
| 0.034         | 362     | 0.03275          |
| 0.036         | 378     | 0.03475          |
| 0.038         | 394     | 0.03675          |
| 0.04          | 410     | 0.03875          |
| 0.15          | 410     | 0.14875          |
| 0.16          | 328     | 0.15875          |

For the concrete material, in the plasticity properties, there are Concrete Damage Plasticity option. This option has three more option as plasticity, compressive behaviour and tensile behaviour. Concrete damage plasticity of this model has been obtained use value from Jankowiak [9] as written in Casita with iteration in viscosity parameter, as seen in Table 5. For compressive and tensile behaviour of steel, use the combination of suggested equation from Eurocode [7] and Pavlovic [14] as written in Tambusay [17][18] as seen in Figure 8 and 9, then input value had been written in Table 6 and 7.
Figure 8. Compressive Behaviour of Concrete

Figure 9. Tensile Behaviour of Concrete

Table 5. Concrete Damage Plasticity

| Dilatation Angel | Eccentricity | f_b0/f_c | K   | Viscosity Parameter |
|------------------|--------------|---------|------|---------------------|
| 38               | 1            | 1.12    | 0.666| 0.02                |

Table 6. Compressive Behaviour of f'_c = 30 MPa concrete

| Stress (N/mm²) | Strain | Inelastic Strain | Stress (N/mm²) | Strain | Inelastic Strain |
|----------------|--------|------------------|----------------|--------|------------------|
| 0              | 0      | 0                | 11.87          | 0.012  | 0.0116           |
| 12             | 0.0004 | 0                | 11.09          | 0.013  | 0.0126           |
| 21.91          | 0.001  | 0.0006           | 10.35          | 0.014  | 0.0136           |
| 25.20          | 0.00125| 0.0008           | 9.64           | 0.015  | 0.0146           |
| 27.62          | 0.0015 | 0.0011           | 8.97           | 0.016  | 0.0156           |
| 29.20          | 0.00175| 0.0013           | 8.32           | 0.017  | 0.0166           |
| 29.94          | 0.002  | 0.0016           | 7.69           | 0.018  | 0.0176           |
| 30.00          | 0.0021 | 0.0017           | 7.09           | 0.019  | 0.0186           |
| 28.94          | 0.0025 | 0.0021           | 6.51           | 0.02   | 0.0196           |
| 27.22          | 0.00275| 0.0023           | 5.95           | 0.021  | 0.0206           |
| 24.62          | 0.003  | 0.0026           | 5.40           | 0.022  | 0.0216           |
| 22.74          | 0.0035 | 0.0031           | 4.87           | 0.023  | 0.0226           |
| 19.52          | 0.005  | 0.0046           | 4.35           | 0.024  | 0.0236           |
| 18.00          | 0.006  | 0.0056           | 3.85           | 0.025  | 0.0246           |
| 16.70          | 0.007  | 0.0066           | 3.36           | 0.026  | 0.0256           |
| 15.56          | 0.008  | 0.0076           | 2.88           | 0.027  | 0.0266           |
| 14.53          | 0.009  | 0.0086           | 2.41           | 0.028  | 0.0276           |
| 13.58          | 0.01   | 0.0096           | 1.95           | 0.029  | 0.0286           |
| 12.69          | 0.011  | 0.0106           |                |        |                  |

Table 7. Tensile Behaviour of f'_c = 30 MPa concrete
| Stress (N/mm²) | Strain | Inelastic Strain |
|---------------|--------|------------------|
| 0             | 0      | 0                |
| 3.05629       | 0.0001 | 0.0000000        |
| 1.67012       | 0.0005 | 0.0003896        |
| 1.26571       | 0.001  | 0.0008896        |
| 0.95923       | 0.002  | 0.0018896        |
| 0.81562       | 0.003  | 0.0028896        |
| 0.72696       | 0.004  | 0.0038896        |
| 0.66488       | 0.005  | 0.0048896        |
| 0.61812       | 0.006  | 0.0058896        |
| 0.58116       | 0.007  | 0.0068896        |
| 0.55093       | 0.008  | 0.0078896        |
| 0.52558       | 0.009  | 0.0088896        |
| 0.50389       | 0.01   | 0.0098896        |
| 0.48504       | 0.011  | 0.0108896        |
| 0.46845       | 0.012  | 0.0118896        |
| 0.45369       | 0.013  | 0.0128896        |
| 0.44044       | 0.014  | 0.0138896        |
| 0.42845       | 0.015  | 0.0148896        |

3.3. Experimental modelling
After define parts and properties of each material, every assign past to be assembly, as seen in experimental model of Jones [10] include its boundary condition (Figure 1). The model assembly, include the boundary condition and loading position had been captured in Figure 10, it is the same to Numerical model by Casita [4]. Bottom-End of the column are hinged, then there is roll in Up-End of it that restraint the column from vertical displacement. Loads are given in Right-End and Left-End of the beam section, using same load as SAC Protocol of Jones (Figure 3), the model displacement curve captured in Figure 11. The Left-End side are given Upright displacement load, then in the Right-End side there are downright displacement load.
4. RESULT AND DISCUSSION
From modelling four types in this research, there are two components that could be compared to. The first one is the von mises stress diagram that could give information about position of the greatest stress value (where the first yield location is and where the possibility of failure location). Figure 12 shows the von mises stress from the model without RBS (BB) and the figure 13 shows the stress from connection model with RBS (BRBS), then the figure 14 and 15 show the location of highest von mises stress of each model. On the last two figures of von mises, there are von mises stress diagram of each model on their last step.
Figure 12. Von mises stress value of BB model (First Yield Stress in Step 3 inc. 7)

Figure 13. Von mises stress value of BRBS model (First Yield Stress in Step 3 inc. 7)

Figure 14. First Yield Location of BB model (in Flange of Beam Connection to RCFT)

Figure 15. First Yield Location of BRBS model (in Reduce Section Cut)

Figure 16. Von mises stress of BB model on the last step (highest stress locate on connection)

Figure 17. Von mises stress of BRBS model on the last step (highest stress locate on Reduced Section Cut)
As seen in figure 12 and figure 13, both in BB or BRBS modelling result, found that the plastic joint position could be planned and it is certain that the first melt of around $f_y = 250$ MPa occurs in same step on both models. But at that same step (step – 3) and increment (increment - 7), value of stress in BRBS model are slightly higher and affect more area (shows from the colour) than BB model.

The different statement had been taken from Figure 14 and Figure 15. RBS presence as look on BRBS model ensure that the plastic joints are formed in the reduced section cut area that is located far from the connection to column area, this condition could affect whole structure of building has a ductile response from earthquake load.

The second information of modelling result is the force – rotation angle diagram that was formed due to cyclic load from each model result. Figure 18 shows the force – rotation angle diagram from BB model compared to the force - displacement diagram from BRBS model. That two model’s result were placed in a diagram so it could be compared to directly.

![Figure 18. Force – Rotation Angle Diagram Result](image)

The ultimate force that can be restrained by BB model ($402$ kN) is higher than BRBS model ($257,18$ kN). However, from the comparison diagram above, the result shows that BRBS model has higher rotation angle (0,057 rad) than BB model (0,045 rad), so it means that BRBS model is more ductile than BB model.

5. CONCLUSION
From result of modelling which have been done in this research, there are some conclusion that can be taken as follows:

1. Both in BB or BRBS modeling result found that the plastic joint position could be planned and it is certain that the first melt of around $f_y = 250$ MPa occurs in same step on both models. But at that same step and increment, value of stress in BRBS model are slightly higher and affect more area than BB model.
2. Stress pattern in BB model shows that failure location possibility is in beam flange near the connection, this behavior needs to be avoided in earthquake resistant building.
3. RBS presence as look on BRBS model ensure that the plastic joints are formed in the reduced section cut area that is located far from the connection to column area. This is the behavior that is needed in earthquake resistant building. So RBS presence is more preferable used in building in earthquake prone area.
4. The ultimate force that can be restrained by BB model (402 kN) is higher than BRBS model (257,18 kN) because of reducing of flange area.

5. BRBS model has higher rotation angle (0.057 rad) than BB model (0.045 rad), so it means that BRBS model is more ductile than BB model and more preferable used in building in earthquake prone area.

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