THE REINFORCEMENT METHODS OF THE JOINT BETWEEN RC FRAMES AND STEEL ROOF

Y. Shimada¹, S. Yamada², S. Kishiki³ and T. Hasegawa⁴

ABSTRACT

This study aims the consideration of the reinforcement method in the roof joint between steel roof and RC column based on a series of cyclic loading test. The reinforcement methods in the test are three; (1) using steel restraint & PC steel bar, (2) using steel restraint & post-installed adhesive anchors, and (3) using steel plate & post-installed adhesive anchors. Obtained results show that the method using steel restraint & PC steel bar is effective to prevent falling down of concrete and to increase strength and displacement than other methods because of sufficient reaction force from RC frame and steel restraint hold concrete. While, the method using steel restraint & post-installed adhesive anchors is effective if there is sufficient anchorage length of post-installed adhesive anchor. The method using steel plate & post-installed adhesive anchors is hardly effective to both increase strength and prevent to concrete falling from side of specimen.

¹Assoc. Professor, Faculty of Engineering, Chiba University, Chiba 263-8522 (email: yshimada@faculty.chiba-u.jp)
²Professor, FIRST, IIR, Tokyo Institute of Technology, Yokohama 227-8503
³Assoc. Professor, FIRST, IIR, Tokyo Institute of Technology, Yokohama 227-8503
⁴Chief Research Engineer, Building Research Institute, Tsukuba 305-0802

The Reinforcement Method of the Joint between RC Frames and Steel roof

Y. Shimada¹, S. Yamada², S. Kishiki³ and T. Hasegawa⁴

ABSTRACT

This study aims the consideration of the reinforcement method in the roof joint between steel roof and RC column based on a series of cyclic loading test. The reinforcement methods in the test are three; (1) using steel restraint & PC steel bar, (2) using steel restraint & post-installed adhesive anchors, and (3) using steel plate & post-installed adhesive anchors. Obtained results show that the method using steel restraint & PC steel bar is effective to prevent falling down of concrete and to increase strength and displacement than other methods because of sufficient reaction force from RC frame and steel restraint hold concrete. While, the method using steel restraint & post-installed adhesive anchors is effective if there is sufficient anchorage length of post-installed adhesive anchor. The method using steel plate & post-installed adhesive anchors is hardly effective to both increase strength and prevent to concrete falling from side of specimen.

Introduction

Due to the 2011 Tohoku Earthquake and 2016 Kumamoto Earthquake, many gymnasiums were seriously damaged [1-2]. One of the typical damage in the gymnasiums was failure at the joint between RC frames and the steel roof as shown Figure 1. It has already shown that the edge failure of joint is easy to occur as edge distance of joint is small [3-4]. Authors have shown in [5] that the maximum strength of the roof joint without sufficient edge distance is similar or smaller than the corn failure strength calculated by design recommendation in Japan [6]. Moreover, the failure mode of these joints changes from edge failure to anchor failure or shear failure as the value of edge distance. However, if the edge distance is enough, the lack of reinforcement for shear force makes these roof joints shear failure. Shear failure generally occurs with less maximum strength than edge failure, therefore, it is quite dangerous for human lives under earthquake [1-2, 4]. In the existing buildings, there is often some excessive concrete at the top of the RC column without sufficient shear reinforcements. The top of the RC column needs to be reinforced enough to prevent early shear.

This study aims the consideration of the reinforcement method in the roof joint. Thinking the

¹Assoc. Professor, Faculty of Engineering, Chiba University, Chiba 263-8522 (email: yshimada@faculty.chiba-u.jp)
²Professor, FIRST, IIR, Tokyo Institute of Technology, Yokohama 227-8503
³Assoc.Professor, FIRST, IIR, Tokyo Institute of Technology, Yokohama 227-8503
⁴Chief Research Engineer, Building Research Institute, Tsukuba 305-0802
previous construction and damage survey, we picked up three reinforcement methods for the roof joint. Each reinforcement method has some advantages and disadvantages in the strength, displacement, and the easiness of construction work, etc. We clarified the effect of each method based on the cyclic loading test.

**Test Specimen**

In order to clarify how is effective the reinforcement methods, a series of loading test in the roof joint is conducted. Figure 1 shows test specimen detail. Specimen is represented the joint between the steel roof and the top of the RC column using four anchor rods. The section of RC column is 480mm*480mm*450mm, and it has eight longitudinal reinforcing bar (nominal diameter is 25mm and steel grade is over 345N/mm²) and some transverse stirrups (rebar with 10mm in nominal diameter and 295N/mm² in grade) @ 70mm. The top end of each reinforcing bar has 180 degrees hook, the bottom end of it is welded to steel plate with 25mm thickness in the bottom of specimen. The mortar in 270mm*270mm section is filled between RC column and base plate. In this test, the mortar is poured one week after RC column was poured. The mortar was kept under non stress condition until test start. Here, the top of RC column in the existing buildings often have the area without both reinforcement bars and stirrups, so that, the depth between the top of reinforcing bar to the top surface of RC column is determined 100mm. Anchor rods are four high-tension bolts (nominal diameter 20mm and grade is 235 N/mm²) with 500mm lengths (the anchorage length is 420mm). A nut is attached at the bottom of each anchor inside the concrete. These are used structural roll-formed anchor rods because the early fracture of the anchors should be prevented and the reinforcement effect for RC column should be considered sufficiently.

![Figure 1. Test specimen detail](image)

The strengths of concrete and mortar are shown in Table 1. Compression strength of concrete is designed 24N/mm², however, the both results of compression test are stronger than the designed values. The strengths of anchor rod, stirrup, PC steel bar and steel plate are shown in Table 2.
Table 1. Strength of concrete and mortar.

<table>
<thead>
<tr>
<th>Test date (Day)</th>
<th>Comp. Strength ( \text{(N/mm}^2 )</th>
<th>Fracture strength ( \text{(N/mm}^2 )</th>
<th>Elastic stiffness ( \text{(N/mm}^2 )</th>
<th>Test date (Day)</th>
<th>Comp. Strength ( \text{(N/mm}^2 )</th>
<th>Fracture strength ( \text{(N/mm}^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>27.0</td>
<td>2.75</td>
<td>25000</td>
<td>27</td>
<td>16.7</td>
<td>1.93</td>
</tr>
<tr>
<td>57</td>
<td>29.4</td>
<td>3.02</td>
<td>25000</td>
<td>50</td>
<td>21.1</td>
<td>2.16</td>
</tr>
</tbody>
</table>

*Each value is the average of three test pieces

Table 2. Strength of Anchor, rebar, PC steel bar, steel restraint and steel plate.

<table>
<thead>
<tr>
<th>Use location</th>
<th>Spec</th>
<th>Yield strength ( \text{[N/mm}^2 )</th>
<th>Tensile strength ( \text{[N/mm}^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor</td>
<td>M20 (ABR400)</td>
<td>358</td>
<td>449</td>
</tr>
<tr>
<td>Reinforcing bar</td>
<td>D25 (SD345)</td>
<td>390</td>
<td>560</td>
</tr>
<tr>
<td>Stirrup</td>
<td>D10 (SD295A)</td>
<td>339</td>
<td>472</td>
</tr>
<tr>
<td>PC steel bar</td>
<td>called 13mm SBPR785/1030</td>
<td>1039</td>
<td>1115</td>
</tr>
<tr>
<td>Post-installed adhesive anchor</td>
<td>D22 (SD345)</td>
<td>E-03</td>
<td>393</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E-04, E-05</td>
<td>396</td>
</tr>
<tr>
<td>Steel restraint &amp; steel plate</td>
<td>PL-9 (SM490A)</td>
<td></td>
<td>412</td>
</tr>
</tbody>
</table>

The test parameter is reinforcement method. E-01 specimen is non-reinforcement specimen. E-02 specimen has a U-shaped steel plate (it calls steel restraint in following) located in the front and both side of the specimen which is made of PL-9 (steel grade is 325N/mm²) with 400mm height from the top surface. The steel restraint has reaction force from reaction jig by four PC steel bars (nominal diameter is 13mm and grades is 785N/mm²). Two PC steel bars are set at 65mm position, and the other two are set at 335mm position from the top surface of RC column. Here, pre-stress for each PC steel bar is set about 1kN. This reason that pre-stress is seldom installed to PC steel bars if the beam or wall of buildings which PC steel bars sanded is thin. E-03 specimen has also U-shaped steel restraint as similar as E-02 specimen. The difference of E-01 and E-02 is how to fix the steel restraint. E-02 specimen uses four post-installed adhesive anchors (rebar with 22mm in nominal diameters and 345N/mm² in grade). The effective anchorage length of them is 178mm in order that the edge of post-installed adhesive anchor located inner than reinforcing bar’s position. Here, nuts of these anchors are tied by hand to prevent extra tension force. Two anchors are set at 65mm position from the top surface of RC column to resist the push-out of steel restraint, and the others are set at 335mm position to retain the steel restraint in original position. E-04 and E-05 specimens use steel plate and post-installed adhesive anchor (the diameters are 22mm and the grades are 345N/mm²). The effective anchorage length in E-04 is 278mm, while, the length in E-05 is 60mm in order to examine the failure mode if the anchorage length of the post-installed adhesive anchor is insufficient. The position of the post-installed adhesive anchor
in E-04 and E-05 specimens are also 65mm and 335mm from the top surface of RC column. The nuts of these anchors are also tied by hand to prevent extra tension force.

Figure 2. The specimen detail.

Test Setup

The test setup is shown in Figure 3. The bottom of specimen is jointed to the loading block which can move to horizontal direction. Horizontal load is added by hydraulic jacks connecting to the loading block. On the other hand, the top of specimen is jointed to the jig which is represented the base of steel roof. The jig is connected to the reaction block through loading beam. Vertical load is added by three hydraulic jacks connecting through the reaction block. These hydraulic jacks for vertical load control the location of the reaction block not to fall to the outside of loading direction.
Measurement

In measurement, shear force \( (Q) \) and axial force \( (P) \) of specimen are obtained using the sum of components of horizontal and vertical forces. These are measured by the bi-directional force meters at the top of the hydraulic jacks and reaction blocks. Bending moment \( (M) \) of specimen at the center of the base plate is obtained using the product between \( Q \) or \( P \) and horizontal and vertical moment arms. The value of the moment arms are modified according to the deformation of the reaction block because the moment arms are valid. Load is controlled by the horizontal force measured by the bi-directional force meters.

The horizontal displacement of specimen \( (\delta_h) \) as shown in Figure 4 is calculated by the difference from the horizontal displacement of the loading jig to the horizontal displacement of the reaction block, and the gap between specimen side and the loading jig. The vertical displacement of specimen \( (\delta_v) \) is the vertical displacement of the reaction block because both the reaction frame and loading jig are rigid. The rotation angle of specimen \( (\theta) \) is measured by two vertical displacement of the reaction block and the distance.

Figure 3. The test setup

Figure 4. The measurement system
Loading Protocol

At the beginning of loading, the specimen is added 50kN for compression as a constant axial force which is represented to steel roof mass. The gap of axial force is kept within ±10kN by controlling the displacements of three vertical hydraulic jacks. The axial force is completed, the horizontal force is added by controlling the load of the horizontal hydraulic jack before some failure in specimen occurs. The positive direction of load and horizontal displacement is defined by the direction of pushing out the specimen’s edge from the forward anchors. The loading amplitude in the first cycle is 30kN which is meant to about 20% of shear strength of anchors against temporary loads. The increment of every loading amplitude is 30kN after the first cycle. The load in an amplitude is repeated twice, the two loading cycle with same amplitude are called a loading set in the study. If concrete failure occurs, the loading amplitude is not able to increase. Therefore, the loading protocol changes to controlling using to the displacement of the loading jig. The positive loading is controlled based on the horizontal displacement difference in the last two loading amplitudes. On the other hand, the negative loading is constant to the negative displacement in the last loading amplitude.

Test Results

The maximum values and material data in each specimen obtained by test results are shown in Table 3. $Q_c$ in these table is meant that the corn failure strength calculated by evaluation formula in composite design specification in Japan [5], which used the presuming strength of concrete obtained from liner interpolation of material test results according to the test age. Here, $Q_c$ is twice of the strength of the two anchors at the side of 125mm in edge distance because it supposes that each anchor received the stress from the base plate equally till the concrete fracture occur.

Table 3. Test results

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Test date (Day)</th>
<th>Concrete estimated strength by test date (N/mm$^2$)</th>
<th>Corn failure strength ($Q_c$) (kN)</th>
<th>Max. strength ($Q_{max}$) (kN)</th>
<th>Disp. when specimen reached max. strength (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-01</td>
<td>41</td>
<td>27.7</td>
<td>137.5</td>
<td>122.5</td>
<td>7.0</td>
</tr>
<tr>
<td>E-02</td>
<td>43</td>
<td>27.9</td>
<td>138.0</td>
<td>269.4</td>
<td>178.5</td>
</tr>
<tr>
<td>E-03</td>
<td>50</td>
<td>28.7</td>
<td>139.7</td>
<td>190.7</td>
<td>132.4</td>
</tr>
<tr>
<td>E-04</td>
<td>54</td>
<td>29.1</td>
<td>140.7</td>
<td>146.8</td>
<td>11.0</td>
</tr>
<tr>
<td>E-05</td>
<td>55</td>
<td>29.2</td>
<td>140.9</td>
<td>137.7</td>
<td>10.2</td>
</tr>
</tbody>
</table>

Figure 5 shows the relationships between shear force and horizontal displacement in each specimen. In Figure 5, white triangle shows the maximum strength of positive loading, the gray line shows the results of E-01 specimen in the close-up relationships of E-02 to E-05 specimens. In all specimen, early failure of base mortar around anchors was occurred, so that, almost horizontal displacement of specimen was occurred between the base plate and RC column till concrete failure happened. The progress of each specimen is shown as following. E-01 specimen occurred shear crack when specimen’s strength was +120.6kN, and shear failure of concrete when the specimen reached the
maximum strength in positive loading (+122.5kN). Here, + in front of the strength value indicates positive loading, the symbol of – indicates negative loading, and this notation method is the same as the following. During the specimen’s strength decreasing after the maximum strength, some concrete block in the front of the specimen felt down by the edge failure of concrete as shown in Figure 5(a) iii).

In E-02 specimen, the internal concrete failure was considered to have occurred when the specimen reached the first peak of the strength (+117.2kN). As described in the next section, the strain of PC steel bar began to rise at the same time as the reduction of specimen’s strength was observed after the first peak, so that, it seems that shear force began to flow to the steel restraint. As the load continued, when specimen’s strength reached +200.8kN, the concrete broke horizontally between the upper and lower reaction jigs as shown in Figure 5(b) iii). In this timing, a large strain switched from the upper PC steel bar to the lower PC steel bar. Ultimately, the lower PC steel bar fractured and specimen’s strength lost suddenly without concrete falling. While, out-of-plane displacement of the steel restraint occurred due to subduction of the base plate into concrete under fully collapse of base mortar and extrusion of concrete out-of-plane. In E-03 specimen, some concrete cracks was observed from the position of the aft anchors to post-installed adhesive anchor when the specimen’s strength once slightly decreases. Second peak of the specimen’s strength was +106.7kN, at the same time, inner concrete failure was occurred according to strain of the steel restraint. The above concrete crack grew and it became large shear concrete failure, however, the concrete did not fall down. One of the reason is that the lower post-installed adhesive anchors were effective to keep the concrete. Another reason is that the steel restraint which did not occur out-of-plane deformation rotated around the lower edge as shown in Figure 5 (c) v), so that the horizontal deformation of the top of this specimen increased.

In E-04 & E-05 specimen, concrete shear cracks and reduction of strength were occurred when the specimen’s strength reached the maximum values. During one-way large deformation added, E-04 specimen with enough effective anchorage length kept the strength 60-70kN, and finally, concrete fell down from side of specimen as shown in Figure 5 (d) iii) and iv). While, E-05 specimen with short effective anchorage length kept the strength 20-30kN, and concrete also fell down from side of specimen at the end as shown in Figure 5 (e) iii) and iv). The steel restraints of E-04 specimen was bent at a position 10mm from the bottom, however, the steel restraint of E-05 specimen did not bent.

According to close-up relationship between shear strength and horizontal displacement, E-02, E-04, and E-05 specimen show similar hysteresis to E-01 specimen. Therefore, the reinforcement methods affect to hysteresis just after concrete failure occurs.
Figure 5. The relationships between shear and horizontal disp.
Conclusions

In order to evaluate the effect of reinforcement method in roof joint between RC frame and steel roof, the seismic performance of three reinforcement method was grasped by cyclic loading test. According to obtained results, the reinforcement method which uses U-shaped steel restraint remarkably increased in maximum strength and displacement than the roof joint without any reinforcement. Here, the steel restraint tied to roof joint with PC steel bar was the largest value in strength and displacement. This is because this reinforcement method got sufficient reaction force from jig represented RC frame. However, these buildings often have RC frame with insufficient strength, the reinforcement method should be decided based on the enough evaluation of buildings ability. While, the reinforcement method which uses post-installed adhesive anchors with sufficient anchorage length instead of PC steel bars are also useful to resist to shear force. Moreover, it is important that the steel restraint is not only cover on the front of roof joint but also the side of roof joint. Only the steel plate in front of joint, concrete might be failed from sides of the joint. Another important thing is that sufficient ensure of anchorage length. The tip of anchor for reinforcement should reach the inner of stirrup position. The effect and conditions in each reinforcement method of roof joint in this study are based on not only joint construction but also the detail and strength around the joint. Therefore, enough survey of the joint detail and consideration of method are needed as reinforcing to existing buildings.

Acknowledgments

This work is supported by Grants-in-Aid for Research from the Building Research Institute in Japan. As executing this study, the collaborative research along Building Research Institute, Tokyo Institute of Technology, Yokohama National University, Osaka Institute of Technology, and Chiba University is organized.

References