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FRACTURE BEHAVIOR OF MULTIPLE ADHESIVE POSTINSTALLED ANCHORS SUBJECTED TO SHEAR FORCE

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Abstract.
In this study, experiments were conducted on post-installed anchors subjected to shear force in order to enhance applicability when post-installed anchors were used for seismic reinforcement. Furthermore, since there were a large number of post-installed anchors when they were actually used, an experiment was conducted in which aăshear force was simultaneously applied to one to four anchors. In this study, it was focused on number and pitch of anchors. Major findings of this study were summarized as follows: in case of 22.46 (N/mm^2) for concrete compressive strength, shear strength of anchors was not double, triple, and quadruple as number of those increased to 2, 3, and 4, and that gradually decreased as number of those increased, the boundary condition between anchor shear rupture and pry-out failure was found that concrete compressive strength was 25.12 (N/mm^2) or less and anchor pitch was 30 to 50 mm, and anchor was tensile strength over SD390.

Keywords: Adhesive post-installed anchor, anchor pitch, multiple anchors, shear strength.

1. Introduction

In Japan, reinforced concrete structures built in 1960s and 1970s were reinforced for sustainable use of buildings due to lack of earthquake resistance. Steel braces were most often used to reinforce buildings, and many anchors were installed in existing buildings to transmit stress to steel braces. Since the stress transmission between the existing building and the steel brace had a high ratio of shear force, when using the post-installed anchor for seismic reinforcement, the anchor reinforcement should be designed with shear performance. However, for post-installed anchors, structural standards in Japan [1] were determined based on tensile performance of one anchor to ensure safety. The above-mentioned problem should be considered in terms of shear performance, but had been limited in effective use due to standards for tensile performance. On the other hand, there were many tensile tests about one anchor, and there were shear tests about it, but in any case, experiment about it had been done according to past studies. Therefore, in this study, experiments were conducted on post-installed anchors subjected to shear force in order to enhance applicability when post-installed anchors were used for seismic reinforcement. Furthermore, experiments were conducted in which not only one anchor but also multiple anchors were subjected to shear force simultaneously.

For post-installed anchors, various factors such as anchor tensile strength, concrete compressive strength, embedding depth, anchor pitch, and clearance distance should be considered. As mentioned above, although there were various factors, it was necessary to narrow down the parameters. Therefore, the embedding depth was constant, and the experiment was conducted focusing on differences in concrete strengths, anchor strengths, and anchor pitches. As an additional note, the anchor bars were installed at a sufficient distance from the edge of the concrete so as not to consider the edge rupture.

2. Test Program

2.1. Specimens

Properties of specimens were summarized in Table 1. There were 23 specimens in total. Most of the test results were based on reference [2]. The added specimens were marked with * in the Table 1. The anchor was used deformed bar of nominal diameter of 10mm(D10). The post-installed anchor arrangement was made such that only one anchor is arranged, two anchors are arranged along loading direction (D_p = 100mm, $D_p/d_a = 10$, d_a: nominal diameter), three anchors are arranged (Dp = 50mm, $D_p/d_a = 5$), and four anchors are arranged (D_p = 30mm, D_p/d_a = 3). In other words, pitches of two, three and four anchors were arranged along loading direction at 100, 50 and 30mm, respectively. The compressive strengths of concrete were 3 types of 23.12, 25.12 and 29.34 (N/mm^2). Materials of anchors were used SD390 and SD295. The embedded depth was constant 70mm ($7\,d_a$). An epoxy resin was used as a fixing agent for the post-installed anchor.

<table>
<tr><th>Serial number</th><th>Material of Anchor</th><th>σ_y MPa</th><th>σ_u MPa</th><th>E_s GPa</th><th>n</th><th>D_p (mm)</th><th>σ_B MPa</th><th>E_c GPa</th><th>Quantity</th></tr>
<tr><td>1</td><td rowspan="12">SD390
D10</td><td rowspan="12">428</td><td rowspan="12">590</td><td rowspan="12">209</td><td>1</td><td>–</td><td rowspan="4">29.34</td><td rowspan="4">26.9</td><td rowspan="4">1</td></tr>
<tr><td>2</td><td>2</td><td>100</td></tr>
<tr><td>3</td><td>3</td><td>50</td></tr>
<tr><td>4</td><td>4</td><td>30</td></tr>
<tr><td>5</td><td>1</td><td>–</td><td rowspan="4">25.12</td><td rowspan="4">23.1</td><td rowspan="4">1</td></tr>
<tr><td>6</td><td>2</td><td>100</td></tr>
<tr><td>7</td><td>3</td><td>50</td></tr>
<tr><td>8</td><td>4</td><td>30</td></tr>
<tr><td>9</td><td>1</td><td>–</td><td rowspan="4">23.12</td><td rowspan="4">24.6</td><td>1</td></tr>
<tr><td>10 - 1,2</td><td>2</td><td>100</td><td>2*</td></tr>
<tr><td>11</td><td>3</td><td>50</td><td>1</td></tr>
<tr><td>12 - 1,2</td><td>4</td><td>30</td><td>2*</td></tr>
<tr><td>13</td><td rowspan="8">SD295
D10</td><td rowspan="8">345</td><td rowspan="8">479</td><td rowspan="8">183</td><td>1</td><td>–</td><td rowspan="4">29.34</td><td rowspan="4">26.9</td><td rowspan="4">1</td></tr>
<tr><td>14</td><td>2</td><td>100</td></tr>
<tr><td>15</td><td>3</td><td>50</td></tr>
<tr><td>16</td><td>4</td><td>30</td></tr>
<tr><td>17</td><td>1</td><td>–</td><td rowspan="4">22.46</td><td rowspan="4">31.4</td><td>1</td></tr>
<tr><td>18</td><td>2</td><td>100</td><td>1</td></tr>
<tr><td>19 - 1,2</td><td>3</td><td>50</td><td>2*</td></tr>
<tr><td>20</td><td>4</td><td>30</td><td>1</td></tr>
</table>

Table 1. Properties of Specimens.

2.2. Loading Method and Instrumentation

A loading apparatus was shown in Figure 1. The loading method was monotonous loading. Shear force was simultaneously applied to a plurality of arranged anchors using a loading frame. Shear force was measured by a load-cell installed outside a loading frame. The displacement between tensile tool and concrete was measured by two displacement transducers. The average value of these outputs was taken as the shear displacement. This value was evaluated as a shear displacement, although the flexural deformation of the anchor bar was included.

3. Test Results

3.1. Shear Force - Shear Displacement Relations

Shear force-shear displacement relations were shown in Figure 2 for each concrete compressive strength and anchor tensile strength. In Figure 2, the experimental values of four anchors, three anchors, two anchors and one anchor were shown by a solid line, a two-dot chain line, a one-dot chain line and a dotted line, respectively. Although some specimens showed experimental values with different initial stiffness due to construction accuracy, they roughly showed the same initial stiffness even when the number and pitches of anchors were different. As the shear force increased, the local concrete gradually failed in compression and the flexural moment of anchors gradually increased. These states could be clearly seen from the history in Figure 2(c) and (e).

3.2. Crack Pattern and Failure Mode

Examples for crack patterns of concrete and shear ruptures of anchors were shown in Figure 3 and 4. Except for specimens numbered 12-1 and 2, the anchors of the other specimens failed in shear rupture. Specimens numbered 12-1 and 2 using four D10(SD390) anchors and a concrete compressive strength of 23.12 (MPa) failed in pry-out. The above mentioned pry-out failure was a type of concrete failure that was scraped as shown in Figure 4(a). As a result, two of the four anchors did not rupture in shear. For a specimen numbered 8 using four D10(SD390) anchors and a concrete compressive strength of 25.12 (MPa), although the anchors eventually failed in shear rupture, as shown in Figure 4(b), diagonal cracks occurred on the back in the loading direction. This could be judged as a sign of a pry-out failure. The cracks for specimens of one and two anchors were isolated as shown in Figure 3(a) and (b). On the other hand, cracks for specimens of three and four anchors were connected as shown in 3(c) and (d). In the next chapter, the maximum shear force and the shear displacement at the maximum shear force were discussed based on the hysteresis, crack and anchor fracture properties.

4. Discussions

4.1. Maximum Shear Force - Number of Anchors Relations

Maximum shear force-number of anchors relations used with SD295 were shown in Figure 5. In Figure 5, maximum shear forces with the compressive

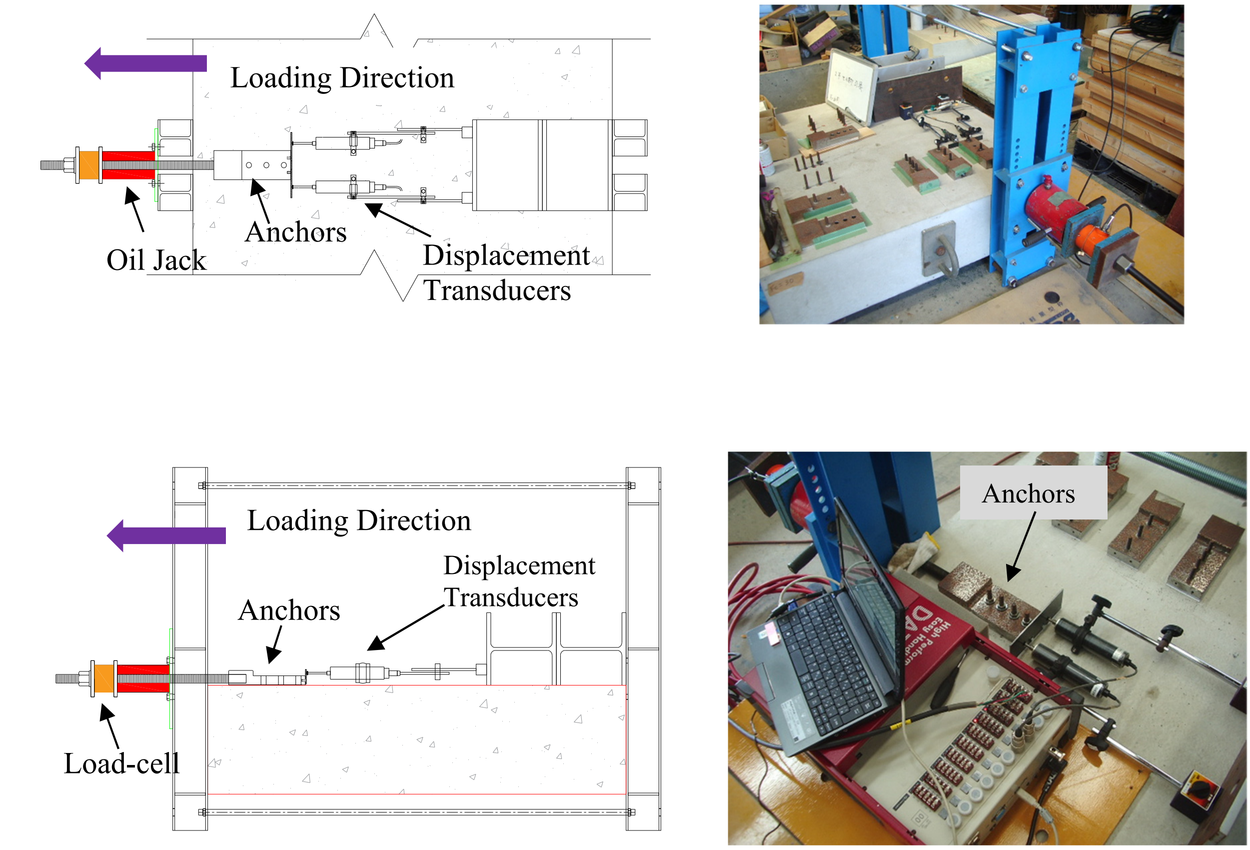


FIGURE 1. (a) Framing Plan of Loading Apparatus, Loading Apparatus. (b) Elevation of Loading Apparatus, Loading Apparatus.

concrete strengths of 22.46 and 29.34 (N/mm^2) were shown by triangles and circles respectively. When the average of the maximum shear force for one anchor was calculated without considering the concrete strength, it was 28.04 (kN). The value obtained by multiplying that by the number of anchors was shown by a dotted line in Figure 5. Maximum shear forces with a concrete strength of 22.46 (N/mm^2) tended to be lower than the dotted line. On the other hand, Maximum shear forces with a concrete strength of 29.34ă(N/mm^2) tended to be larger than the dotted line.

Maximum shear force-number of anchors relations used with SD390 were shown in Figure 6. In Figure 6, maximum shear forces with the compressive concrete strengths of 23.12, 25.12 and 29.34 (N/mm^2) were shown by squares, diamonds and circles respectively. The maximum shear forces with the compressive concrete strengths of 23.12 and 25.12 (N/mm^2) for specimens failed in pry-out were shown by asterisks and a cross respectively. When the average of the maximum shear force for one anchor was calculated without considering the concrete strength, it was 35.96 (kN). The value obtained by multiplying that by the number of anchors was shown by a dotted line in Figureă4. Maximum shear forces with a concrete strength of 23.12 (N/mm^2) tended to be lower than the dotted line. Maximum shear forces with a concrete strength of 29.34 (N/mm^2) were almost on the dotted line. Considering these results and the above-mentioned crack patterns, the boundary condition between anchor shear rupture and pry-out failure was found that concrete compressive strength was 25.12 (N/mm^2) or less and anchor pitch was 30 to 50mm, and anchor was tensile strength over SD390. In this study, since the embedded depth of the anchor was constant 70mm (7da), the embedded depth was not considered. When the hysteresis of the four anchors and that of the three anchors in Figure 2 were compared again from the above viewpoint, signs could be confirmed that the second stiffness was almost the same. Furthermore, by examining the boundary conditions precisely hereafter, it would be possible to install the anchor at a shorter pitch than the current standards [1] in Japan when using the anchor for seismic reinforcement.

4.2. Displacement at Maximum Shear Force - Pitches of Anchors Relations

Displacement at maximum shear force-pitches of anchors relations used with SD295 were shown in Figure 7. In Figure 7, displacements at maximum shear force with the compressive concrete strengths of 22.46 and 29.34 (N/mm^2) were shown by triangles and circles respectively. Linea approximation lines with the compressive concrete strengths of 22.46 and 29.34 (N/mm^2) were shown by a dotted and one-dot chain

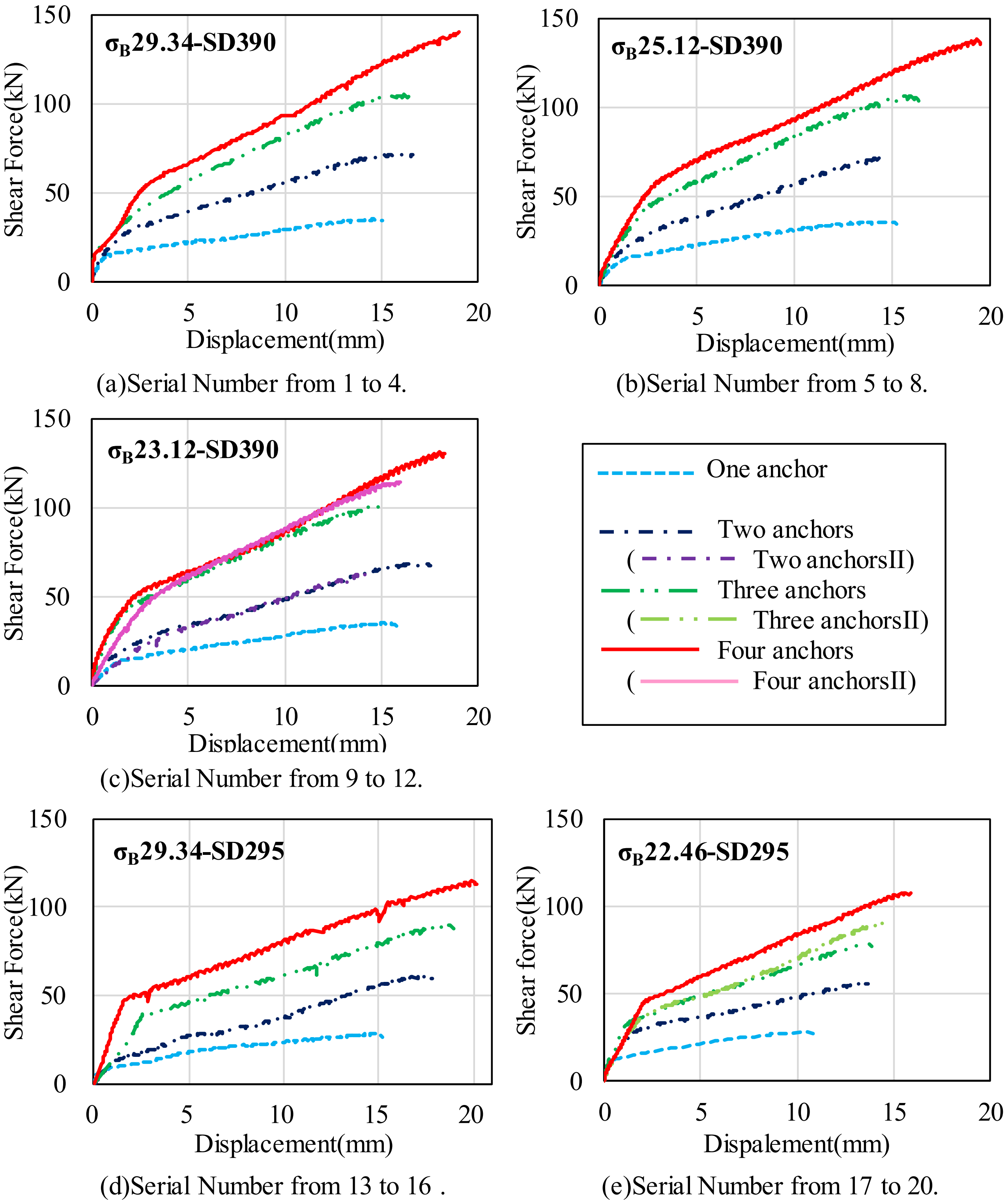
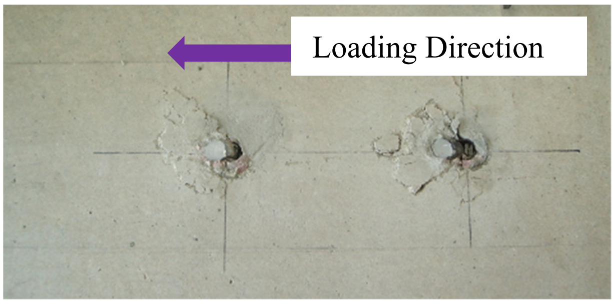


FIGURE 2. Shear Force - Shear Displacement Relations.

(a). Serial Number 17 (one anchor).

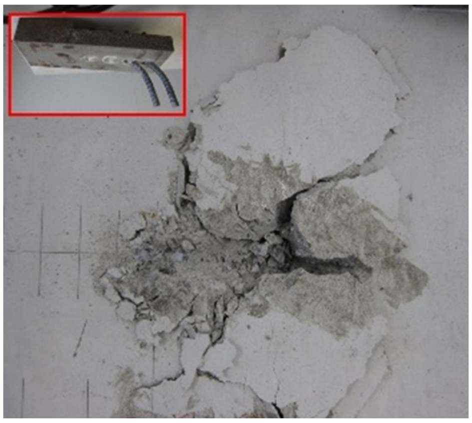


(b). Serial Number 18 (two anchors).

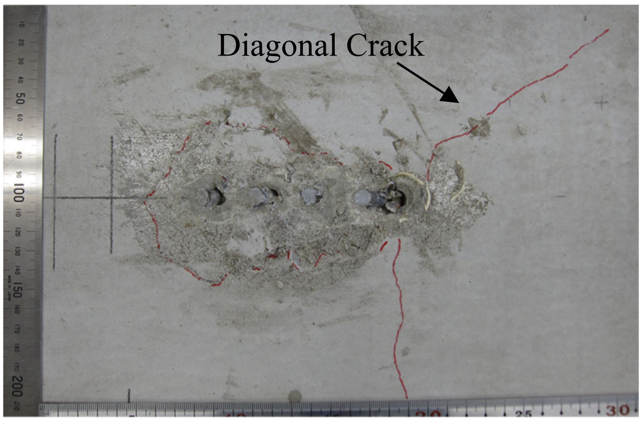
(c). Serial Number 19-1 (three anchors).

(d). Serial Number 20 (four anchors).

Figure 3. Examples for Crack Patterns of Concrete and Shear Ruptures of Anchors.



(a). Serial Number 12-1 (four anchors).



(b). Serial Number 8 (four anchors).

Figure 4. Pry-out Failure and Diagonal Cracks (Sign of Pry-out Failure).

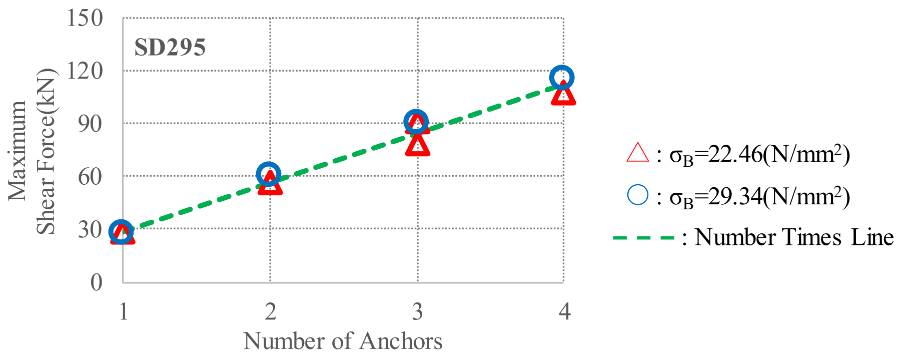


Figure 5. Maximum shear force-number of anchors relations. (SD295).

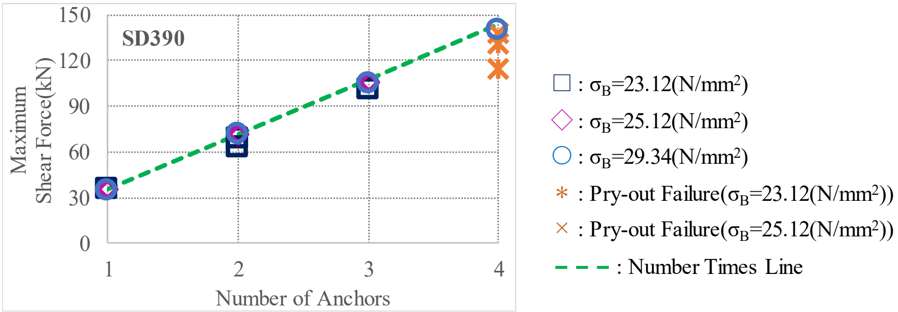


FIGURE 6. Maximum shear force - number of anchors relations. (SD390).

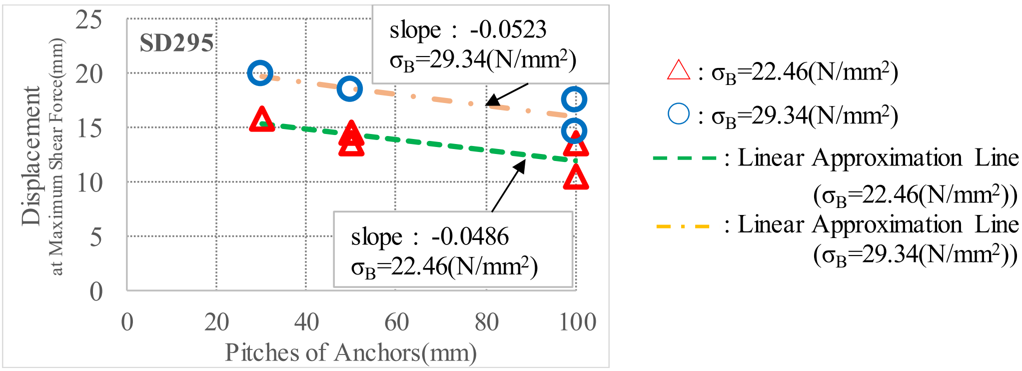


FIGURE 7. Displacement at maximum shear force - pitches of anchors relations. (SD295)

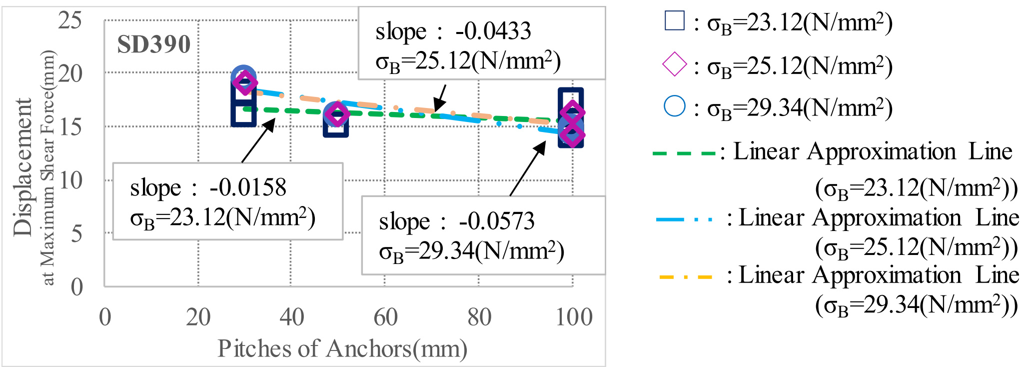


FIGURE 8. Displacement at maximum shear force - pitches of anchors relations. (SD390)

line respectively in Figure 7. The anchor pitch was considered appropriate for the horizontal axis when evaluating shear displacement, but one anchor did not have a pitch. Therefore, the crack pattern for the two anchors was referred to in Figure 3(b). The pitch for the two anchors was 100 (mm), the cracks did not interfere each other. Consequently, the pitch of one anchor was considered as 100mm and discussed afterwards. In Figure 7, the slopes of the linear approximation line for each concrete strength were shown. These slopes tended to increase the displacement at maximum shear force as the pitch became shorter.

Displacement at maximum shear force-pitches of anchors relations used with SD390 were shown in Figure 8. In Figure 8, displacements at maximum shear force with the compressive concrete strengths of 23.12, 25.12 and 29.34 (N/mm^2) were shown by squares, diamonds and circles respectively. Linea approximation lines with the compressive concrete strengths of 23.12, 25.12 and 29.34 (N/mm^2) were shown by a dotted, two-dot chain and one-dot chain line respectively in Figure 8. With the same idea as above, the pitch of one anchor was considered as 100mm and discussed afterwards. In Figure 8, the slopes of the linear approximation line for each concrete strength were shown. Although the slope with SD390 was lower than the slope with SD295, the displacement at maximum shear force tended to increase as the anchor pitch became shorter.

These meant that as the anchor pitch became shorter, the compressive failure zone for the concrete was expected deeper from the surface.

5. CONCLUSIONS

The following conclusions can be drawn from the present study about multiple adhesive post-installed anchors subjected to shear force:

1. Except for two specimens, the anchors of the other specimens failed in shear rupture. The two specimens with four D10(SD390) anchors and a concrete compressive strength of 23.12 (MPa) failed in pry-out. For the specimen with four D10(SD390) anchors and a concrete compressive strength of 25.12 (MPa), although the anchors eventually failed in shear rupture, diagonal cracks occurred on the back in the loading direction. This could be judged as a sign of a pry-out failure.
2. Maximum shear forces with a concrete strength of 22.46 (N/mm^2) tended to be lower than the line obtained by multiplying the maximum shear force for one anchor by the number. In other words, in case of 22.46 (N/mm^2) for concrete compressive strength, shear strength of anchors was not double, triple, and quadruple as number of those increased to 2, 3, and 4, and that gradually decreased as number of those increased.

Considering these results, the boundary condition between anchor shear rupture and pry-out failure was found that concrete compressive strength was 25.12 (N/mm^2) or less and anchor pitch was 30 to 50mm, and anchor was tensile strength over SD390.

3. Considering the pitch of one anchor as 100ămm, the slopes of the linear approximation line for each concrete strength tended to increase the displacement at maximum shear force as the pitch became shorter.

As a result, when the anchor pitch was shortened, the compressive failure zone for the concrete was expected deeper from the surface, and the displacement at the maximum shear force was increased.

From the above conclusions, it was found qualitatively that the correlation between concrete compressive strength, anchor pitch and anchor tensile strength at the boundary condition between anchor shear rapture and pry-out failure when the embedded depth for anchor was constant. In the future, it is necessary to conduct experiments that can quantitatively evaluate the boundary conditions, and research the relationship between the depth of the compressive zone and the anchor pitch.

And, using these results, we plan to conduct an experiment to investigate the sustained shear load performance of adhesive post-installed anchors as an aid to the sustainable use of the building.

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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the authors' organization, JSPS or MEXT

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