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Basic Properties of Maximum Shear Strength Per One of Densely-Placed Post-Installed Anchors

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Abstract

This study aimed at the development of high strength joint method of reinforced concrete and steel frame, the basic properties of the maximum shear strength per one of densely-placed post-installed anchors were examined experimentally. A total of 20 pull-out specimens were tested to better understand the maximum shear strength per one of densely-placed post-installed anchors. This study conducted a parametric test to find the influential factor, such as anchor arrangement (number of anchors, and anchor pitch length = D_p : center-to-center spacing along loading direction), concrete strength and anchor strength, upon to the maximum shear strength per one of densely-placed post-installed anchors. The anchors used were deformed bar of nominal diameter of 10mm (D10). The post-installed anchors arrangement were made as follows only one anchor was arranged, two anchors were arranged along loading direction (D_p = 100mm, D_p/d_a = 10, d_a: nominal diameter), three anchors were arranged (D_p = 50mm, D_p/d_a = 5), and four anchors were arranged (D_p = 30mm, D_p/d_a = 3). The specified design strengths of concrete were assumed 3 types of 15 N/mm^2, 18 N/mm^2, and 30 N/mm^2. Materials of anchors used were SD390 and SD295. The embedded length was 70mm (7d_a). An epoxy resin was used as a fixing agent for the post-installed anchor. The loading method was monotonous loading. Shear force was simultaneously applied to a plurality of arranged anchors using a loading frame.

Major findings of this study were summarized as below:

1) When SD390 were used, anchors arranged densely with a pitch length of only 3.0d_a can still possess shear strength (per anchor) about 93% of the shear strength of single anchor.
2) When SD295 were used, anchors arranged densely with a pitch length of only 3.0d_a can still possess shear strength (per anchor) about 88% of the shear strength of single anchor.
3) The strength deterioration of maximum shear strength per one post-installed anchors of the anchor material of SD390 was less than that of the anchor material of SD295.

Keywords: Maximum shear strength, Strength deterioration, Anchor pitch, High strength joint method

1. Introduction

In April 2016, great earthquakes were occurred in the Kumamoto region of Kumamoto Prefecture, Japan. Many old RC (reinforced concrete) buildings were severely damaged by the earthquakes [1]. For these reasons, we recognized the importance of seismic retrofitting of old RC buildings. In order to efficiently reinforce of the seismic performance of old RC buildings, the joint between the reinforcing elements such as steel elements, and the main structural elements of the existing RC buildings is also important. In previous studies, we had been studying the shear connection between SFRCC (steel-fiber-reinforced cementitious composites) and densely arranged headed studs to develop a high-strength joint between concrete and steel using SFRCC [2]. Although these were mainly for the steel side at the joint between concrete and steel. On the other hand, the joint on the concrete side was left to be studied. Therefore, the authors experimentally investigated the remaining properties of the joint on the concrete side, especially the basic properties of the maximum shear strength per one of densely-placed post-installed anchors. In addition, the effect of the material strength of the anchor on the maximum shear strength per one of densely-placed post-installed anchors were investigated.

2. Outline of monotonic loading shear test of post-installed anchor

2.1 Outline of test specimens

Table 1 shows the specifications of the test specimens (experiment results will be described later), and Fig. 1 shows the outline of specimens. A total of 20 pull-out specimens were tested to better understand the maximum shear strength per one of densely-placed post-installed anchors.

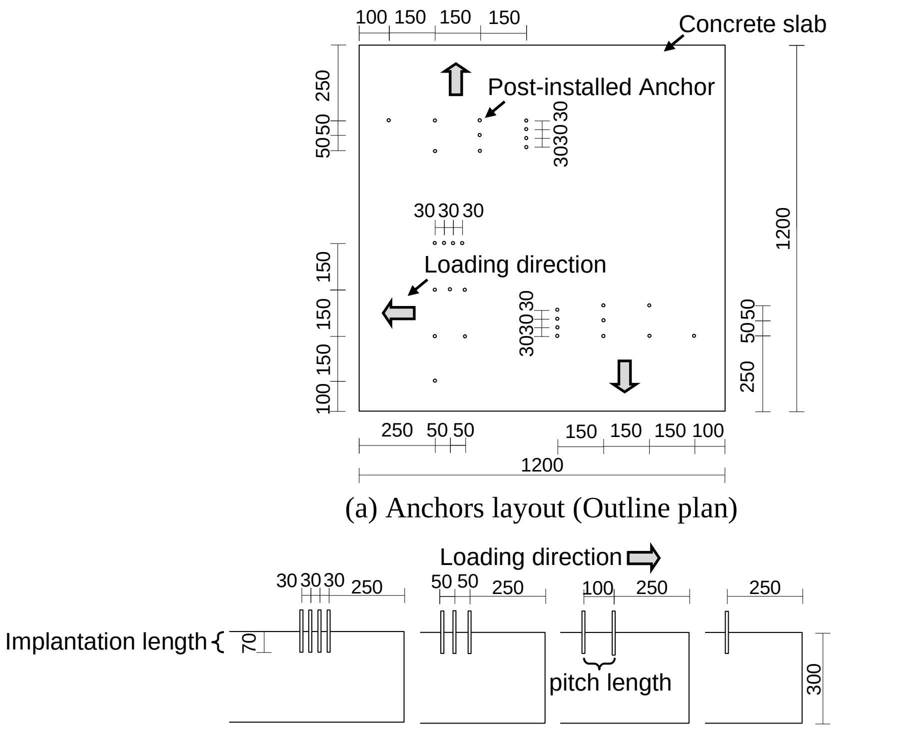
Table 1. Specimen List

No.	Specimen details and material properties										Calculated value		Experimental result		
	Material of anchor	σ_y (N/mm²)	σ_u (N/mm²)	E_s (N/mm²)	n	D_p (mm)	D_p/d_a	F_c (N/mm²)	σ_B (N/mm²)	E_c (N/mm²)	Q_{a1} (kN)	Q_{a2} (kN)	P_{max} (kN)	Failure mode	P_{anchor} (kN)
1	SD390 D10	428	590	2.09×10⁵	1	–	–	15	23.12	2.46×10⁴	①29.5 ②21.4 ③19.5	21.5	35.1	S	35.1
2					2	100	10						68.7		34.4
3					3	50	5						101.1		33.7
4					4	30	3						130.9	C	32.7
5					1	–	–	18	25.12	2.31×10⁴		21.7	35.8	S	35.8
6					2	100	10						71.8		35.9
7					3	50	5						106.1		35.4
8					4	30	3						137.7		34.4
9					1	–	–	30	29.34	2.69×10⁴		25.3	35.0		35.0
10					2	100	10						71.6		35.8
11					3	50	5						104.8		34.9
12					4	30	3						140.4		35.1
13	SD295 D10	345	479	1.83×10⁵	1	–	–	13.5	22.46	3.14×10⁴	①23.9 ②17.2 ③14.7	24.0	28.2		28.2
14					2	100	10						48.4		24.2
15					3	50	5						78.5		26.2
16					4	30	3						107.7		26.9
17					1	–	–	30	29.34	2.69×10⁴		25.3	32.5		32.5
18					2	100	10						64.0		32.0
19					3	50	5						89.8		29.9
20					4	30	3						114.8		28.7

Note: σ_y = Yield strength of anchor; σ_u = Tensile strength of anchor; E_s = Young's modulus of anchor; n = Number of arrangement anchor in the pitch direction; D_p, = Anchor pitch length(center-to-center spacing along loading direction); d_a = Nominal diameter of anchor; F_c = Design standard strength of concrete, σ_B = Compressive strength of corresponding concrete cylinder test; E_c = Young's modulus of concrete; Q_{a1} = Calculated value of anchor shear failure of equation (1) in section 2.4(① was the case using tensile strength of anchor for σ_y', ② was the case using yield strength of anchor for σ_y',③ was the case using standard yield strength of anchor for σ_y'); Q_{a2} = Calculated value of concrete failure of equation (2) in section 2.4; P_{max} = Maximum shear force; Failure mode (see section 3.2) = S was anchor shear failure type, C was concrete failure type; P_{anchor} = per anchor strength, which was obtained by dividing P_{max} by the number of anchor n (P_{max}/n).

This study conducted a parametric test to find the influential factor, such as anchor arrangement (number of anchors, and anchor pitch length = D_p : center-to-center spacing along loading direction), concrete strength and anchor strength, upon to the maximum shear strength per one of densely-placed post-installed anchors. The anchors used were deformed bar of nominal diameter of 10mm (D10). The materials of anchors used were SD390 and SD290. The post-installed anchors arrangement were made as follows only one anchor was arranged, two anchors were arranged along loading direction (D_p = 100mm, D_p/d_a = 10, d_a: nominal diameter), three anchors were arranged (D_p = 50 mm, D_p/d_a = 5), and four anchors were arranged (D_p = 30mm, D_p/d_a = 3). For these, a range smaller than the minimum value of D_p (7.5d_a) shown in Ref.[3] is also studied. The implantation length was 70 mm (7d_a). This is the minimum effective implantation length (7d_a) shown in Ref.[3].

These anchors were installed on a 1200 × 1200 × 300 unreinforced concrete slab. The design standard strength of concrete was assumed 3 types of 15 N/mm^2, 18 N/mm^2, and 30 N/mm^2. An epoxy resin was used as a fixing agent for the post-installed anchors. For the purpose of the discussion below, the name of each concrete slab was used using the material anchor and the design standard strength of concrete. For example, SD390-FC15 indicates specimens with serial numbers 1-4.



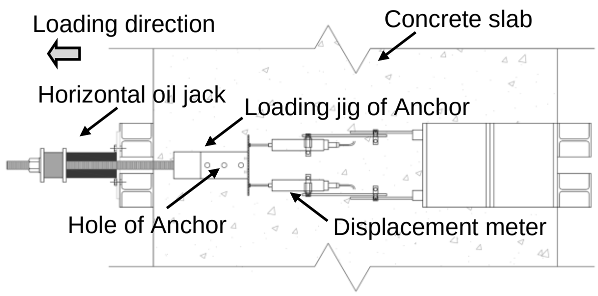
(a) Anchors layout (Outline plan)

(b) Implantation length of anchors (Schematic cross section)

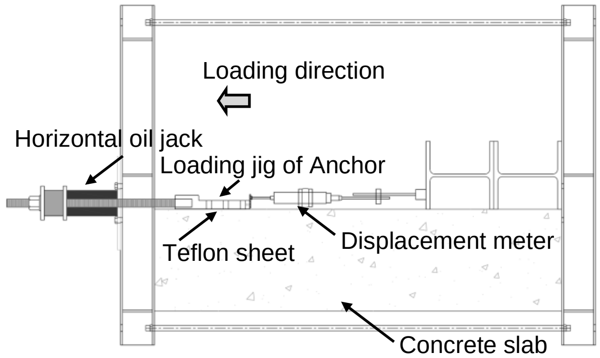
Figure 1. Outline of specimens

2.2 Experiment method

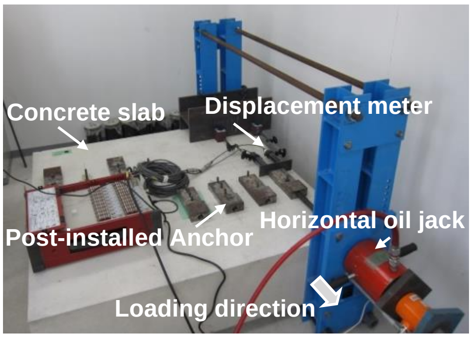
Fig. 2 shows the outline of test. The loading method was monotonous loading. Shear force was simultaneously applied to a plurality of arranged anchors using the loading jig of anchor. The loading jig of anchor had hole for anchor installation (hole of anchor), and the post-installed anchors were passed through the hole of anchor. After that, it was fixed using a washer and a nut so that tension was not applied to the anchor to prevent the loading jig of anchor from floating (the exposed portions of the anchors were threaded). Grout was injected into the gap between the anchor and the hole. A Teflon sheet (1 mm thick) was inserted between the loading jig of anchor and the concrete slab to reduce frictional force.



(a) Outline plan



(b) Rough elevation



(c) Experimental situation

Figure 2. Outline of test

2.3 Measurement method

The values of the load cell attached to the horizontal jack were measured as the shear force acting on the anchors. The displacement of the loading jig of anchor was measured with two displacement meters, and the average values were used as the displacement (shear displacement) of the post-installed anchors. The experiment was terminated when the post-installed anchors were fractured, or the concrete slab was severely damaged, and the load decreased significantly.

2.4 Calculation method of the calculated value of maximum shear strength

The calculated value of maximum shear strength per post-installed anchors is also shown in Table 1. Equations (1) and (2) show how to calculate the calculated value of maximum shear strength per one post-installed anchors [3]. Equation (1) is determined by the strength of the anchors, and equation (2) is determined by the bearing capacity of the concrete.

$$Q_{a1} = 0.7\sigma'_y \cdot {}_s a'_e \quad (1)$$

$$Q_{a2} = 0.4\sqrt{E'_c \cdot \sigma'_B} \cdot {}_s a'_e \quad (2)$$

Here, σ'_y: standard yield strength of anchor, ${}_s a'_e$: cross-sectional area of anchor, E'_c: Young's modulus of concrete, σ'_B: compressive strength of concrete. In this study, σ'_B, E'_c, and σ'_y were used the results of material tests. In all the specimens were used the anchor material of SD390, the calculated value is smaller in equation (2), and the failure mode is expected to be "concrete failure type".

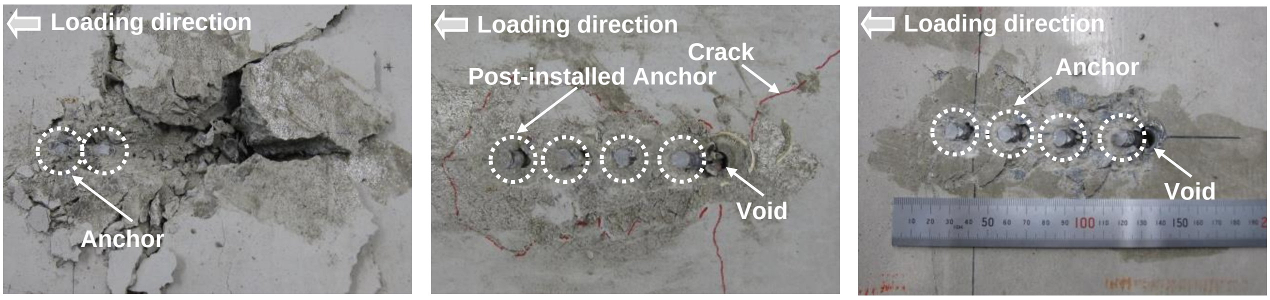
3. Experimental results

3.1 Outline of experimental results

Outline of the experimental results is also shown in Table 1. The maximum shear strength (P_{max}) of the anchor group is the maximum value obtained from the load cell attached to the horizontal jack. The maximum shear strength per one post-installed anchors (P_{anchor}) is the value obtained by dividing P_{max} by the number of anchors (n) arranged in the pitch direction. The following summarizes the failure modes and the shear force - shear displacement relationships.

3.2 Failure modes

In this experiment, the failure modes were roughly classified into the following two types. The case where all the post-installed anchors were fractured were defined as "anchor shear failure type", and the others were defined as "concrete failure type". As an example, Figure 3 shows the damage of a test specimen (D_p/d_a = 3) with four anchors after the experiment. In SD390-FC15, which was became the "concrete failure type", two out of four anchors were fractured, and the other two were pulled out of the concrete slab. The concrete slab was extremely damaged. On the other hand, SD390-FC18 and SD390-FC30 had all four anchors fractured. SD390-FC18 had cracks on the surface layer of the concrete slab but did not show any anchors pulling out. The failure mode in this experiment was "anchor shear failure type" (including the anchor material of SD295) except for all four arrangements of SD390-FC15 (D_p/d_a = 3).



(a) SD390-FC15
(Concrete failure type)

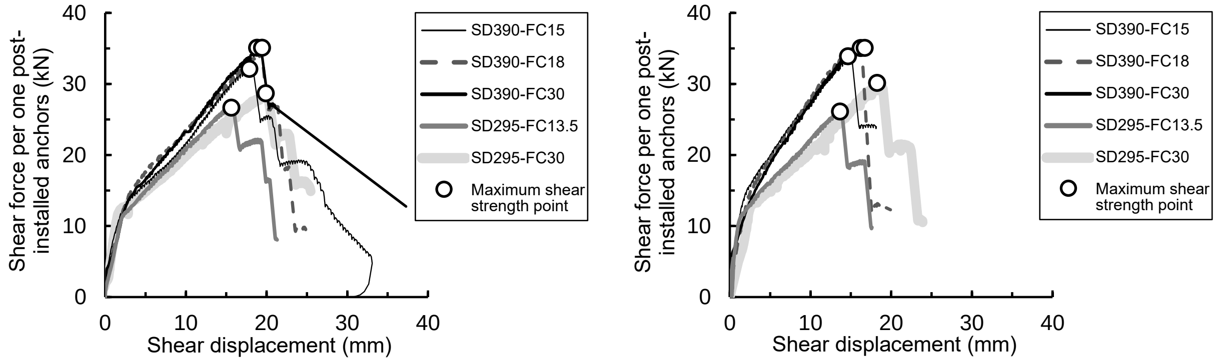
(b) SD390-FC18
(Anchor shear failure type)

(c) SD390-FC30
(Anchor shear failure type)

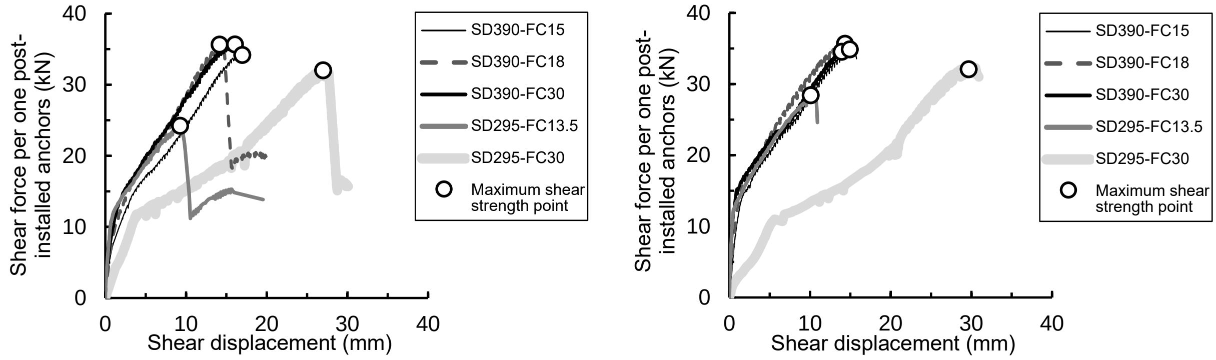
Figure 3. Major damage patterns of specimens

3.3 The shear force - shear displacement relationships

Figure 4 shows the shear force - shear displacement relationship of each specimen for each number of anchors (D_p/d_a). The shear force per one post-installed anchors on the vertical axis is the value obtained by dividing the value obtained from the load cell attached to the horizontal jack by the number of anchors arranged. In the specimen where the failure mode was "anchor shear failure type", the shear force suddenly was decreased after the fracture of the anchors were started. Thus, the fracturing start point of the anchors are the maximum shear strength point. In the test specimens where anchors were densely arranged, not all anchors were fractured at the same time, but sometimes they were fractured several times (for example, the specimen in which four anchors were densely arranged, D_p/d_a = 3).



(a) Four anchors (D_p/d_a=3) (b) Three anchors (D_p/d_a=5)



(c) Two anchors (D_p/d_a=10) (d) One anchor

Figure 4. The shear force – shear displacement relationships

4. Relationship between anchor pitch (D_p) and maximum shear strength

4.1 Evaluation of maximum shear strength per one post-installed anchors (P_{anchor}).

Figure 5 shows comparison between the experimental value and the calculated value of P_{anchor}. For the calculated values, based on the failure mode judged from the experimental results, the value of equation (1) was used for "anchor shear failure type" and the value of equation (2) for "concrete failure type". The experimental values of P_{anchor} are about 1.01 to 1.52 times (average about 1.21 times) the calculated values. In other words, the calculated values are evaluated on the safe side even for the densely-placed post-installed anchors. By the way, the failure mode of the specimens using the anchor material of SD390 were different from the predictions described above, except for one of the specimens of SD390-FC15 (D_p/d_a = 3) in which four anchors were densely arranged. The method of classifying the failure mode of specimens with densely-placed post-installed anchors will be reviewed again.

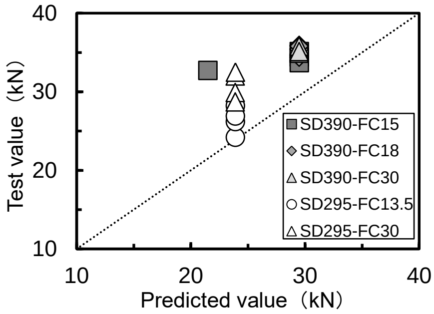
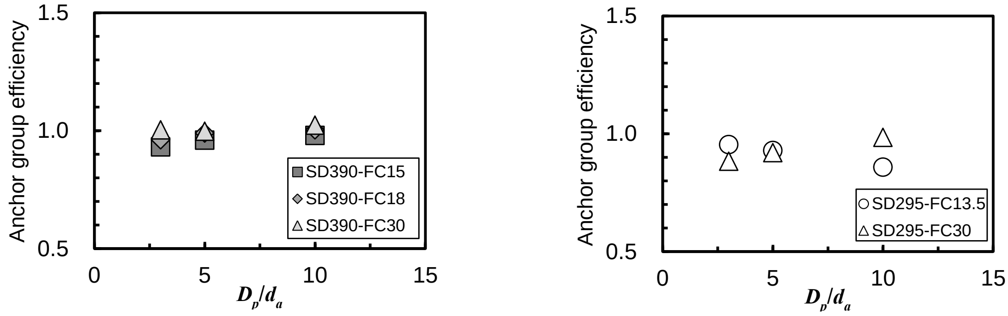


Figure 5. Verification on evaluation method

4.2 Anchor group efficiency using the anchor material of SD390 - D_p/d_a relationships

Figure 6 shows the relationships between the anchor group efficiency and the D_p/d_a of the test specimens using the anchor material of SD390. Here, the anchor group efficiency was defined as the ratio of P_{anchor} with densely-placed post-installed anchors to P_{anchor} with only one post-installed anchor. The anchor group efficiency of SD390-FC15 were 0.98 for D_p/d_a = 10, 0.96 for D_p/d_a = 5, and 0.93 for D_p/d_a = 3. On the other hand, the anchor group efficiency of SD390-FC30 were 1.02 for D_p/d_a = 10, 1.00 for D_p/d_a = 5, and 1.00 for D_p/d_a = 3, and there was no decrease in the strength of P_{anchor} due to the densely-placed post-installed anchors. The lower concrete strength, the smaller the pitch, the smaller the anchor group efficiency becomes. However, up to D_p/d_a = 3, the P_{anchor} of densely-placed post-installed anchors had the shear strength of about 93% for the specimen with single anchor. By the way, the anchor group efficiency of SD295-FC13.5 using the anchor material of SD295 were 0.88 for D_p/d_a = 10, 0.93 for D_p/d_a = 5, and 0.95 for D_p/d_a = 3. On the other hand, the anchor group efficiency of SD295-FC30 were 0.98 for D_p/d_a = 10, 0.92 for D_p/da = 5, and 0.88 for D_p/d_a = 3. At D_p/d_a = 3, the specimen with lower concrete strength had higher anchor group efficiency. In other words, the lower concrete strength, the smaller the decrease in the strength of the P_{anchor} due to the dense arrangement of post-installed anchors. When used the anchor material of SD295, up to D_p/d_a = 3, the P_{anchor} of densely-placed post-installed anchors had the shear strength of about 88% for the specimen with single anchor.



(a) Anchor of SD390　　(b) Anchor of SD295

Figure 6. The Anchor group efficiency - D_p/d_a relationships

4.3 Effect of anchor strength difference on P_{anchor}

In order to investigate the effect of the difference in anchor strength on P_{anchor}, we examined using SD390-FC30 and SD295-FC30, which have the same compressive strength and Young's modulus of concrete slabs. Figure 5 shows the anchor group efficiency - D_p/d_a relationship of SD390-FC30 and SD295-FC30. The anchor group efficiency of SD390-FC30 were all higher than that of SD295-FC30. In other words, the specimens with higher anchor strength were had the characteristics that less decrease in the strength of the P_{anchor} result from the dense arrangement of post-installed anchors.

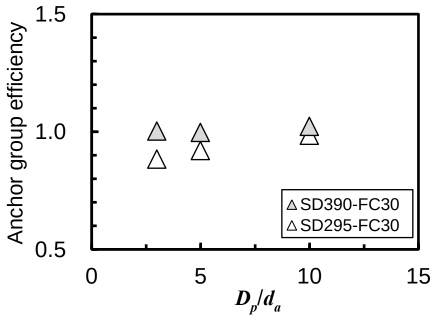


Figure 7. The Anchor group efficiency - $\boldsymbol{D_p/d_a}$ relationship due to difference in anchor strength

5. Conclusion

Major findings of this study were summarized as below:

1) When SD390 were used, anchors arranged densely with a pitch length of only 3.0d_a can still possess shear strength (per anchor) about 93% of the shear strength of single anchor.

2) When SD295 were used, anchors arranged densely with a pitch length of only 3.0d_a can still possess shear strength (per anchor) about 88% of the shear strength of single anchor.

3) The strength deterioration of maximum shear strength per one post-installed anchors of the anchor material of SD390 was less than that of the anchor material of SD295.

6. Acknowledgments

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7. References

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