EXPERIMENTAL STUDIES ON SHEAR CAPACITY OF DISC ANCHORS IN LOW STRENGTH CONCRETE

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Abstract

Conventional post-installed anchors are widely used in the retrofit works of existing buildings where new reinforced concrete members are attached to the existing structure. Especially in the case of using externally added frames for retrofit, failure of anchors and disintegration of retrofit members can threaten the safety of the entire structure. Considering the fact that, existing structures that requires retrofit generally exhibits quite low concrete strength, it is crucial for the anchors to safely transfer shear forces between existing and new members.

Conventional anchors subjected to shear forces tend to fail due to shear yielding of anchor bolts or crushing of concrete. Integrated Disc Anchors on the other hand, can provide a reliable solution with substantially enhanced shear capacity. Unlike conventional anchors, Disc Anchors consist of a disc-shaped head integrated with the actual anchor. In application, Disk Anchor is installed into existing concrete members so that disc remains on the connection surface of connecting members and as the disk of the anchor is much larger than conventional anchors, shear force can be effectively transferred between members even in the case of low strength concrete. A bolt screwed into the Disc Anchor that remains in the new added member ensures the connection.

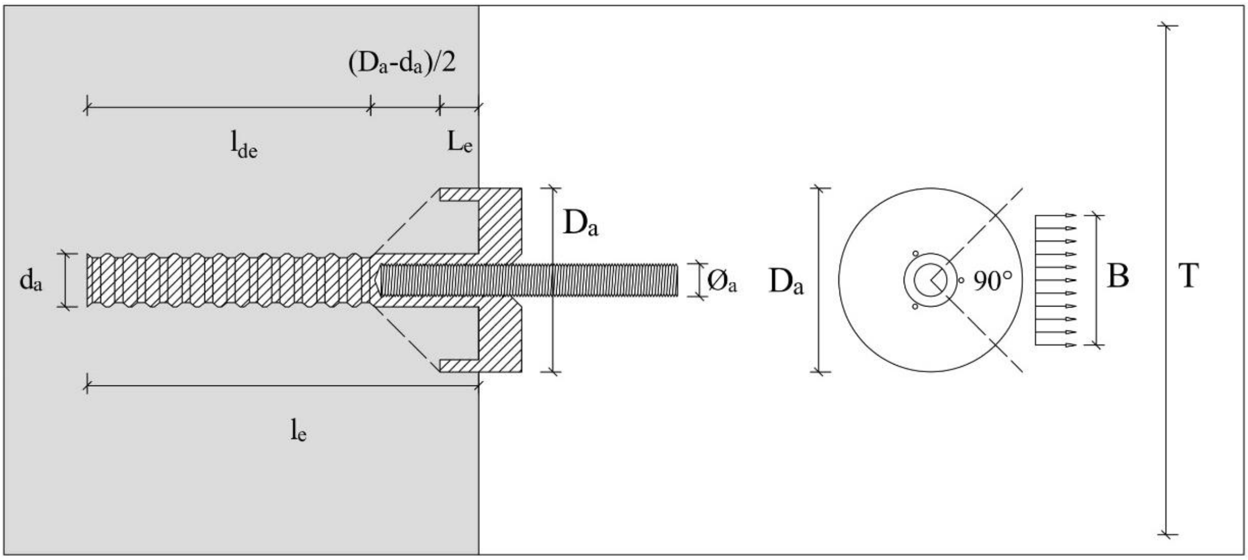
In this study, shear capacity of Disc Anchors was investigated through experimental works. A set of pure shear experiments was conducted to comprehend the behavior of the Disc Anchors with two different embedment depth in low strength concrete grades ranging between 8MPa to 16MPa compressive strength. The test results show that, disc anchors exceeded the design shear force levels determined according to relevant guidelines. Moreover, disc anchors experienced a significant deformation after reaching a maximum strength with a slight decrease in shear capacity due to their greater material quality and shear transfer surface. A simple shear behavior model is proposed for analytical applications of the Disc Anchors, as well.

Keywords: experimental works; shear tests; disc anchors; seismic retrofit

1. Introduction

Conventional anchors are widely used in construction works. In a new construction, anchors are used for the integration of non-monolithic elements. In case of retrofit applications, post-installed adhesive anchors are applied to integrate new RC members with the existing structure so that global behavior of the system is improved. Concrete quality of the existing structures is generally low and lacks shear capacity that is required to transfer the loads between existing RC structure and retrofitting RC members. Moreover, shear failure will prevent ductile behavior that is expected as an outcome of retrofit. Under these circumstances, seismic performance of an anchor becomes critical which is a relatively new research topic. A variety of anchor types as well as more realistic design procedures and principles for conventional anchors were developed in accordance with the need over the last decades by Cook *et al.* [1,2]. Fuchs *et al.* [3] and Lotze *et al.* [4] have investigated the shear and pullout behaviors of anchors statically. Next, Shirvani *et al.* [5] and Muratli *et al.* [6] examined anchors subjected to dynamic and static loads and developed design procedures for each failure mode. Eligehausen *et al.* [7] developed a design model for chemical anchorages subjected to tensile loading. In their study on low strength concrete, Caliskan *et al.* [8] investigated shear strength of anchorages varying in bond type, embedment depth and diameter. Epackachi *et al.* [9] examined the behavior of adhesive bonded anchors subjected to combined tension and shear loads.

Seismic safety of anchors can be ensured by eliminating the shear failure of the anchor providing controlled behavior. Unlike conventional anchors, Disc Anchors consist of an anchor bolt and a disc which remains on the connection interface of two members. Due to greater shear area, brittle shear failure is prevented. Properties of Disc Anchors and related definitions are shown in Fig. 1.



$Ø_a$: Diameter of the connecting bolt (mm)
d_a : Diameter of the anchor bolt (mm)
D_a : Diameter of the disc (mm)
B : Effective bearing width (mm)
l_e : Embedded depth of the anchor (mm)
L_e : Embedded depth of the disc (mm)
l_{de} : Effective bond embedded length (mm)
T : Effective member width (mm)

Fig. 1 - Overview of an Integrated Disc Anchor

In this study, shear capacity of disc anchors was investigated through experimental works. A pure shear experiment was conducted to comprehend the behavior of the disc anchors with embedded depth of 160mm and 192mm in low strength concrete. The test results show that, disc anchors reached a shear capacity of approximately twice their design shear strength levels. Moreover, disc anchors experienced a significant deformation with a slight decrease in shear force due to their greater material quality and shear bearing area.

As a result, Disc Anchors exhibit a superior performance compared to conventional anchors in terms of shear capacity which leads to a smaller number of anchors required in application, less workmanship and saving on time.

2. Experimental Works

Pure-shear experiments were conducted on Disc Anchors that had been installed on existing concrete blocks using chemical adhesives to evaluate the behavior and compare with conventional anchors.

2.1 Specimens

Concrete blocks, each measuring 2,500 mm in length, 1,500 mm in width, and 500 mm in height, were prepared; each cast block was turned upside down for a smooth anchor application surface; and six anchors were embedded on each block (Fig. 2). The experiment variables that were used include the concrete strength (8.0 to 16.0 N/mm^2), and the embedment length (160 mm to 192 mm). In the naming of anchor specimens, the first two components of the specimen name indicate the type of Disc Anchor. The subsequent numbers indicate the average concrete strength, the embedded length and the specimen no as three specimens are tested for each type. Table 1 provides details on the specimens that were used, including the average concrete strength on the test day.

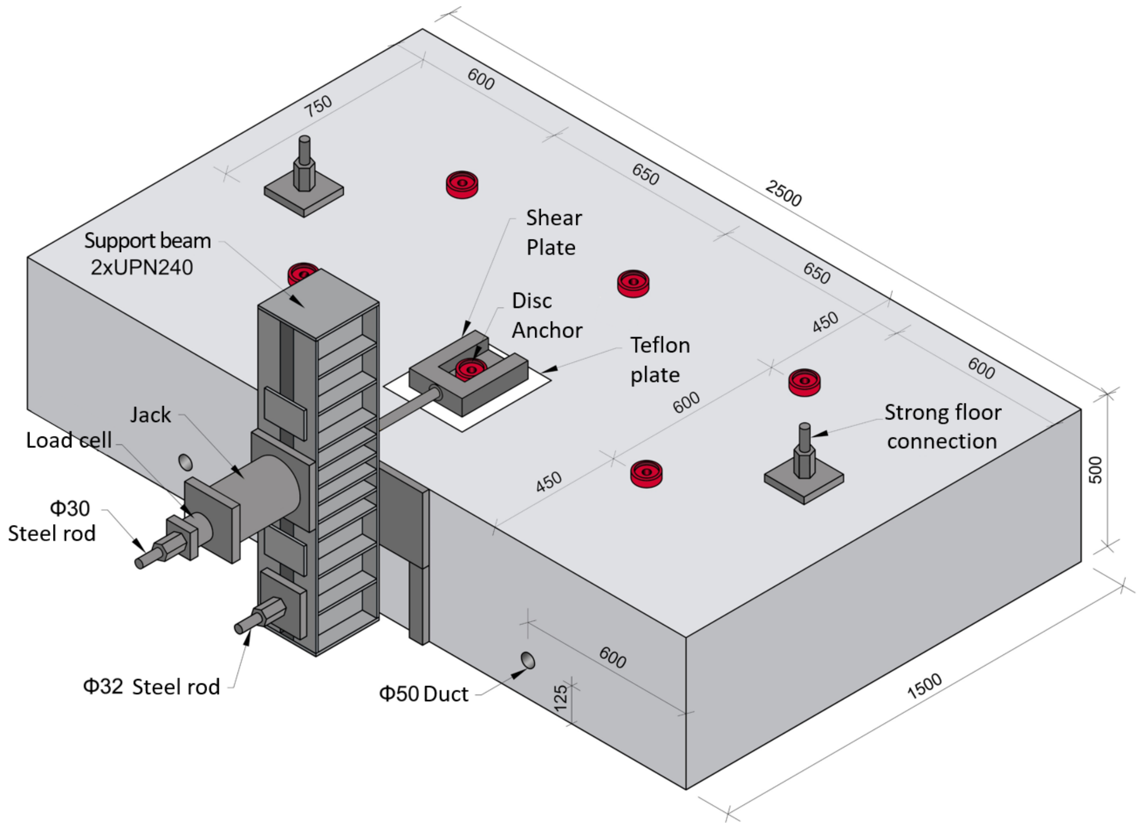


Fig. 2 - Shear test lay-out, specimen positions and loading direction

Table 1 - Test specimen details

Anchor Type	No	Specimen Name	Concrete Strength σ_B [N/mm^2]	Connecting Bolt Diameter $Ø_a$ [mm]	Anchor Bolt Diameter d_a [mm]
Integrated Disc Anchor	1	DA-I-C8-160-1	7.47	16	26
	2	DA-I-C8-160-2			
	3	DA-I-C8-160-3			
	4	DA-I-C8-192-1			
	5	DA-I-C8-192-2			
	6	DA-I-C8-192-3			
	7	DA-I-C12-160-1	11.85		
	8	DA-I-C12-160-2			
	9	DA-I-C12-160-3			
	10	DA-I-C12-192-1			
	11	DA-I-C12-192-2			
	12	DA-I-C12-192-3			
	13	DA-I-C16-160-1	16.81		
	14	DA-I-C16-160-2			
	15	DA-I-C16-160-3			
	16	DA-I-C16-192-1			
	17	DA-I-C16-192-2			
	18	DA-I-C16-192-3			

2.2 Shear Test

Shear load-deformation relation of Disc Anchors is investigated through pure shear tests. Shear test aims to simulate the extreme shear forces and deformations that could occur on a single Disc Anchor during a seismic event.

2.2.1 Test setup

Shear test set-up is shown in Fig. 3 and Fig. 4. Loading setup was designed with the intention of observing pure shear deformation under pure shear force without any additional loads. The concrete block is firmly attached to the strong floor by applying post tensioning on slab connection bars. An additional stability connection measure was considered to counter the potential rotation of support beam due to slight eccentricity between the axis of PC bar and the bearing plate. Therefore, an additional post tensioned bar parallel to the loading direction was introduced passing through the support beam and concrete block, to prevent the support beam from rotating at higher loading levels. Finally, a steel bearing plate that is capable of keeping the concrete block intact, was placed between the support beam and block.

Shear plate was designed so that entire surface of the disk is in contact with the restraining plate, and an additional plate was screwed onto the disc anchor to prevent the shear plate from overturning. Additionally, a 1mm thick teflon sheet was placed under the shear plate to eliminate friction as shown in Fig. 5.

A high strength steel bar of 30 mm in diameter was attached to the shear plate, and monotonic single direction loading was applied using a center-hole hydraulic jack with 500 kN capacity. The set-up generates a pure shear force acting on the disc by means of the shear plate (Fig. 3 and Fig. 5). This loading mechanism closely represents the effects that could occur during an earthquake event on a Disc Anchor used for retrofit by integrating new members on to an existing structure.

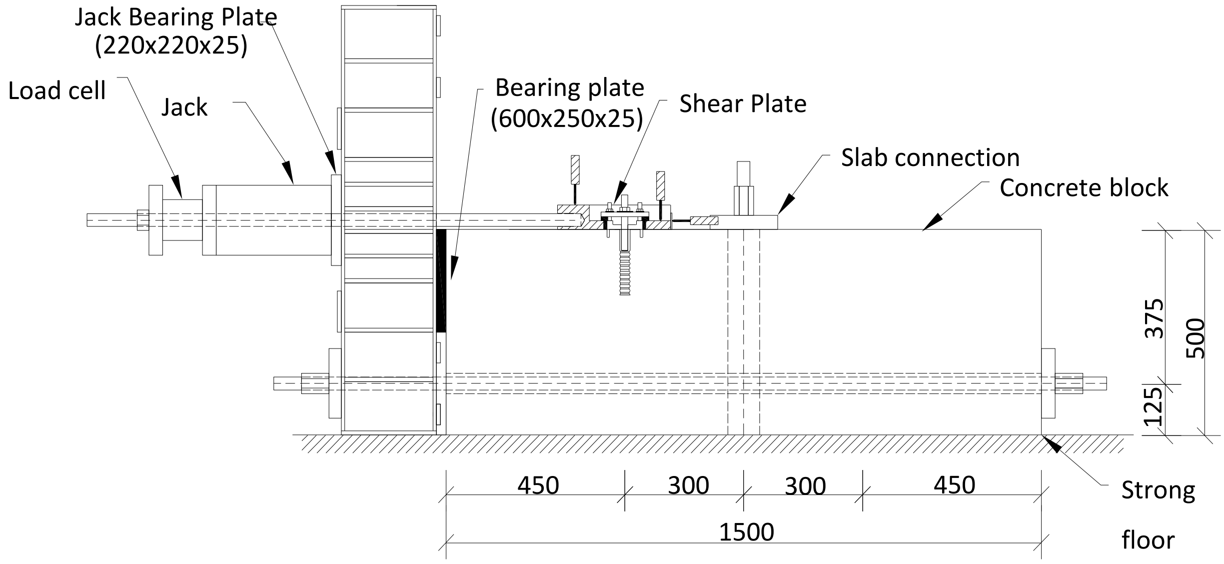


Fig. 3 - Shear test setup

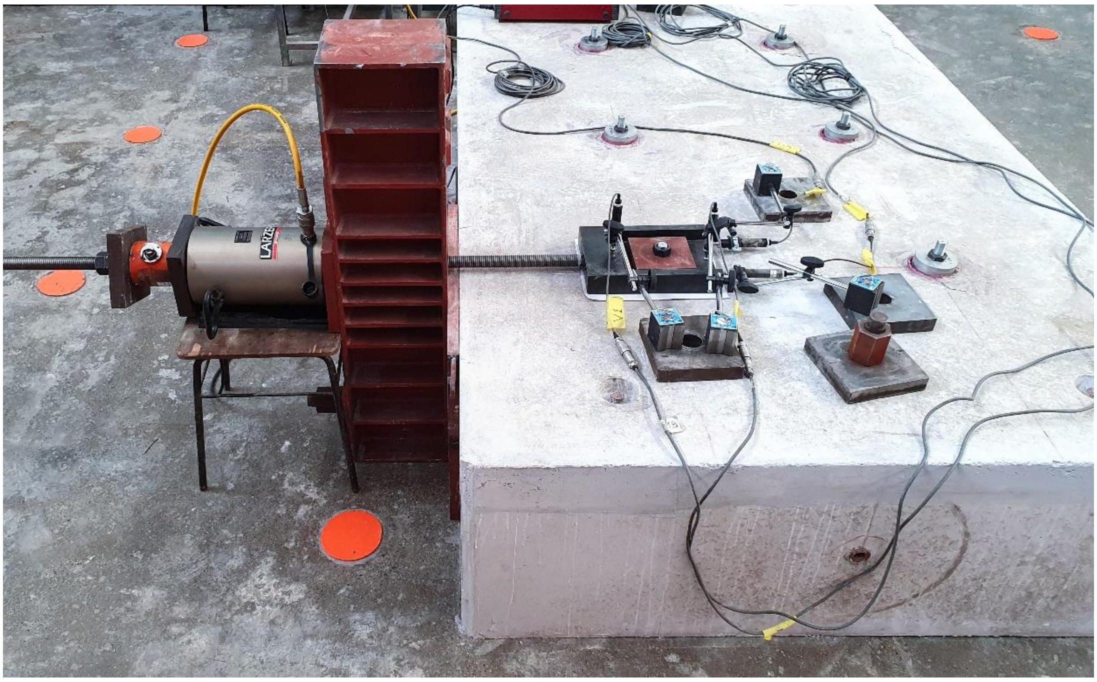


Fig. 4 - Experimental setup lay-out image

2.2.2 Measuring instrumentation

All displacements were measured using 4 LVDT type transducers situated where two vertical and two horizontal displacement measurements were monitored on the shear plate (Fig. 5). Vertical LVDTs were used to monitor the rotation of the shear plate, while the average of measurements in horizontal LVDTs was used to determine the shear deformation. On the other hand, shear force was measured with a center-hole load-cell located serial to the hydraulic jack (Fig. 3 and Fig. 4).

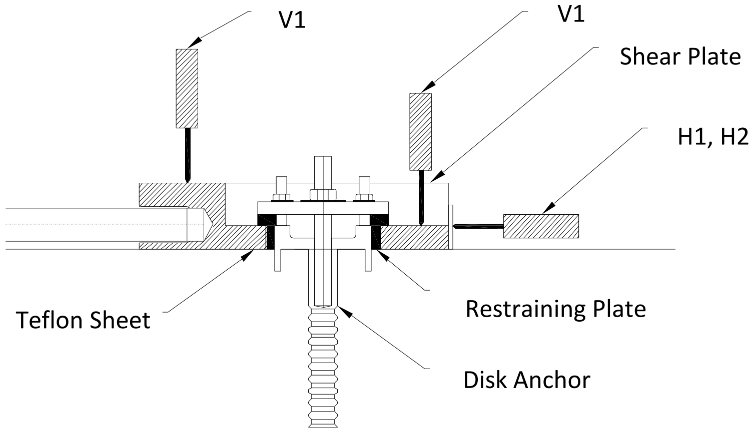


Fig. 5 - Components of the loading section and measurement instrumentation

2.3 Disc Anchor Design Strength

Shear force level at 2 mm displacement is the shear capacity criteria according to the "Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings" [10] , published by the Japan Building Disaster Prevention Association (JBDPA).

The design shear strength at 2 mm displacement of Disc Anchors, Q_{Da} is calculated using Eq. (1) and Eq.(2) for the ultimate state of concrete bearing for the existing frame according to the "MaSTER FRAME Retrofit Method: Design and Construction Guidelines''[11]. According to Eq. (1) it can be seen that shear failure of post-installed anchors is governed by a function of anchor depth, effective shear area between the anchor and concrete surface and concrete strength.

$$Q_{Da} = \alpha \cdot \gamma \cdot \kappa \cdot B \cdot L_e \cdot (T/B)^{0.63} \cdot 8\sigma_B^{0.5} \quad (1)$$

$$\text{where, } \alpha = min\left\{0.9\ ;\ 0.9\left(\frac{\sigma_B}{22.5} + 0.2\right)\right\}, \quad \kappa = \frac{d_a\sqrt{l_e - L_e}}{285}, \quad T/B \leq 10 \quad (2)$$

α : Strength reduction factor
γ : Coefficient related to concrete type (1.0: Normal concrete, 0.9: Lightweight concrete)
l_e : Embedded depth of the existing frame from the concrete surface do the tip of the anchor (mm)
B : (=63.6 mm) Outer diameter of the disc $(D_a) \times \cos 45°$
L_e: Embedded depth of the disc into the concrete of the existing frame (mm)
T : Effective member width ($\leq$ 600 mm) (mm)
σ_B: Compressive strength of the concrete for the existing frame (N/mm2)
d_a: Diameter of the anchor for the existing frame

2.4 Test Result

Shear test of the disc anchors was conducted as a displacement-controlled loading, i.e. shear force was applied until 10 mm of horizontal displacement was reached for concrete grade of 8 and 12MPa. During the tests conducted with 16MPa concrete, the first specimen (DA-I-C16-160-1) failed by shear around 7.8mm shear displacement. For safety reasons, the rest of the tests with 16MPa concrete has been terminated at 5mm displacement. Fig. 6 shows the shear test results of each specimen. In Fig. 6 shear design strength levels obtained according to previous section are shown with red dashed lines. In shear tests all specimens exceeded the design strength at 2 mm displacement. The specimens reached to the majority of their maximum strength when the shear deformation reached around 2 mm, which is one of the characteristics of the relationship between shear force and displacement for Disc Anchors.

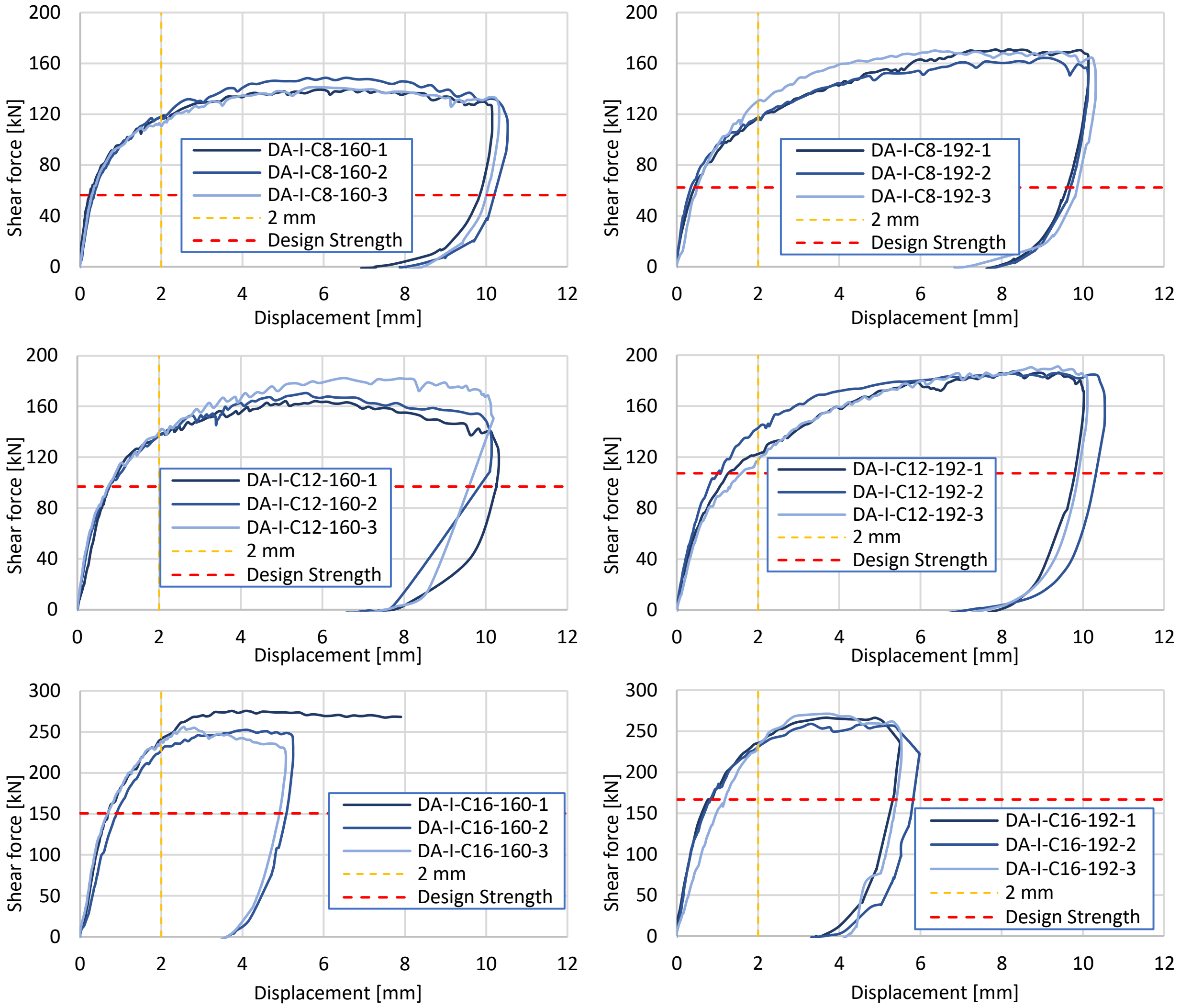


Fig. 6 - Shear test results of Disc Anchors

Representative shear test ultimate conditions are shown in Fig. 7. As seen in the figure, concrete crushing is observed in a wider area because of the disc head, compared to conventional anchors.

DA-I-C8-192-1

DA-I-C12-192-1

DA-I-C16-192-1

Fig. 7 - Typical failure condition after the shear test

Fig. 8 shows the comparison of shear capacity for 2 different embedment depth (160mm and 192mm) in 12MPa concrete. Other concrete grades also yielded similar result. From the figure it can be observed that, embedment depth does not greatly influence the shear capacity or shear stiffness, but after 2mm shear deformation is exceeded, shear force at anchors with larger embedment depth keeps increasing, similar to a hardening type behavior.

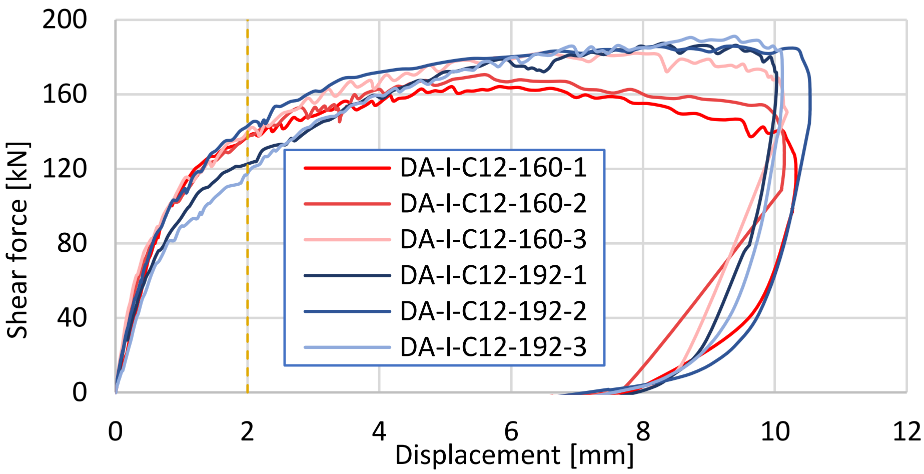


Fig. 8 - Shear test results of Disc Anchors

Fig. 9 shows the comparison of shear tests under different concrete grades for 160mm embedment depth. It is clearly visible that concrete strength has an obvious influence on the anchor strength. In addition summary of test results and design strength were given in Table 2.

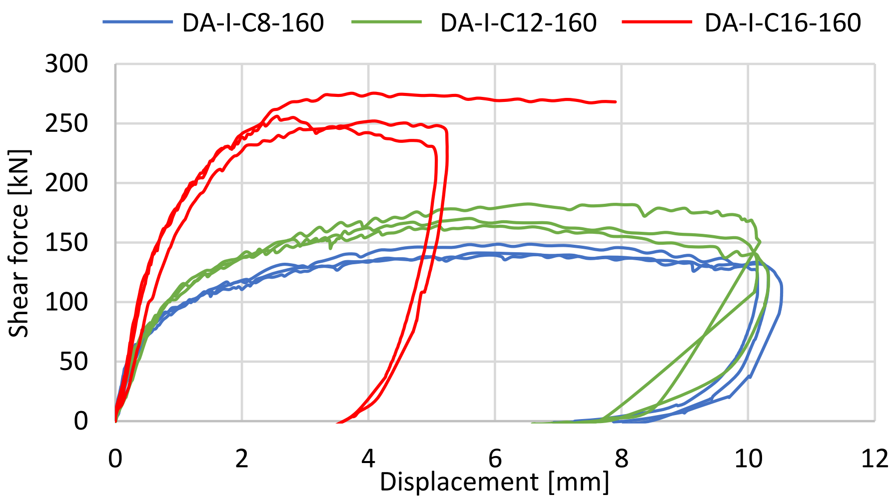


Fig. 9 - Shear tests comparison of Disc Anchors in different concrete grades

Table 2 - Comparison of test results and design strength

No	Specimen Name	Design shear strength Q_{Da} [kN]	Shear test result Q_{test}@2mm [kN]	$\frac{Q_{test}}{Q_{Da}}$
1	DA-I-C8-160-1	56.37	118.12	2.10
2	DA-I-C8-160-2		115.35	2.05
3	DA-I-C8-160-3		110.65	1.96
4	DA-I-C8-192-1	62.43	117.01	1.87
5	DA-I-C8-192-2		117.31	1.88
6	DA-I-C8-192-3		130.12	2.08
7	DA-I-C12-160-1	96.97	137.08	1.41
8	DA-I-C12-160-2		137.47	1.42
9	DA-I-C12-160-3		139.63	1.44
10	DA-I-C12-192-1	107.41	122.65	1.14
11	DA-I-C12-192-2		142.91	1.33
12	DA-I-C12-192-3		117.31	1.09
13	DA-I-C16-160-1	150.53	241.22	1.60
14	DA-I-C16-160-2		227.23	1.51
15	DA-I-C16-160-3		238.36	1.58
16	DA-I-C16-192-1	166.74	235.72	1.41
17	DA-I-C16-192-2		230.72	1.38
18	DA-I-C16-192-3		232.06	1.39

2.5 Conclusion

Shear capacity of Integrated Disc Anchors was investigated through experimental studies. A pure shear experiment was conducted to investigate the behavior of the disc anchors with two different embedding depth in three different levels of low strength concrete. Following conclusions has been derived:

- In shear tests all specimens exceeded the design strength at 2 mm displacement and all specimens have failed due to the concrete crushing, except one specimen which resulted with shear failure of anchor bolt.
- The shear capacity of disc anchors significantly change in the range of 8MPa to 16MPa concrete blocks. The difference is more obvious between 12-16MPa concrete.
- It can be concluded that, compared to conventional anchors, Disc Anchors may significantly reduce construction time by reducing the amount of required anchor for their greater shear capacity

3. Acknowledgements

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