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DEVELOPMENT OF ONSITE SHEAR TEST EQUIPMENT FOR POST-INSTALLED ANCHORS USED IN SEISMIC RETROFIT WORK

K. Kobayashi(1), K. Katori (2) , H. Taniguchi (3) , S. Terasaki (4)

(1) *Professor Emeritus, University of Fukui JAPAN, katsumik@u-fukui.ac.jp*
(2) *Professor, Toyo University JAPAN, katori@toyo.jp*
(3) *Representative Director, Trust Co., Ltd., h-taniguchi@trust-gr.com*
(4) *Structural maintenance division, Group leader, Maeda Kosen Co., Ltd., terasaki@mdk.co.jp*

Abstract

Post-installed anchors are used as a means for transmitting shear force from existing buildings to seismic strengthening members. A safe and rational seismic retrofit design is quite difficult without the onsite test data to evaluate the transferable shear force through the post-installed anchors. And also onsite shear tests are necessary for construction quality control. However, no onsite shear tests are conducted to obtain the data for structural design of post-installed anchors and no onsite shear tests for construction quality control are conducted, because there is no shear test equipment that is availabe onsite.

A compact shear test equipment that is available onsite was developed. It can be handled by hands. The convex part and concave part are combined so as to slide in parallel. It can reproduce the shear test condition of post-installed anchor constructed on the concrete-concrete interface simply by closely fixing the test anchor bars with the equipment. The characteristics as test equipment were investigated by comparing with the other shear-off test result that was done in the laboratory. The test results by this equipment well correspond to those of the other shear-off test results by setting up with some lifting height from the concrete surface according to the anchor bar size.

Onsite shear tests for post-installed anchors could be done easily by using this developed test equipment, and it is expected to be useful for improving design reliability and construction quality control. It goes without saying that a lot of experiments can be carried out easily in the laboratory, and can also be used for research and development of post-installed anchor technology.

Keywords: Seismic retrofit; Post-installed anchor; Shear test equipment; Onsite shear test; Construction quality control

1. Introduction

Post-installed anchors are often used as a means for attaching the seismic strengthening members to an existing building and transmitting shearing force. For rational seismic retrofit design, it is necessary to evaluate the transferable shear force considering the deformation conformity of each component, and onsite shear tests are necessary for construction quality control. However, there is no shear test equipment that can be used onsite, no shear test data for post-installed anchors has been obtained for each building to be reinforced, and no shear test for construction quality control has been performed.

The seismic retrofit design guideline [1] does not target the concrete strength of less than 13.5N/mm^2, but in reality there are many demands for seismic strengthening even at around 10N/mm^2. However, there is no measures to know the effective shear strength of post-installed anchors onsite. If the effective shear strength can be evaluated by properly grasping the relationship between the deformation of the post-installed anchor and the transferable shear force for each building to be seismic retrofitted, the design reliability can be much improved by eliminating excessive design or under-design. In this study, we first develop a compact shear test equipment that can be used easily onsite. The objective is extended to develop a test equipment that can easily perform many experiments even when used in the laboratory.

2. Mechanism of shear test equipment

The test equipment must reproduce the state of deformation in Fig. 1, where the test anchor bar on the concrete-concrete interface receives the shear force (V) and deforms inversed-symmetrically.

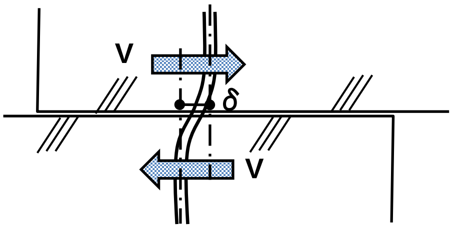
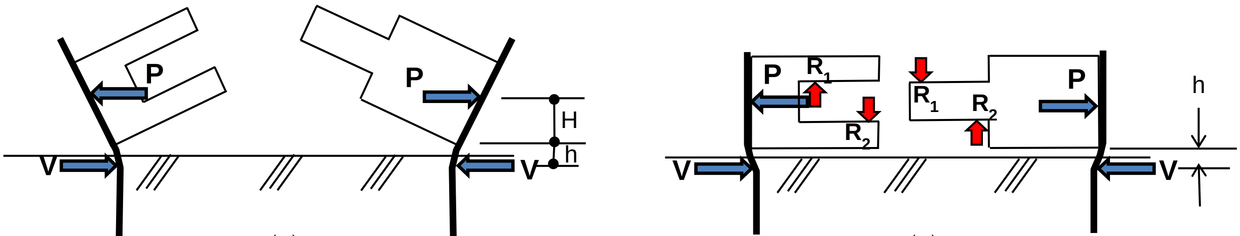


Fig. 1 – State of deformation of anchor bar on the concrete-concrete interface

The upper concrete in Fig. 1 is replaced with the test equipment. As shown in Fig. 2(a), when a horizontal force (P) is applied with a hydraulic jack getting reaction force on the two anchor bars, the anchor bars will be rotated and deformed due to the moment of P(H+h). And they are rotated back with the force of R_1 and R_2 (R_1=R_2) as shown in Fig. 2(b). If the convex part and the concave part are combined and slid, R_1 and R_2 of the convex part and the concave part act and react with each other.



(a) (b)

Fig. 2 – Mechanism of test equipment

The bending moment diagram when applying horizontal force (P) is assumed as shown in Fig. 3. Assuming that the bending moment of the anchor bar near the concrete surface is M_B (= R1·a) in the elastic range, the edge strain (ε) of the convex base is:

$$\varepsilon = \frac{3 \cdot P(H+h)}{b \cdot D^2 \cdot E} \tag{1}$$

Here, b and D are the width and depth of the convex part, and E is the Young's modulus of the convex part. The calculated value with h assuming twice the anchor bar diameter is shown by the solid line in Fig. 4. If the concrete around the anchor bar is plastically deformed, h will gradually increase, and the edge strain should increase for the same horizontal force (P). In the initial state, the measured values agreed well with the calculated values, and the measured values gradually increased according to the increase of P, confirming the rotating back mechanism in Fig. 2.

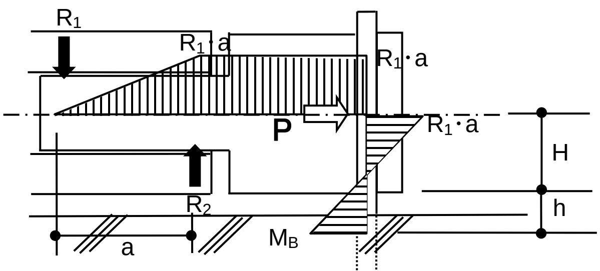


Fig. 3 – Assumption of moment diagram in the elastic range

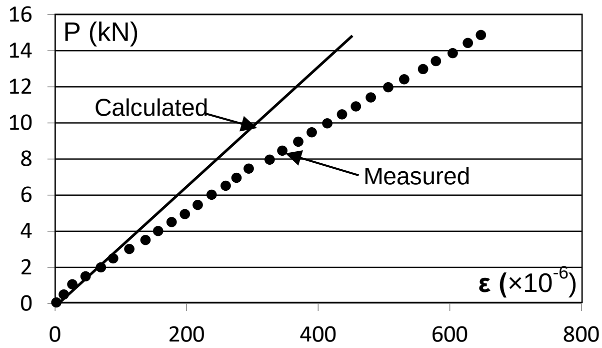


Fig. 4 – Calculated and measured edge strain of the convex base

3. Prototype shear test equipment and its characteristics

3.1 Section size of the convex part

The maximum stress is generated at the base of the convex part. If the test anchor bar plasticizes and exhibits the maximum shear force in the h-region in Fig. 3, the bending moment diagram is as shown in Fig. 5.

$$V_u = 2 \cdot M_u / h \tag{2}$$

The maximum bending moment at the base of the convex part is:

$$M_{max} = V_u \cdot (H + \frac{h}{2}) \tag{3}$$

On the other hand, the base of the convex part needs to maintain elasticity. When the test anchor bar was D19 of SD345 and H was the horizontal jack radius and h was assumed to be twice the test bar diameter, the convex section was 9mm×100mm. Here high-strength materials were used for the convex part and quenched. Since the cover plate is attached to the concave part and has enough sectional area, there is no stress problem in the concave part.

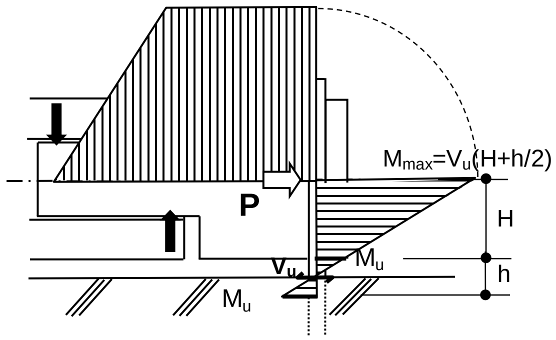
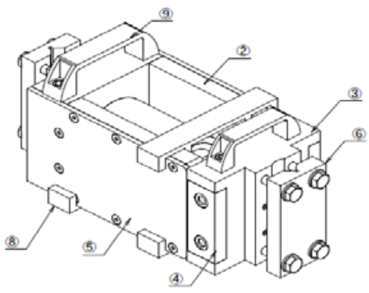


Fig. 5 – Assumption of moment diagram in the plastic range

3.2 Feature of the compact shear test equipment

A prototype with V_u=200kN of Eq. (2) is shown in Fig. 6. As shown in Fig. 6, the test anchor bars were set at interval of 300mm, and the test anchor bars were fixed by tightening with bolts to the equipment. The 200kN hydraulic jack placed on the inside is a commercial product with 86mm in diameter, 127mm in length, and 50mm of stroke. The 200kN load cell is a special order product with 59mm in diameter and 44mm in length. It is small and weighs about 25kg excluding the hydraulic jack, and can be handled by hands. The gauge holder to which the displacement transducers were attached in advance was structured so that it could be just put on the concrete surface adjusting the measurement reference point. As a result, the loading test could be completed in a short time including the time required for test preparation.



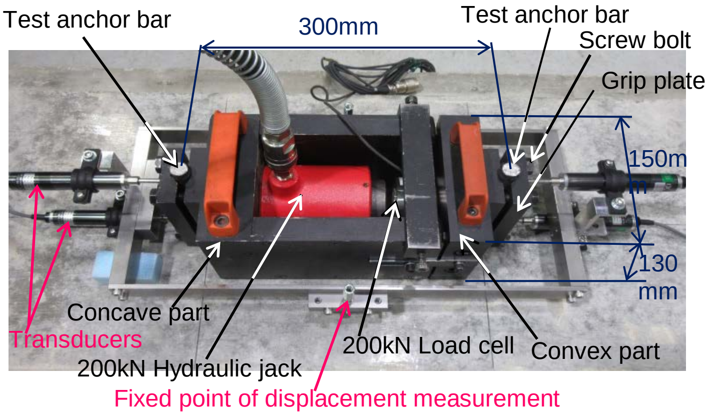


Fig. 6 – Feature of the test equipment

3.3 Friction of the sliding parts

When sliding and getting R_1 and R_2 of Fig. 2 in order to rotate the anchor bar back, the convex part and the concave part contact and a frictional force is generated on the contact surface. The contact surface was coated with Teflon. As shown in Fig. 7(a), the legs of steel blocks fixed at both ends of the test equipment were connected with a round bar, and the tensile force (T) was measured using a strain gauge to determine the frictional force (P-T). It was found that approximately 4% of the load cell output (P) was frictional force and the rest was shearing force (V) as shown is Fig. 7(b). If the frequency of use increases, the coating on the contact surface deteriorates and the frictional force increases. Therefore, it is necessary to periodically examine the frictional force.

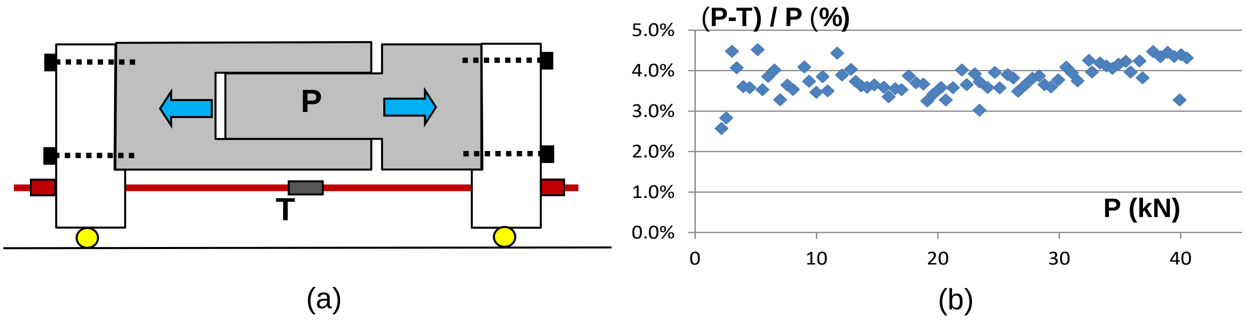


Fig. 7 – Measuring method of frictional force and measurement results

3.4 Rotation constraint of the test anchor bars

The rotational displacement was obtained by dividing the horizontal displacement difference between the two upper and lower displacement transducers in Fig. 6 with their interval of 100mm. Fig. 8(a) shows an example in which the test anchor bar is D19. Although 1.5 to 2/1000rad of the rotation occurs at the initial stage with small load, this is the amount of rotation until the convex part and the concave part contact each other due to the clearance of the sliding part. After that, it is thought that the rotational displacement increases with the load gain due to the slip of the anchor bar from the grip of the test equipment, crush of the libs of the test anchor bar, etc.(Fig. 8(b)), but the absolute value is small and judged to be negligible for practical use.

In this test equipment, it is important that the anchor bars do not to be bent when fixing them to the test equipment through the grip plate by screwing. So, an auxiliary anchor bar holding device is used as shown in Fig. 21, that holds the two test anchor bars vertically and in parallel during construction.

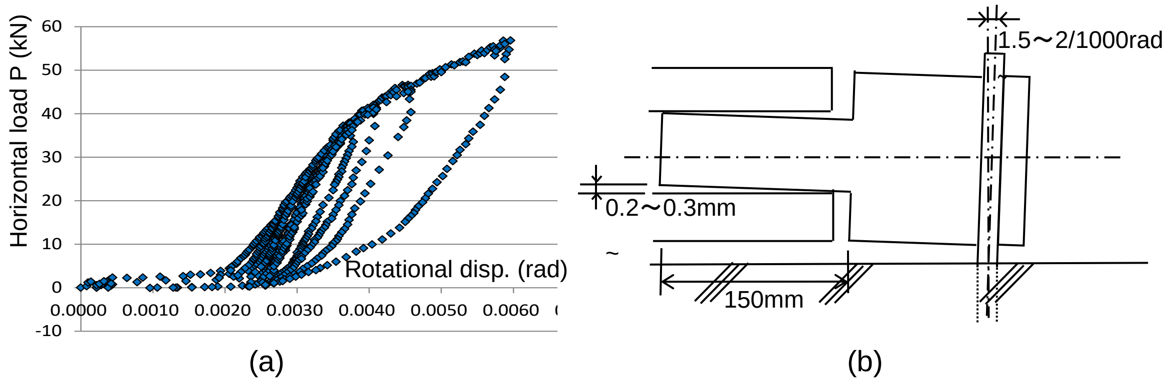


Fig. 8 – Example of the measured rotational displacement and the cause of the initial displacement

3.5 Shear force (V) - Horizontal displacement (δ) relation

Figure 9(a) is the relation between the shear force and the horizontal displacement that is the average of the two transduces in Fig. 6. In the initial state, after a slight horizontal force is applied, the rigidity decreases, the horizontal displacement increases, and after that the rigidity recovers. For the same reason as in the previous section, the horizontal displacement occurs at the horizontal loading position level due to the rotational displacement caused by the clearance of the slide part when the load is small. As the horizontal displacement is measured at a position farther from the concrete surface, the horizontal displacement due to rotational displacement becomes larger. This amount may be corrected to obtain the horizontal displacement of the test anchor bar as shown in Fig. 9(b), but could be ignored. Or the horizontal displacement of the lower transducer could be adopted as the horizontal displacement of the test anchor bar as shown in Fig. 9(c).

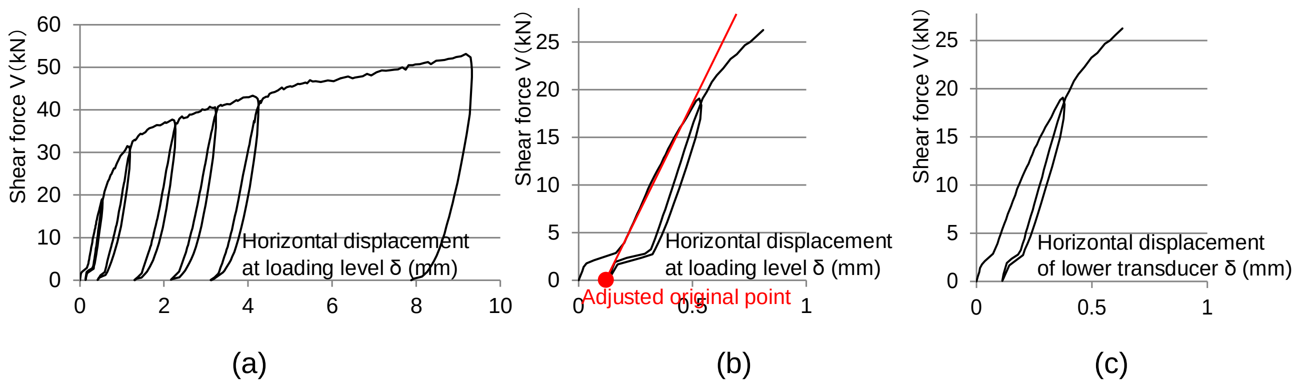


Fig. 9 – Relation between the shear force and displacement

3.6 Setup height from the concrete surface

This test equipment has an advantage to be set lifting up from the concrete surface in spite of the unevenness of the concrete surface. The higher the lifting height, the larger the region where there is no concrete around the test anchor bar and only the anchor bars are deformed, so the initial stiffness and shear capacity are getting small. Figure 10 shows the relations between the horizontal load and displacement of the test anchor bar D16 depending on the lifting height. In order to correspond to the behavior of the anchor bar constructed on the concrete-concrete interface, it is necessary to determine the appropriate lifting height and to conduct the shear test.

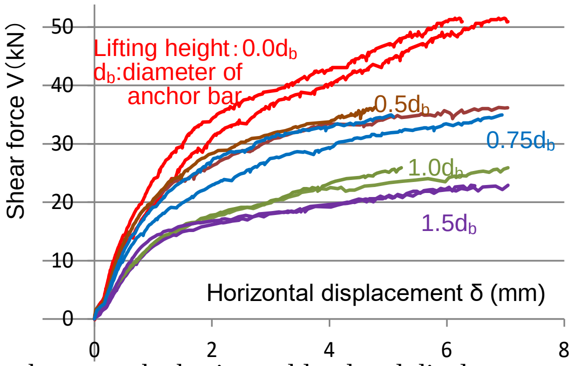


Fig. 10 – Relation between the horizontal load and displacement depending on the lifting height

4. Correspondence to the anchor bars constructed on the concrete-concrete interface

4.1 Shear test of the anchor bars constructed on the concrete-concrete interface

In order to obtain the comparative data with the shear behavior of post-installed anchors constructed on the concrete-concrete interface, the laboratory shear experiments in Fig. 11 were performed. Two test anchor bars were installed on the lower block (300 × 350 × 760mm) in Fig. 12. After that, the concrete of the upper block (186 × 350 × 760mm) was cast. The attachments for applying shear force were attached to the upper and lower blocks, so that only shearing force was applied to the concrete-concrete interface. In order to keep the test specimen horizontal, the parallel link mechanism was attached to the upper block. The lower block is not fixed to the floor. Figure 13 is a photograph of the test setup.

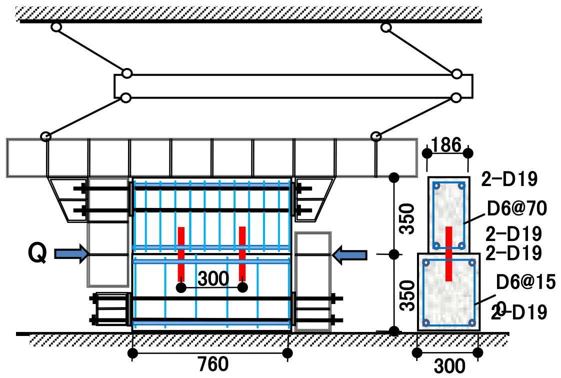


Fig. 11 – Loading apparatus for shear experiment in laboratory

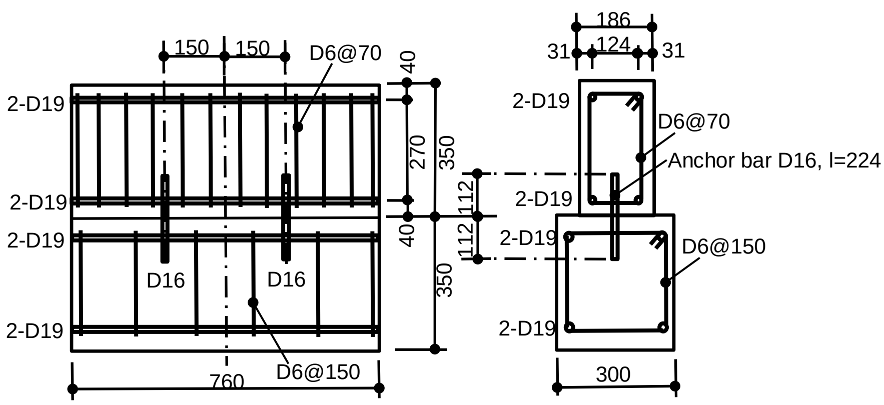


Fig. 12 – Test specimen

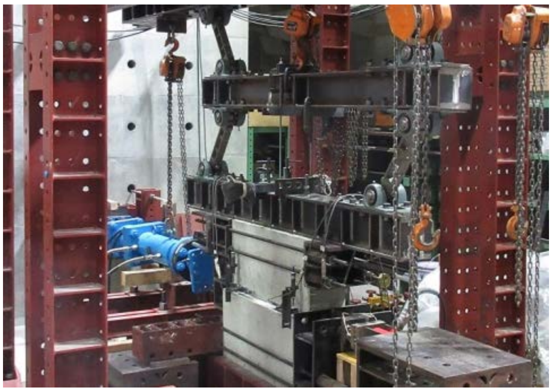
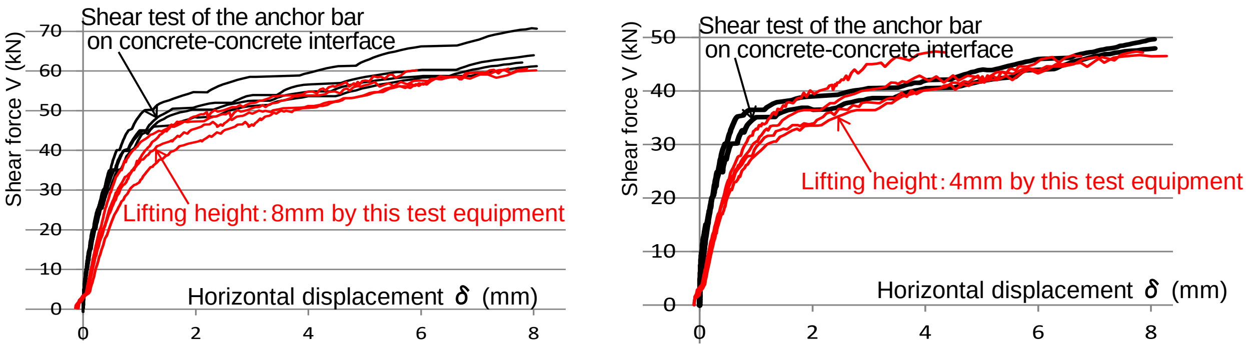


Fig. 13 – Test setup

4.2 Shear test results

The relations between the shear force (V) and the horizontal displacement (δ) are shown in Fig. 14. In Fig. 14(a) the anchor bar is D19 and its yield strength is 388 N/mm^2. The embedding length is 7 times of bar diameter. The concrete strength of the lower block is 30 N/mm^2 and that of the upper block is 29 N/mm^2.The test result of setting the lifting height to 8mm by this test equipment is slightly smaller in the initial stiffness, but the secondary stiffness and the shear capacity correspond well with the results of shear test of Fig.11. The secondary stiffness is after the anchor bar yield, and the effect of the lifting height is not significant. In order to make the initial stiffness correspond to the test result of the anchor bar constructed on the concrete-concrete interface, the correlation between the results of both test methods should be discussed. Figure 14(b) is the same test result for D16 as Fig 14(a) for D19. Here the yield strength of D16 is 377 N/mm^2. The embedding length is 7 times of bar diameter. The concrete strength of the lower block is 28 N/mm^2 and that of the upper block is 31 N/mm^2. The test result of setting the lifting height to 4mm by this test equipment is slightly smaller in initial stiffness as in case of D19 in Fig. 14(a), but the secondary stiffness and shear capacity of both test results correspond well to each other.



(a) D19 (b) D16

Fig. 14 – Relations between the shear force and the horizontal displacement

4.3 Initial secant stiffness

Figure 15 shows a comparison of the initial secant stiffness between the shear test of Fig. 11 and this test equipment. The initial secant stiffness for a horizontal displacement of 0.5mm was obtained. In case of this test equipment, the secant stiffness tends to be smaller than in case of the shear test of Fig. 11 in the order of D10, D13, D16, and D19, but it can be seen that the dispersion is large for each anchor bar size. In average, the initial secant stiffness is found to be about 2/3 of the shear test of Fig. 11. The large variation is thought due to the construction state near the concrete surface, but it should be understood that the variation is unavoidable characteristics.

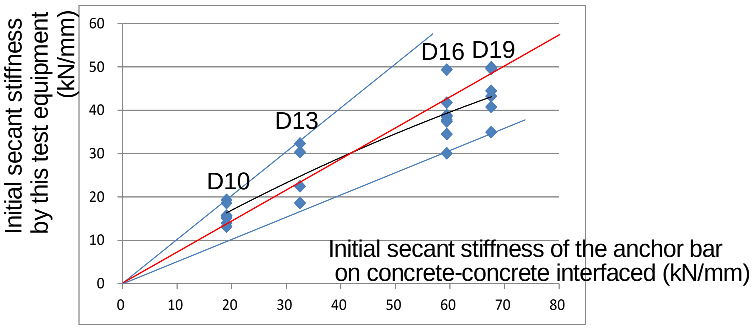


Fig. 15 – Initial secant stiffness

5. Correspondence to the shear test results by JCAA method [2]

Japan Construction Anchor Association (JCAA) proposes a shear test method for post-installed anchors [2]. This is a method in which the shearing force is applied through a steel plate with a hole having a diameter substantially equal to the diameter of the test anchor bar as shown in Fig. 16. The steel plate is placed on the test anchor bar, and the floating of the plate from the concrete surface is constrained. The reaction force when applying the shearing force is taken on the side of the concrete block where the anchor bar is constructed. It is absolutely difficult to adopt onsite. This is an almost same test method as ASTM method [3].

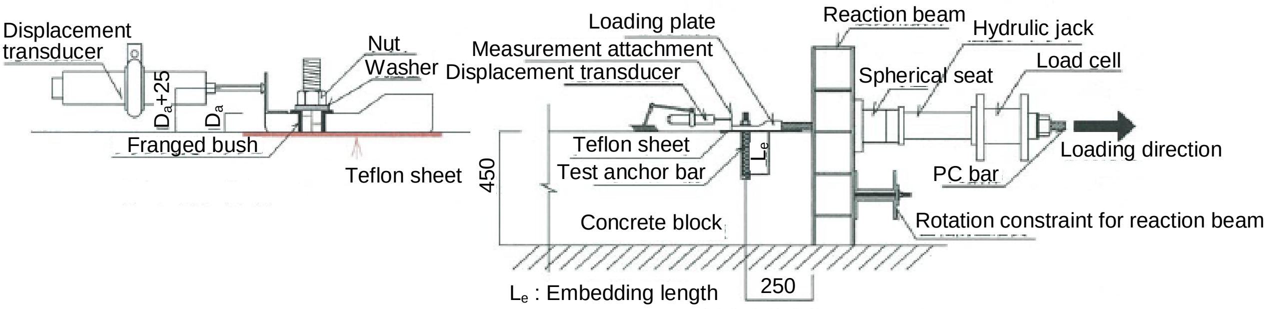


Fig. 16 – JCAA shear test method [2]

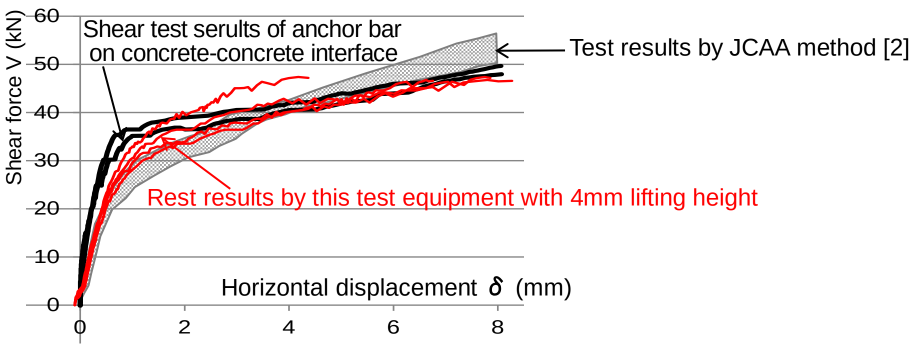


Fig. 17 – Comparison of the test by this test equipment with JCAA method [2]

Reference [4] includes the shear test results with JCAA Method [2]. This is a citation of JCAA product certification experiment data, and the anchor bar is D16, the concrete strength is 32 N/mm2, the embedding length is 7 times of bar diameter. The digital data is not available. So, the five test results were read from the figures and shown in the shaded part of Fig. 17. The method using this test equipment with lifting height of

0mm and the JCAA method give almost the same results. However, neither the secondary stiffness nor the shear capacity corresponds to the shear test results of anchor bars constructed on the concrete-concrete interface. If a slight lifting height is provided for this test equipment, the secondary stiffness and the shear capacity are better compatible with the results of anchor bars constructed on the concrete-concrete interface.

6. Procedure for the construction of test anchor bars and preparation of the test

6.1 Centering

Points A and B where the test anchor bars are to be constructed are decided drawing lines a, b and c as shown in Fig. 18. The interval between point A and B is 300mm.

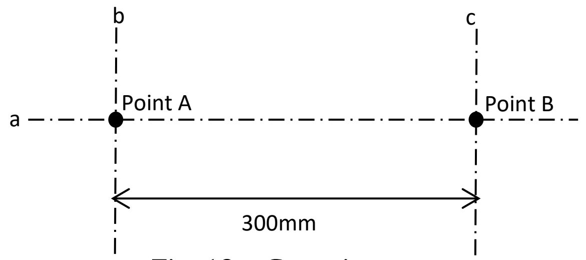


Fig. 18 – Centering

6.2 Setup of an auxiliary device for drilling

Adjust the distance of two drilling guides to 300mm in advance, and align the center of the drilling guides with points A and B. Next, set the auxiliary device parallel to the concrete surface with its leveling screw bolts as shown in Fig. 19.

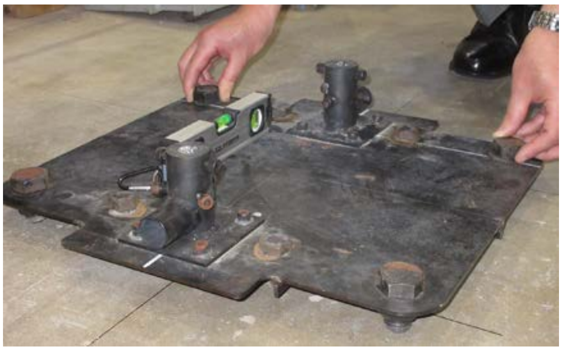


Fig. 19 – Setup of an auxiliary device for drilling

6.3 Drilling

Standing on the auxiliary device for drilling so as to prevent the device from moving, insert a bit into the drilling guide, and drill a predetermined depth as shown in Fig.20.

Mark the bit and be careful not to drill deeper than necessary. At this time, a vacuum cleaner hose is connected to the drilling guide to suck up the drilled powder. After drilling, pull out the bit and insert the same size round bar as the bit into the drilled hole so that the center of drilling guide and the drilled hole do not shift. After confirming the center of the other drilling guide matches with Point B, drill the other hole.

After drilling, the inside of the holes is cleaned up with a brush and vacuum cleaner.

Insert the test anchor bars and confirm that the required depth is drilled. If there is a shortage, drill further and clean up again.

Fig. 20 – Drilling

6.4 Confirmative setup of test anchor bars

Attach the two test anchor bars to an auxiliary anchor bar holding device. The holding device keeps the two test anchor bars in parallel and slides horizontally according to the distance between the drilled holes. The enbedding length of the two test anchor bars is adjusted, and they are securely attached to the anchor bar holding device. Check that it can be set by inserting it into the drilled holes, and adjust it with four screw bolts so that it can be set perpendicular to the concrete surface using a tool for levelling.

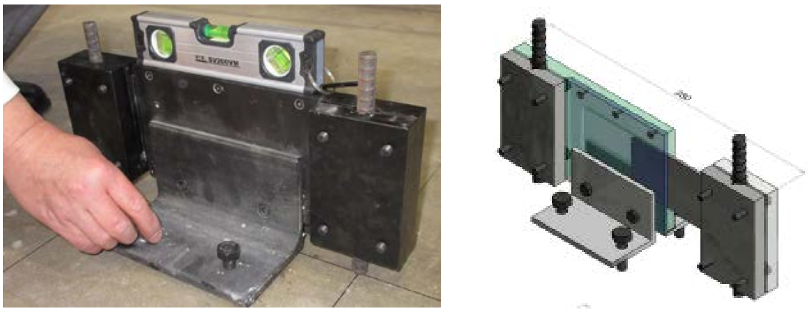


Fig. 21 – Setup of test anchor bars with an auxiliary anchor bar holding device

6.5 Installation of test anchor bars

The holding device to which two test anchor bars are attached is once removed, and the holes are filled with the adhesive material following the specification, and then the anchor bars fixed by the anchor bar holding device are inserted. The concrete surface around the holes is protected with tape, and the overflowed adhesive material is removed before the adhesive is cured.

After specified curing time, the anchor bar holding device is removed.

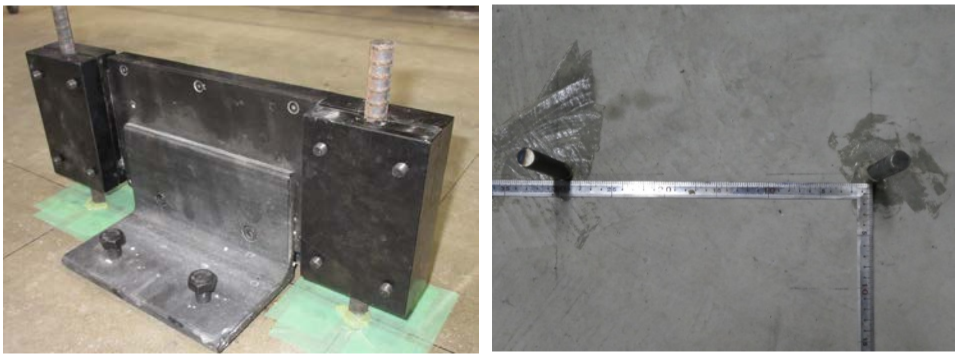


Fig. 22 – Installation of test anchor bars

6.6 Setup of the test equipment

Loosen the bolts on the grip plates of the test equipment sufficiently, and lower the test equipment to the concrete surface so that the test anchor bars are inserted between the test equipment main body and the grip plates. At this time, confirm that the bolts of the safety device on the slide part of the test equipment are loosened.

In order to ensure the lifting height of the test equipment, the height is adjusted with the adjustment bolts attached to the lower part of the test equipment. Alternatively, prepare a spacer of the required thickness and place it on the bottom of the test equipment.

Lightly tighten the bolts of the grip plates so that the test anchor bars are in close contact with the test equipment main body and the grip plates, and fix the test equipment to the test anchor bars. Next, loosen the lifting height adjustment bolts attached to the lower part of the test equpment. Alternatively, the spacer sandwiched between the bottom surface of the test equipment and the concrete surface is removed so that the test equipment is separated from the concrete surface by a required lifting height. After that, tighten the bolts of the grip plates little by little so that the tension of the four bolts is constant. Use a torque wrench to manage the constant torque.

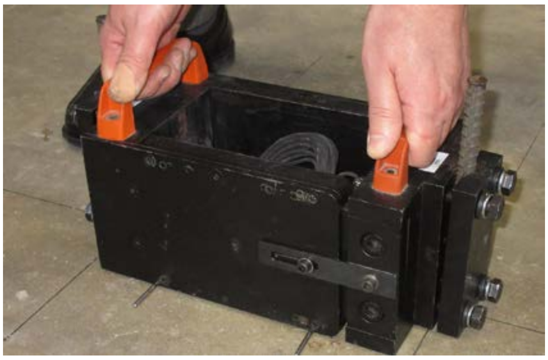


Fig. 23 – Setup of the test equipment

6.7 Setup of the gage holder

Place a gage holder with displacement transducers attached in advance, and adjust the position of the transducers to the desired height with the two adjustment bolts attached to the center of the gage holder.

A wedge-shaped piece made of foamed plastic is placed under one side of the gage holder and the rotation of the gage holder is stopped. Next, adjust the stroke of the transducers. The stroke should be at least more than 10mm.

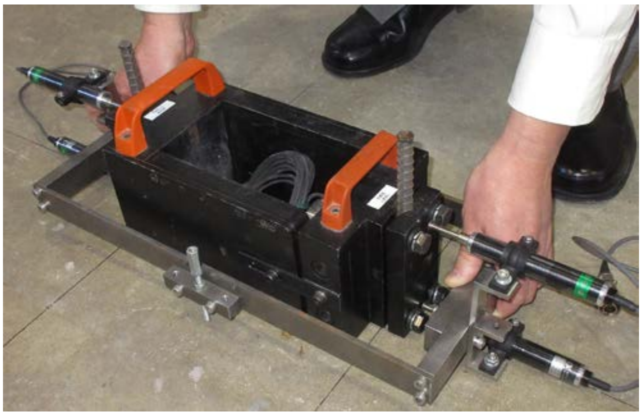


Fig. 24 – Setup of the gage holder

6.8 Completion of the test preparation

Finally insert the hydraulic jack into the test equipment and connect it to the hydraulic pump. Then connect the load cell and displacement transducer cables to the measuring system. The test preparation is now complete.

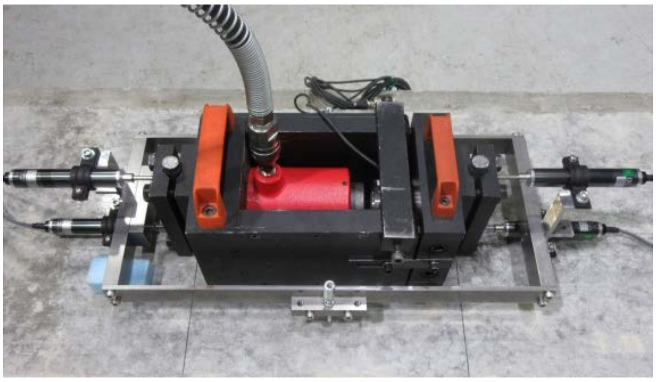


Fig. 25 – Completion of the test preparation

7. Conclusions

We developed shear test equipment that can be easily used onsite, and showed its operating characteristics. There is an advantage that can be used lifted up from the concrete surface, and by lifting up 1, 2, 4, and 8mm for D10, D13, D16, and D19 respectively, the test result well corresponds to the behavior of the post-installed anchor constructed on the concrete-concrete interface. It shows about 2/3 of the initial stiffness of the anchors constructed at the concrete-concrete interface, but the secondary stiffness and the maximum load well agree with those at the concrete-concrete interface.

The developed test equipment can be handled by manpower, can perform a lot of tests in a short time with simple work, and is useful for conducting shear tests of post-installed anchors onsite. Of course, it is also useful in the laboratory, and a lot of experiments can be easily performed.

We hope that the compact shear test equipment developed in this study will be used onsite, which will contribute to the rationalization of design and the improvement of construction quality control.

Acknowledgements

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