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EXPERIMENTAL STUDY ON PERFORMANCE OF BONDED ANCHORS IN THE LOW STRENGTH REINFORCED CONCRETE

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SUMMARY

With existing RC buildings, in extreme cases, compressive strength is even less than 1/3 of design characteristic. No useful documents showing range of shear/pull-out loads for post-install anchors are available when anchoring at connections between new and existing concrete to retrofit such the buildings. From this background, planned research about anchoring with the object of seismic retrofit for low strength concrete buildings. Defined, as low strength concrete is one whose compressive strength is 13.5N/mm^2 or less as per seismic diagnosis guideline. Used, as test parameters are compressive strength, anchor rod diameter/embedment, and edge distance. Tested group shear and single shear/pull-out. Also, from tests this time, shear and pull-out strength equations of post-install bonded anchors used for low strength concrete were proposed. These equations, on seismic reinforcement of low strength concrete buildings, concerning design of post-install bonded anchors, useful equations were proposed.

INTRODUCTION

With existing RC buildings, compressive strength is even less than 1/3 of standards one. No useful documents for behaviors in concrete blocks and post-install anchors on shear/pull-out force have been available when anchoring at connections between new and existing concrete to retrofit such the buildings. From this background, planned research about anchoring with the object of seismic retrofit for low strength concrete buildings. Defined, as low strength concrete is one whose compressive strength is 13.5N/mm^2 or less as per seismic diagnosis guideline. Used as test parameters are compressive strength, anchor rod diameter/embedment, and edge distance. There were tests for group shear and single shear/pull-out. Also, from tests, at this time, shear and pull-out strength formulas of post-install bonded anchors used for low strength concrete were proposed. These formulas, on seismic reinforcement of low strength concrete buildings, concerning design of post-install bonded anchors, useful formulas were proposed and retrofit design guideline’s formulas and test values were compared.

OUTLINE OF THE TESTS

Concept for tests

The testing plans were made to reflect the results from tests into the actual design as soon as possible with considering the present situation that the quick working for the reinforcement on buildings to resist against earthquakes would be needed.

Especially, bonded post-install anchors were taken into consideration as the method of construction to resist against earthquakes with the steel frames and many embedded anchors.

Kinds of tests and summary for tests

Shear tests on the group anchor

The part of connections between new and existing concrete to retrofit was made to tests relationship with strength and displacement and investigate the behaviors at cracks in the brace with steel frames.

Shear/pull-out tests on the single anchor

Single anchor shear/pull-out tests were performed to investigate basic behaviors between strength and displacement and crack ones. The number of concrete blocks on which the anchor was embedded, were saved with tests at both sides.

Parameters were decided as followings

Compressive strength in the concrete blocks:

Ordinary concrete, 5.0N/mm^2, 10.0N/mm^2 and 15.0N/mm^2.

Post-install anchors:

D16, D19 and D22. (D means “deformed rods”)

Edge distances:

Distance(c) is equal to 200mm in shear force tests, and 300mm in pull-out tests. It was the standard types and distance(c) is equal to 100mm in all eccentric types.

Two types for effective embedded length of anchors:7d_a and 10d_a (d_a; anchor diameter).

However, there was one kind of 7d_a for group shear test.

Configurations of specimens

Shear test with group anchors

The standard specimen with edge distance as 200mm, and the eccentric specimen with edge distance as 100mm are showed in Fig. 1. There were 15 specimens as all cases in Table 1. There was one additional specimen for each concrete strength that had strain gauges to investigate behaviors in the anchor at the center of the concrete blocks and in the concrete around this anchor.

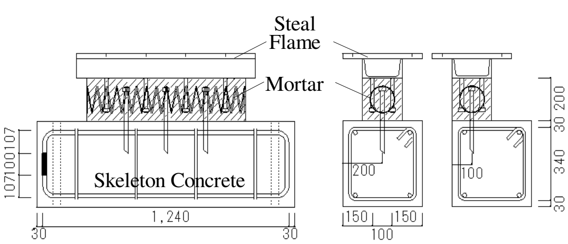
Shear test with a single anchor

The detail bar arrangement is showed in Fig.2. There were 108 specimens for all in Table 2.

Pull-out test with a single anchor

The bar arrangement is the same for the case of shear test.

However, difference between shear tests is the embedded positions. The number of specimens is 108 same as shear test cases in Table 2.



a)Side Section b)Standard c) Eccentric

Fig.1 Group Shear Test Specimens

Table1 All case of Group Anchors Specimens

Concrete Qualities (N/mm^2)	Anchor Diameter (mm)	Edge Distance		TOTAL
		Standard	Eccentric	
Fc 5	19	**2**	**1**	**3**
	22	**1**	**1**	**2**
Fc 10	19	**2**	**1**	**3**
	22	**1**	**1**	**2**
Fc 15	19	**2**	**1**	**3**
	22	**1**	**1**	**2**

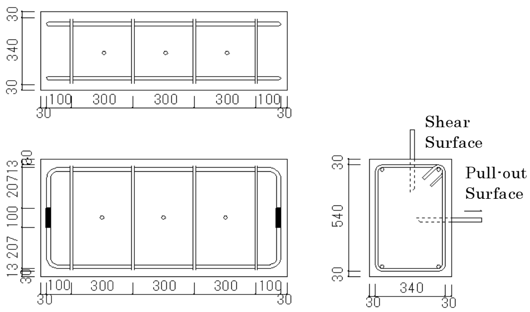


Fig.2 Single Shear&Pull-out Test Specimens

Table2 All case of Single Anchor Specimens

Concrete Qualities (N/mm^2)	Anchor Diameter (mm)	Effective Embeded (mm)	Edge Distance		TOTAL
			Standard	Eccentric	
Fc 5	16	$7d_a$	3	3	12
		$10d_a$	3	3	
	19	$7d_a$	3	3	12
		$10d_a$	3	3	
	22	$7d_a$	3	3	12
		$10d_a$	3	3	
Fc 10	16	$7d_a$	3	3	12
		$10d_a$	3	3	
	19	$7d_a$	3	3	12
		$10d_a$	3	3	
	22	$7d_a$	3	3	12
		$10d_a$	3	3	
Fc 15	16	$7d_a$	3	3	12
		$10d_a$	3	3	
	19	$7d_a$	3	3	12
		$10d_a$	3	3	
	22	$7d_a$	3	3	12
		$10d_a$	3	3	

EQUIPMENT FOR LOADING AND METHOD OF MEASUREMENT

The case for test on group anchors with shear force

The equipment for loading is showed in Fig.3. It was the real object to apply the horizontal force only along the surface between the concrete block and the filler mortar with a steel member. However, self-loading from equipments about $0.1N/mm^2$ was also applied as lateral force. Without this influence, shear force (Q) and displacement (δ) in the horizontal direction were measured. Displacement (δ) would be measured able to separate into the slip displacement (δ_{SM}) at the boundary part on the steel member and the filler mortar, and the slip one(δ_{MC}) among the filler mortar and the concrete block. The five cyclic loadings were basically applied.

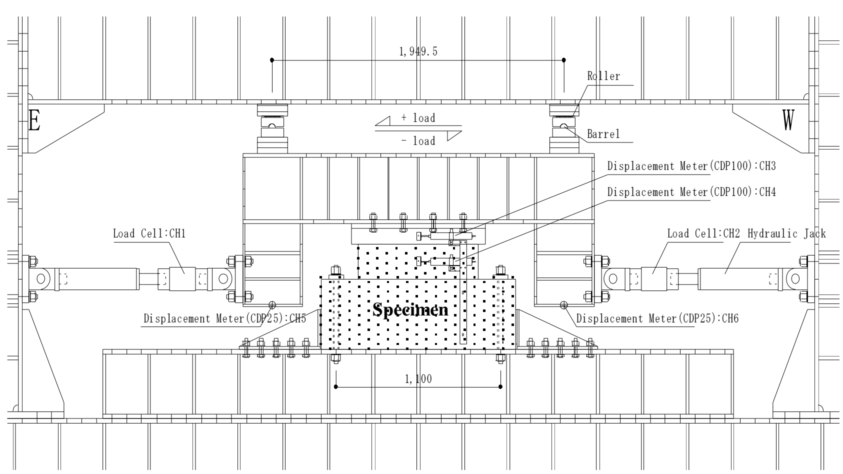


Fig.3 Apparatus for Group Shear Test

Test on the single anchor with shear force

We developed the special equipment with an oil jack showed in Fig.4 to apply the shear force in the exact direction coincided with the edge line of the concrete block. The value of loading was measured with the load cell. The relative horizontal displacement between concrete block and an anchor was measured at each loading steps. The loading was performed as monotonic load in each step.

Test on single anchor with pull-out force

The loading equipment showed in Fig.5 was used in this test. The monotonic pull-out loading was applied for an anchor. It would be possible to give influence for the measured strength in the case of the corn type failure with interference between the each failure, as anchors put in nearly every 300mm.

By this reason, tests were performed at first time for the left anchor, and next for the right anchor. Lastly, the center anchor was applied with pull-out force. Please reference the diagram in Fig.8. The quantity of the relative displacement (δ) by pull-out force between the concrete block and the anchor was measured.

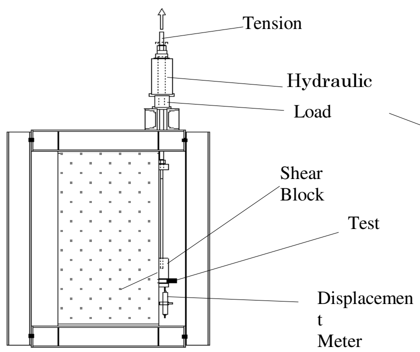


Fig.4 Apparatus for Single Shear Test

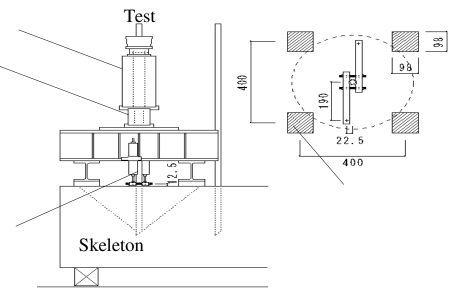


Fig.5 Apparatus for Single Pull-out Test

MATERIALS

Concrete

Mixing plan for the low strength concrete

Three types of specimens were made as 5N/mm^2, 10N/mm^2, and 15N/mm^2 for the compressive strength after 4 weeks from making them such as standard curing. Specimens with lower strength were made by reduction of quantity of cement with keeping the same quantity of water. As water-cement ratio for the lower strength concrete are larger, rock powder was installed instead of cement. Ratio of water/(cement + rock powder) was keeping as the same value (=0.66). As the results, slump values were almost same such as about 18cm for every strength concrete. Specimens were made of ready mixed concrete.

Test results

Compressive strength on the three types of concrete were curing standard and sealed. Test results are showed in Table 3. Compressive strengths of concrete in sealed curing were used in the analysis for shear test and pull-out test.

Filling mortar without contraction

Pre-Mix type mortar without contraction was used to fill another parts of specimens. Compressive strength from test results are showed in Table 3.

Steel bars and anchors

Material characteristics for the steel bars and anchors are showed in Table 4. All steel bars were standardized steel at the Japanese Industrial Standard G 3112 and SD345, without steel bars for the wire net (D6).

Table3 Test Results of Concrete

Type	Design Strength (N/mm²)	Actual Measurement at Placement: Slump	Actual Measurement at Placement: Air Volume (%)	Compressive Strength (N/mm²): Normal	Compressive Strength (N/mm²): Wet Cured	Split Tensile Strength (N/mm²): Normal	Split Tensile Strength (N/mm²): Wet Cured	Young's Modulus (10^5N/mm²): Wet Cured	Strength at Testing: Compressive Strength (N/mm²)	Strength at Testing: Split Tensile Strength (N/mm²)
concrete	5	18.0	4.7	3.18 (7) 4.20 (28)	3.85 (14) 3.72 (28)	0.44 (7) 0.55 (28)	0.55 (14) 0.66 (28)	21 (14) 14 (28)	4.50 (91)	0.58 (91)
concrete	10	17.0	4.8	5.61 (7) 7.68 (28)	6.59 (14) 8.50 (28)	0.82 (7) 1.06 (28)	0.84 (14) 0.91 (28)	20 (14) 19 (28)	9.93 (91)	0.89 (91)
concrete	15	18.0	3.9	8.94 (7) 13.90 (28)	11.96 (14) 14.11 (28)	1.17 (7) 1.00 (28)	1.27 (14) 1.00 (28)	22 (14) 24 (28)	16.07 (90)	1.28 (90)
mortar	80	-	-	-	79.77 (20)	-	2.97 (20)	31 (20)	77.67 (70)	3.13 (70)

Table4 Test Results of Rebars

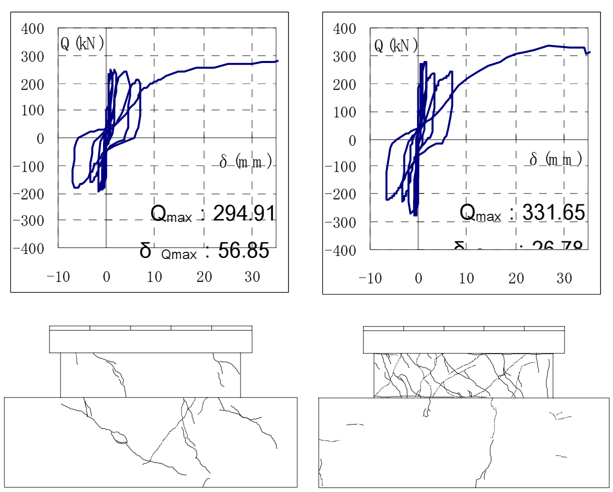
Designation	Normal Cross Section (cm²)	Yield Strength σ_y (N/mm²)	Max. Strength σ_{max} (N/mm²)	Break Elongation
D6	0.32	199.9	241.1	28.9
D13	1.267	378.3	570.4	2.83
D16	1.986	391.0	595.8	23.3
D19	2.865	375.3	567.4	23.9
D22	3.871	376.3	570.9	24.9

( ) is age in Day

RESULTS FROM TEST

Shear test on the group of anchors

Relation between shear force (Q) and displacement (δ), and crack diagram in the concrete block on two standard specimens, QG-C05-19S and QG-C15-19S are showed in Fig.6. There is not much difference in two specimens, though maximum strength (Q_{max}) is larger with the compressive strength. The number of cracks at the concrete blocks decreased in the concrete block with stronger compressive strength. However, the number of crack at filler mortar increased in the model of the concrete block with the stronger compressive strength. With comparing two specimens by putting anchors in the eccentric lines, QG-C05-19E and QG-C15-19E, loading values increased on according to the larger displacements. The number of cracks in the concrete blocks increased in the eccentric models. There were many cracks on the surface of the concrete block in C05 model with lower concrete strength, as many cracks on the filler mortar in the C15 model were able to see, by the reason that loading values were larger than C05 model.



a) QG-C05-19S b) QG-C15-19S

Fig6. Q-δCurve & Clacks of Group Shear Test

Shear test on a single anchor

Relation between shear force (Q) and displacement (δ), and crack diagram in the concrete block on two standard specimens, Q7-C05-19S and Q7-C15-19S are showed in Fig.7. Initial stiffness for both specimens with different compressive strength were almost same in the Q- δ curve, as there was the polyethylene sheet under the block for working shear force. Loading values were increased with accord to increase on the displacement. The maximum shear strength (Q_{max}) in the C15 model was about twice as much as the value in C05. The number of crack decreased in accordance with higher compressive strength in the concrete block. However, the zone with the compression failure in the concrete block was enlarged with the higher compressive strength.

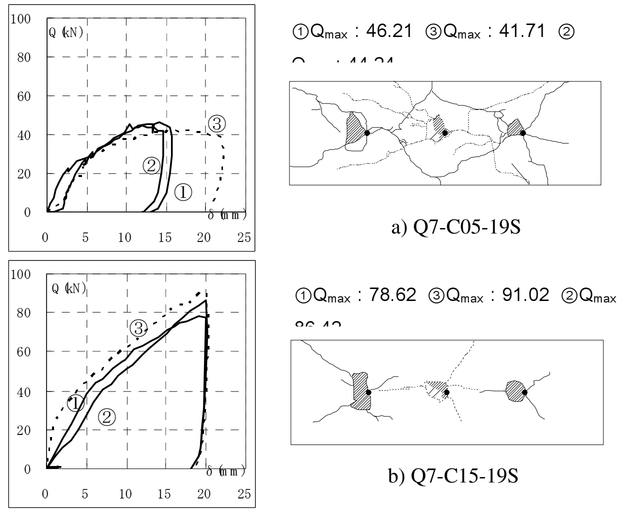


Fig7. Q-δ Curve & Clacks of Single Shear Test

The maximum shear strength (Q_{max}) was larger in the concrete block with the higher compressive strength from the results in the cases of eccentric anchors. There were not influences with the difference between initial stiffness. The slip displacement in the case of eccentric model was small with compare to the case of central anchor model and, also there were not toughness in the lower concrete and the maximum shear strength (Q_{max}) was also small. There was a tendency that failure in the edge distance was severe on the concrete blocks with low compressive strength.

Pull-out test with a single anchor

Relation between pull-out forces (T) and displacements (δ) with those force and the diagrams for cracks are showed at the cases of T7-C05-19S and T7-C15-19S that had the distances from edges to the center of anchors as 300mm in Fig.8. There was not much difference at the initial stiffness for the compressive strength. However, the maximum pulled-out force in the concrete block with the larger compressive strength was about twice as high as the other pulled-out force. There is better capacity to correspondence to large displacement for concrete blocks with the higher compressive strength than the lower one; there is much difference for the ability to absorb the total energy between them. The cracks are spread out in the entire concrete block with the lower compressive strength. It is clear that there are much influences with the compressive strength. There were same behaviors in the case of eccentric models with embedded anchors a part from the edge of concrete block as 100mm (C).

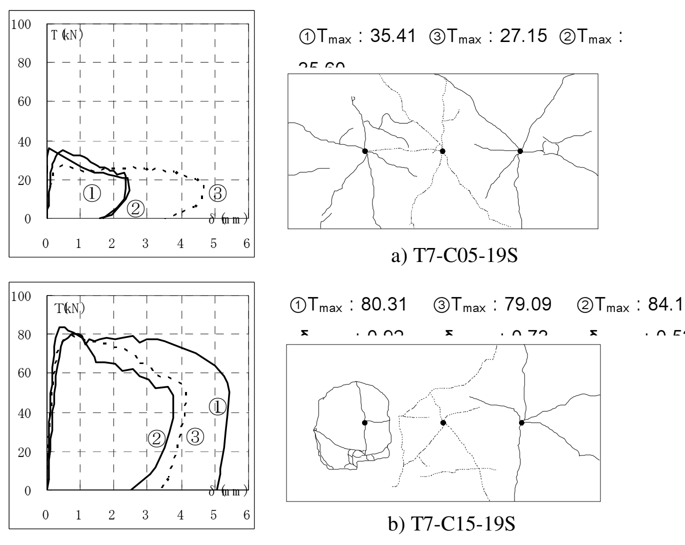


Fig8. Q-δ Curve & Clacks of Single Pull-out Test

However, there was much influence with edge distance even in the larger compressive strength model. Cracks concentrated on the surface of the concrete block in spite of the compressive strength.

INVESTIGATION FOR EXPERIMENTAL RESULTS

With the results from serial of tests, we propose the formulas for shear strength and also pull-out strength on the post-install bonded anchors in the concrete block with low compressive strength.
In this paper, our proposed formulas were induced by using the values in the case of only one kind failure mode that means the mode with failure of concrete, as the compressive strength of concrete (σ_B) would be smaller than equal to 15N/mm^2. There were the cases that the anchors had been yielded before concrete blocks had been crashed in cases of D16 or D19 were used. In these formulas, there were not considerations about those, as those problems would be exceptions. This is the difference between the old and new formulas.

Induction of the formula for shear strength

The relations between the compressive strength of the concrete (σ_B) and the unit shear strength of the group anchor testing (τ_{mg}) and a single anchor testing (τ_{ms}) from the testing results are showed in Fig.9.a. $\tau_{mg} > \tau_{ms}$ are understood if the same σ_B was used in the concrete block. The difference in the results between the group anchor testing and a single anchor testing would be hypothesized by the fact that though there are large resistance on the boundary among the concrete block and filler mortars, there are not resistance between the equipment to perform the shear force and the concrete block with the polyethylene.
With considering the tensile yielding strength σ_y of SD345 used as anchors, formulas for group anchor testing and a single anchor testing were induced without falling down the experimental data by the bearing strength line paralleled to two regression lines as showed in Fig.9a.

Group anchor testing : $\tau_{mg} = \{0.602 + 0.019\,\sigma_B\}\,\sigma_y$ ------(1)

Single anchor testing : $\tau_{ms} = \{0.205 + 0.036\,\sigma_B\}\,\sigma_y$ ------(2)

It is remarks : $\tau_{mg}, \tau_{ms} \leqq \sigma_y$ σ_y : tensile yielding strength

Factors (ϕ_1) was evaluated by using the results in Fig.9 b and by the hypothesis that the bearing shear strength was fallen down like a line with thickening the diameter of anchors as followings.

$\phi_1 = 0.84 - 0.05(d_a-22)$ ------(3)

It is the fact that the bearing shear strength would be generally larger with big edge distance.
However, influence with edge distance (C) would be smaller with needing 100mm at edge distance (C) in Fig.9c. By these reasons, Factors (ϕ_2) was decided as followings.

$\phi_2 = 0.85(C/100)^{0.15}$ ------(4)

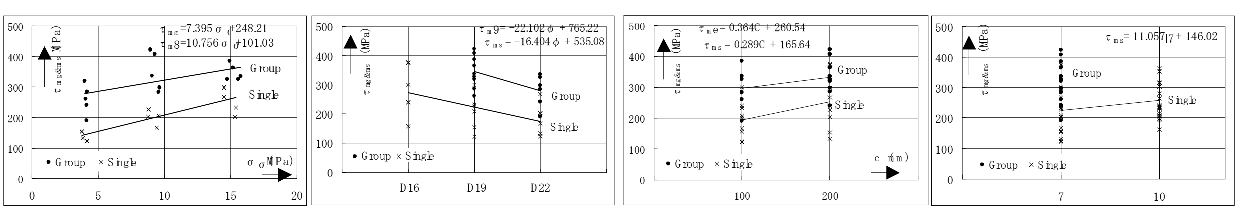
However, ϕ_2 is smaller than equal to 1.0. Unit of C is “mm”.

ϕ_3 is evaluated as standard value “1.0” at 7d_a as putting length (l_e), and “1.15” at 10d_a by inspecting the diagram in Fig.9d. By considering these parameters, shear strength (Q_A) is evaluated as followings.

For the group anchors : $Q_A = \phi_1 \cdot \phi_2 \cdot \phi_3 \cdot \tau_{mg} \cdot A_a$ ------(5)

For a single anchor : $Q_A = \phi_1 \cdot \phi_2 \cdot \phi_3 \cdot \tau_{ms} \cdot A_a$ ------(6)

A_a: Section area for anchors



a) σ_B -$\tau_{mg\,\&\,ms}$ Relationship　b) Φ -$\tau_{mg\,\&\,ms}$ Relationship　c) C-$\tau_{mg\,\&\,ms}$ Relationship　d) l_e-$\tau_{mg\,\&\,ms}$ Relationship

Fig.9 Influence of Parameter

Those formulas were evaluated by only using maximum bearing shear strength without considering the displacements. It is necessary to take the caution that the result (Q_A) would be dangerous side, when D22 and compressive strength (σ_B) in the concrete block is smaller than and equal to 10N/mm^2.

Strength for pull-out force on a single anchor

Similarly, some formulas were evaluated with results by pull-out test for a single anchor .The basic raw formula was evaluated with the low limit from a regression line in Fig.10a by the results for the standard specimens as followings.

σ_t=10.0 σ_B+63.7-------(7)

Factors (ϕ_1) was evaluated by the regression lines in Fig.10b. Factors (ϕ_1) are 1.16 for D16, 1.00 for D19, and 0.94 for D22.

Factors (ϕ_2) was decided with the result in Fig.11a as followings.

$\phi_2 = 0.85(C/100)^{0.15}$ -----(8)

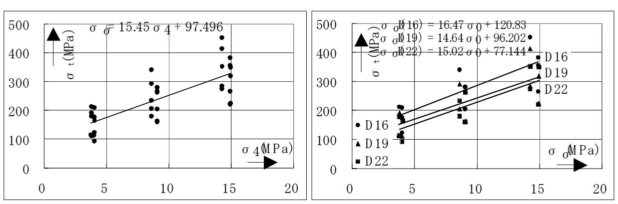
ϕ_3 is evaluated as standard value "1.0" at 7d_a as embedded length (l_e), and "1.15" at 10d_a by inspecting the diagram in Fig.11b.

Lastly, the maximum bearing pulling-out strength (T_A) is expressed as followings.

$T_A = \phi_1 \cdot \phi_2 \cdot \phi_3 \cdot \sigma_t \cdot A_a$ -----(9)

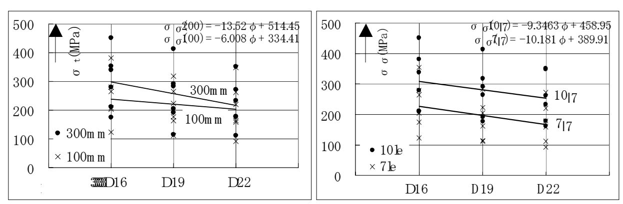
σ_t: Tensile yielding stress for anchors

A_a: Section area for anchors



a) σ_B -σ_t Relationship b) ϕ-σ_t Relationship

Fig.10 Influence of σ_t&φ



a) C-σ_t Relationship b) l_e-σ_t Relationship

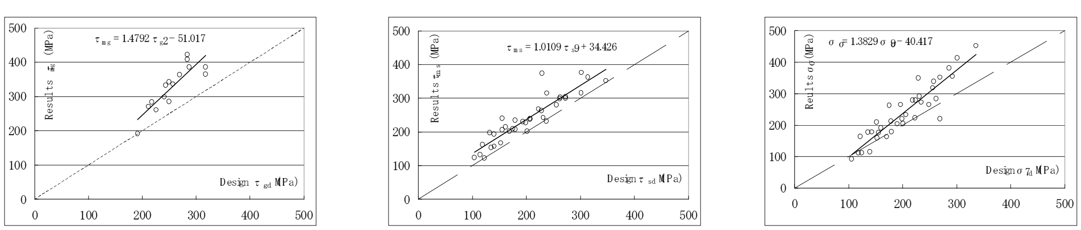
Fig.11 Influence of C & l_e

COMPARISON EVERY BEARING STRENGTH WITH THE TESTING RESULTS

Relation between the proposed formulas and the test results

The basic formulas for shear strength, and for pull-out strength, formulas for them with amendment by the influence factors, and the results from the test are showed together from Fig.12a to Fig.12c. The tensile yielded strength for anchors were hypothesized as 350N/mm^2 (correspond to SD345) to evaluate the bearing strength for the shear and pull-out strength. And also, the standard strength for design of concrete was used as σ_B, and Young's Modulus for concrete was showed as followings.

$Ec = 2.1\times10^4 \cdot (\gamma/2.3)^{1.5} \cdot \sqrt{(\sigma_B/20)}$ γ: Weight of concrete per unit value



a) Shearing stress of Group Shear Test b) Shearing stress of Single Shear Test c) Pulling-out stress of Group Shear Test

Fig.12 Comparison of Design - Results

Investigation for calculated data and test results

All test results are larger than calculated results in Fig.12a. It would be reason that large strengths on the tests were influenced with the values of σ_y on anchors. These values were from 375～377 N/mm^2. The test strengths were bigger than calculated data by about 1.07(375/350). However, as τ_{mg} that concrete strengths were smaller, reserved power was small. It will be necessary to check it carefully. τ_{ms}, that means shear stress for a single anchor, is coincided the test results almost in Fig 12b. It is clear there are no reserved power scarcely among calculated data and test results. In checking data in Fig.12c, pull-out strength with calculation is almost proportional to the testing results. There are some lower calculated values than the testing results. It is the case the lower compressive strength of concrete (5N/mm^2) was used by anchors with D22. It is necessary to take care for using calculated values.

Treatment for safety faction

It is important to evaluate the safety factor for the proposal formulas in order to work effectively for the actual design. It would be real to decrease the proposed formulas with taking about 1.33 for safety factor, though calculated formulas would be safer than testing values. There is basically reserved strength at the yielding stress in anchor with comparing to design values for this reason. It would be a idea to multiply bearing shear strength τ_{mg} by 0.8 still more in the case that slope by relative member displacement would be limited as 1/250.

CONCLUSION

There was sufficient bearing strength for the cases of the putting anchors in the low strength concrete block, when the results from testing were corresponding with the design formulas in the guideline recommended by the agency. However, proposed formulas were issued with considering many parameters in the concrete blocks that anchors were put in, by referencing to the ACI318. There were narrow variations in the formulas for strength with considering diameter of anchors, embedded length, and the edge distance. In the case of the lower concrete strength, σ_B =15N/mm^2, applicability on the proposed formulas is better than the formulas used to now. The better results were gotten. It is urgent to reinforce the concrete building with low strength. There would be many cases that bonded post-install anchors would be used to reinforce these buildings. It is one main object to investigate definitely the efficient values to design. From now, still the meaningful study must be performed with the simulation by using Finite Element Method.

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