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SHEAR AND TENSILE STRENGTH OF EXPANSION ANCHOR

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SUMMARY

In case of enlargement of buildings or seismic retrofitting of existing buildings, expansion anchor are frequently used. However, there are neither industrial standard of the anchors nor reliable design calculation method. Shear test on 48 specimens and pull-out test on 407 specimens of expansion anchor of several types are reported. Improved expansion anchors in which no thread comes to boundary surface are ductile for shear, but some of previous equations give much higher strength than test results on the anchors.

INTRODUCTION

Recently,a number of existing building of reinforced concrete in Japan are improved in their performance against earthquakes. In order to increase their strengths or ductilities installing in-filled walls or reinforcing of columns is done. One of the important problems on those works is detail of joint between new concrete and existing old concrete. Expansion anchors are installed in the old concrete and new concrete is poured. In order to design the expansion anchors, Ref.1 was published in which design by analysis and design by testing were shown. In the design by analysis, tensile strength shall be decided by the strength of anchor steel so that the pull-out strength of concrete calculated based on tensile strength of concrete acting on the projected area of stress cone shall be greater than the strength of steel. Shear friction strength is applied to the shear strength of the boundary with anchors. Cyclic behaviors of the joint subjected to shear, however, have not been studied so much. And tension behavior of the anchor is a problem, because a lot of field test show considerablly lower strength than both strength of steel and concrete pull-out strength. These two points are the objectives of this study.

SHEAR TEST

Test Specimen Expansion anchors adopted in the specimens are shown in table 1 and Fig.1. Specimens of the shear test are shown in Fig.2. Mechanical properties of materials for shear test specimens are listed in Table 2. Parameters in 83-A are spiral reinforcement and loading history, and parameters in 83-B are types of anchor and loading history. Parameters of 84 are types of anchor sizes, scratching and loading history. Scratching was done with pick-hammer on the face of old concrete. It is commonly specified to do in practical work of seismic retrofit.

Table 1 Test Specimens of Shear Test

(a) 83 Series

No.	Joint Bar	L	Spiral Hoop
A-No. 1	MB6φ	a	—
No. 2	MB6φ	b	—
No. 3	MB6φ	c	—
No. 4	MB6φ	c	2φ
No. 5	MB6φ	c	3φ
No. 6	MB6φ	d	—
No. 7	MB6φ	d	2φ
No. 8	MB6φ	d	3φ
B-No. 1	MB10φ	a	—
No. 2	MB10φ	c	—
No. 3	MB10φ	d	—
No. 4	MBD10φ	a	—
No. 5	MBD10φ	c	—
No. 6	MBD10φ	d	—
No. 7	CB10φ	a	—
No. 8	CB10φ	c	—
No. 9	CB10φ	d	—
No. 10	CBD10φ	a	—
No. 11	CBD10φ	c	—
No. 12	CBD10φ	d	—

L; Loading Hysteresis
- a: simple loading
- b: simple loading with axial force (1 ton)
- c: reversed cyclic loading of controlled by shift disp.
- d: reversed cyclid loading of controlled by shear force

S; Scratching

(b) 84 Series

No.	Joint Bar	f_c' kg/cm²	S g/cm²	L
No. 1	6φ	180	—	a
No. 2	9φ	180	—	a
No. 3	13φ	180	—	a
No. 4	13φ	180	—	a
No. 5	13φ	180	—	a
No. 6	D10	180	—	a
No. 7	13φ	135	—	a
No. 8	D10	135	—	a
No. 9	6φ	135	—	a
No. 10	9φ	135	—	a
No. 11	D10	180	0.049	a
No. 12	D10	180	0.062	a
No. 13	D10	180	0.048	c
No. 14	D10	180	0.058	c
No. 15	6φ	180	0.091	c
No. 16	6φ	180	—	c
No. 17	9φ	180	—	c
No. 18	9φ	180	—	c
No. 19	13φ	180	—	c
No. 20	13φ	180	—	c
No. 21	D10	180	—	c
No. 22	D10	180	—	c
No. 23	13φ	135	—	c
No. 24	13φ	135	—	c
No. 25	D10	135	—	c
No. 26	D10	135	—	c
No. 27	6φ	180	—	c
No. 28	6φ	180	—	c

Table 2 Properties of the Material of Shear Test

83 Series Steel	a_t cm²	σ_y kg/cm²	σ_{max} kg/cm²
Main Bar D10	0.71	3680	5730
Stirrup 4φ	0.12	3890	5140
Spiral Hoop 2φ	0.030	2840	3760
Spiral Hoop 3φ	0.075	4180	5290
Bolt M6	0.226	4440	5330
Bolt M10	0.579	4340	5500

83 Series Mortal	f_c' kg/cm²	$_c\sigma_t$ kg/cm²	$E_c \times 10^5$ kg/cm²
Beam	302	28	2.58
Loading Beam, Wall	219	21	2.19

84 Series Steel	a_t cm²	σ_y kg/cm²	σ_{max} kg/cm²
D10	0.71	3850	5500
13φ Anchor Bolt	1.32	4630	5000
9φ Anchor Bolt	0.63	5730	5990
6φ Anchor Bolt	0.27	6430	6600
9φ Bolt	0.61	4090	4590
6φ Bolt	0.21	4730	5430
4φ Bolt	0.086	5530	6290

84 Series Concrete	F_c kg/cm²	f_c' kg/cm²
Beam	180	172
	135	140
Loading Beam	180	162
	135	212

(Anchor adopted in the specimens)

Expansion Anchor 1 : An anchor with female screw is knocked into bore hole, then the cone expand the tip of the bolt. Entire length of the bolts is embeded into existing concrete. Male bolt is screwed into the anchor in order to connect old and new concretes. So threaded portion of the male bolt comes at the boundary surface.

Expansion Anchor 2 : To avoid threaded portion of bolt at the boundary surface long anchor bolt embeded in old concrete for only half of its length was designed by Saito et al.(Ref.4)

Adhesive Anchor : After polyester enclosed in a capsule is inserted into bore hole, a turning reinforcing bar or a entire threaded bolt is inserted so that the capsule is broken and the polyester is mixed to be hardened.

Mortar Anchor : Reinforcing bar is inserted bore hole grouted with fresh mortar.

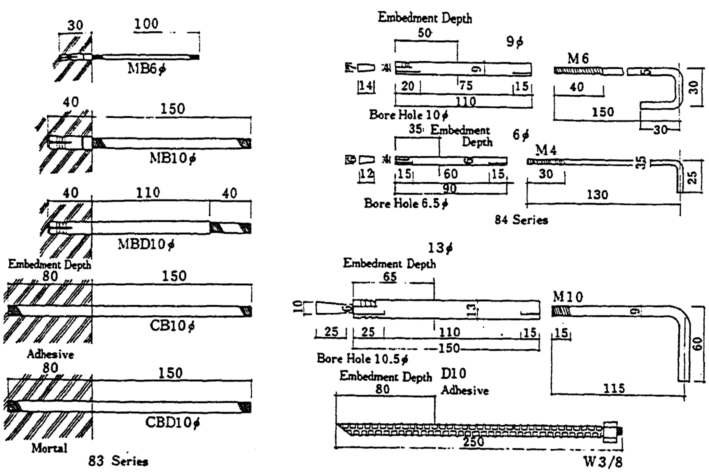


Figure 1 Forms and Dimensions of Each Type of Anchor

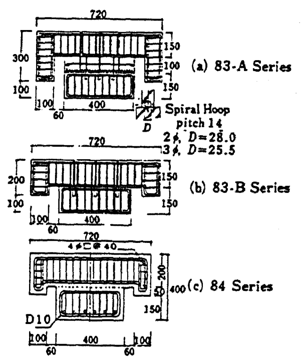


Figure 2 Specimens

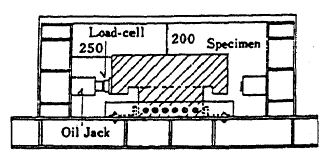


Figure 3 Loading Apparatus of Shear Test

Loading Apparatus   Loading set-up for shear test is shown in Fig.3. Center line of horizontal loading jacks coincided to the center line of the boundary surface of the specimen. Lateral relative displacements (shift displacements) and vertical relative displacements were measured by means of electric transducers.

Test Results and Calculated Values   Several formulae for design calculation or predicting the shear strength of the joints are listed in Fig.4 in which mutual relationship between calculated values by those formulae is shown. The maximum shear forces of test results were compared with calculated values by means of those formulae in Fig.5. In these figures, correlation coefficient, standard deviation, average of ratio of shear strength to calculated ones and the number of data are shown. In general the calculated values by Eq.Q13 and Eq.Q5 are lower than the experimental values. In these figures most data are in the safety zone. The mean value of the ratios of the maximum shear forces obtained by the tests to the calculated values by Eq.Q12 was 0.9, but the data in this figure are very widely scattered. This formula roughly predicted the test results. The correlation coefficient of the relationship on Eq.Q5 is 0.87, and standard deviation is 0.12. The calculated value by Eq.Q5 predicted the test values fairly well.

The Equations to be used in the calculation

$Q1 = aa \cdot \sigma m/\sqrt{3}$ (1) (Ref.1)

$Q2 = 0.4\ aa\sqrt{Fc \cdot Ec}$ (2) (Ref.1)

$Q3 = 0.225\ aa\sqrt{Fc \cdot Ec}$ (3) (Ref.2)

$Q4 = 0.85\,\mu \cdot \sigma y \cdot aa$ (4) (Ref.3)

$Q5 = Aw\ (4.5ps + 6.7)$ (5) (Ref.4)

$Q6 = Aw\ (17.2\ ps + 6.53)$ (6) (Ref.5)

$Q7 = Aw\ (0.0101\ ps \cdot \sigma y - 2.09)$ (7) (Ref.6)

$Q8 = 0.5\ aa\sqrt{Fc \cdot Ec}$ (8) (Ref.7)

$Q9 = 1.3\ Da^2\sqrt{\sigma y \cdot Fc}$ (9) (Ref.8)

Note

aa : sectional area of steel (anchor),

$\sigma m, \sigma y$: maximum, yielding strength of steel (anchor),

μ : the coefficient of friction (=1.0),

Aw : area of boundary, $Aw = lw \cdot t$

lw : length of boundary, t : thickness of boundary,

ps : ratio of total cross sectional area of anchor to that of boundary,

$ps = 100\ aa/(P \cdot t)$

(cf.Eq.5 : $0.4 < ps < 1.0$)

P : pitch of anchor

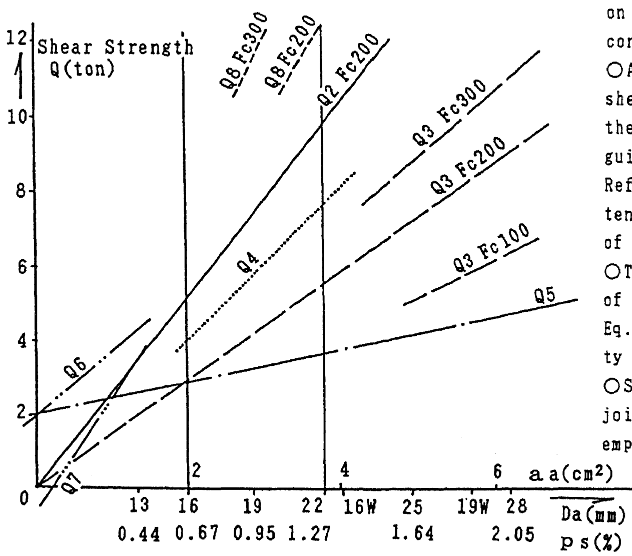
Fc, Ec : strength and modulus of elasticity of concrete

○The Eq.8 proposed by W. Fisher et al. on shear strength of the boundary with connectors is often used.

○According to yield criteria by Von Mises shear strength of ductile steel is 1/3 of the tension strength. The most popular guideline for seismic retrofit in Japan Ref.1 adopted that criteria but maximum tension strength, σm, was used instead of tension yield strength there.

○The Eq.8 was proposed for calculation of stud connector. The Ref.1 adopted this Eq. for design of joint, multiplying safety factor 0.8.

○Saito et al. published test results on joint with expansion anchor and proposed empirical formula Eq.5.



(assumption of calculation)

t = 200 cm

P = 150 cm

$Ec = 2.1 \times 10^5\ kg/cm^2$

Figure 4 Mutual Relationship among Calculated values

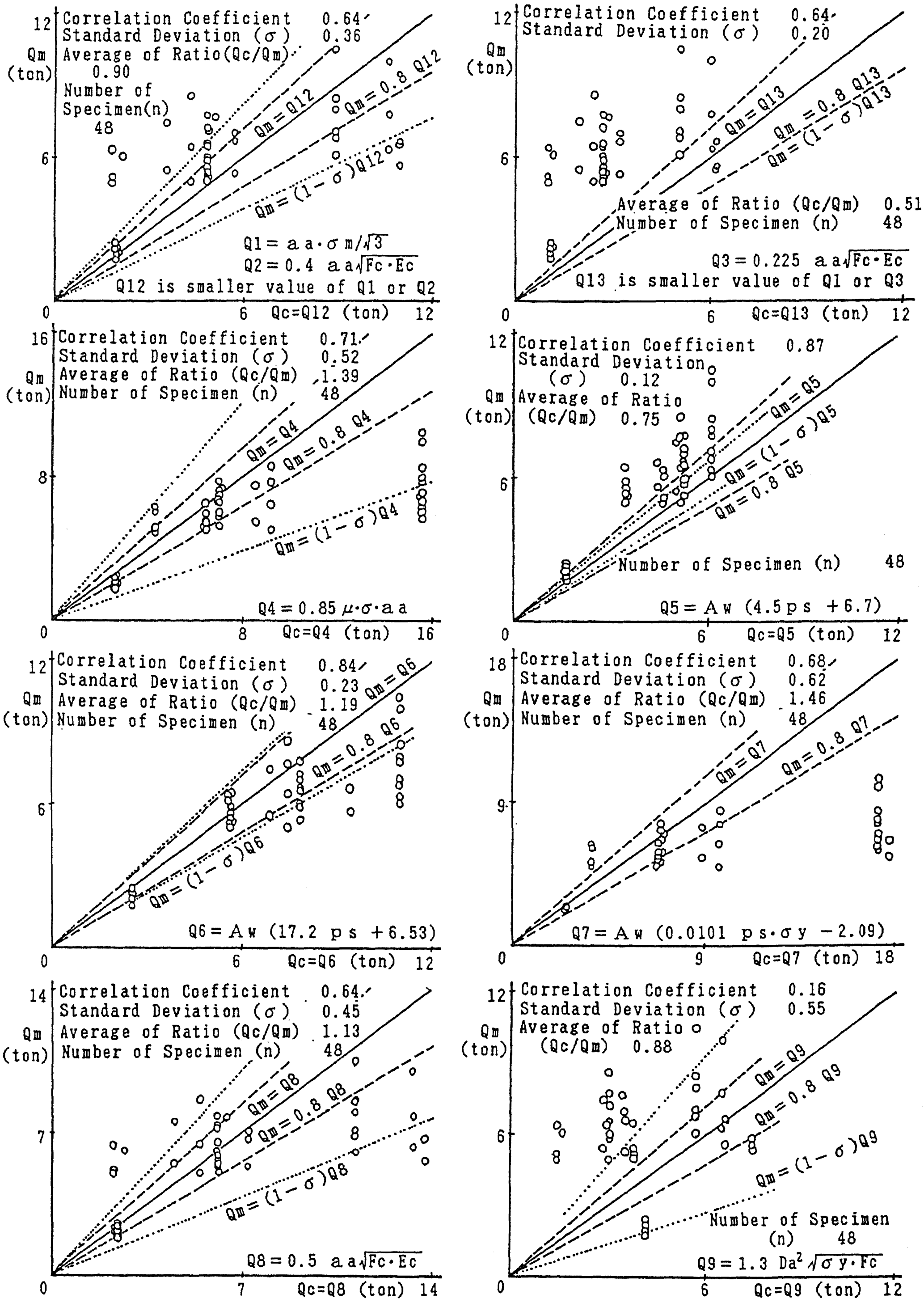


Figure 5 Relationships between Calculated values and Test Result of Shear Test

PULL-OUT TEST

Test Specimen The detail of specimen and anchor adopted in this test are shown in Fig.6 and Table 3. The anchors tested are 407, and main variables in this test are types of anchor, sizes, concrete strength, distance from concrete edge.

Loading Apparatus The test arrangement of the pull-out test is shown in Fig.7. To investigate the tensile behavior of these expansion anchors, each of them was subjected to static tensile loading. The pulling out displacements at the lower part of the tension bar were measured using displacement transducers.

Test Results and Calculated Values The test results of the pull-out strength are compared with calculated ones by means of several formulae for predicting the maximum pull-out load. The relationship between the measured pull-out strength and calculated ones are shown in Fig.8 respectively. In the relationship between the calculated values by Eq.P1 and the test results, general measured strengths are lower than the calculated ones. In the figure of relationship between the calculated values by Eq.P2 and the pull-out strength obtained from the test, most data are in the safety zone. The mean value of the ratio of the measured pull-out strength to the calculated values by Eq.P4 is closed to 1.0. The most popular guideline for seismic retrofit Ref.1 adopted the Eq.P1 but the measured pull-out strength of so many data are lower than the calculated ones.

Table 3 Test Specimens and Materials of Pull-Out Test

Fc kg/cm²		150	152	159	199	241	243	272	417	Total
A	13φ	31	6	54	43	1	35		13	183
	16φ		8			25	41	25	12	111
	19φ							5		5
304	22φ							5		5
B	14φ	11	3	11	11		3		3	42
	15φ							3		3
54	17φ							9		9
C	12φ	4		6	5					15
24	16φ		3					3	3	9
D	12φ	6		5	5					16
25	16φ		3					3	3	9
	Total	52	23	76	64	26	79	53	34	407

A ; Improved Anchor C ; Wedge Anchor

B ; Follow up Expansion Anchor D ; Internal Cone Anchor

Equation

$Ac = \pi \cdot La\ (La + Da)$ (10)(Ref.3)

$P1 = 0.45\ La\ (1 + La/Da)\ Fc \cdot aa/Da$ (11)(Ref.1)

$P2 = 0.75\ \phi 1 \cdot Ac \sqrt{Fc}$ (12)(Ref.2)

$P3 = \phi 2 \cdot \sigma y \cdot aa$ (13)(Ref.2)

$P4 = 1.06\ \pi \cdot \phi \cdot La^2 \sqrt{Fc}$ (14)(Ref.3)

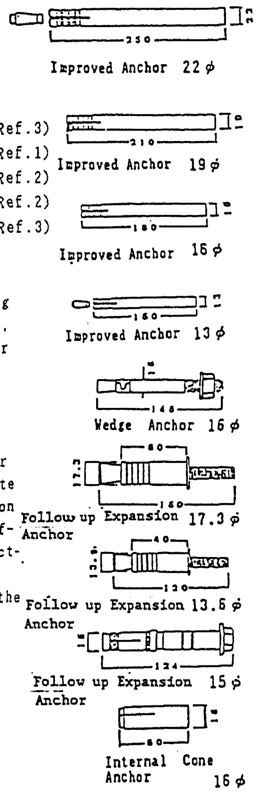
Note

Ac : calculated projected area of pulling out concrete cone, La : embedment length, Da : outside diameter of embedment anchor aa : section area of expansion anchor, Fc : concrete strength, $\phi 1, \phi 2, \phi$: strength evaluation safety factor, in which $\phi 1 = \phi 2 = \phi = 1.0$, σy : yielding stress of expansion anchor

○The design pull-out strength of concrete for expansion anchors are usually based on an uniform tensile stress acting on an effective stress area defined as the projected area of stress cones radiating toward the attachment from the bearing edge of the anchors.

Properties of the Materials

Anchor	Improved Anchor				Following Expansion Anchor			Wedge Anchor		Internal Cone Anchor	
	13φ	16φ	19φ	22φ	14φ	15φ	17φ	12φ	16φ	12φ	16φ
Sectional Area Aa cm²	1.33	2.03	2.83	3.78	0.58	0.84	0.84	0.69	1.33	0.63	1.13
Yield Strength σy kg/cm²	6050	5610	5290	5080	—	6400	—	6080	6080	5790	5790
Maximum Strength σm kg/cm²	6220	5860	5440	6050	5240	8000	5440	8170	8170	7380	7380



Forms and Dimensions of Each Type of Anchor

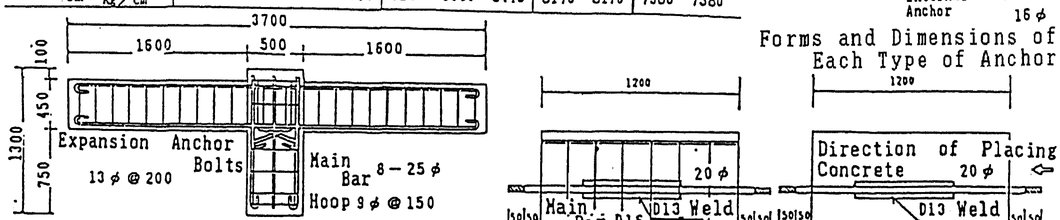


Figure 6 Specimens of Pull-Out Test

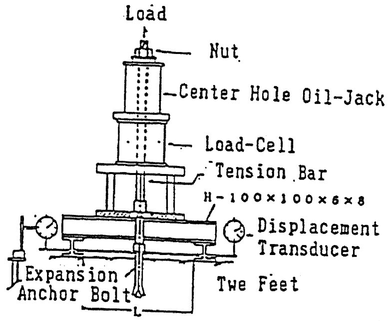


Figure 7 Loading Apparatus of Pull-Out Test

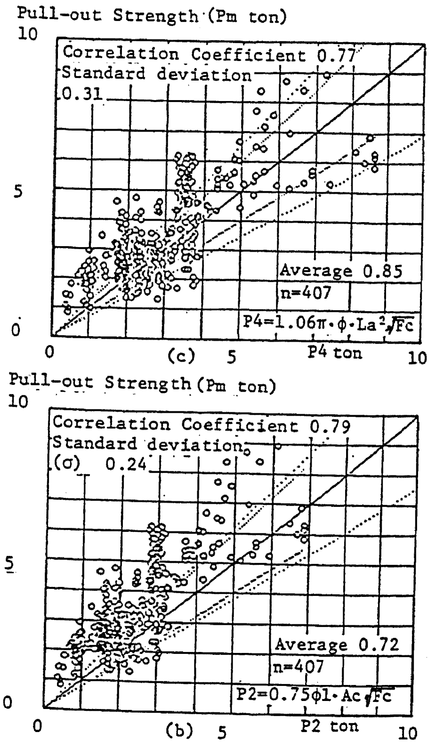
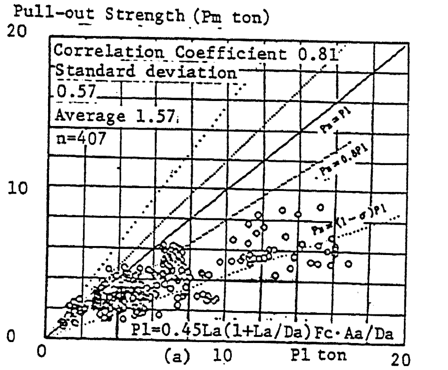



Figure 8 Relationships between Calculated Values and Test Results of Pull-Out Test

CONCLUDING REMARKS

The design shear strength for anchors are usually based on Ref.7 in Japan. Depend on our experiment, however, this design formula roughly predicted the test results. The figure of the relationship between the test results and calculated ones by Eq.Q8 shows the wide scattering. In the figure on Eq.Q5, most data are in the safety zone.

The design pull-out strength for expansion anchors are usually based on an uniform tensile stress acting on an effective stress area defined as the projected area of stress cones radiating toward the attachment from the bearing edge of the anchors. Depend on our experiment this design are apt to get an upper-bound value.

REFERENCES

1. The Japan Building Disaster Prevention Association, "Design Guideline for Aseismic Retrofitting of Existing Reinforced Concrete Buildings", 1977.3.
2. Architectural Institute of Japan, "Design Recommendation for Composite Constructions", 1985.
3. American Concrete Institute Standard, "Building Code Requirements for Reinforced Concrete", ACI 318-77.
4. Saito, T. et al., "Shear Tests for Construction Joint of Reinforced Concrete Beam-Wall by Expansion Anchors" Annual Conference of AIJ, 1977.10. pp.1805
5. Bessho, S. et al., "Shear Test on Dowel Joint of In-Filled Wall with Expansion Anchor", Annual Conference of AIJ, 1979.9. pp.1363
6. Noguti, H. et al., "Shear Test on Dowel Joint of In-Filled Wall with Adhesive Anchor", Annual Conference of AIJ, 1983.9. pp.2145
7. Fisher, W. et al., "Shear Strength of Stud Connectors in Lightweight and Normal-Weight Concrete", AISC Engineering Journal, 1971.4. pp.55
8. Rasumussen, B. H., Betoninstobe, "Tvaerbelastede Boltes og Dornes Baereevne", Laboratoriet for Bygningastatik, Moddelelse, Vol.34, No.2, 1962.