Study on Strength and Ductility of Post-installed Adhesive Anchoring System –Comparison and analysis of experimental values, various values in ultimate strength and design strength-

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SUMMARY:
This paper described strength and ductility of tensile strength in Post-installed adhesive injection anchoring system based on two experiments, that is single anchors and a group of anchors. And a conclusion regarding relationships between ultimate strength of tensile and displacement performance as they relate to the various failure modes were provided. As expected it was found that steel and bond failure provides improved ductility when compared to concrete breakout failure mode. Second, predictive equations calculating ultimate capacity of single and group post-installed anchoring systems by Japanese standard design guideline were compared with experimental values of the same condition. We proposed a new predictive equation based on Japanese seismic retrofitting guideline. Finally comparisons between a Japanese standard guideline, Europe and US in tensile design strength were shown in the same conditions of the above experiments. We provided precious basic data.

Keywords: Post-installed adhesive anchor, tensile and ductility, Japanese design, prediction, ETAG and ACI

1. INTRODUCTION

Post-installed adhesive anchoring systems are used in important joints among structure members on seismic retrofitting and renewal applications today. It also increases that needs implement seismic retrofitting and renewal with living in buildings [1]. Especially many cases make seismic retrofitting using post-installed anchors in joints between existing structure members and reinforcing elements exist [2]. Sheer loads act in the joints mainly in these cases. In fact there are many seismic retrofitting systems in Japan. Side wall retrofitting systems are also one of methods implement it with living in buildings [3][4][5]. Positions acted tensile loads in the joints in this system exist. Of course ultimate strength equations in tensile and sheer are specified in Japanese standard design guideline of seismic retrofitting. However post-installed anchors in joints are designed as sheer loads acting in seismic retrofitting basically. Therefore only a few reports regarding strength and ductility of tensile in single and group adhesive anchoring systems exist [6] in Japan. Additionally few reports in comparing and analysing between Japanese design equations and EU & US equations regarding predictive failure load and tensile design strength exist. In the near future globalization accelerates more and more in Japanese construction industry so that universal design method in Asia or all over the world may be established in post-installed anchors. Hence we implement experiments in single and group post-installed adhesive anchoring systems. And we propose a new predictive equation of failure and ultimate tensile strength after comparing a Japanese architectural ultimate equation [7] (below 'JBDPA') to experimental values. Additionally we compare Japanese guideline to EU design (below 'ETAG') and US design (below 'ACI') in several tensile design strengths and provide basic data in post-installed adhesive anchoring systems based on globalization of Japan and Asia.

2. TENSILE STRENGTH EQUATIONS IN JBDPA

Tensile strength design equations in a single anchor are defined in current Japanese seismic retrofitting design guideline, 'JBDAP' as the following below;
(Note: 'JBDAP' = Japan Building Disaster Prevention Association)

$$T_a = \min \left[T_{a1}, T_{a2}, T_{a3}\right] \tag{2.1}$$
$$T_{a1} = \sigma_y \cdot a_0 \tag{2.2}$$
$$T_{a2} = 0.23 \cdot \sqrt{(\sigma_B)} \cdot A_c \quad (A_c = \pi \cdot l_e(l_e + d_a)) \tag{2.3}$$
$$T_{a3} = \tau_a \cdot \pi \cdot d_a \cdot l_e \quad (\tau_a = 10 \cdot \sqrt{(\sigma_B/21)}) \tag{2.4}$$

(T_{a1}: Tensile strength in steel failure, T_{a2}: Tensile strength in concrete corn failure, T_{a3} : Tensile strength in bond failure, σ_y : Yield tensile strength in rebar (N/mm^2), a_o : Nominal area in rebar (mm^2), σ_B: Concrete compressive strength (N/mm^2), A_c: Effective area projected of a single anchor in concrete failure (mm^2), l_e: Effective embedment depth (mm), d_a : Diameter in rebar (mm), τ_a : Bond strength (N/mm^2), σ_B (Range of concrete design strength):15-36(N/mm^2))

From the above equations when D19 (SD345) as a deformed rebar and 15 (N/mm^2) in concrete strength are assumed, the following three categories are grouped as the below (a)-(c) in Figure 1, that is (a): the range of concrete cone failure mode, (b): the range of bond failure mode, (c) the range of steel failure mode. Therefore we refer to ductility of a single anchor in tensile strength with experimental data in these three failure modes.

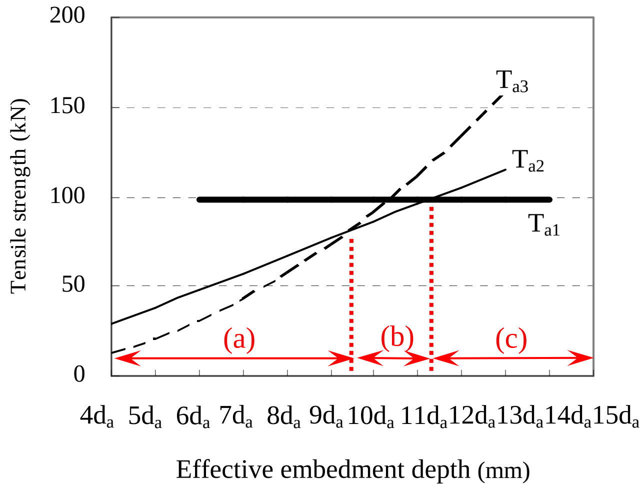

Figure 1. Categories area in each failure mode in tensile strength formula

3. BRIEF IN EXPERIMENT OF SINGLE ANCHORS, RESULT AND DISCUSSION

3.1. Brief Summary Experiment

This experiment in a single anchor of adhesive is implemented as tensile in reference to a standard testing method in post-installed anchors described by JCAA (Japan Construction Anchor Association). A concrete block with no reinforcing rebar, the 2000mm-by-3000mm-400mm high, is used. The positions in installed anchors are decided with no influence of anchor spacing and edge distance to install in the concrete. And silent diamond core drill system [1][12][13] by hands is used considering to retrofitting with living in buildings when under holes are drilled. Additionally injection adhesive anchors of cartridge type [12][13] in high performance epoxy resin are used. Deformed rebar of D19 (SD345, SD295A) are used. Material test results in tensile of deformed rebar are shown in Table 3.1. Loading devices in tensile experiments is shown by Figure 2. Force methods adopt Monotonous loading. Displacement is measured as movement distances from the surface of concrete.

Table 3.1. Results of material tests in rebar anchors

	Yield strength (MPa)	Tensile strength (MPa)	Tensile strain (%)
D19 (SD295A)	366	534	26
D19 (SD345)	406	603	22

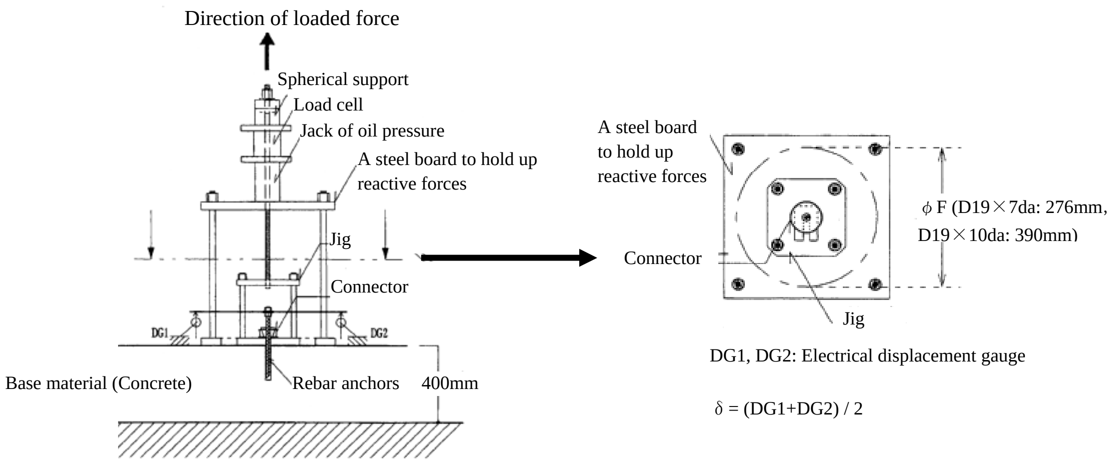

Figure 2. Loading devices in tensile experiments

Table 3.2. Results of experiments in single anchors

Spec-imens' numbers	Failure mode	Concrete real strength (MPa)	Standard in rebar	Embedment depth (l) (mm)	Effective embedment depth (l_e) (mm)	Maximum tensile load(P_{max}) (kN)	Displace-ment (Pu) (P_{max}*0.8) (mm)	Average displacement in each failure mode (mm)
(1)	Steel	16.5	SD295A	190 ($10d_a$)	190 ($10d_a$)	150.5	22.4	21.7
(2)						152.9	21.4	
(3)						153.1	21.5	
(4)	**Concrete Corn**	16.5	SD345	133 ($7d_a$)	133 ($7d_a$)	128.7	6.1	5.1
(5)						117.5	4.3	
(6)						123.2	5.0	
(7)	Bond	35.5	SD295A	133 ($7d_a$)	133 ($7d_a$)	152.4	19.0	16.7
(8)						144.3	15.0	
(9)				190($10d_a$)	190($10d_a$)	138.4	16.3	

3.2. Result of Experiment

Anchors in detailed used in the experiments, tensile strength in maximum load and average displacements are shown as Table 3.2. Load displacement curves in each anchor in a number of specimens are shown as Figure.3. Results in the categories ranged in several failure modes of Figure.1. are shown. D19 in all anchors are used. Actual tested concrete compressive strengths are written as concrete real strength in Table 3.2. The concrete strengths in the base material are 16.5(MPa) and 35.5(MPa). SD295A and SD345 as the standard of anchor rebar are used. Embedment depths are 190mm ($10d_a$) and 133mm ($7d_a$) (Effective embedment depth: 190mm ($10d_a$) and 133mm ($7d_a$)). In each numbers of specimens maximum tensile loads (P_{max})(kN), displacements [14][15][16] are shown. Average displacements in several failure modes are also showed. And displacements in 'P_{max}*0.8' are used in these experiments as them in ultimate strengths. Anchor rebars failure soon after a tensile load exceeds a maximum tensile load (P_{max}) in the rebar failure mode. Therefore the displacements in maximum tensile loads are described in a rebar failure mode.

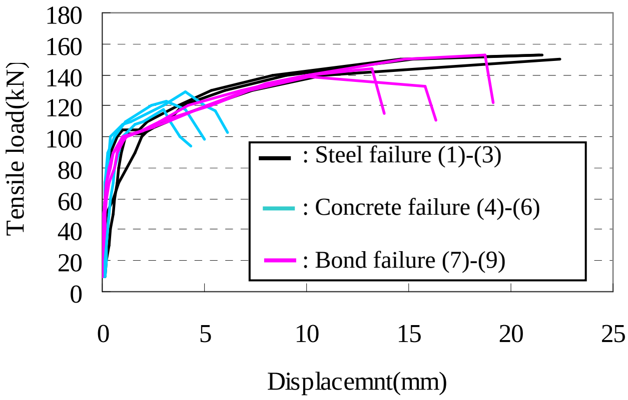

Figure 3. Load displacement curve

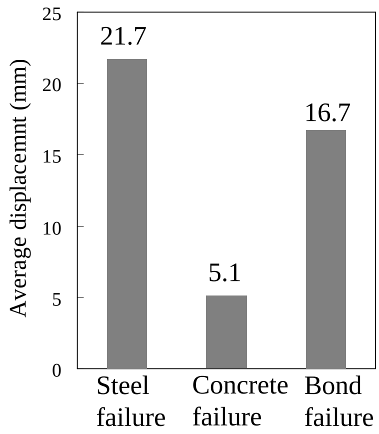

Figure 4. Average displacement

3.3. Discussion

No difference among failure modes are shown by about 100 kN in a tension load on the load and displacement curve of Figure 3. After exceeding 100 kN clear differences among several failure modes are able to be realized to achieving the maximum tensile load. Especially large differences among failure modes are shown in the average displacements of each failure modes as references of Table.3.2. and Figure 4. A concrete corn failure mode is most brittle compared to steel and bond failure modes in looking at Figure 3. and Figure 4. Additionally the deformation performance in steel failure mode is about 3.7 times larger than it in a concrete failure mode. Similarly the deformation performance in bond failure mode is also about 2.7 times larger than it in a concrete failure mode.

4. BRIEF IN EXPERIMENT OF GROUP ANCHOR, RESULT AND DISCUSSION

4.1. Brief Summary Experiment

This experiment images joints between existing foundation beam and new side walls using post-installed adhesive injection anchors as a kind of seismic retrofitting systems, that is side wall seismic retrofitting system [3] with living in buildings. That is to say, it is an actual-size experiment of tensile post-installed adhesive anchoring systems in group. A specimen in detailed, dimensional drawing and pictures are shown in a Figure 6., a Figure 7., a Figure 8. and a Figure 9. The experiment is one specimen. There are four rebar anchors (D19 (SD345)) in group. Embedment depth is 228mm ($12d_a$) (effective embedment depth : $12d_a$). Force application devise in antisymmetric type is used and horizontal direction is kept by pantograph. Therefore horizontal loads are about zero in any times for four group anchors. And tensile loads are acted in the four group anchors continuously by the ultimate load after tensile loads and compressive loads, ±78.4kN, ±156.8kN, ±235.2kN are acted in them. Positions installed post-installed anchors in a foundation beam are shown as a Figure 5. and Figure 6. (Anchor spacing : 200mm, edge distance : 120mm, 180mm). Hammer drills are used to install rebar anchors. And injection adhesive anchors of cartridge type [12][13] in high performance epoxy resin are used. Tensile strengths of rebar anchors in Table 4.1. are used as the same as Table 3.1. although material tests are not implemented. The concrete strength in the base material is 25.0(MPa).

Table 4.1. Results of material tests in rebar anchors

	Yield strength (MPa)	Tensile strength (MPa)	Tensile strain (%)
D19 (SD345)	406	603	22

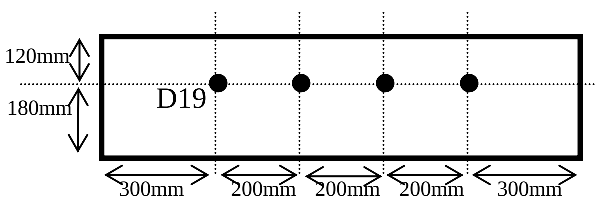

Figure 5. Layout plan view of group anchors

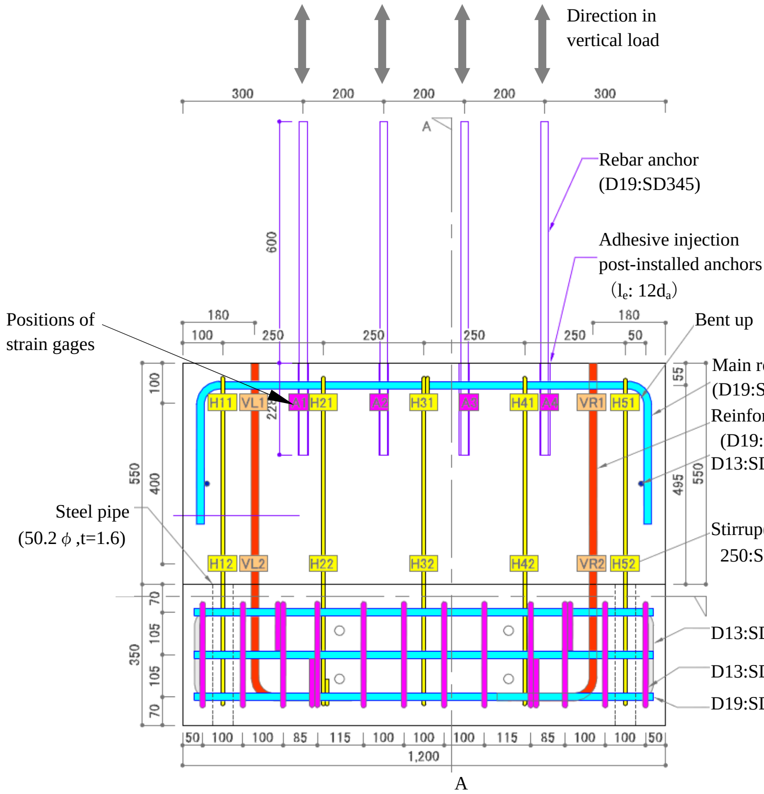

Figure 6. Elevation view in south (Unit: mm)

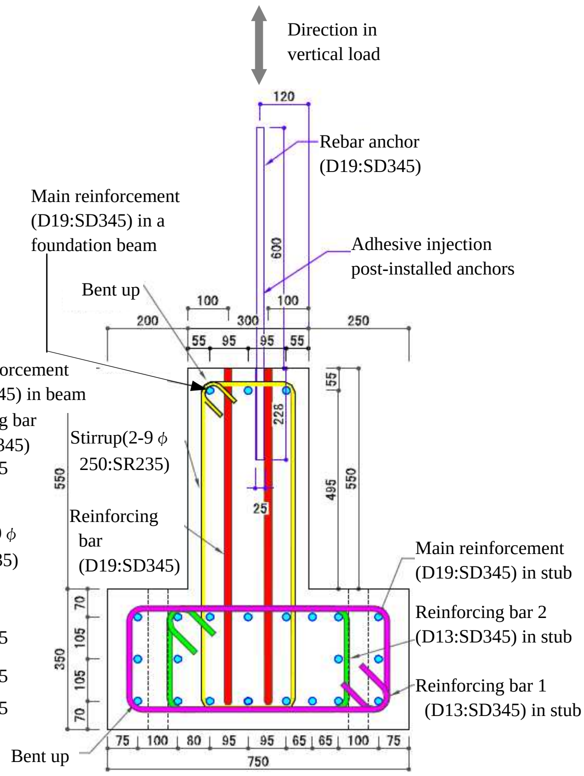

Figure 7. Cross-section view in east (Unit: mm)

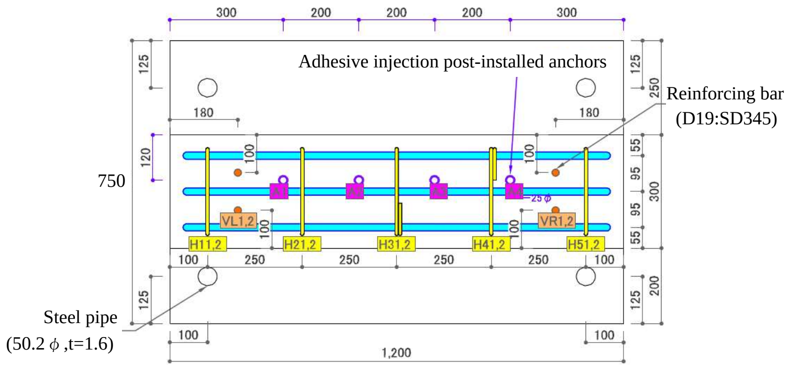

Figure 8. Brief overview of a specimen (Unit: mm)

Figure 9. Pictures of a specimen

4.2. Result of Experiment

Anchors in detailed, tensile strength in a maximum load and failure mode are shown as a figure 4.2. Failure behaviour pictures in maximum and ultimate load are shown as Figure 10. and Figure 11. The specimen is no changes by tensile and compressive load, ±78.4kN, ±156.8kN, ±235.2kN. In the process from 235.2kN to 359.6kN cracks in concrete surface around group rebars and among anchor spacings proceed and suddenly brittle failure in concrete corn of four group anchors arise extremely in maximum tensile load (448.8kN). After that the tensile load decreases dramatically. Additionally all rebar anchors of D19 do not yield in maximum and ultimate load.

Table 4.2. Results of experiments in group anchors

Spec-imens' numbers	Failure mode	Concrete design strength (MPa)	Concrete real strength (MPa)	Standard in rebar	Embedment depth (l) (mm)	Effective embedment depth (l_e) (mm)	Maximum tensile load(P_{max}) (kN)
(10)	Concrete	15.0	25.0	SD345	228 ($12d_a$)	228 ($12d_a$)	448.8

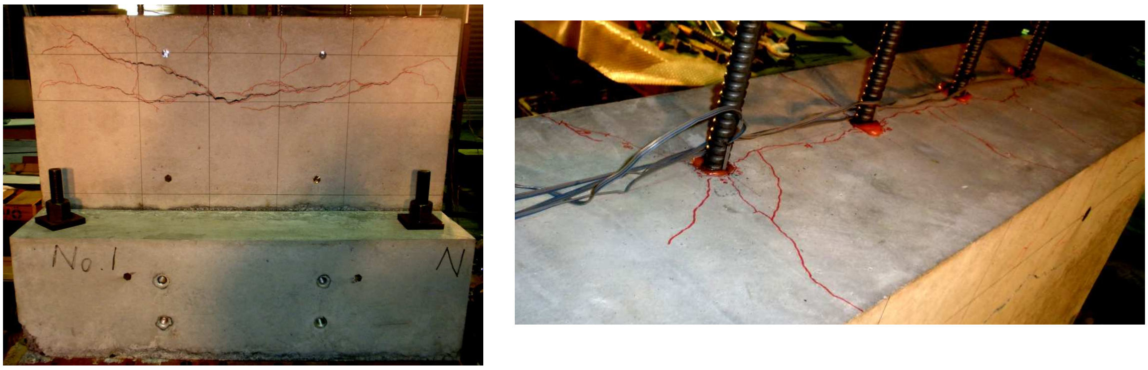

Figure 9. Pictures of the specimen in ultimate state

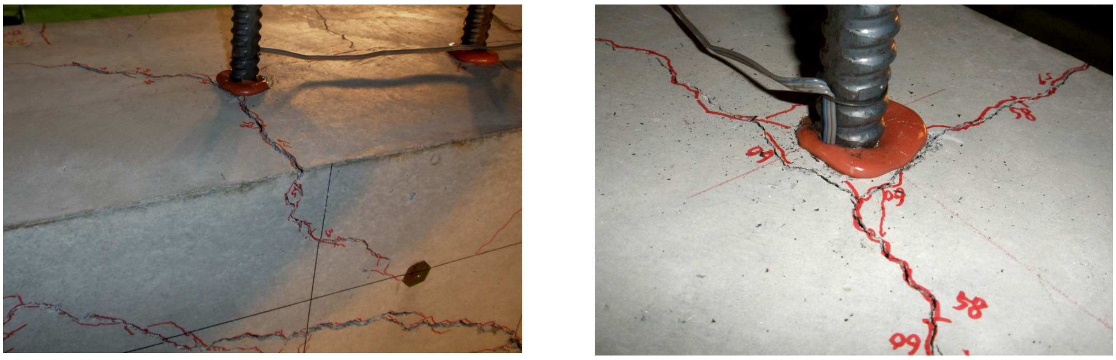

Figure 10. Pictures of post-installed anchors in ultimate state

4.3. Discussion

Maximum tensile strength 112.2kN (= 448.8kN / 4) in one rebar anchor of the group experiment is smaller than the result of a single anchor, looking at Table 3.2, although the effective embedment depth, 228mm($12d_a$) is larger than a single anchor (Table 3.2) and reinforced main rebars and stirrups in foundation beam exist in the group experiment. Considering the result of experiments both single and group, it is recognised that decreasing in tensile strength is affected significantly by anchor spaces and edge distances. In group anchors concrete failure mode is much brittle failure as the same results of single anchors.

5. PROPOSE PREDICTIVE TENSILE FAILURE STRENGTH EQUATION IN JBDPA

5.1. Comparison JBDPA Ultimate Strength to Experimental Values

We compare calculations' values in JBDPA ultimate tensile strength to experimental values using the same conditions of single and group anchors in a chapter 3., a chapter 4. An actual tensile strengths in rebar anchors (σ_{ut}) in materials instead of σ_y in (2.2) formula, actual concrete strengths (σ_{Bt}) in materials in (2.3) formula and actual test bond strengths (τ_{ut}) on the same conditions in reference to the literature [18] in (2.4) are used in these calculations. The results of calculations are shown as a figure 5.1. The results in condition ① and ③ on failure modes are different from the results in single anchors' experiments, using σ_{ut}, σ_{Bt}, τ_{ut}. Considering this reason, JBDPA concrete failure equations tend to be calculated much lower than the actual values. Therefore we propose a 'α_1 factor' (using α_1=1.5 in these calculations). The α_1 factor is multiplied by formula (2.2). Using the α_1 factor in concrete ultimate strength calculations' values and failure mode in JBDPA, ultimate tensile strengths conform to experimental values and failure modes totally.

Table 5.1. Comparison between JBDPA calculating formula and experimental values

	Single anchor ①	Single anchor ②	Single anchor ③	Group of 4 anchors
	Table 3.2.(1)(2)(3)	Table 3.2.(3)(4)(5)	Table 3.2.(6)(7)	Table 4.2.(10)
Le (mm)	190(10d_a)	133(7d_a)	133(7d_a)	228(12d_a)
Concrete real strength σ_{Bt} (MPa)	16.5	16.5	35.5	25.0
Tensile strength in rebar σ_{ut} (MPa)	534 (SD295A)	603 (SD345)	534 (SD295A)	603 (SD345)
Bond strength in tests τ_{ut} (MPa) [18]	16	16	16	19
T_{a1u} (Steel)(kN)	153	173	153	691
T_{a2u} (Concrete)(kN)	116	59	87	276
T_{a3u} (Bond)(kN)	181	127	127	1,034
T_{au} in formula (kN)	116	59	87	276
Failure mode in formula	Concrete	Concrete	Concrete	Concrete
P_{max} (kN): Tensile load in experiments	152.1	123.1	148.3	448.8
P_u (kN): Ultimate tensile load (P_{max} *0.8)	121.7	98.5	118.6	359.0
Failure mode in experiments	**Steel**	**Concrete**	**Bond**	**Concrete**
$T_{a2u'}$ (Concrete)(kN) $T_{a2u'} = T_{a2u} * \alpha_1$ (α_1=1.5)	**175**	**89**	**130**	**414**
$T_{au'}$ = Min [T_{a1u}, $T_{a2u'}$, T_{a3u}]	**153**	**89**	**127**	**414**
Failure mode in new formula	**Steel**	**Concrete**	**Bond**	**Concrete**

5.2. Propose Predictive Failure Strength Values (T_{apu}) based on JBDPA

$$T_{apu} = \min \left[T_{a1pu}, T_{a2pu}, T_{a3pu} \right] \quad (5.1)$$

$$T_{a1pu} = \sigma_{ut} \cdot a_0 \quad (5.2)$$

$$T_{a2pu} = \alpha_1 \cdot 0.23 \cdot \sqrt{(\sigma_{Bt})} \cdot A_c \quad (A_c = \pi \cdot l_e(l_e+d_a)) \quad (\alpha_1=1.5) \quad (5.3)$$

$$T_{a3pu} = \beta_1 \cdot \tau_{ut} \cdot \pi \cdot d_a \cdot l_e \quad (\beta_1=1.0) \quad (5.4)$$

(σ_{ut} : Actual ultimate strength in material tensile tests(N/mm^2), σ_{Bt}: Actual concrete strength in material tests(N/mm^2), τ_{ut} : Bond strength in tests(N/mm^2)[18], α_1 : Adjustment factor, β_1 : Environmental influence factor in bond strength)

We propose predictive failure strength values (T_{apu}), equations (5.1)-(5.4) based on JBDPA ultimate failure strength equations compared to experimental values in chapter 5.1. Basically they are the same structure as JBDPA equations. In the proposal (T_{apu}) , (σ_{ut}) instead of (σ_y), σ_{Bt}, and (τ_{ut}) instead of (τ_a) are used in the calculations. And in the new equation adjustment factor (α_1) is also multiplied (α_1=1.5 is used in this verification). Additionally we also propose a (β_1) factor (β_1=1.0 is used in this verification.). Looking at reference to Table 5. and literature [18], when (τ_{ut}) is calculated in considering of predictive failure strength values, ultimate bond strengths change depends on the installation devices, environmental conditions, humidity and temperature conditions and clean-up conditions in borehole. Regarding a definition in (α_1) and (β_1) factors accumulation of many data and many analyses have to be done. We'd like to keep examine the problems.

6. COMPARISON TO DESIGN TENSILE STRENGTH IN VERIOUS DESIGN GUIDELINE

Various tensile design strength equations in post-installed adhesive anchoring systems are proposed in Japan and the world. We compare and calculate between Japanese composite structure design guideline [19] (blow AIJ) in tensile, ETAG [8][9] (Guideline for European Technical Approval) and ACI CODE [10][11] (American Concrete Institute Building Code). The conditions in calculations are the same as Table 5.1①②③ and four group anchors. The conditions in detailed are shown as the below.

Table 6.1. Conditions in calculating of each pattern

	Single anchor ①	Single anchor ②	Single anchor ③	Group of 4 anchors
L_e (mm)	190(10d_a)	133(7d_a)	133(7d_a)	228(12d_a)
Diameter in drill bit (mm)	25	25	25	25
Concrete (design) strength σ_{Bt} (MPa) (Non-cracked)	16.5	16.5	35.5	15
Tensile standard strength in rebar σ_y (MPa)	295(SD295A)	345(SD345)	295(SD295A)	345(SD345)
Thickness in base material (mm)	400	400	400	550
Installation equipment	Core drill	Core drill	Core drill	Hammer drill
Concrete temperatures (℃)	25	25	25	25
Anchor spacing	―	―	―	Figure 5.
Edge distance	―	―	―	Figure 5.

6.1. Tensile Design Strength in AIJ Guideline (Allowable Stress for Temporary Loading)

$$\mathbf{p_a = \min\,[p_{a1},\ \ p_{a3}]} \qquad \mathbf{(6.1)}$$

$$p_{a1} = n \cdot \varphi_1 \cdot {}_s\sigma_{pa} \cdot {}_{sc}a \qquad (6.2)$$

$$p_{a3} = n \cdot \varphi_3 \cdot \tau_a \cdot \pi \cdot d_a \cdot l_{ce} \qquad (6.3)$$

$$\tau_a = \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \tau_{bavg} \qquad (6.4)$$

$$\alpha_n = 0.5(c_n / l_e) + 0.5 \qquad (6.5)$$

(in case $(c_n / l_e) \geqq 1.0$, $(c_n / l_e)=1.0$)

(in case $l_e \geqq 10d_a$, $l_e=10d_a$)

$$\tau_{bavg} = 7\sqrt{(F_c/21)} \qquad (6.6)$$

$$l_{ce} = l_e - 2d_a \qquad (6.7)$$

(p_{a1}:Steel failure, yield strength mode in short term(kN), p_{a3}:Bond failure mode in short term(kN))

6.2. ETAG／EOTA Design Method (TR 029)

$$N_{Rd}=\min〔\ N_{Rk,s}/\phi_1,\quad N_{Rk,p}/\phi_2,\quad N_{Rk,c}/\phi_3,\quad N_{Rk,sp}/\phi_4\ 〕 \tag{6.8}$$
$$N_{Rk,s}=n\cdot A_s\cdot f_{uk} \tag{6.9}$$
$$N_{Rk,p}=N^0_{Rk,p}\cdot(A_{p,N}／A^0_{p,N})\cdot\Psi_{s,Np}\cdot\Psi_{g,Np}\cdot\Psi_{ec,Np}\cdot\Psi_{re,Np} \tag{6.10}$$
$$N^0_{Rk,p}=\pi\cdot d\cdot h_{ef}\cdot\tau_{Rk} \tag{6.11}$$
$$N_{Rk,c}=N^0_{Rk,c}\cdot(A_{c,N}／A^0_{c,N})\cdot\Psi_{s,N}\cdot\Psi_{re,N}\cdot\Psi_{ec,N} \tag{6.12}$$
$$N^0_{Rk,c}=k_1\cdot\sqrt{(f_{ck,cube})}\cdot h'^{1.5}_{ef} \tag{6.13}$$
$$N_{Rk,sp}=N^0_{Rk,c}\cdot(A_{c,N}／A^0_{c,N})\cdot\Psi_{s,N}\cdot\Psi_{re,N}\cdot\Psi_{ec,N}\cdot\Psi_{h,sp} \tag{6.14}$$

(Partial safety factors; ϕ_1:1.4, ϕ_2:2.1, ϕ_3:2.1, ϕ_4:2.1)

($N_{Rk,s}$: Characteristic tensile strength in steel failure, $N_{Rk,p}$: Characteristic tensile strength in Concrete corn and pull-out fauilure mode, $N_{Rk,c}$: Characteristic tensile strength in concrete corn failure mode, $N_{Rk,sp}$: Characteristic tensile strength in splitting failure mode)

6.3. ACI318 Adhesive Anchor Design Method (ICC-ES)

$$N_{Rk}=\min〔\phi_s\cdot N_{sa},\quad \phi_c\cdot N_{cbg},\quad \phi_a\cdot N_{ag}\ 〕 \tag{6.15}$$
$$N_{sa}=n\cdot A_{se,N}\cdot f_{uta} \tag{6.16}$$
$$N_{cbg}=(A_{Nc}／A_{Nc0})\cdot\Psi_{ec,N}\cdot\Psi_{ed,N}\cdot\Psi_{c,N}\cdot\Psi_{rp,N}\cdot N_b \tag{6.17}$$
$$N_b=k_{c,uncr}\cdot\sqrt{(f'_c)}\cdot h'^{1.5}_{ef} \tag{6.18}$$
$$N_{ag}=(A_{Na}／A_{Na0})\cdot\Psi_{ed,Na}\cdot\Psi_{g,Na}\cdot\Psi_{ec,Na}\cdot\Psi_{p,Na}\cdot N_{a0} \tag{6.19}$$
$$N_{a0}=\tau_{k,uncr}\cdot\pi\cdot d\cdot h_{ef} \tag{6.20}$$

(Partial safety factors; ϕ_s:0.7, ϕ_c:0.65, ϕ_{ah}:0.65(Drill bit), ϕ_{ac}:0.55(Core drill))

(N_{sa}: Tensile design strength in steel failure mode, N_{cbg}: Tensile design strength in concrete break-out failure, N_{ag}: Tensile design strength in pull-out failure mode)

6.4. Result and Discussion

The results of calculations are shown as Table 6.4. As a reference experimental values in Table 5.1., maximum tensile loads, ultimate tensile loads and failure mode are also shown.

Table 6.4. Results in calculating of each pattern

		Single anchor ①	Single anchor ②	Single anchor ③	Group of 4 anchors
ETAG	Design strength(kN)	55.5	32.5	47.7	46.7
	Failure mode	Concrete	Concrete	Concrete	Concrete
ACI	Design strength(kN)	62.4	44.1	61.2	62.8
	Failure mode	Steel	Concrete	Steel	Concrete
AIJ	Design strength(kN)	37.5	23.5	34.4	84.3
	Failure mode	Bond	Bond	Bond	Bond
Exper-iments	Maximum tensile load(kN)	152.1	123.1	148.3	448.8
	Failure mode	Steel	Concrete	Bond	Concrete
	Ultimate (kN)	121.7	98.5	118.6	359.0

Japanese design concept by AIJ (Architectural Institute of Japan) is different from ETAG and ACI in post-installed adhesive injection anchoring systems. For example, service loads, safety factors and design concept are different from them. Therefore results calculating Japanese tensile design strength are difficult to be simply compared to the same results of ETAG and ACI. However basically tensile design strength exceeds a service load, all engineers usually consider in structure design all of the world. Its basic consideration is common in all countries. Looking at Table 6.4., Japanese AIJ design strength is safer than ETAG and ACI in single anchors. On the other hand, in group anchors ETAG and ACI design strength are safer than AIJ. Failure modes in design are different from actual failure mode in experiments naturally. And it is been able to recognise that all tensile design strength is much safer than the actual experimental values. We'd like to keep examine the problems and to keep implementing more analyses.

7. CONCLUSION

We experimented for elemental adhesive injection anchoring systems in single and group anchors based on seismic retrofitting and renewal methods in Reinforced Concrete structures with living in buildings in this paper. And we referred to strength and ductility, analysing tensile data followed by failure modes based on JBDPA ultimate strength formula. As the result it is recognised that concrete failure mode is brittle and low deformation performance compared to bond and steel failure mode. Second we proposed predictive failure strength values based on JBDPA ultimate tensile equations. It was shown that the possibility that the new proposal values and failure modes may be able to approximate the experimental values and its failure modes. Finally using the same conditions, we compared Japanese design tensile strength by AIJ to ETAG and ACI in design. In the near future we'd like to keep studying and analyzing the different in background, conditions, design concept, how to consider safety factor and how to consider seismic design between Japanese guideline and ETAG and ACI and propose the specific numbers based on this experiments and studies. Additionally we hope that this experiments and studies contribute to the progression of adhesive post-installed anchors' design in the near future and provide a basis data in establishing universal Asia design method in the world in the future.

8. REFERENCE

[1]Seira Owa, Kazuhiro Watanabe, Kazuyuki Tuiji, Muneomi Takahashi, (2012) Experimental Study on Evaluation in Influence for Surrounding Environment of Renovation Method in Existing RC Related Buildings, (Experiment and Applicability of Comparative Verifications of Noise, Vibration and Dust in Post-installed Anchoring Work and Cutting and Removal Work in Existing Apartment Housing of Box Frame Construction.), *AIJ journal*, (Posting)

[2]Tsuneo Okada, (1995) Fastenings For Seismic Retrofitting, State Of The Art Report, Comite Euro-International Du Beton, *Thomas Telford*, pp.1-38

[3]Takaya Nakamura, Yasuhiro Abe, Manabu Yoshimura, Seira Owa, Masaya Hirosawa, (2012) Seismic Retrofit of RC Columns With Side Walls by Increasing Width, *AIJ journal*, (Posting)

[4]Tatsuya Kondo, Yukio Ban, Mitsuharu Kato, Yasutoshi Yamamoto, (2011) Experimental Study on Bending Retrofitting in Existing Column Attached Side Walls, *JCI journal*, Vol.33, No.2, pp.1345-1350

[5]Yukio Ban, Yasutoshi Yamamoto, Tatsuya Kondo, Seira Owa, (2011) Experimental Study of Group Anchors on Retrofitting Column Attached Side Wall in Existing Buildings, *JCI journal*, Vol.33, No.2, pp.1423-1428

[6]Andreas Unterweger, Ronald Mihara, Konrad Bergmeister, Yoshiaki Nakano, (2010) Retrofitting by High Sophisticated Bonded Anchorage, *Kobe*, Japan

[7](2001) Seismic Retrofitting Design Guideline in Reinforced Concrete Existing Buildings, *The Japan Building Disaster Prevention Association*

[8](2007) Design of Bond Anchors, Technical Report 029, *European Organization for Technical Approvals*, pp.1-36

[9](2009)Injection System Hilti HIT-RE500, European Technical Approval ETA-04/0027, *DIBt*, pp.1-30

[10](2011)Appendix-D, Anchoring To Concrete, *ACI* 318-11: *Building Code and Commentary*, pp.409-438

[11](2007)Hilti HIT-RE 500-SD Adhesive Anchors in Concrete, *ICC-ES Technical Report*, ESR-2322, pp.1-52

[12]Kazuyuki Tsuji, Koichi Oguma,(2009) Post-installing Anchoring Work, Special Topics; Basic Knowledge of Seismic Evaluations and Retrofitting in Reinforced Concrete structures, *Archtectual Tchnology,* pp.158

[13]Muneomi Takahashi,(2010) Post-installing Anchoring Work, Special Topics; Important Points in Actual Work of Seismic Retrofitting, *Archtectual Tchnology*, pp.162-163

[14](1999)Design Guideline for Earthquake Resistant Reinforced Concrete Buildings Based on Inelastic Displacement Concept, *Architectural Institute of Japan (AIJ),* pp.119-120

[15]Kensuke Yogo, Yasuaki Goto, Osamu Joh, (2008) Analytical Study For Ductility Evaluation Subjected To Shear Failing R/C Column Strengthened By Carbon Fiber Sheets, *AIJ journal*, Technical Des. Vol. 14, No.27, pp.109-114

[16]Mareyasu Doi, (2003) Evaluation of deformation Capacity and Energy Absorption Capacity for SRC Member under Varying Axial Force, *AIJ journal*, pp.1149-1150

[17]Takaya Nakamura, Manabu Yoshimura, Seira Owa, (2002) Axial Load Carrying Capacity Of Reinforced Concrete Short Columns With Shear Mode, *AIJ Journal* Struct. Constr. Eng. No.561, pp.193-199

[18]Hanae Setouchi, Takahide Abe, Yuya Takase, Shinichiro Sato, Muneomi Takahashi, Takashi Sato, (2010) Experimental study to confirm the performance of Post-installed Anchor that uses core drill method. Part2. Test of bond strength that uses Injection type anchor, *AIJ journal*, pp.149-150

[19](2010) Design Recommendations for Composite Constructions, *AIJ*, pp.252-269, 274-308