UPGRADING THE DEFORMATION CAPACITY OF ANCHOR-BOLTS IN THE EXPOSED-TYPE COLUMN BASES OF EXISTING OLD STEEL STRUCTURES

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ABSTRACT :

A main reason for early tensile brittle fracture of the anchor-bolts in the steel exposed-type column bases under the past earthquake is that the thread part has the decreased sectional area of 75% of the regular part of the anchor-bolt. Many existing old steel structures in Japan might contain such anchor-bolts whose deformation capacity is very poor and urgent diagnosis and upgrading is needed. This study proposes the method of upgrading the performance of anchor-bolts in existing old steel structures. A high-strength bolt equivalent to F14T is screwed to reinforce the thread part, after the hole is emptied from the top of the anchor bolt. This paper shows the performance of the upgraded anchor-bolts through the experimental studies.

KEYWORDS: Deformation capacity, Tensile test, Pull-out Test,Upgrading,Exposed-type column base

1. INTRODUCTION

In the Hygoken-Nanbu earthquake exposed-type steel column bases are damaged and many low rise steel structures are collapsed. One of the main reasons is early tensile fracture at the thread part of the anchor-bolts, whose sectional area is about 75% of the regular part. Japan Steel Structures Cooperation (JSSC) published the Standards for the set of anchor bolt, nut and washer in 2000 and revised them in 2004 (JSS II 13-2004 and 14-2004) to secure the deformation capacity of the anchor-bolts. Now, the anchor-bolts satisfying these standards are being used for constructions of new steel buildings. According to this fact many existing steel structures constructed before 2000 in Japan might contain the anchor-bolts whose deformation capacity is very poor and urgent upgrading is needed. This study proposes the method of upgrading the performance of these anchor-bolts and the method of prediction of the strengths and deformation capacity of them.

2. A BASIC IDEA OF REINFORCEMENT OF ANCHOR-BOLT

Figure 1 shows the basic idea of reinforcement of anchor-bolt. A high-strength bolt equivalent to F14T is screwed to reinforce the thread part, after the hole is emptied from the top of the anchor bolt. This gives rise to yielding of the regular part of the anchor-bolt and brings enough total deformation capacity. According to Hasegawa(2000), the demanded rotation capacity of exposed-type column bases in the low-rise steel buildings is more than 0.03rad, which is roughly equivalent to 3% axial strain of the anchor-bolt. It is required that the following strength factor should achieve 1.12 to secure this strain in the JSSC Standard(2004). In this paper the strength factor α is defined as the ratio of the maximum strength of the thread part against the yield strength of the regular part. Therefore, $\alpha \times \sigma_y$ indicates the stress of the regular part when the thread part reaches maximum strength. Fracture is expected to occur at the two sections ① and ② of the reinforced anchor-bolt. The strength factor for each fracture is shown in the following equation.

$$\alpha = (1-\beta^2)/YR \qquad (2.1) \qquad \text{for section ①}$$
$$\alpha = [\beta^2(0.74\sigma_{ub}/\sigma_u - 1) + 0.75]/YR \qquad (2.2) \qquad \text{for section ②}$$

where $\beta = r/R$, r and σ_{ub}: radius and tensile strength of High strength bolt, R, σ_u and YR: radius, tensile strength and Yield Ratio of of anchor-bolts. In eq.(2.2) 0.74 and 0.75 indicate the approximate ratio of sectional area of thread part to regular part of the high-strength bolt and anchor-bolt, seperately.

According to statistical data on yield and tensile strength of steel bar, probability of YR>80% is about 1.4%,. Figure 2 shows eqs.(2.1) and (2.2), when YR=80% and tensile strength=475N/mm^2 are adopted as an upper limit. Reinforcement by F14T(M10) bolt gives recommendable strength factor α =1.09 and F20T(M8) gives 1.13. When strength factor is small, the designer can expect the additional plastic deformation of the extended hole.

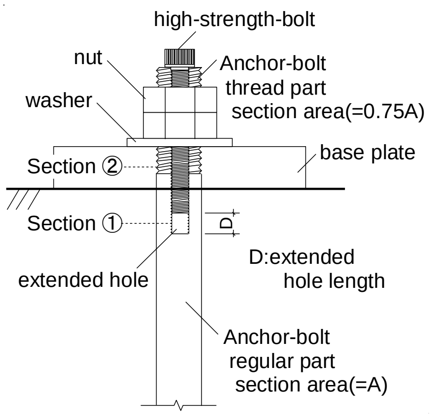


Figure 1 Basic idea of reinforcement

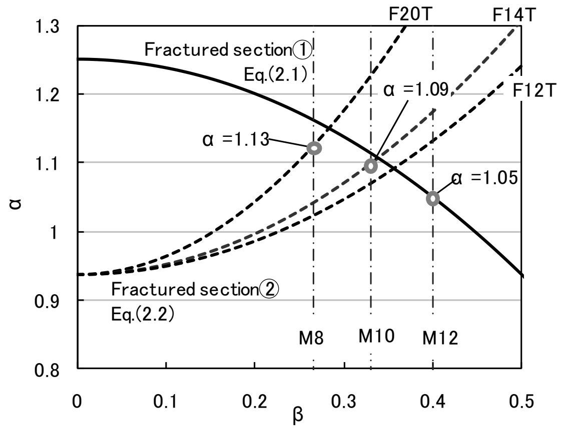


Figure 2 Strength factor α for combination of β = r/R

3. EXPERIMENTAL PLAN

Two series of experiments are planned consisting of tensile tests of reinforced anchor-bolts and pull-out test of anchor-bolt from RC column base. Tensile tests are made to know the performance of the anchor-bolt and to verify effectiveness of eqs.(2.1) and (2.2). Pull-out tests are made to know the adhesive effect of concrete. Tables 1 and 2 show the mechanical properties of steel and concrete used in this experiments. Figures 3 and 4 show representative shape and size and naming rules of tensile test specimens. Figure 5(b) shows the pull-out test specimen. Adopted diameters of anchor-bolts are 30 and 24mm. Adopted sizes of high-strength bolt are M6, M8, M10 and M12. Extended hole lengths to secure the additional plastic deformation are 10, 50 and 100mm. Measuring method of deformation, positions of strain gauges and loading method for tensile test and pull-out test are illustrated in Figure 5.

Table 1 Mechanical properties of steel

Material	Size	Yield point	Tensile strength	YR	Elongation
	(mm)	(N/mm^2)	(N/mm^2)	(%)	(%)
Anchor-bolt	24	309	458	67	35
	30	308	451	68	35
High-stregth-bolt	M6	1325	1448	-	10
	M8	1352	1468	-	10
	M10	1300	1414	-	11
	M12	1323	1420	-	10

Table 2 Mechanical properties of concrete

Compressive strength	Split tensile strength
(N/mm^2)	(N/mm^2)
26.73	2.7

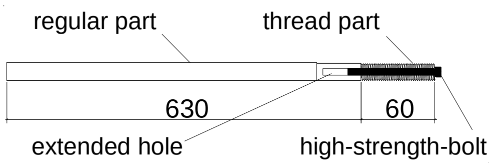


Figure 3 Shape and size of tensile specimen

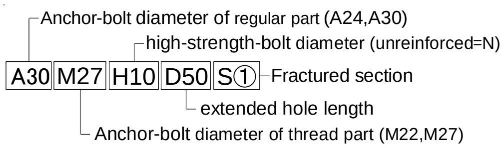
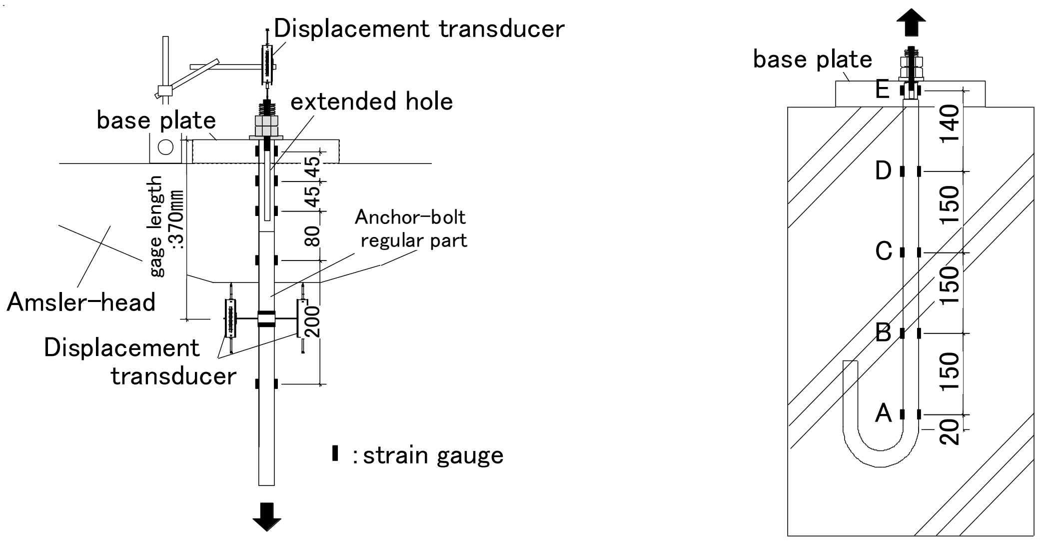


Figure 4 Naming rule of tensile specimens



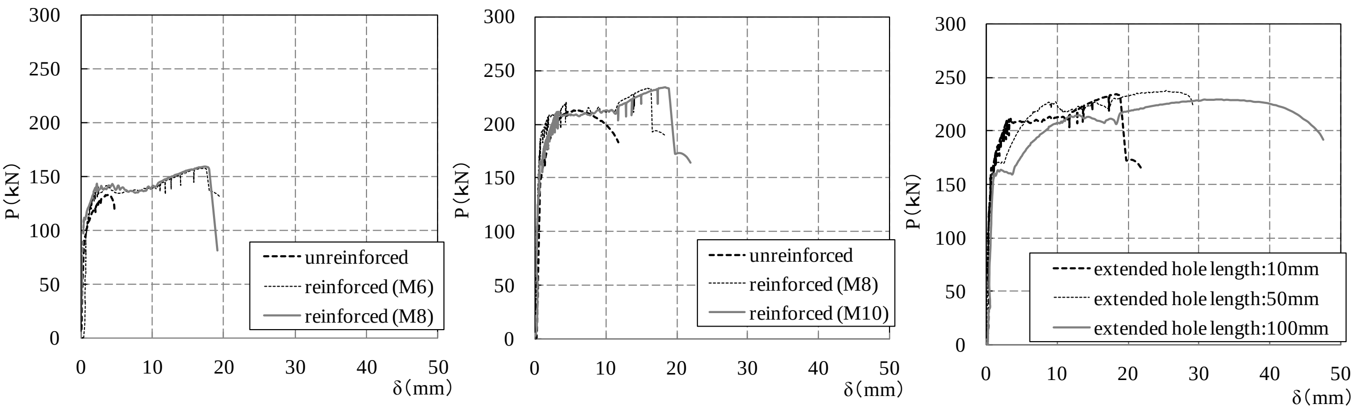
(a) Tensile test (b) Pull-out test

Figure 5 Loading and measuring methods

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1. Experimental Results of Tensile Test

Table 3 shows the experimental and analytical maximum strength, strength factor and fractured section. Analytical results are obtained from eqs.(2.1) and (2.2). Figures 6 show load- total deformation relation of anchor-bolts. Figure 6(a) and (b) show that reinforcement by the high-strength bolt gives rise to large amount of increase of deformation capacity. Figure 6(c) shows that the longer extended hole results the more additional plastic deformation.



(a) A24M22 (b) A30M27 (c) Extended hole

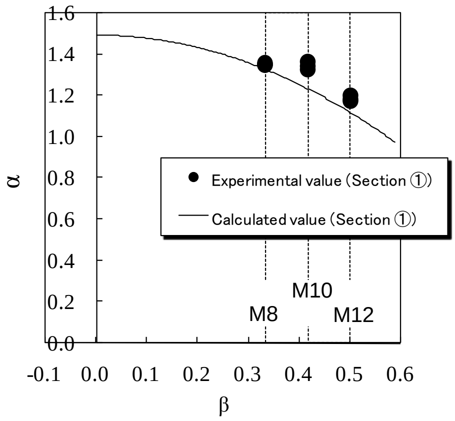
Figure 6 Load- total deformation relation

Table 3 Experimental Results

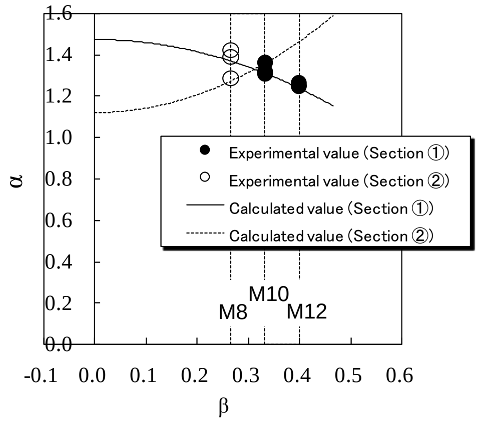
Kind of test	Name	No.	Experimental value: Max. Strength (kN)	Experimental value: α	Experimental value: Fractured section	Calculated value: Max. Strength (kN)	Calculated value: α	Calculated value: Fractured section	Experiment / Calculate
Tensile test	A24M24HNDN②	1	163	1.14	②	157	1.10	②	1.04
		2	181	1.27	②	156	1.10	②	1.16
		3	179	1.26	②	156	1.10	②	1.15
	A24M24H8D10①	1	192	1.36	①	183	1.30	①	1.05
		2	191	1.35	①	184	1.30	①	1.04
		3	192	1.35	①	184	1.30	①	1.04
	A24M24H10D10①	1	186	1.34	①	170	1.23	①	1.09
		2	189	1.37	①	170	1.23	①	1.11
		3	183	1.33	①	170	1.23	①	1.08
	A24M24H12D10①	1	166	1.20	①	152	1.10	①	1.10
		2	163	1.18	①	151	1.09	①	1.08
		3	163	1.18	①	152	1.10	①	1.07
	A30M30HNDN②	1	288	1.35	②	237	1.11	②	1.21
		2	268	1.26	②	237	1.11	②	1.13
		3	281	1.32	②	236	1.11	②	1.19
	A30M30H8D10②	1	294	1.39	②	268	1.26	②	1.10
		2	273	1.28	②	269	1.26	②	1.01
		3	299	1.42	②	267	1.27	②	1.12
	A30M30H10D10①	1	299	1.36	①	285	1.30	①	1.05
		2	290	1.32	①	286	1.30	①	1.02
		3	285	1.31	①	282	1.30	①	1.01
	A30M30H12D10①	1	282	1.26	①	271	1.22	①	1.04
		2	279	1.25	①	271	1.22	①	1.03
		3	279	1.25	①	272	1.22	①	1.03
	A24M22HNDN②	1	145	1.08	②	130	0.97	②	1.12
		2	150	1.10	②	130	0.95	②	1.15
	A24M22H6D10②	1	160	1.16	②	148	1.07	②	1.08
		2	158	1.14	②	146	1.06	②	1.08
		3	158	1.15	②	146	1.06	②	1.08
	A24M22HNDNS②	1	139	0.99	②	131	0.93	②	1.06
		2	135	0.96	②	131	0.93	②	1.03
	A24M22H8D10S①	1	162	1.17	②	148 (161)	1.07 (1.16)	①	1.10 (1.00)
		2	159	1.18	②	149 (160)	1.11 (1.19)	①	1.06 (1.00)
		3	159	1.17	②	149 (160)	1.10 (1.18)	①	1.07 (1.00)
	A30M27HNDN②	1	218	0.98	②	198	0.89	②	1.10
		2	210	0.94	②	198	0.89	②	1.06
	A30M27H8D10②	1	235	1.11	②	225	1.06	②	1.04
		2	243	1.15	②	225	1.06	②	1.08
		3	237	1.12	②	225	1.06	②	1.05
	A30M27HNDNS②	1	217	0.99	②	195	0.89	②	1.11
		2	220	1.00	②	195	0.89	②	1.13
	A30M27H10D10S①	1	234	1.10	②	225 (240)	1.06 (1.13)	①	1.04 (0.98)
		2	236	1.08	②	227 (243)	1.04 (1.11)	①	1.04 (0.98)
	A30M27H10D10S①	2	225	1.03	①	210	0.97	①	1.07
	A30M27H12D10S①	1	243	1.15	①	225	1.06	①	1.08
		2	241	1.13	①	223	1.04	①	1.08
	A30M27H10D50②	1	245	1.16	②	241	1.14	②	1.02
	A30M27H10D100②	1	251	1.19	②	241	1.14	②	1.04
		2	256	1.21	②	241	1.14	②	1.06
	A30M27H10D50S①	1	238	1.07	①	228	1.02	①	1.04
		2	232	1.05	①	226	1.03	①	1.03
	A30M27H10D100S①	1	234	1.06	①	226	1.02	①	1.04
		2	230	1.04	①	227	1.03	①	1.01
Pull-out test	A24M22H8D10①	1	167	1.22	①	149	1.09	①	1.12
	A30M27H8D10②	1	206	0.97	②	224	1.05	②	0.92
		2	213	1.00	②	224	1.05	②	0.95
	A30M27H10D50②	1	241	1.14	②	241	1.14	②	1.00
		2	254	1.20	②	241	1.14	②	1.05
	A30M27H10D100②	1	252	1.19	②	241	1.14	②	1.05
	A30M27H10D10S①	1	257	1.28	①	217	1.08	①	1.18
		2	256	1.28	①	218	1.09	①	1.17
	A30M27H10D50S①	1	233	1.09	①	222	1.04	①	1.05
		2	224	1.05	①	221	1.04	①	1.01
	A30M27H10D100S①	1	232	1.09	①	221	1.04	①	1.05
		2	230	1.08	①	221	1.04	①	1.04

4.2. The Maximum Strength of Reinforced Anchor-bolts

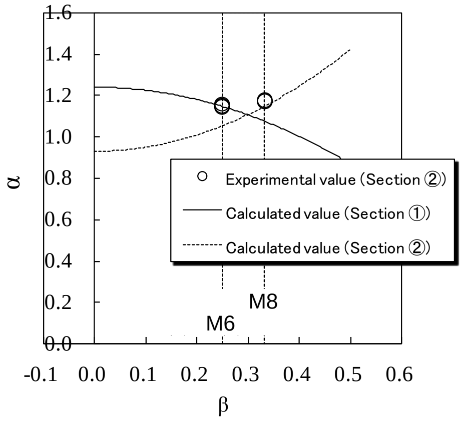
Table 3 shows the ratio between experimental strength and analytical strength given by eqs.(2.1) and (2.2). Figures 7 show the several examples of comparison between experimental and analytical strength factor. These tables and figures show that equations (2.1) and (2.2) give good prediction to the maximum strength and strength factor of actual reinforced anchor-bolts.



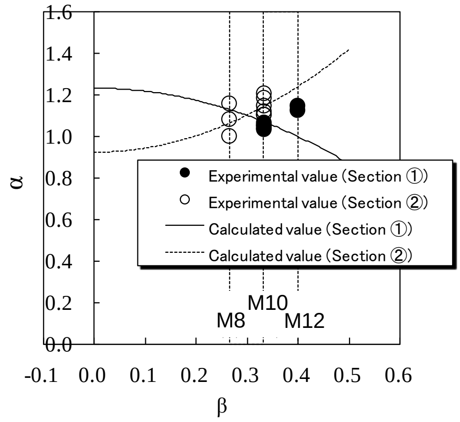
(a) A24M24



(b)A30M30



(c)A24M22



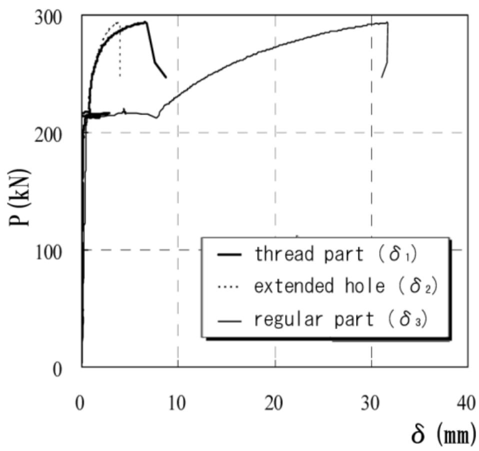
(d)A30M27

Figure 7 Comparison between experimental and analytical strength factor

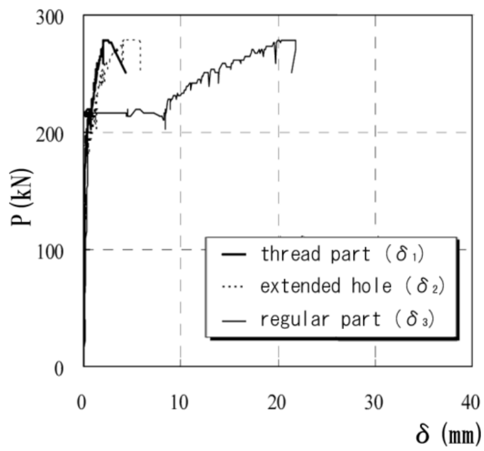
4.3. Total Deformation of Reinforced Anchor-bolt

In Fig.6 total deformation δ is measured through displacement transducers. It consists of the deformation of thread part δ_1, that of extended hole δ_2, and that of regular part δ_3, where δ_2 and δ_3 is obtained by length of each part multiplied by measured strain. Figure 8 shows the examples of experimental relation between tensile load and deformation of each part.

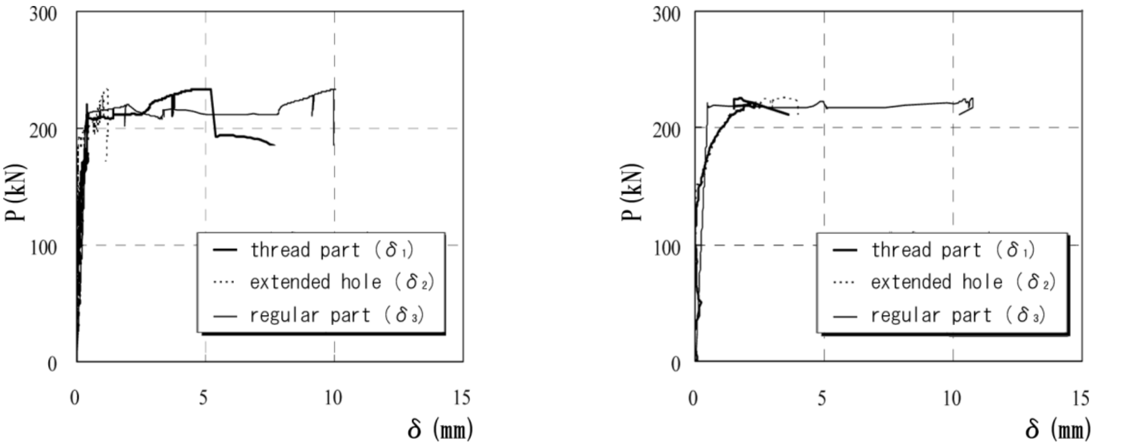
$$\delta = \delta_1 + \delta_2 + \delta_3 \qquad (4.1)$$



(a) Fractured in section ②(A30M30H8)



(b) Fractured in section ①(A30M30H12)



(c) Fractured in section ②(A30M27H10) (d) Fractured in section ①(A30M27H12)

Figure 8 Relations between tensile load and deformation of each part

4.3.1 Deformation of thread part δ_1

Deformation of thread part is derived from $\delta_1 = \delta - \delta_2 - \delta_3$. According to Fig. 8 deformation of thread part for the anchor bolt fractured in section ① is much smaller than that of anchor-bolt fractured in section ②.

4.3.2 Deformation of Extended hole δ_2

If the strength factor is smaller than 1.12 (JSSC(2004)), designers can expect additional plastic deformation in extended hole to increase the total deformation capacity of the anchor-bolt. Figure 9 shows the strain distribution along the anchor-bolt. Strain at the extended hole of the anchor-bolts fractured in section ② is less than 8%. On the other hand that of anchor-bolts fractured in section ① reached around 20%. Figure 10 shows the relation between load and deformation of extended hole, where deformation is calculated from extended length multiplied by measured strain. Elongation of extended hole is roughly proportional to extended hole length.

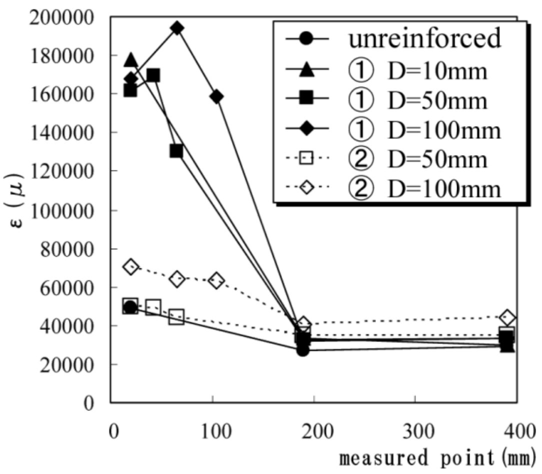


Figure 9 Strain distribution along the anchor-bolt

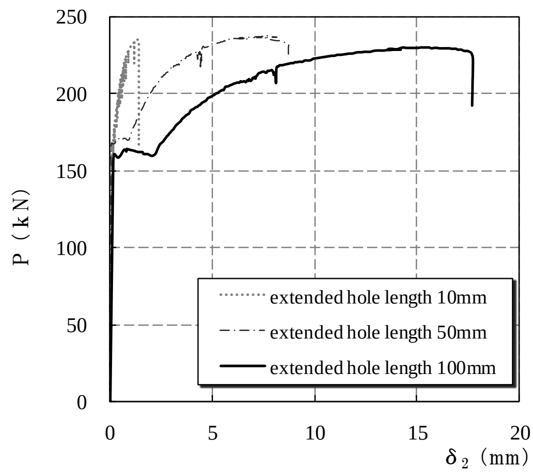


Figure 10 Relation load- deformation of extended hole

4.3.3 Deformation of Regular part δ_3

Figure 11 shows measured curves of stress and strain relation of the regular part, where stress is the tensile force devided by sectional area of the regular part. Measured curves of all reinforced anchor-bolts show almost the same behavior and agree well with the stress-strain curve of this material. However, the final strain corresponding to maximum stress marked with " ∇ " is different depending upon the strength factor α of each specimen. According to these results, the final deformation of regular part δ_3 can be predicted by the combination of the strength factor calculated by eqs. (2.1) or (2.2) and stress-strain curve of the material. This procedures are illustrated in Fig.12.

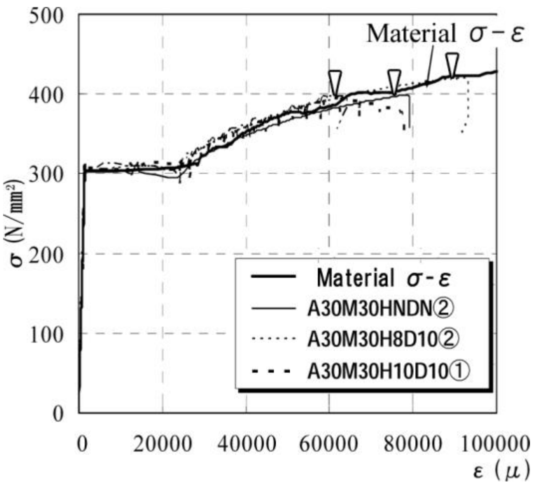


Figure 11 Measured curves of stress-strain of regular part

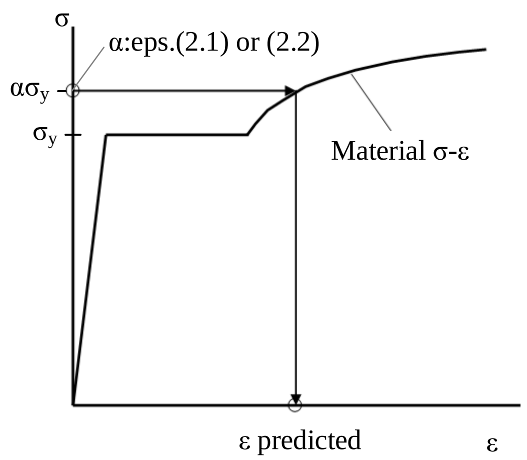


Figure12 Predicted strain at the regular part

4.3.4 Prediction of Total Elongation of Reinforced Anchor-bolts

As the high-strength bolts have high Yield Ratio of around 90% and small elongation, the reinforced anchor-bolt is recommended to be fractured in section ①, where high-strength bolt is not fractured. In this case deformation of thread part δ_1 is assumed to be zero, and about 20% strain can be expected at the extended hole. Prediction of deformation of the regular part is explained in Fig.12. Tables 4 and 5 show experimental and predicted deformation of the anchor-bolts fractured in section ①, where this predicting method gives the deformation in safe side in comparison to the experimental results.

Table 4 Prediction of deformation of anchor-bolts(Series of A30M30)

Size of HS-bolt	D	Max. Strength	Fractured section	Deformation at Max.Strength (mm)								Experiment / Calculate
				Experimental value				Calculated value				
	(mm)	(kN)		δ1	δ2	δ3	δ	δ1	δ2	δ3	δ	
M10	10	299	①	7.4	1.7	29.4	38.5	0	1.6	22.5	24.1	1.59
	10	290		8.1	1.9	28.3	38.3	0	1.6	22.5	24.1	1.59
	10	285		7.2	1.7	25.3	34.2	0	1.6	22.5	24.1	1.42
M12	10	282		12.9	1.7	20.4	35.0	0	1.8	18.3	20.1	1.74
	10	279		6.3	1.7	21.0	29.0	0	1.8	18.3	20.1	1.44
	10	279		7.1	1.9	21.0	30.0	0	1.8	18.3	20.1	1.49

Table 5 Prediction of deformation of anchor-bolts(Series of A30M27)

Size of HS-bolt	D (mm)	Max. Strength (kN)	Fractured section	Deformation at Max.Strength (mm)								Experiment / Calculate
				Experimental value				Calculated value				
				δ1	δ2	δ3	δ	δ1	δ2	δ3	δ	
M10	10	243	①	7.3	1.8	11.4	20.5	0	1.6	9.8	11.4	1.78
	10	241		8.4	1.9	11.3	21.6	0	2.0	11.2	13.2	1.64
M12	10	225		3.9	1.8	10.4	16.1	0	2.0	8.5	10.5	1.53
M10	50	238		7.6	9.4	8.9	25.9	0	9.0	9.6	18.6	1.39
	50	232		6.4	8.8	9.3	24.5	0	9.0	9.6	18.6	1.32
	100	234		9.1	19.4	7.6	36.1	0	18.0	7.9	25.9	1.39
	100	230		8.5	17.0	7.5	33.0	0	18.0	7.9	25.9	1.27

4.4. Pull-out Test of Reinforced Anchor-bolt

Figure 13 shows change of strain of each measuring point shown in Fig.5(b). Most measuring points show the behavior similar to material properties. However, measuring point A shows a different behavior from material properties, which indicate that adhesive resistence remained to the regions near the point A. Figure 14 shows tensile load – total deformation relation of pull-out test comparing with tensile test of the reinforced anchor-bolt. Though adhesive resistence remains to point A, total behaviors of pull-out test and tensile test are almost the same. According to this results adhesive resistence between concrete and steel bar is small and can be neglected.

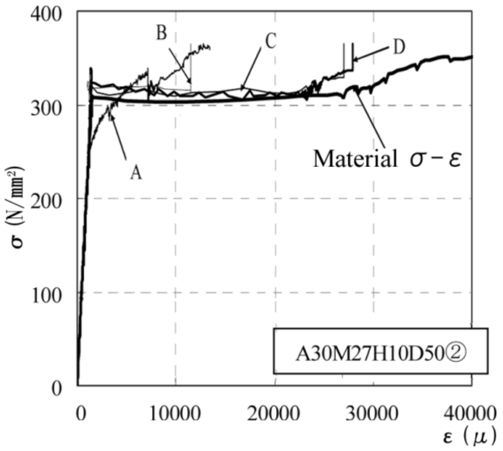


Figure 13 Change of strain at each measuring point

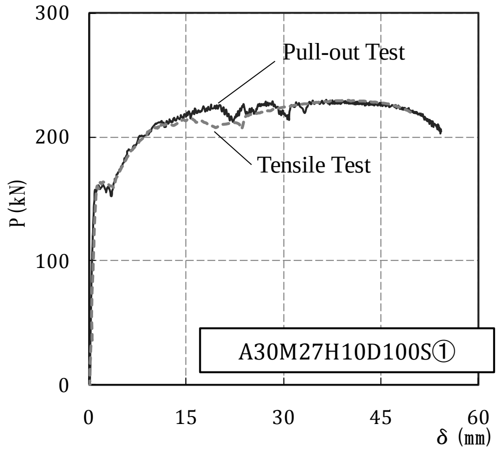


Figure 14 Load-deformation relations

4. CONCLUSIONS

In this paper upgrading method of the performance of anchor-bolt is proposed. According to tensile tests and pull-out test of reinforced anchor-bolts, the following conclusions are obtained.

(1) Proposed method brought about improvement of deformation capacity of anchor-bolt.
(2) Equations (2.1) and (2.2) agree well with experimental strength factors.
(3) Extended hole increases total deformation capacity of the anchor-bolts.
(4) Adhesive resistance between concrete and steel bar can be neglected in the upgrading design.
(5) It is possible to predict the total deformation capacity of reinforced anchor-bolts in the safe side, if material properties of anchor-bolt are given.

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