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ULTIMATE STRENGTH OF UNEMBEDDED TYPE COLUMN BASES IN SRC STRUCTURES UNDER SHEAR SLIP FAILURE

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ABSTRACT :

The shear slip failure of unenbedded type column bases in SRC structures were reported by Hyogoken-Nanbu earthquake in Japan and the experimental research in recent years. However, there has been no study that tried to evaluate ultimate shear strength of unenbedded type column bases. We describe the structural test carried out in order to study ultimate shear strength and hysteresis property of unenbedded type column bases. Structural test made it clear that mechanical property depends on the axial force level, and the anchor bolts is not valid for ultimate shear strength. We proposed the evaluation method of ultimate shear strength. Ultimate shear strength of column bases is calculate by applying the superposed strength method, in which the ultimate shear strength of the anchor bolts and friction between the base plate and the concrete below the base plate is taken to be the sum of the punching shear strength of the RC portion surrounding the base plate. Proposed evaluation method of ultimate shear strength is in accordance with the test result well.

KEYWORDS: Shear slip failure, Anchor bolt, Ultimate shear Strength

1. INTRODUCTION

It was reported that column base connection in Steel Reinforced Concrete (SRC) buildings were damaged seriously owing to 1995 Hyogoken-Nanbu earth-quake in Japan [1]. Moreover, it was clear that many of damaged column bases were unenbedded type column bases. Unenbedded type column bases do not bury the column steel in the reinforced concrete (RC) footing beam, and the column steel is set on the surface of footing beam, and connected with the footing beam by anchor bolts. In general, the outside columns of first floor of the high-rise building are subject to a large tensile force by change of an axial force. It is thought that a tensile force is the reason for damage.

After the Hyogoken-Nanbu earthquake, the design method of embedding the column steel in the footing beam is recommended for the design of SRC building in Japan. However, the embedded type column base is more disadvantageous than the bare type column base for the workability and the economy. Therefore, the experiment carried out in order to study mechanical property of unenbedded type column bases connection. From the test results, it was shown that ultimate flexural strength can be estimated to superposed strength in AIJ design code [2] and limiting deformation capability decreases with increasing axial tension, which is similar to the behavior of a column bases under the axial compression [3],[4],[5].

However, there has been no study that tried to evaluate ultimate shear strength of unenbedded type column base in SRC building. Good earthquake-resistant design requires a deep knowledge of how SRC structures behave under earthquake loading. A structural design which merely meets flexural design is not satisfactory.

From this point of view, this paper presents the results of the experiment carried out in order to study ultimate shear strength and hysteresis property of unenbedded type column bases connection subjected to repeated shear force under the constant axial force (axial compression and axial tension). We call the shear slip failure that failure pattern of column bases subject to lateral slide. The main discussion is concentrated on the maximum strength, the behavior after the attainment of the maximum strength and the hysteretic characteristics involved in the large deformation range. In addition, We show that the proposed evaluation method of ultimate shear strength is in accordance with the test result well.

2. EXPERIMENTAL WORK

2.1. Test specimens and loading system

A total of 9 specimens were tested to investigate the elasto-plastic shear behavior of unenbedded type column base connection. Table 1 shows test program, and the bar arrangements and dimensions are shown in figure 1 and in figure 2, respectively. The specimens had a column section of 400mm×400mm, and a column steel was using H-250×125×6×9 (Grade SM490). Moreover, all specimens were designed so that shear failure of column base happened earlier than flexural failure of column base or the failure of footing beam. As a result, shear failure was caused in the column base. The following experimental parameters were selected, axial load level and the composition of column base section. The mechanical properties of concrete cylinder and steel are shown in Table 3 and in Table 4, respectively.

Table 1 Test program

Specimen	Column Section	Reinforcement	Anchor bolt	Anchorage length of Anchor bolt $_aL$ (mm)	Axial load N (kN)	Axial load ratio
No.1	Type A	16-D13 (SD345)	4-M24(SS490)	480 (20$_ad$)	1000	n_c = 0.18
No.2					0	n_c = 0
No.3					-500	n_t = 0.36
No.4	Type B	20-D13 (SD345)	4-M18(SS490)	360 (20$_ad$)	0	n_c = 0
No.5					-500	n_t = 0.38
No.6	Type C	16-D13 (SD345)	—	—	1000	n_c = 0.18
No.7					0	n_c = 0
No.8					-500	n_t = 0.64
No.9	Type D	24-D13 (SD345)	—	—	-500	n_t = 0.43

$n_c=N/N_{cu}$, $n_t=N/N_{tu}$, $N_{cu}=b\cdot D\cdot \sigma_c$, $N_{tu}={}_an\cdot {}_aA_0\cdot {}_a\sigma_y+{}_mn\cdot {}_mA\cdot {}_m\sigma_y$

b,D, σ_c:width of column, depth of column, compressive strength of concrete

${}_an$, ${}_aA_0$, ${}_a\sigma_y$: number of anchor bolts, sectional area of anchor bolts, yield strength of anchor bolts

${}_mn$, ${}_mA$, ${}_m\sigma_y$: number of reinforcement, sectional area of reinforcement, yield strength of reinforcement

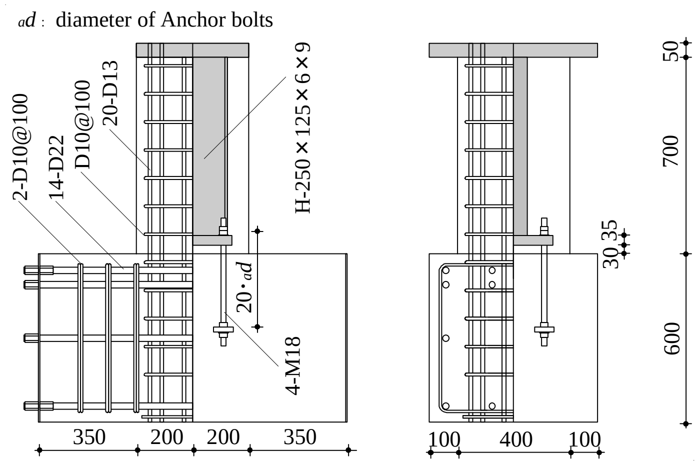


Figure 1 Test specimen No.4 (Unit:mm)

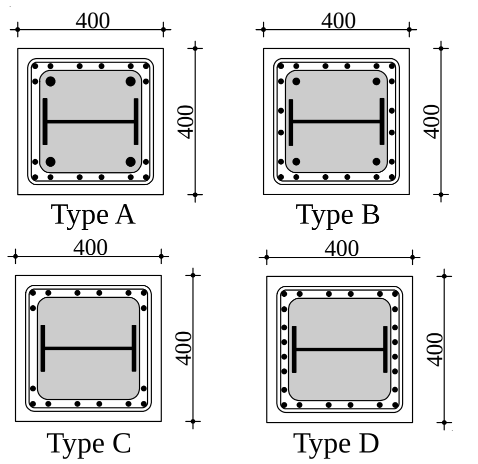


Figure 2 Section of column bases (Unit:mm)

Table 2 Mechanical properties of concrete

Concrete	Compressive strength (N/mm^2)	Cleavage strength (N/mm^2)	Young's modulus (N/mm^2)
Column	34.6	2.50	2.71×10^4
Footing beam	47.6	3.31	3.46×10^4
Grout mortal	48.5	2.91	2.36×10^4

Table 3 Mechanical properties of steel

Steel	Yield stress (N/mm^2)	Tensile stress (N/mm^2)	Elongation (%)
D13 Column reinforcement	384	561	23.1
D10 Hoop	389	520	19.2
D22 Footing beam reinforcement	437	631	16.6
D10 Stirrup	976	1126	6.1
M24 anchor bolt	345	541	27.3
M18 anchor bolt	337	538	24.1
Steel flange,Steel web	364	464	20.9

All of the specimens have been tested using the test setup system as shown in figure.3. As for column base of the specimen, the rotation was fixed to the steel-block mounted to the loading frame. Therefore, only axial force and punching shear force act on the column base. All specimens were subjected to a cyclic lateral force and a constant axial force. The axial load level is three stages (N=1000kN, 0kN and -500kN). The cyclic lateral loading is applied on every displacement of column base δ_{UB} =1mm under displacement control, where δ_{UB} means the relative displacement of base plate to the footing beam.

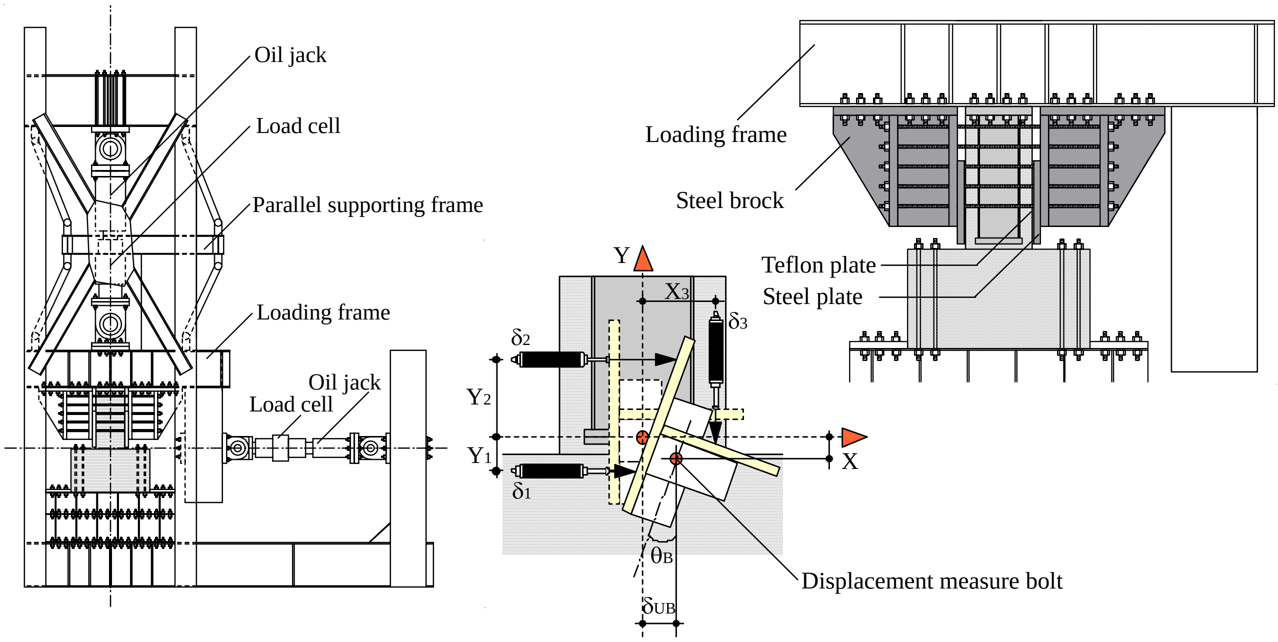
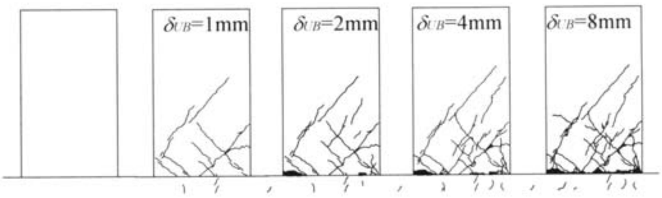


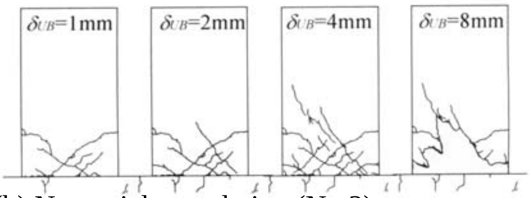
Figure 3 Test setup system

2. 2. Destruction state

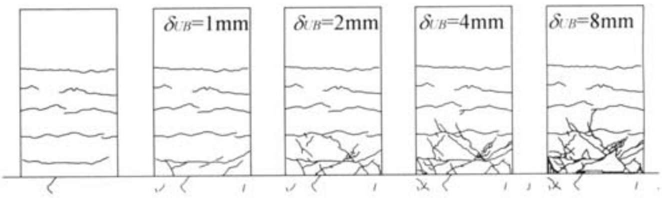
Figure 4 shows the crack patterns, and the final destruction state is shown in photo. 1 and in photo. 2, respectively. As for the specimen under tensile force, as a beginning, cracks of horizontal direction occurs at most equal intervals in the column subjected to tensile force. The cracks of horizontal direction are caused at the arrangement of the hoop. Then, as for the cracks of column bases subjected to shear force, the diagonal cracks occur at the column bases when column base slip from about 1mm regardless of the axial tension. In addition, the diagonal cracks of the column bases have progressed to the upper part of the column when the amplitude is increased gradually. Column bases under the axial compression are received have been greatly damaged compared with column bases under the axial tension.



(a) Under the axial completion (No.1)

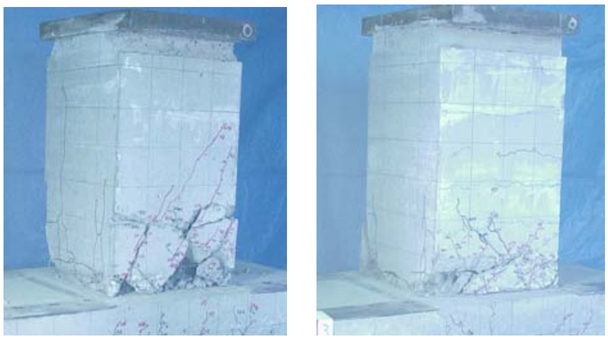


(b) Non axial completion (No.2)



(c) Under the axial tension (No.3)

Figure 4 Crack patterns



No. 1 No.3

Photo. 1 Final destruction state

No. 5

Photo. 2 After removing concrete

2. 3. Hysteresis characteristics

The experimental relations of horizontal load H and displacement of column base δ_{UB} are shown in figure 5. It is

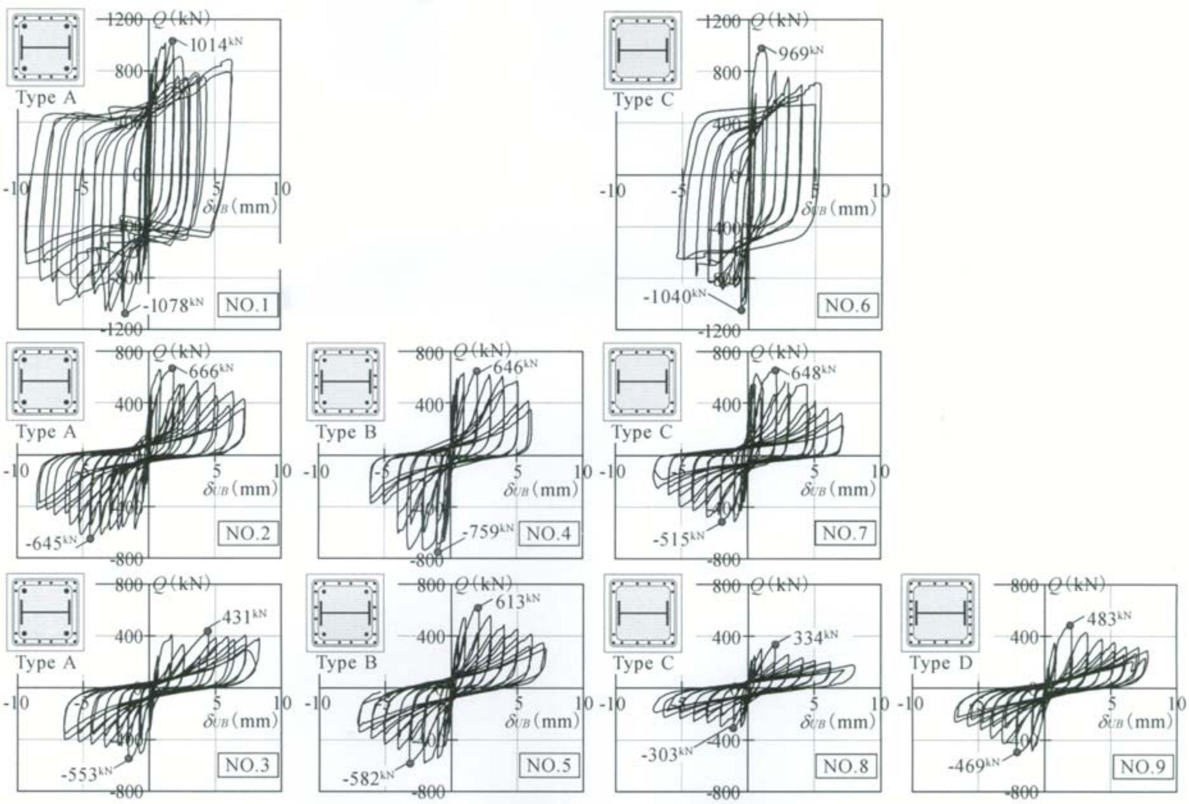


Figure 5 Hysteresis Characteristics

clear that all specimens reach the maximum strength when column base slip from 1 to 2mm. The comparison by the experimental parameter is shown as follows.

No.6, No.7, and No.8 compare the influences by the axial load, and are specimens without anchor bolts. The hysteresis loops under the compressive axial force are spindle shaped at large deformations. That is the reason why the specimen under the compressive axial force has frictional resistance between the base plate and concrete under the base plate. The reason for the strength decrease since the maximum strength is that the shear friction resistance in the RC portion surrounding the base plate decrease as the failure of column base progresses. Moreover, it was confirmed from the observation of the experiment that RC portion surrounding the base plate is failed from the influence of a bearing force by the effect of dowel.No.1, No.2, and No.3 are specimens that increased the anchor bolts of M24 to No.6, No.7, and No.8. The maximum strength of No.1 and No.2 is almost the same as the maximum strength of No.6 and No.7. This reason for is that the anchor bolts did not resist the shear force when displacement of the column base is small. There is a clearance between the hole of base plate and the anchor bolt for workability. However, since the anchor bolt resists shear force when displacement of the column base becomes large, strength deterioration after the maximum strength of the specimen with the anchor bolt is small. When No.3 is compared with No.8, the maximum strength of No.3 with the anchor bolt is large. In the specimen under the tensile axial force, the anchor bolts resist a tensile force. As a result, tensile axial force of RC portion is reduced, and a shear resistance force of RC portion becomes large. Therefore, the maximum strength of No.3 becomes larger than the maximum strength of No.8.

3. ULTIMATE SHEAR STRENGTH

3. 1. Evaluation method in the past

It is shown in reference [2] and [7] respectively for the ultimate shear strength Q of the column base.
The ultimate shear strength Q_1 according to the AIJ SRC Standard [2] is given as follows:

$$Q_{u1} = {}_aQ + {}_rQ + {}_bQ \tag{1}$$

for members without axial force or subjected to a compression, and

$$Q_{u1} = {}_aQ + {}_rQ \tag{2}$$

for members subjected to a tension.
${}_aQ$: shear resistance of anchor bolt
${}_rQ$: shear resistance of main reinforcement
${}_bQ$: shear resistance of concrete under base plate
On the other hand, the ultimate shear strength Q_2 according to the guidelines for seismic evaluation of existing steel reinforced concrete buildings [7] is given as follows:

$$Q_{u2} = {}_aQ + {}_rQ_{\mathrm{dwl}} + {}_cQ \tag{3}$$

for members without an axial force or subjected to a compression, and

$$Q_{u2} = ({}_aQ + {}_rQ_{\mathrm{dwl}}) \cdot (N + N_{tu}) / N_{tu} + {}_cQ \tag{4}$$

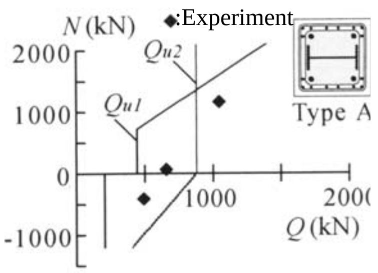
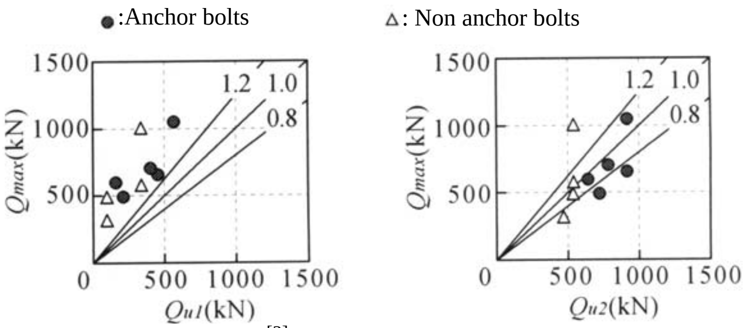


figure 6 Relationships of N and Q



(a) AIJ standard [2] (b) Guidelines for Seismic Evaluation [7]

figure 7 Calculation accuracy

for members subjected to a tension.
${}_{r}Q_{\mathrm{dwl}}$: dowel resistance of main reinforcement
${}_{c}Q$: shear resistance of concrete surround base plate
N_{tu} : the ultimate tensile strength of column base
Calculation accuracy is shown in figure 6 and in figure 7. Dotted points refer to the experimental maximum strength. It is understood that the ultimate shear strength obtained from Q_1 can evaluate to the safety side and the ultimate shear strength obtained from Q_2 can evaluate to a dangerous side.

3. 2. Proposed evaluation method

We are proposed the ultimate shear strength of column bases shown in table 4. Proposed ultimate shear strength is calculate by applying the superposed strength method, in which the ultimate shear strength of the anchor bolts and friction between the base plate and the concrete below the base plate is taken to be the sum of the punching shear strength of the RC portion surrounding the base plate. However, the anchor bolts might not be able to resist shearing force because there is a clearance between the hole of baseplate and the anchor bolts. Then, the following two methods are examined.

[Assumption Ⅰ]

Q_{su1} : The anchor bolt resists tensile force and shearing force.

$$N_{su} = {}_{rc}N_u + {}_{b}N_u + {}_{a}N_u \tag{5.a}$$
$$Q_{su1} = {}_{rc}Q_u + {}_{b}Q_u + {}_{a}Q_u \tag{5.b}$$

[Assumption Ⅱ]

Q_{su2} : It does not resist shearing force though the anchor bolt resists tensile force.

$$N_{su} = {}_{rc}N_u + {}_{b}N_u + {}_{a}N_u \tag{6.a}$$
$$Q_{su2} = {}_{rc}Q_u + {}_{b}Q_u \tag{6.b}$$

Table 4 Ultimate shear strength of column bases applying the superposed strength method

i) $0.66\sigma_c \cdot A_{c0} - {}_{m}n \cdot {}_{m}A \cdot {}_{m}\sigma_y + {}_{b}N_{cu} \leqq N_u \leqq {}_{rc}N_{cu} + {}_{b}N_{cu}$
$N_{su} = {}_{b}N_{cu} + {}_{rc}N_{cu}$
$Q_{su1} = 0.5\,{}_{b}Q_{cu} + {}_{rc}Q_u + {}_{a}Q_{u0}$

ii) ${}_{b}N_{cu} < N_u \leqq 0.66\sigma_c \cdot A_{c0} - {}_{m}n \cdot {}_{m}A \cdot {}_{m}\sigma_y + {}_{b}N_{cu}$
$N_{su} = {}_{b}N_{cu} + {}_{rc}N_u$
$Q_{su1} = 0.5\,{}_{b}N_{cu} + {}_{rc}Q_u + {}_{a}Q_{u0}$

iii) $0 \leqq N_u \leqq {}_{b}N_{cu}$ の場合
$N_{su} = {}_{b}N_u$
$Q_{su1} = 0.5\,{}_{b}N_u + \mathrm{kmin} \cdot \{0.22\sigma_c + 0.49 \cdot ({}_{m}n \cdot {}_{m}A / A_{c0} \cdot {}_{m}\sigma_y)\} \cdot A_{c0} + {}_{a}Q_{u0}$

iv) $0.33\sigma_c \cdot A_{c0} - {}_{m}n \cdot {}_{m}A \cdot {}_{m}\sigma_y \leqq N_u \leqq 0$
$N_{su} = {}_{rc}N_u$
$Q_{su1} = {}_{rc}Q_u + {}_{a}Q_{u0}$

v) ${}_{rc}N_{tu} \leqq N_u \leqq 0.33\sigma_c \cdot A_{c0} - {}_{m}n \cdot {}_{m}A \cdot {}_{m}\sigma_y$
$N_{su} = {}_{rc}N_u$
$Q_{su1} = {}_{rc}Q_u + {}_{a}Q_{u0}$

vi) ${}_{rc}N_{tu} + {}_{a}N_{tu} \leqq N_u \leqq {}_{rc}N_{tu}$
$N_{su} = {}_{rc}N_{tu} + {}_{a}N_u$
$Q_{su1} = \mathrm{kmin} \cdot (0.98 + 0.1\sigma_c) \cdot A_{c0} + {}_{a}Q_u$

${}_{b}N_{cu}$:Compressive strength of the concrete below the base plate, ${}_{rc}N_{cu}$:Compressive strength of the RC portion surrounding the base plate, ${}_{rc}N_{tu}$:Tensile strength of the RC portion surrounding the base plate, ${}_{a}N_{tu}$:Tensile strength of anchor bolt, ${}_{a}Q_{u0}$: Shear strength of anchor bolt

The ultimate shear strength of column bases applying the superposed strength method based on equation (5.a,b) is shown in table 4. As for strength based on equation (6.a,b), it only has to think both $_aQ_{u0}$ and $_aQ_u$ equal 0. It follows reference [6] and [8] for $_{rc}Q_u$, $_bQ_u$, and $_aQ_u$ respectively.
Calculation accuracy is shown in figure 8, figure 9 and in figure 10. Dotted points refer to the experimental maximum strength. It is understood that the ultimate shear strength obtained from Q_{su1} is in accordance with the test result well, and the ultimate shear strength obtained from Q_{su2} can evaluate to the safety side.

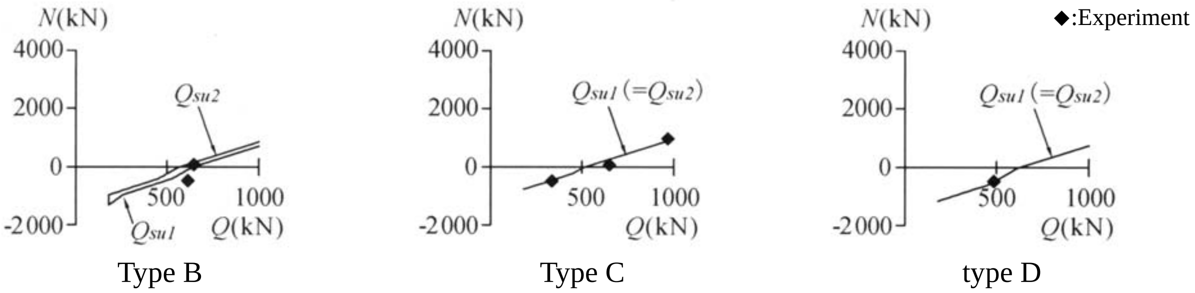


figure 8 Relationships of N and Q

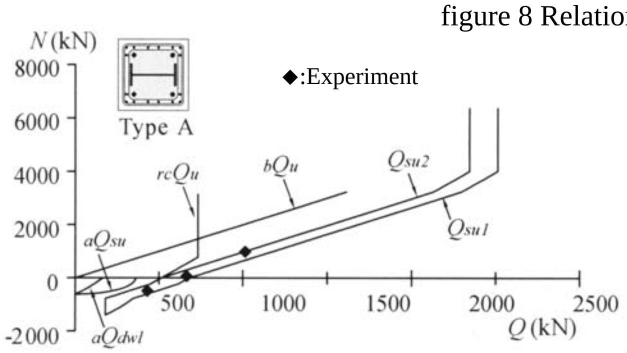


figure 9 Relationships of N and Q

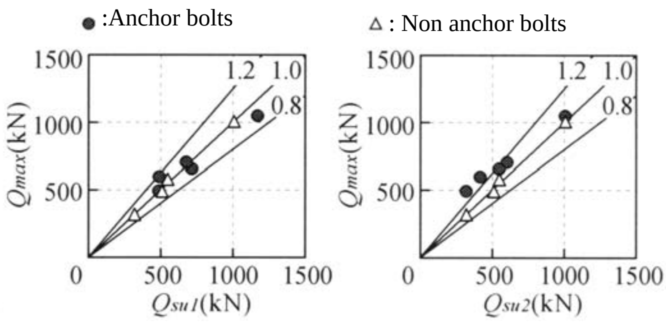


figure 10 Calculation accuracy

4. CONCLUSION

The structural test carried out in order to study ultimate shear strength and hysteresis property of unenbedded type column bases subjected to repeated shear force under the constant axial force. It has become clear from the test results that:

1. Ultimate shear strength according to the design code in AIJ can be evaluated to a safety side.
2. Ultimate shear strength according to the guidelines for seismic evaluation of existing steel reinforced concrete buildings might be evaluated to a dangerous side. This reason is that the anchor bolts cannot resist shearing force.
3. Proposed evaluation method of ultimate shear strength is in accordance with the test result well.

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