8th Canadian Conference on Earthquake Engineering / 8ième Conférence canadienne sur le génie paraséismique
Vancouver – 1999

# Effects of Crack Prevention Reinforcement on the Ductility of Boundary Connection of Retrofitted Shear Steel Wall

Keiji Shinohara[1], Yukio Kobayashi[2], Kiyoshi Imai[3] and Hiroshi Sato[4]

## Abstract

A series of experimental studies on the behaviors of the connection of the steel framed concrete wall have been carried out. To examine the effects of these reinforcement methods on the ductility of connection, 17 reduced (half size of the actual connection) specimens with the different three crack prevention reinforcements, i.e, the spiral reinforcement (S-type:6 specimens), ladder reinforcement (L-type:6) and mesh reinforcement (M-type:5) were tested. Specimens were loaded by the displacement-controlled loading machine. The relation between the strength and the displacement of the wall connection was observed.

From tests results, it became clear that the difference of the reinforcement method had no effect upon the process up to the maximum strength. But on the ductility of the connection, L-type and M-type were superior to S-type. On the basis of these test results, Kanagawa prefecture has decided to use the mesh reinforcement instead of the spiral reinforcement as the crack prevention reinforcement.

## Introduction

The 1995 Hyogoken-Nambu Earthquake with a magnitude of 7.2 on the JMA scale caused much damage to reinforced concrete structures. After this earthquake, many studies on the safety evaluation of existing buildings, their strengthening method, and also the seismic upgrading of the damaged building have been actively carried out. It is a matter of great importance in the prefectural policy of Kanagawa to secure existing structures against earthquakes. To obtain a foothold for taking steps to secure the collection of information from the medical relief and emergency countermeasure activities, the earthquake-proofness of prefectural and other public facilities has been examined. The standard of aseismic diagnosis was established first, and a structure judged to be not up to standard was given council to be either rebuilt or reinforced. From an economical perspective, it has been determined to more cost effective to strengthen the earthquake-proofness of public facilities and extend the period of their durability rather than rebuild existing structures.

There are many methods available to reinforce the earthquake-proofness of existing structures (as shown in Fig.1;Yasushi YAMAMOTO et.al, 1983;1987). We also have proposed the method of adding a steel frame

1 Chief Researcher, Kanagawa Industrial Technology Research Institute, Member of CAEE

2 Chief Researcher, Kanagawa Industrial Technology Research Institute

3 Manager, KFC Ltd.

4 Professor, Dept.of Civil Engineering National Defence Academy, Member of CAEE

to a portion of existing window frames. The features of our proposed method are (1) to uniformly distribute the shear forces by the shaking during earthquake, (2) to expect good construction circumstances by using a light and slender bracing, and (3) to be able to maintain almost the same size of opening as before the strengthening. This method enables development of both the strength and ductility of whole structures if the steel frame and the existing concrete body could be worked as one. As the bracing of the steel frame is designed to be broken prior to the steel frame itself, the boundary connection between the existing R/C member and the added strengthening member should have enough strength to withstand an earthquake. To secure the effectiveness of these reinforcement methods, it is very important to confirm the strength and ductility of the connection. In this case, the crack prevention reinforcement plays an important role in the performance of the connection.

Although the spiral reinforcement was used, this method has the fatal hardness on the construction method that is difficult due to the arrangement of studs and anchors. Then, we need new types of crack prevention reinforcement with the same or higher ability as the spiral reinforcement.

The main aim of this study is to find out a new crack prevention reinforcement with an easy construction method instead of the current spiral reinforcement. Here, as with new types of the reinforcement, we consider the behavior of the ladder type reinforcement and the mesh type reinforcement under various conditions.

## Test specimens

To examine the effects of crack prevention reinforcements on the ductility of boundary connection of retrofitted shear steel wall, the reduced model (half size of the actual connection) was used as shown in fig.2. Seventeen specimens with different three types of prevention reinforcements, the spiral reinforcement (S-type), ladder reinforcement (L-type) and the mesh reinforcement (M-type) with the three kinds of the diameters of reinforced steel bar, and with the three kinds of intervals of studs were used as shown in table-1.

This model was consisted of the concrete block corresponding to the existing R/C wall and the Channel-shape steel corresponding to the steel frame for reinforcement. After setting up the connecting members on the concrete, pre-mixed non-contraction mortar was compressed into the mold. The properties of materials used for specimen are shown in Table-1. The concrete in the specimen differs in length with specimen types (A:120x15x35cm, B:120x37.5x30cm). The upper face of the concrete, which was in contact with the mortar, was roughcast to improve the bond effect with the mortar.

## Test procedures

Setting up of a specimen on the testing machine is illustrated in Fig.2. Two H-shaped steel beams were fixed on the bed with bolts. A specimen was then put on the beams and fixed together with 8 high-tensioned bolts to prevent from moving vertically. The horizontal move of a specimen was restricted by the reaction frame. The horizontal shear force was loaded toward the top face of the concrete in contact with the mortar through the L-formed H-beam. A loading was executed manually by the displacement-controlled loading machine. In this manner, loading was done until the maximum carrying load of the specimen was obtained. (Load was the repeated and one directional loading). Since the vertical force does not act in the connection, it is liable to break the front part of a specimen due to lifting up its end. Then, in the beginning to check the failure of a specimen, the load of 100kg was applied to the L-shaped H-beam upward from below by an oil jack as shown in Fig.2. Of 15 displacement sensors with the precision of 1/100mm, 8 sensors were used for measuring the horizontal displacement and 7 of them were used for measuring the vertical displacement (as shown inFig.2). To measure the strain in steel, the strain gages with length of 2mm were attached to studs, anchors and reinforcing bars. Figure 4 shows an example of gage positions in studs and anchors.

## Results and considerations

Results of these experiments are summarized in Table 2.

(1) The relation between the carrying load and displacement

Figure 5 shows the relation between the carrying load and displacement.

The maximum strengths of these three types are not so different. But, comparing the displacement at 80% strength level after the maximum strength, as M- and L-type specimen are much larger than the S-type specimen, it is considered that the M-type and L-type reinforcement have a good performance concerned with the ductility of the connection.

(2) Cracking pattern of the specimen

Figure 6 shows the final cracking pattern appearing in the connection of each specimen.

In the S-type and L-type specimens, the number of cracks of mortar was only a few, but in the M-type specimen, many cracks were appeared on the entire surface of mortar.

(3) Behaviors of the strain in the studs and resin anchors

Figure 7 shows the condition of yielding in the studs and anchors.

In figures, numerals ①、②、③ ,・・ mean the number of yielded strain gages among all strain gages. For example, the numeral ④ in the M-type, means that in this part of the stud, 4 specimens among 5 specimens were yielded. Figure 8 shows the ratio of the number of yielded strain gages to all strain gages at the maximum strength level and 80% strength level after the maximum strength. As a whole, the yield ratio of the M-type reinforcement become high. This means that in case of the M-type, the shear force acted on the connection is resisted by the whole portion of the mortar. This is a reason why the M-type reinforcement is superior to the current S-type reinforcement for the ductility of the connection.

(4) Effects of the crack prevention reinforcement on the ductility of the connection

Generally, the reinforcement to resist the shear crack of the column is the transverse reinforcement perpendicular to the crack (as shown in Fig.9a). Then, it is important to arrange the crack prevention reinforcement to resist these cracks of the connection. On the other hand, the spiral type reinforcement and ladder type reinforcement (as shown in Fig.9c) are useful for the crack so as to split the connection. In this type of reinforcement, the bracing of steel frame is designed to break prior to the steel frame itself, and the connection of the steel framed concrete wall should have enough strength. Then, using the high strength mortar at the connection, it is hard to occur the split type collapse at the mortar. This means the

M-type reinforcement is useful for the case of the crack pattern as shown in Fig.6. (Keiji SHINOHARA et.al,1994;1995)

## Concluding remarks

This study is to examine the effects of the difference of reinforcement methods of the connection on the ductility at the connection. Seventeen reduced specimens with the different three crack prevention reinforcement were tested.

Results obtained from this study can be concluded as follows:

(1) The difference of crack prevention reinforcements does not show a remarkable effect on the maximum strength. But the proposed mesh reinforcement has the effect of increase in deformation after the maximum strength.

(2) Arranging the mesh reinforcement to the connection, it is possible to diffuse the crack on the whole, and to share the stress by many connectors, resulting in the high stable connection to resist as a whole.

(3) As steel bars perpendicular to the crack direction are useful for the shear force acting on the connection, steel bars arranged parallel to the shear force have an important role in the ductility of the connection.

(4) The usage of the mesh reinforcement makes possible high performance connection with easy construction method and high ductility.

These facts are very important for the actual application to the strengthening of existing buildings. On the basis of these test results, Kanagawa prefecture has decided to use the mesh reinforcement instead of the spiral reinforcement as the crack prevention reinforcement.

## References

Keiji SHINOHARA, Yukio KOBAYASHI, Hiroshi SATO, "Experimental studies on joint menbers of steel frame wall developed for aseismic reinforcement of existing duildings", The 9th Japan Earthquake Engineering Symposium, pp2149 — 2154, 1994.12, in Japanese

Keiji SHINOHARA, Yukio KOBAYASHI, Hiroshi SATO, "Experimental study on the Crack Prevention Reinfocement Used in the Connection of Steel Framed Reinforced Concrete Shear Wall in Exsisting Structures", 7CCEE, pp879 — 886, 1995.6

Yashushi YAMAMOTO, Hiroshi HIRAYAMA, Hiroyuki AOYAMA, "A STUDY ON SEISMIC STRENGTHENING OF EXISTING REINFORCED CONCRETE BUILDING BY STEEL ELEMENTS" , Journal of Structural Engineering,Vol.33B, 1987.3, pp221 — 232, in Japanese

Yashushi YAMAMOTO, Seishi KIYOTA, "Experimental Study on the Strengthening of Reinforced Concrete Buildings Part 2. Strengthening by Steel System", The 29th Journal of Structural Engineering, 1983.2, pp91 — 98, in Japanese

Table-1 Test Materials Condition

| | Speceimen | Studs $\phi$ | Studs $P_i$ | Studs $\sigma_y$ | Studs $\sigma_t$ | Anchors $\phi$ | Anchors $P_i$ | Anchors $L_a$ | Anchors $\sigma_y$ | Anchors $\sigma_t$ | Crack Prevention Bars Ty | | $P_{wx}$ | $P_{wy}$ | $P_{wz}$ | $P_i$ | $\sigma_y$ | $\sigma_t$ | Concrete Sc | $\sigma_{BC}$ | $E_C$ | Mortar $\sigma_{BM}$ | $E_M$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S | S4- 75 | 8 | 75 | 2652 | 4701 | D10 | 75 | 80 | 3541 | 5588 | S | 4 | 0.100 | 0.048 | 0.039 | 75 | 5297 | 5584 | A | 204 | 2.01 | 587 | 2.79 |
| | S4-100 | 8 | 100 | 2434 | 4887 | D10 | 100 | 80 | 3932 | 5667 | p | 4 | 0.124 | 0.044 | 0.035 | 100 | 3767 | 4416 | A | 187 | 1.71 | 482 | 2.65 |
| | S4-125 | 8 | 125 | 2652 | 4701 | D10 | 125 | 80 | 3541 | 5588 | i | 4 | 0.139 | 0.040 | 0.032 | 125 | 5297 | 5584 | A | 204 | 2.01 | 590 | 2.78 |
| | S6- 75 | 8 | 75 | 2434 | 4887 | D10 | 75 | 80 | 3932 | 5667 | r | 6 | 0.226 | 0.109 | 0.087 | 75 | 3767 | 4416 | A | 182 | 1.83 | 496 | 2.62 |
| | S6-100 | 8 | 100 | 2434 | 4887 | D10 | 100 | 80 | 3932 | 5667 | a | 6 | 0.278 | 0.099 | 0.079 | 100 | 3767 | 4416 | A | 184 | 1.80 | 513 | 2.61 |
| | S6-125 | 8 | 125 | 2434 | 4887 | D10 | 125 | 80 | 3932 | 5667 | l | 6 | 0.314 | 0.090 | 0.072 | 125 | 3767 | 4416 | A | 179 | 1.84 | 493 | 2.61 |
| L | L4 75 | 8 | 75 | 2652 | 4701 | D10 | 75 | 80 | 3541 | 5588 | L | 4 | 0.402 | 0.335 | 0.000 | 75 | 5297 | 5584 | A | 204 | 2.01 | 578 | 2.77 |
| | L4-100 | 8 | 100 | 2434 | 4887 | D10 | 100 | 80 | 3932 | 5667 | a | 4 | 0.402 | 0.279 | 0.000 | 100 | 3767 | 4416 | A | 187 | 1.71 | 482 | 2.65 |
| | L4-125 | 8 | 125 | 2652 | 4701 | D10 | 125 | 80 | 3541 | 5588 | d | 4 | 0.402 | 0.223 | 0.000 | 125 | 5297 | 5584 | A | 204 | 2.01 | 605 | 2.77 |
| | L6- 75 | 8 | 75 | 2434 | 4887 | D10 | 75 | 80 | 3932 | 5667 | d | 6 | 0.904 | 0.754 | 0.000 | 75 | 3767 | 4416 | A | 182 | 1.83 | 529 | 2.69 |
| | L6-100 | 8 | 100 | 2434 | 4887 | D10 | 100 | 80 | 3932 | 5667 | e | 6 | 0.904 | 0.628 | 0.000 | 100 | 3767 | 4416 | A | 184 | 1.80 | 476 | 2.65 |
| | L6-125 | 8 | 125 | 2434 | 4887 | D10 | 125 | 80 | 3932 | 5667 | r | 6 | 0.904 | 0.502 | 0.000 | 125 | 3767 | 4416 | A | 179 | 1.84 | 481 | 2.55 |
| M | M2.6-50 | 8 | 50 | 2652 | 4701 | D10 | 50 | 80 | 3541 | 5588 | M | 2.6 | 0.254 | 0.000 | 0.170 | 50 | – | 7524 | B | 152 | 1.50 | 503 | 2.63 |
| | M2.6-100 | 8 | 100 | 2652 | 4701 | D10 | 100 | 80 | 3541 | 5588 | e | 2.6 | 0.170 | 0.000 | 0.094 | 100 | – | 7524 | B | 152 | 1.50 | 503 | 2.63 |
| | M4- 50 | 8 | 50 | 2652 | 4701 | D10 | 50 | 80 | 3541 | 5588 | s | 4 | 0.603 | 0.000 | 0.402 | 50 | 3770 | 4466 | B | 152 | 1.50 | 460 | 2.34 |
| | M4-75 | 8 | 75 | 2652 | 4701 | D10 | 75 | 80 | 3541 | 5588 | h | 4 | 0.402 | 0.000 | 0.268 | 75 | 3770 | 4466 | B | 152 | 1.50 | 483 | 2.37 |
| | M6-100 | 8 | 100 | 2652 | 4701 | D10 | 100 | 80 | 3541 | 5588 | | 6 | 0.904 | 0.000 | 0.502 | 100 | 3770 | 4466 | B | 152 | 1.50 | 478 | 2.29 |

〔comment〕

$\phi$ ; connectors diameter(mm),

$P_i$ ; space of connectors arrangement(mm),

$\sigma_y$, $\sigma_t$ ; yield point and strength of connectors(kgf/cm$^2$),

$L_a$ ; effective length of anchors in concrete,

$T_y$ ; type of crack prevention bars,

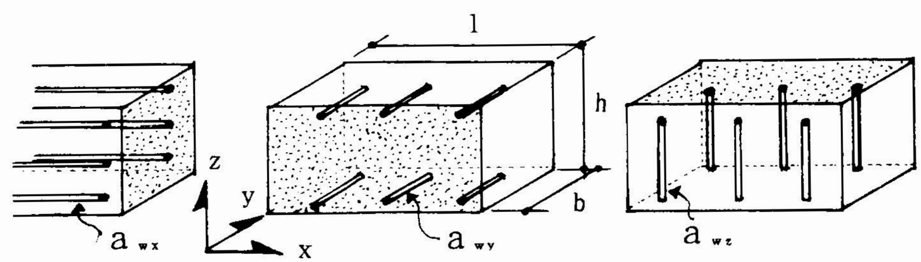
$P_{wx}$, $P_{wy}$, $P_{wz}$ ; ratio of crack prevention bars in x, y and z drection respectively(see right fig.),

Sc ; type of concrete, A;120x15x35 cm, B;120x37.5x30 cm,

$\sigma_{BC}$, $\sigma_{BM}$ : compressive strength of concrete and mortar, respectively(kgf/cm$^2$),

$E_C$, $E_M$ ; elastic modulus of concrete and mortar, respectively (kgf/cm$^2$)

$$P_{wx} = \frac{\Sigma a_{wx}}{b \cdot h} \qquad P_{wy} = \frac{\Sigma a_{wy}}{l \cdot h} \qquad P_{wz} = \frac{\Sigma a_{wz}}{l \cdot b}$$



## Table-2 Results of test

| Type | Specei-men | δ 0.20 / R 1/500 Q tf | δ 0.40 / R 1/250 Q tf | δ 1.00 / R 1/100 Q tf | δ 2.00 / R 1/50 Q tf | Maximum $Q_M$ tf | Maximum δ mm | Average Q tf | Average δ mm | Yield of Connectors MAX S (%) | MAX A (%) | 80% S (%) | 80% A (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S | S4- 75 | 4.86 | 6.46 | 7.20 | 6.44 | 7.74 | 0.77 | | | 16.7 | 4.2 | 58.3 | 29.2 |
| | S4-100 | 6.45 | 7.52 | 9.37 | 10.08 | 10.42 | 1.67 | MAX. | | 33.3 | 5.6 | 33.3 | 5.6 |
| | S4-125 | 5.40 | 7.29 | 8.36 | 6.54 | 8.48 | 0.67 | 9.29 | 1.02 | 33.3 | 21.8 | 33.3 | 39.1 |
| | S6- 75 | 5.95 | 7.25 | 10.03 | – | 10.08 | 1.04 | | | 50.0 | 11.1 | 50.0 | 16.7 |
| | S6-100 | 6.32 | 7.25 | 9.33 | 7.77 | 9.33 | 1.00 | 80% | | 25.0 | 11.1 | 58.3 | 16.7 |
| | S6-125 | 6.91 | 8.21 | 9.71 | 5.88 | 9.71 | 0.98 | 7.43 | 1.81 | 18.2 | 16.7 | 25.0 | 16.7 |
| L | L4 75 | 4.47 | 6.49 | 8.92 | 8.23 | 9.46 | 1.21 | | | 41.7 | 26.1 | 41.7 | 60.9 |
| | L4-100 | 4.77 | 6.79 | 9.51 | 8.69 | 9.83 | 1.40 | MAX. | | 25.0 | 16.7 | 25.0 | 55.6 |
| | L4-125 | 4.96 | 6.51 | 8.70 | 7.46 | 8.70 | 0.97 | 9.64 | 1.22 | 36.4 | 26.1 | 45.5 | 45.8 |
| | L6- 75 | 6.52 | 7.75 | 9.53 | 7.80 | 9.53 | 1.00 | | | 33.3 | 22.2 | 41.7 | 61.1 |
| | L6-100 | 5.91 | 8.73 | 9.39 | 9.35 | 10.03 | 1.69 | 80% | | 25.0 | 22.2 | 50.0 | 66.6 |
| | L6-125 | 6.79 | 8.25 | 10.26 | 8.41 | 10.28 | 1.04 | 7.71 | 4.88 | 8.3 | 5.6 | 8.3 | 50.0 |
| M | M2.6-50 | 3.70 | 6.37 | 9.00 | 8.84 | 10.09 | 1.36 | MAX. | | 58.3 | 37.5 | 75.0 | 50.0 |
| | M2.6-100 | 5.17 | 7.68 | 9.50 | 9.78 | 9.92 | 1.15 | 10.32 | 2.04 | 50.0 | 25.0 | 83.3 | 58.3 |
| | M4- 50 | 4.39 | 7.20 | 9.84 | 11.50 | 12.07 | 2.65 | | | 66.7 | 62.5 | 75.0 | 75.0 |
| | M4-75 | 4.40 | 6.67 | 8.84 | 10.49 | 10.58 | 2.19 | 80% | | 25.0 | 33.3 | 33.3 | 58.3 |
| | M6-100 | 5.14 | 6.73 | 8.04 | 8.66 | 8.94 | 2.83 | 8.26 | 4.75 | 50.0 | 58.3 | 58.3 | 58.3 |

δ ; displacement(mm), R ; rotation angle(radian), Q ; shear load(tf), S ; studs, A ; anchors

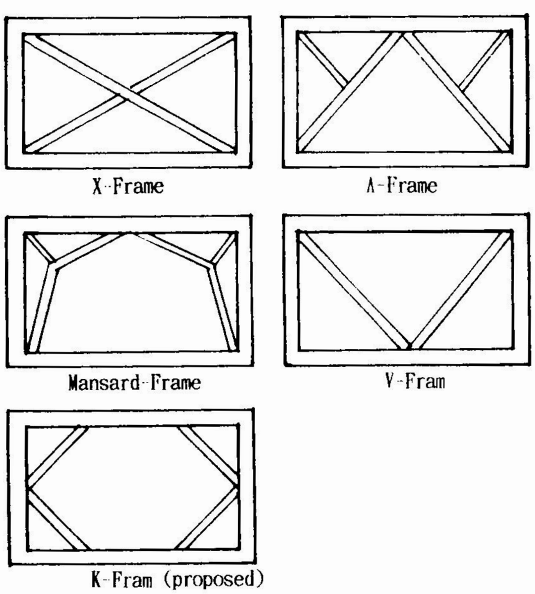



FIg. 1 Steel frame types

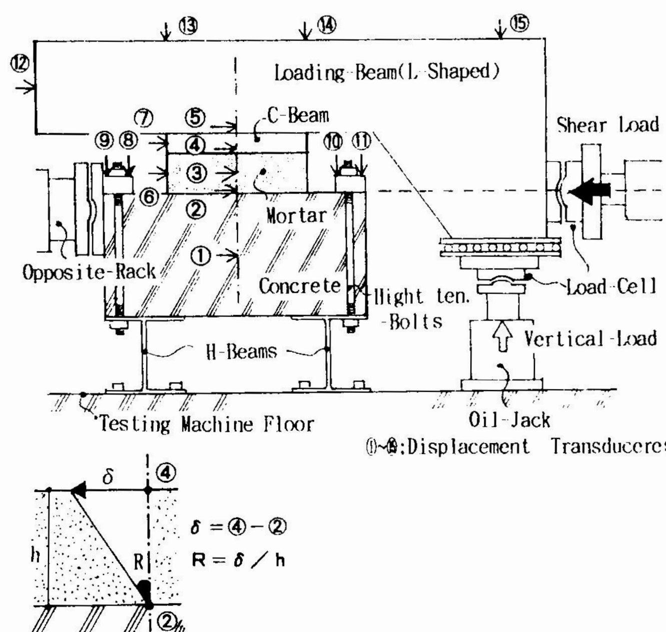



FIg. 2 Configuration of test speciemens and point displacement

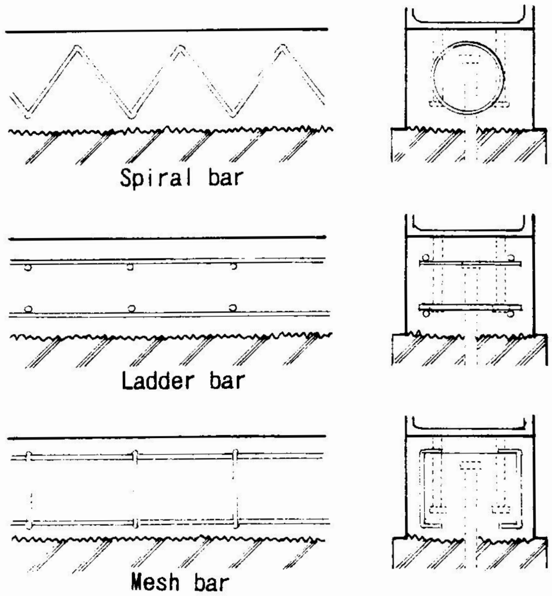



Fig. 3 Types of crack prevention bars

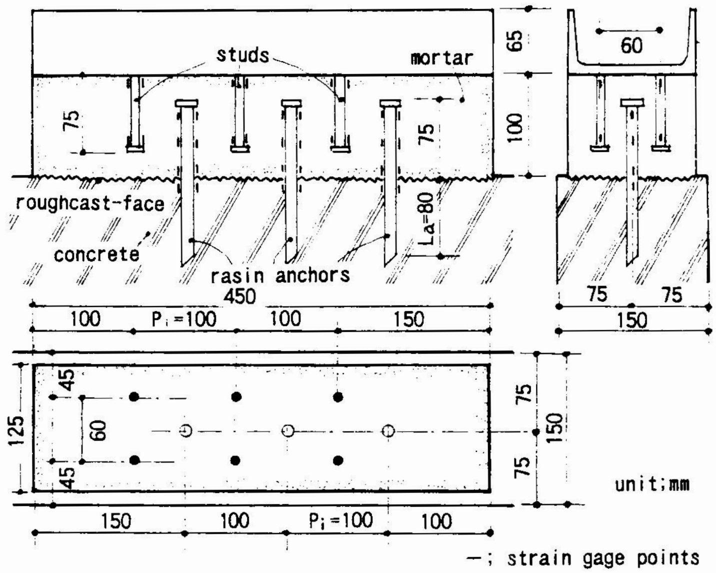



Fig. 4 Gage positions in studs and resin anchors

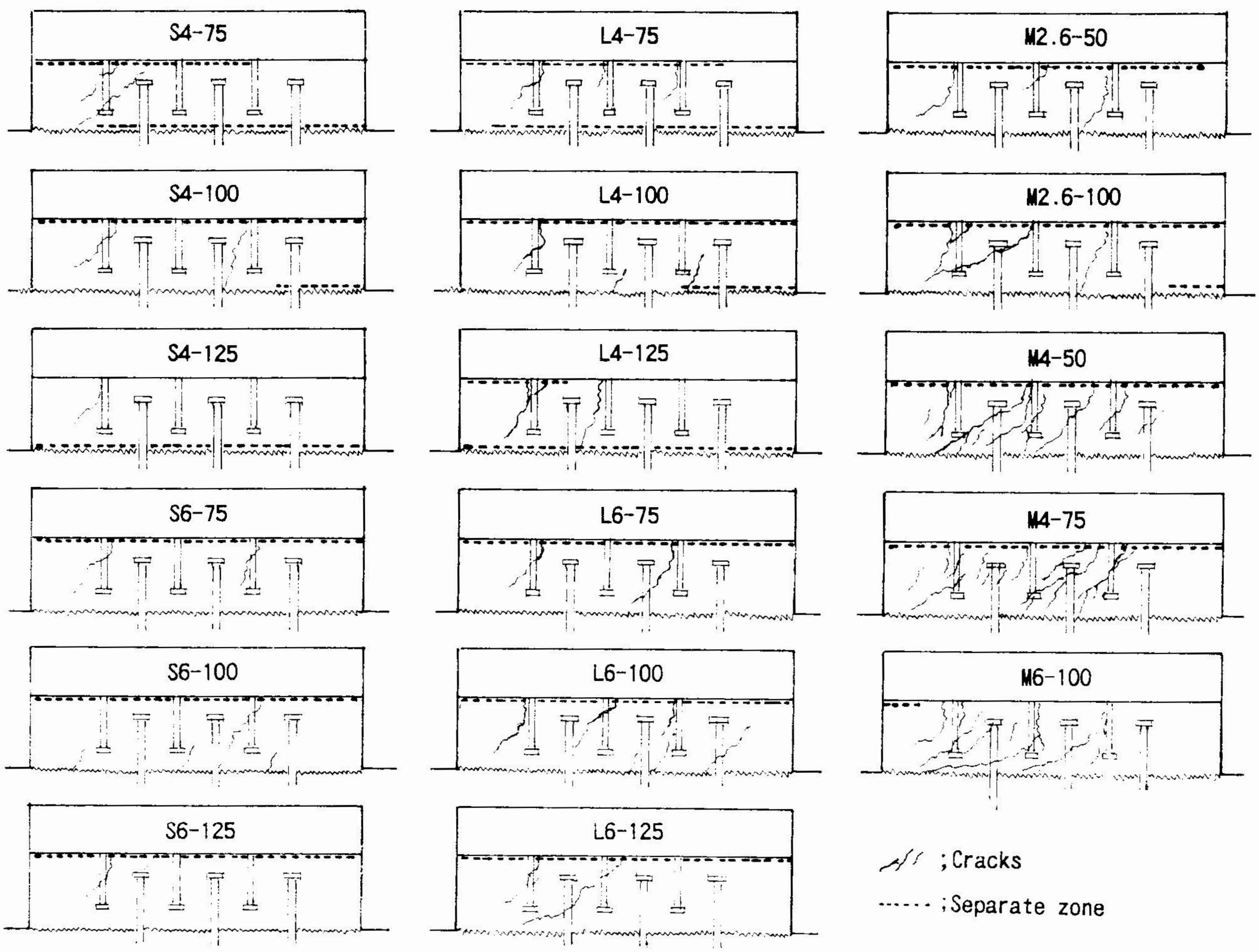



Fig. 6 Cracks pattern of test specimens

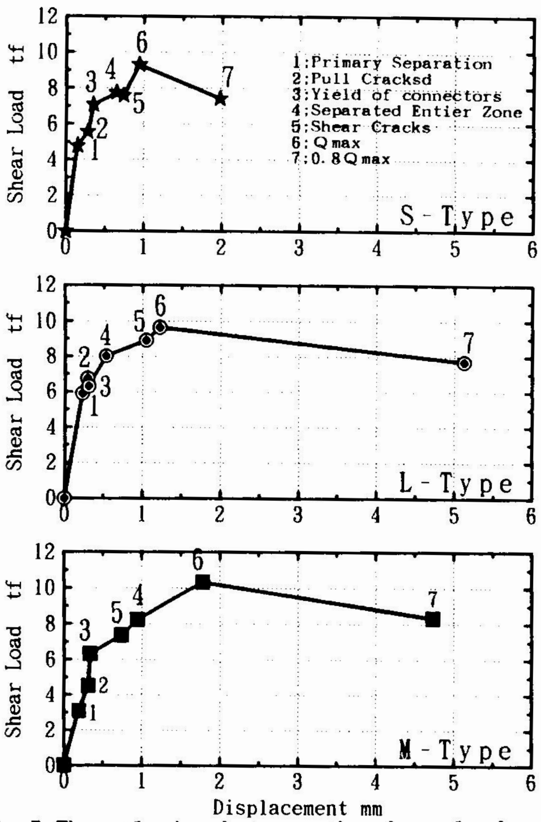



Fig. 5 The relation between the shear load and displacement

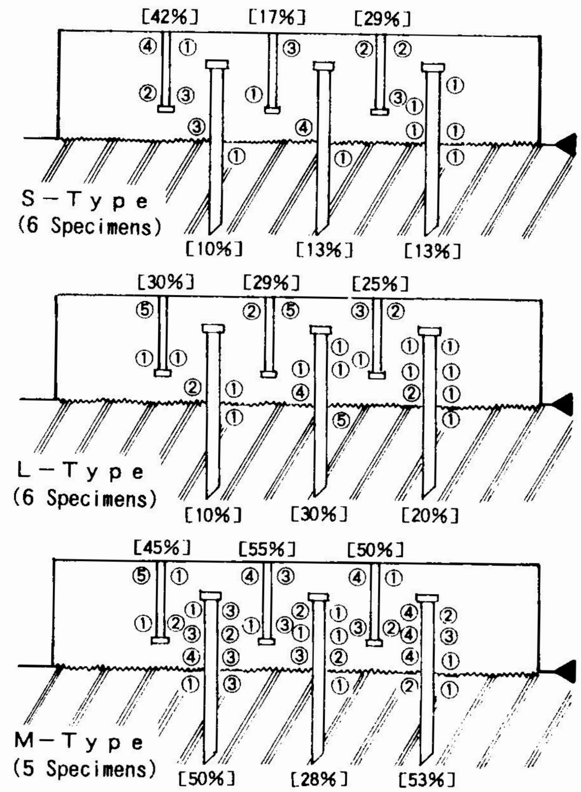



Fig. 7 Yielded gages of connectors

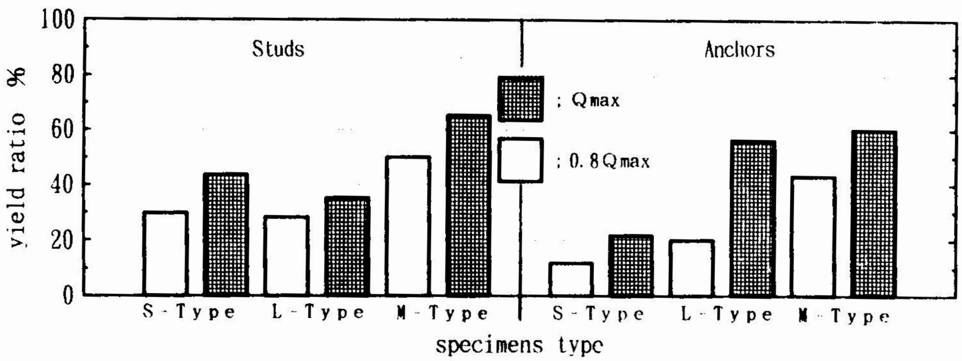
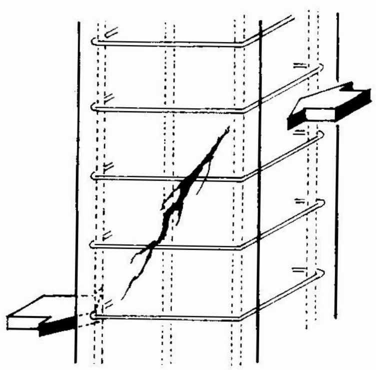
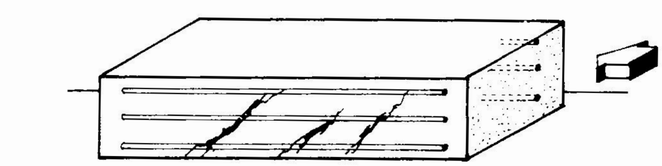
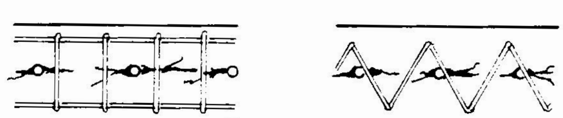



Fig. 8
Yield ratio of connectors





b. Cracks in the connection and reinforcement



a. Typical cracks in concrete columns

c. Effective reinforcement resist to the sprit of mortar

Fig. 9 Effective arrangement of crack prevention bar in concrete column or mortar boundary conection