13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 1270

FLEXURAL CHARACTERISTICS OF RC COLUMNS WITH PLASTIC HINGES LOCALIZED BY MUCH TRANSVERSE REINFORCEMENT

Ichizo Kishimoto[1], Yoshiteru Ohno[1], Seiji Nishina[1], Takao Nakagawa[1], Takao Iguchi[1], Yuji Yamaguchi[1]

SUMMARY

To investigate the possibility of the localization of damaged when the reinforce concrete (RC) column are subjected to an earthquake motion, experimental study on RC column with various types of transverse reinforcement was conducted. Localization of the damage would be planned to effectuate by using much transverse reinforcement (which spacing is very close). As a result of this experiment, equipment of the much transverse reinforcement was effective to preserve splitting of the member by occurring shear crack and improve the ductility of the members but was not useful to make damage localize at the planned area.

INTRODUCTION

In recent years, it has significant meaning to predict the damage level of buildings when they are subjected to an earthquake motion. That needs to make clear the relation the damage of concrete members and the deformation. But it is quite difficult because concrete as a material is not homogeneous. There are many phenomenon which reduce the performance as a structural member, cracking, loss of bonding between concrete and steel bar, and so on which caused by non-homogeneous substance. If we look at this problem from a different angle, namely if damaged area will be localized as planned by using some sort of way it is quite useful. In this paper we report the experimental study on the loading test to columns planed to localized the damaged area subjected horizontal loading by using much transverse reinforcement. And as a new trial to investigate the damage of reinforced concrete columns in detail, we used a high performance digital camera.

EXPERIMENTAL PROGRAM

Six RC columns measuring 1000mm in length and having typical 250mm square section were tested to evaluate the effect of transverse reinforcement on the flexural capacity and behavior of RC columns (Fig. 1). Each specimen has its own type of transverse reinforcement at its both ends. Details are shown as

[1] Osaka University Graduate school of Engineering Architectural Engineering, JAPAN

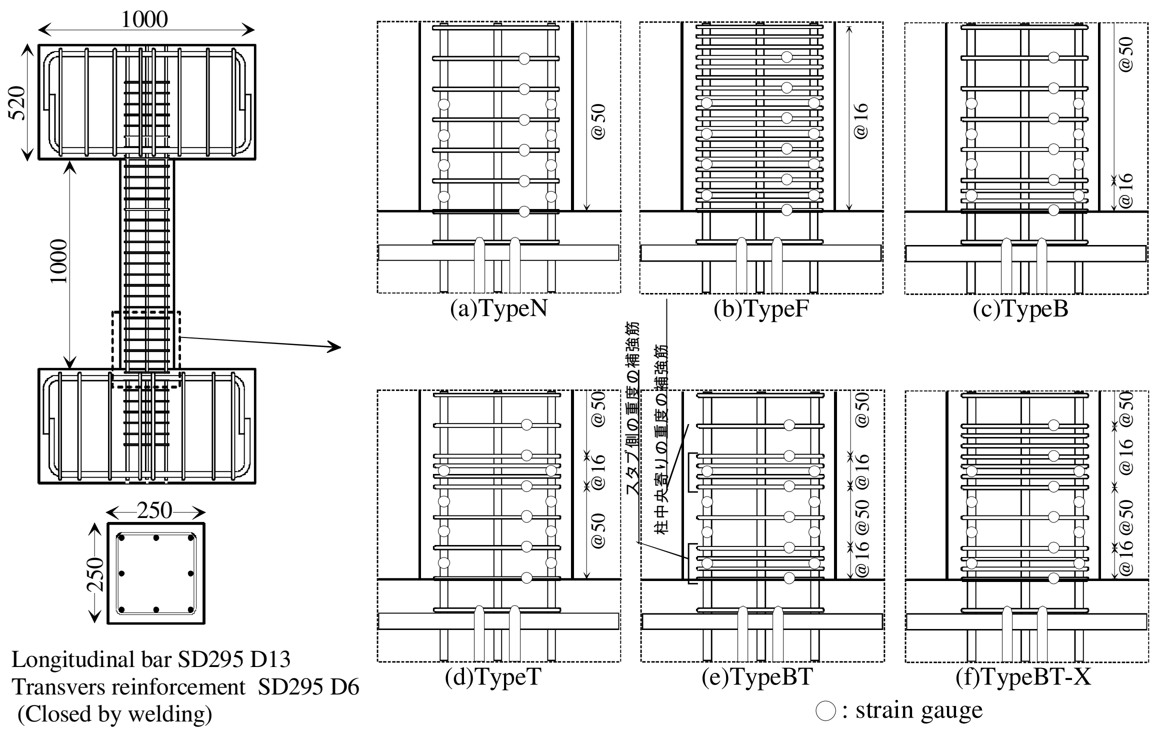

Fig.1 Specimens

following. Type N is defined as a standard specimen and has conventional transverse reinforcement (6mm diameter stirrup and spacing is 50mm over the entire length of the specimen: pw=0.51% : pw =atr/(D*s) atr: a cross section of transverse reinforcement, D: length of column section, s: spacing of transverse reinforcement in axial direction). Type F has largest amount of transverse reinforcement of all specimens and the much transverse reinforcement are provided by 6mm diameter stirrup and 17mm spacing. The length of much reinforced area is 300mm from the face of the stub on both ends of the column.

Table 1 Characteristics of steel and concrete

	Yield Strength [N/mm^2]	Tensil Strength [N/mm^2]	Young Modulus [N/mm^2]
Longetudina bar (D13)	359	495	1.76E+5
Transverse reinforcement (D6)	381	513	1.79E+5
	Compression Strength [N/mm^2]		Young Modulus [N/mm^2]
Concrete	42.7		2.43E+4

As shown by Fig. 1, Type BT and BT-X specimens were planned to fail at the limited area (the length is 100mm) between two parts confined by the much transverse reinforcement. For more detail research of the effect of much transverse reinforcement, Type T and B specimens were tested. Type T was a specimen removed the much transverse reinforcement arranged in the lower area (close to stub area) from Type BT and Type B was a specimen removed that arranged in upper area. The ratio of bending strength[2] and shear strength[3] of the standard specimen (Type N) was 1.25 and all test specimens were expected to fractured by bending mode. In table 1 the characteristics of the concrete and steel used are shown. Fig.2 shows test set up and specimens are loaded vertically under the constant normal stress of
0.5AcFc (Ac : cross section of column, Fc : concrete strength in planning 30MPa) commonly. Loading

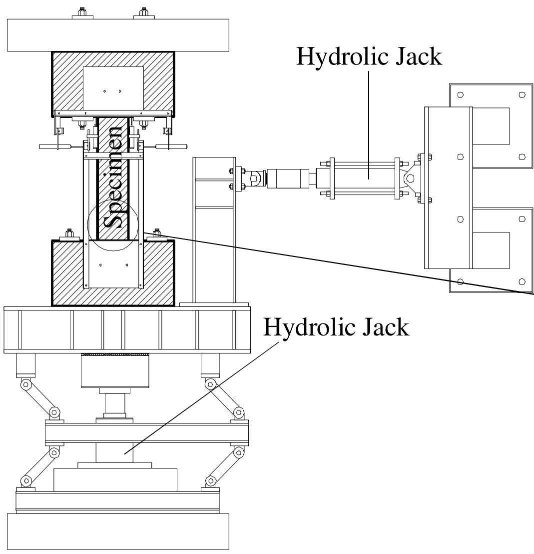

Fig.2 Loading Setup

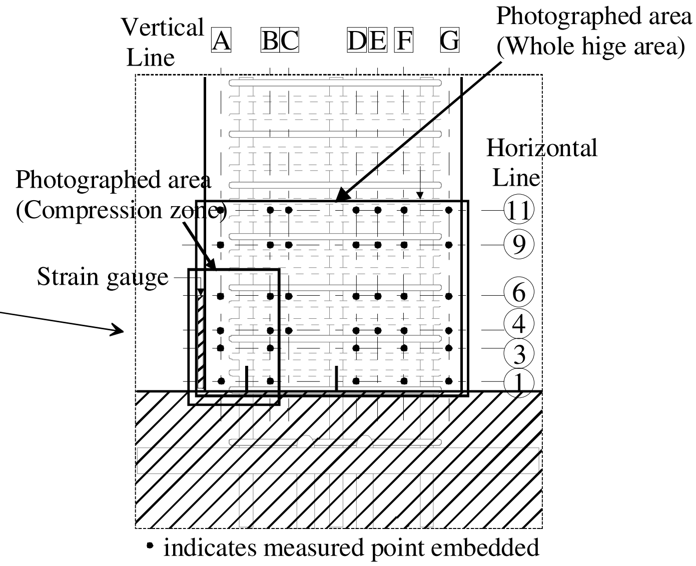

Fig.3 Photographed area and measured points

path was controlled by rotation angle counted by the deformation between the stubs of specimen and in each rotation angle employed (R=1/200, 1/100, 1/50, 1/33, 1/20) three times alternating loading were performed. Electrical resistance gages were used to measure the strain of longitudinal bar and transverse reinforcement and the location is shown as white marks in Fig.1. To investigate the detail behavior of plastic hinge of RC column, high performance digital cameras (4,500×3,000 pixel) were used. The area captured by the digital cameras is shown in Fig.3. Two area were focalized to be measured and one was whole plastic hinge area and other was local area where is immediate vicinity of the boundary between column and stub. Accuracy of observation by the digital camera is about 0.06mm/dot in whole plastic hinge area and about 0.03mm/dot in the local area. The distortion of the lenses used in this experiment was about 5% in the outer edge. The influence of the distortion of this level to the accuracy of the tests was no so serious and correction for test results was not made. Points measured by the digital cameras were made of 150mm steel sticks which were embedded in the specimen and were brushed up to a conical shape. The number of sticks embedded in the specimen was 38 per unit and the location embedded is shown in Fig.3.

RESULTS AND CONSIDERATION

Load-displacement relation and summarize

Load displacement relation for every specimen was shown in Fig.5. At a deformation below rotation angle (R) 1/50 noticeable difference in the characteristics such as maximum strength and deteriorate degree of the strength following cyclic loading were not detected. This results means that the bending behavior of RC columns were not affected by the arrangement of transverse reinforcement in hinge area at the deformation below R=1/50. On the other hand, Significant influence of the transverse reinforcement arranged in the both ends of columns is detected on the deteriorate degree of the strength following cyclic

Fig.4 Camera Setting

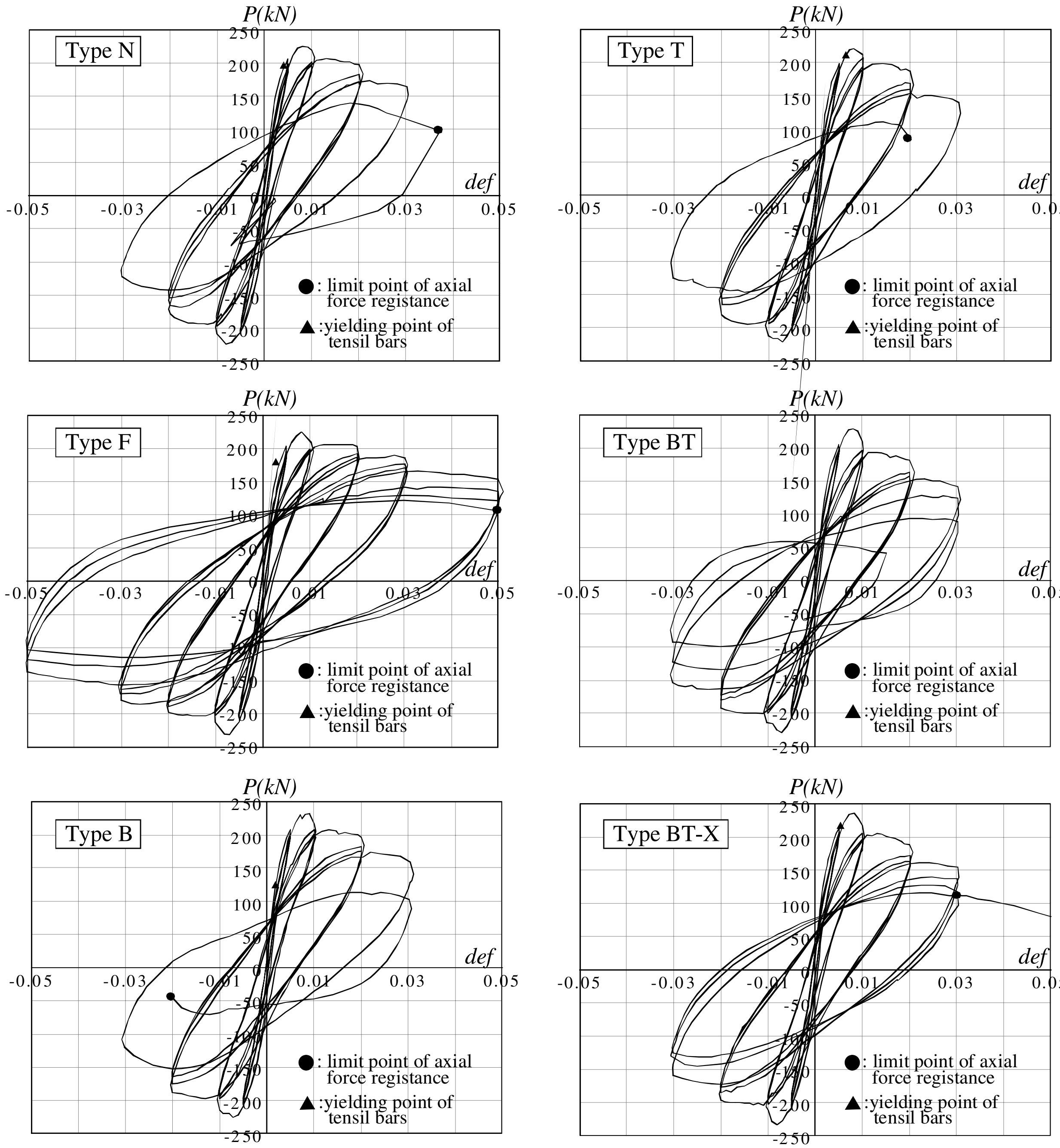

Fig.5 Load-Displacement relation for specimens

loading at the deformation above R=1/50 and on the ultimate deformation determined by the axial force limitation. The outline of the results is described below. (1) In Type N, which had a conventional transverse reinforcement (the spacing is 50mm: pw=0.51%), the strength remarkably declines by repeated loading and the limit rotation angle of the column was smallest of all specimens.

(2) In Type B and Type T which has much confinement at the area near the stub and at the area toward center side of the specimen respectively, in spite of the much transverse reinforcement, the deterioration of

the strength by repeated loading and the limit rotation angle were almost same in case of the conventional transverse reinforcement specimen (Type N).

(3) In Type BT and Type BT-X the much confinement at the both area (near the stub and toward center side of column) make the deterioration of the strength smaller than that of the specimens above mentioned and improve the ductility of the columns.

(4) Type F which has most amount of transverse reinforcement in plastic hinge area of all specimens shows stuble load displacement relation and can resist against the longitudinal force above R=1/20 deformation sufficiently.

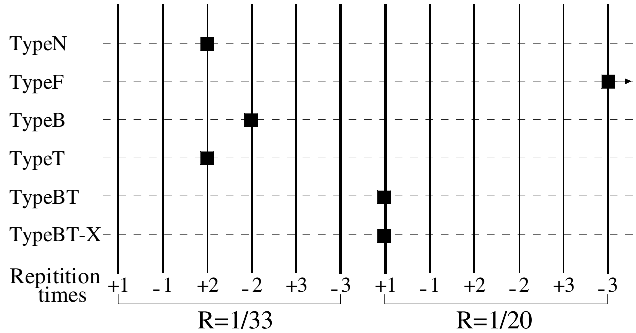

Fig.6 Limit of axial force resistance of specimen and repitition times

Study on the condition under R=1/50 deformation

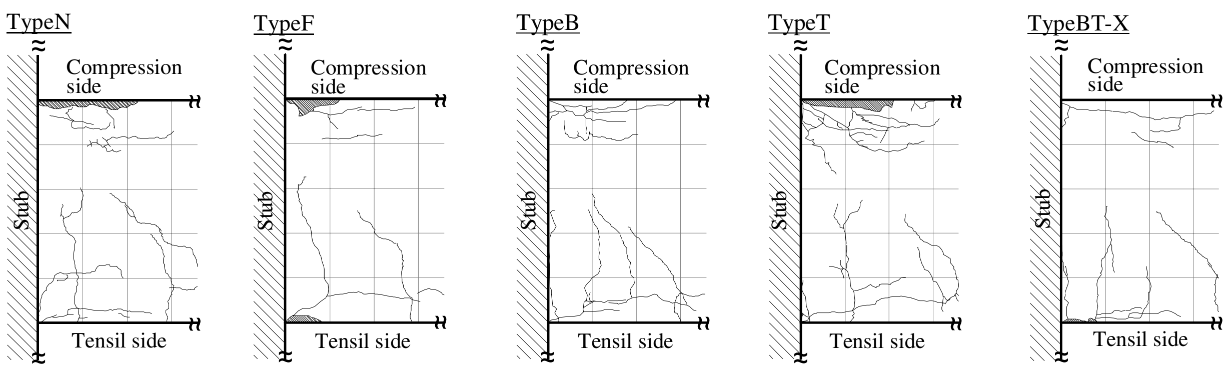

Fig.7 State of crack progress (R=1/50 the first time)

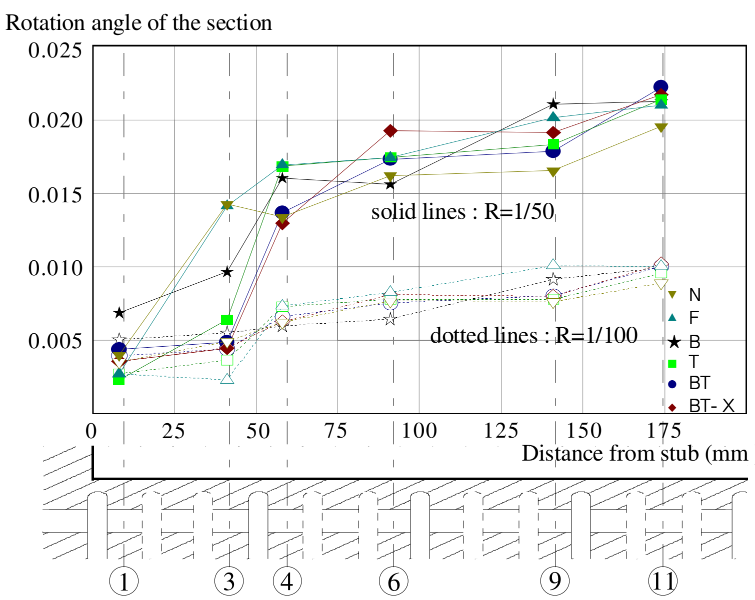

Fig.8 Rotation angle of the seciton - Distance from stub relation

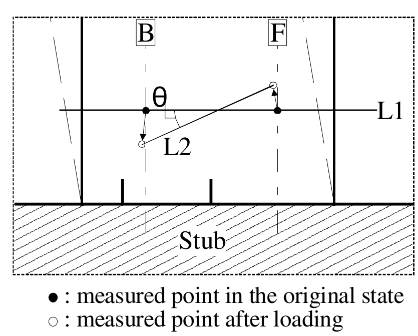

Fig.9 Measurement of the rotation angle of the section

On this section detail study on plastic hinge behavior of specimens and state of the crack development under R=1/50 deformation, i.e. deformation level that no effect of configuration of transverse reinforcement to the load deformation relation reveal are discussed. Fig.7 shows the state of the crack development at the plastic hinge area in R=1/50 (the first time). In this figure all specimens do not differ much in the state of the crack development. Three (four in Type B) main cracks has been occurred in the tensile side of the plastic hinge zone in all specimens and in compressive side cover concrete which locate outside of the longitudinal bar were exfoliated with parallel cracking to the longitudinal bar. Fig.8 shows the rotation angle of the section – the distance from the stub when the rotation angle of the member is 1/100 and 1/50 respectively.

The rotation angle of the section are calculated by the angle of the intersection of the straight lines before and after loading which connect the measured points located B and F line as shown Fig.9 and measurement of the points is done by the pictures taken by the digital camera. No remarkable difference in the relation between the angle of the section and the distance from the stub was recognized in the same manner as the state of crack development. On the other hand, there was noticeable difference in the relation depending on the degree of the deformation. In case of R=1/100 the rotation of the members are mainly caused by the crack occurred in the boundary area between the column and the stub and the ratio of the deformation by this crack to that caused in the hinge area was approximately 40 to 50%. In case of R=1/50 the rate of rotation increased around 50mm's distance from the stub is remarkable and the ratio of the deformation increase to that in the hinge area is approximately 50%. This phenomenon was dependent on the second crack of three main cracks from the stub. The third crack locates around 150mm's distance from the stub and rotation increase on this area is almost as same as those at the front and the rear area. Consequently the deformation of the member mainly depend on the first and second cracks from the stub, namely, the crack occurred in the boundary area between the column and the stub and the next one toward center of the member. So we would be able to make accurate estimation of the member deformation to calculate the width of those crack.

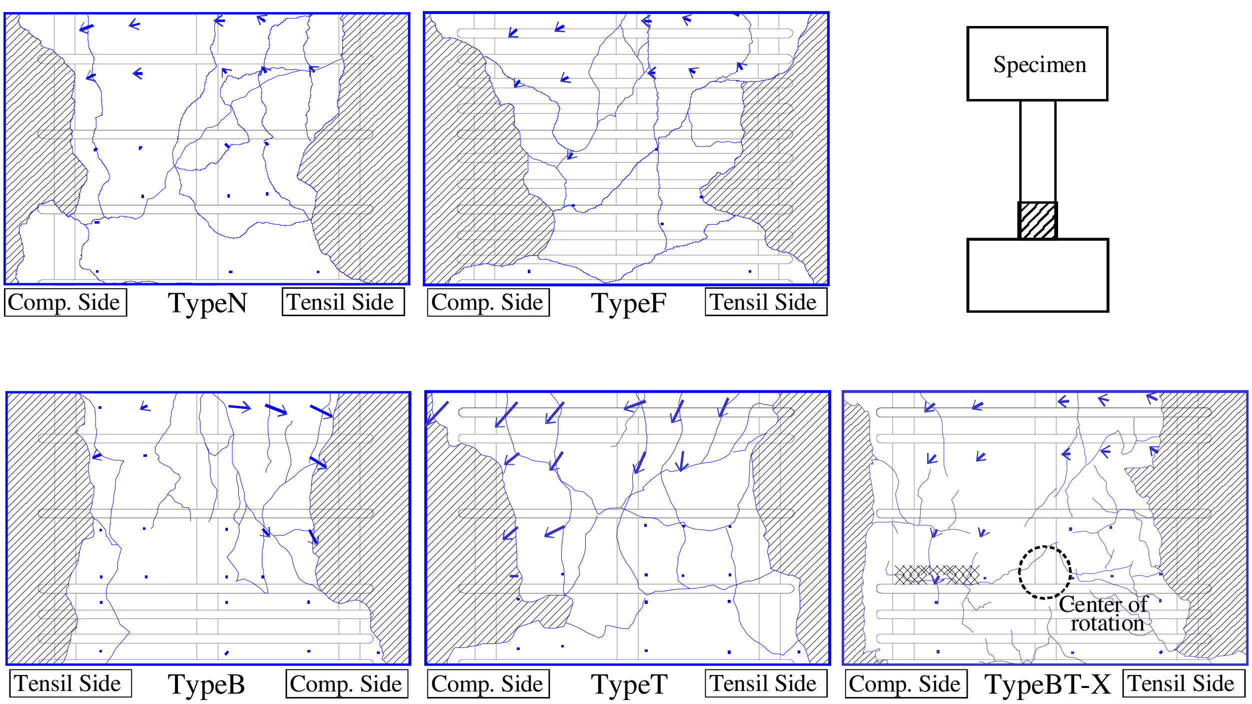

Fig.10 Crack pattern and behavior of measured points
(imediate before the limit of axial force resistance)

Study on the condition under R=1/50 deformation

On this section we study on the effect of configuration of the transverse reinforcement to the ultimate state of the members on the basis of behavior at the limit condition of the axial force resistance.

Fig. 10 shows the movement of the measured points and state of the crack development immediately before the ultimate limit state (limit state to resist to axial force). The behavior of the measured points was indicated by the arrows.

From the Fig.10, it is seen following.

(1) In Type N and Type B without much transverse reinforcement at the area toward center side of the specimen, shear crack occurred from the center of the specimen and it split the specimen. In Type B, right side block forced in compression shifts to right side greatly. In Type N hinge area shifts to left side as a whole and movement of the right side block is larger than that of the left side block. So this specimen are also split by the shear crack occurred from the center.

(2) Type T is a specimen which had much transverse reinforcement at the area toward center side of the specimen but do not had it at the boundary area between the column and the stub. The much transverse reinforcement at the area toward center side of the specimen prevented splitting of the specimen as seen in Type B and Type N. But the whole body shift to toward left lower direction and failed by shear.

(3) Contrary to above three specimens, in Type BT-X which has much transverse reinforcement at the both area, namely, the boundary area between the column and the stub and the area toward center side of the specimen every measured point rotates about the area surrounded by the circle line in Fig. 10.

This behavior clarify that the deformation of the Type BT-X is progressed on bending mode and the serious damage by shear crack is avoidable by using above much transverse reinforcement arranged at the both area. Judging from shifting of the measured points which locate before and behind the stage of loading shown in Fig 10, around the marked area in Fig.10 the strain in axial direction were estimated to be very large and it caused the compressed limit of the specimen.

(4) In Type F with much transverse reinforcement at 300mm's area from the face of the stub consecutively the behavior of the measured points was the same manner as Type BT-X as mentioned above.

However as stated in the chapter 3.1, Type BT-X do not reach the limit of axial force resistance and the shift of measured points is smallest of all specimen.

CONCLUSIONS

The results of the experimental study on the columns with much transverse reinforcement in their both ends indicate the following.

(1)The much transverse reinforcement arranged at the ends of column do not make remarkable difference on the bending characteristics of the columns below member rotation angle (R)=1/50.

In the ultimate stage of loading test only when much transverse reinforcement are arranged at the both area, namely, the boundary area between the column and the stub and the area tower center side, it is effective to preserve splitting of the member by occurring shear crack and improve the ductility of the members.

(2) The most part of the deformation of the column is induced by the two main cracks occured at the boundary area between the column and the stub and at the area toward center side of the specimen.

REFERENCES

1. Iguchi Takao, Kishimoto Ichizo, Ohno Yoshiteru, 'Bending behavior of the reinforced concrete columns confined by much transverse reinforcement.' Proceedings of the Japan Concrete Institute, Vol.10 No.2, 2003
2. Japan Architectural Institute, 'Design Guidelines for Earthquake Resistant Reinforced Concrete Buildings Based on Inelastic Displacement Concept, 1997

3. Japan Architectural Institute, ‘AIJ Standard for Structural Calculation of Reinforced Concrete Structures -Based on Allowable Stress Concrept-, 1999