THE HYSTERETIC BEHAVIOR OF SHEAR WALLS IN THE BUILDING OF TOHOKU UNIVERSITY DURING THE MIYAGI-KEN-OKI EARTHQUAKE

Junichi Takahashi (I)
Akenori Shibata (II)
Toshio Shiga (III)
Presenting Author : Junichi Takahashi

SUMMARY

A 9-story steel reinforced concrete building of Tohoku University was subjected to a strong ground motion during the Miyagi-ken-oki earthquake of 1978 and suffered minor damage. To investigate the inelastic behavior and the structural damage of shear walls of this building, a model test of shear walls was conducted, and the relation between the crack width and the experienced maximum story drift index was examined. From the comparison of the crack patterns and the crack widths for the specimens with those for the actual shear wall of the 3rd story, the experienced maximum story drift index of this part is estimated to be about 3/1000 during the earthquake.

INTODUCTION

A 9-story steel reinforced concrete building which houses the architectural and civil engineering departments of Tohoku University was subjected to a strong ground motion during the Miyagi-ken-oki earthquake on June 12, 1978. Although the maximum acceleration of about 1G was recorded at the 9th floor of this building, the structural damage of the building was found fairly minor and repairable. This is considered due to the fact that the main shear walls which are located in the east and west sides as well as around the two cores of the building were quite effective against earthquake forces.

To investigate the inelastic behavior and the structural damage of the shear wall, the scale models of the east side shear wall whose damage was most severe were tested, and the relations between the residual and maximum crack widths and the experienced maximum story drift index were examined.

DAMAGE OF THE BUILDING CAUSED BY THE EARTHQUAKE

The plan and section of the building are shown in Fig. 1. The shear wall are located around two cores and in the east and west sides.

Small shear and flexural cracks were observed in the main shear walls, adjacent beams and a few columns of the third and fourth floor after the Miyagi-ken-oki earthquake. The crack pattern of the shear wall is shown in Fig. 2. The maximum width of shear cracks in the shear walls and that of flexural cracks in the columns and beams were 1.0 to 1.5 mm (Ref. 1).

(I) Research Assistant, Faculty of Engineering, Tohoku University, Japan
(II) Assosiate Professor, Faculty of Engineering, Tohoku University, Japan
(III) Professor, Faculty of Engineering, Tohoku University, Japan

TEST SPECIMEN AND TESTING PROCEDURE

The test specimen is four-storied model representing the 3rd to 6th story of the east side shear wall where the damage was observed. Two specimens were tested. The shear span ratio of the specimens was determined considering the moment distribution obtained from the earthquake response analysis (Ref. 1), as shown in Fig. 3. The dimension of the specimen and the detail of its reinforcement are shown in Fig. 4. The dimension of the specimen is one-tenth of that of the actual shear wall. The wall thickness is 3 cm. The dimension of the column is 15 x 7 cm. The maximum size of the aggregate used is 5 mm. The both sides of the specimen was unfinished. The mechanical characteristics of the materials used are shown in Table 1.

The three column in the wall were subjected to equal axial forces (Fc/6 x column area) simulating the gravity load. Cyclic lateral force was applied on the top of the specimen. The shear span ratio in the test is 1.01. The loading program for each specimen is shown in Fig. 5. The loading was controlled by monitoring the first story drift. The peak value of the drift was increased at each loading stage according to the loading program shown in Fig. 5. In one test, the drift was repeated for one cycle and in the other test for three cycles at each drift stage.

The applied load were measured by load cells. The schematic elevation of the instrumentation for the measurement is shown in Fig. 6. This instrumentation was arranged to obtain data on lateral displacements, rotations, shear deformations, using electrical dial gages and differential transformers.

The crack widths at paticular parts of the specimens were measured in each loading cycle at the time when the first story drift index was at the maximum and when the lateral load was removed. The former is named the maximum crack width, and the latter the residual crack width. Crack scales were used for the measurements of the crack widths. Grids on the specimen for the measurements of crack widths are shown in Fig. 7. The cracks were measured at hatched parts of the grids.

FAILURE MODE, STRENGTH AND LOAD-DISPLACEMENT OF SPECIMEN

The both specimens showed ductile behavior up to 10/1000 of the first story drift. Considerable strength decay began after 10/1000, then concrete at bottom of the column and at coner of the wall panel of the first story spalled off, and main reinforcements of the column and wall reinforcements buckled and then the compression part of column crushed.

Comparison of the computed and measured strengths of the specimens are shown in Table 2. The computed strengths were calculated by the equations for strength analysis given in Refs. 2 to 4. The measured cracking load are 50 to 90 percent and the measured flexural strengths are 120 to 170 percent of the computed values, respectively. The difference in the cracking load will be due to small cracks from the shrinkage of concrete before the tests.

The load-displacement diagrams of the specimens at the first story are shown in Fig. 9. The total displacement is lateral displacement at the mid column, and the flexural deformation is obtained from the integration of rotation angles which were calculated from vertical displacements measured at the columns at both sides. The shear deformation is obtained from the difference between the total displacement and the flexural deformation. The calculated shear deformation coinsides well with the shear deformation directly measured by the differential transformers.

The followings are observed from Fig. 9. 1) The shear force-flexural deformation diagram shows a spindle shape, whereas the shear force-shear deformation diagram shows a pinched shape and the shear force-total displacement diagram shows a slightly pinched shape. 2) The restoring force of the specimen continues to increase after the tensile yielding of mid column, and reaches ultimate flexural yielding state with the tensile yielding of mid column. 3) Strength decay due to cyclic loading is not significant up to the first story drift of 10/1000.

CRACK WIDTH OF SPECIMEN

Maximum and Residual Crack Widths

The relation between the maximum crack widths and the residual crack widths for flexural and shear cracks which were measured at the first story of the Specimen ST-2 are shown in Fig. 10. In this figure, the crack widths for each loading except for the loading at 16/1000 are plotted. The plotting points are 310 for shear cracks and 260 for flexural cracks, respectively. Straight line in the figure shows the overall relation between the maximum crack widths and the residual crack widths.

As is seen from the figure, the ratio of the residual crack widths to the maximum one is about 0.3 both for the flexural and shear cracks. But in the shear cracks, the ratio tends to increase with the increase in the maximum crack widths.

Experienced Maximum Story Drift and Maximum Crack Widths

The relation between the experienced maximum story drift at the first story and the average maximum crack widths in each horizontal grid level (grids A to N) are shown in Fig. 11.

The average maximum crack widths for flexural cracks are nealy proportional to the experienced maximum story drift in grid levels A, B and C where the moment are high. The maximum crack widths for flexure in grid levels F and J subjected low moment are almost proportional to the maximum story drift in the small drift range, but are nealy constant for the drift larger than 6/1000.

The relation between the maximum story drift and the maximum widths for the shear cracks tend to show the same characteristics as the flexural cracks.

Experienced Maximum Story Drift and Residual Crack Widths

The relation between the maximum story drift at the first story and the average residual crack widths is shown in Fig. 12.

The average residual crack widths for the flexural cracks in grids A, B and C are proportional to the experienced maximum story drift. The residual crack widths in grids F and J are nealy constant for the first story drift larger than the flexural yielding, 6/1000.

The average residual crack widths for shear cracks also show almost the same characteristics as the flexural cracks.

<u>Effect of Cyclic Loading on Crack Widths</u>

The relation between the crack widths at the third loading and those at the first loading at 6/1000 for the Specimen ST-2 is shown in Fig. 13.

The increase of crack widths by the cyclic loading at the same amplitude is seen. Both the maximum and residual crack widths at the third loading are from 1.2 to 1.3 times those at the first loading.

COMPARISON OF CRACK PATTERNS FOR THE ACTUAL SHEAR WALL AND SPECIMEN

The comparison of the crack patterns for the test specimen and that of the corresponding part of the actual shear wall is shown in Fig. 14.

From the comparison of the crack patterns for the third story of the actual shear wall and the first story of the specimens, the experienced maximum story drift of this part is estimated to be about 3/1000 during the earthquake. This value also coinsides well with the value obtained from the inelastic analysis of this building (Ref. 1).

CONCLUSION

The relation between the maximum crack widths and the residual crack widths and the relation between the experienced maximum story drift and the residual crack widths obtained from the test were found to be useful for the detailed evaluation of the damage levels of the 9-story steel reinforced concrete building.

ACKNOWLEDGEMENTS

The authors are indepted to Mr. Junichi Shibuya for his helpful discussion and valuable suggestions. Graduate student Hirohiko Sugita assisted the testing.

REFERENCES

1) Shiga, T., Shibata, A., Shibuya, J. and Takahashi, J., "Performance of the Building of Faculty of Engineering, Tohoku University, during the 1978 Miyagi-ken-oki Earthquake", 7th WCEE, Vol.7, Istanbule, 1981, pp. 357-364
2) Hirosawa, M., "Past Experimental Results on Reinforced Concrete Shear Walls and Analysis on Them", Building Research Institute, Ministry of Construction, Japanese Goverment, March 1975 (In Japanese)
3) Sugano, S., "Study on Restoring Force Characteristics of Reinforced Concrete Members", Concrete Journal, Vol.11, No.2, 1973, pp. 1-6 (In Japanese)
4) The Japan Building Disaster Prevention Association, "Standard for Seismic Capacity Evaluation of Existing Reinforced Concrete Building", 1977 (In Japanese)

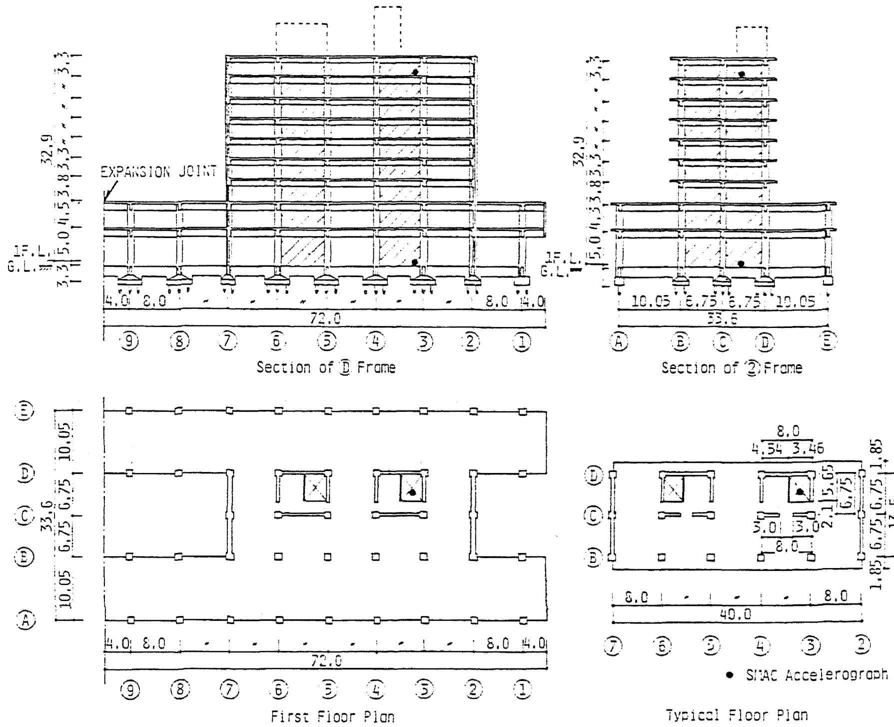

Fig.1 Plan and Section of the Building (Unit : M)

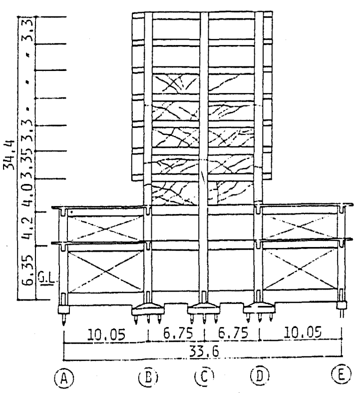

Fig.2 Crack Pattern Caused by the Miyagi-ken-oki Earthquake

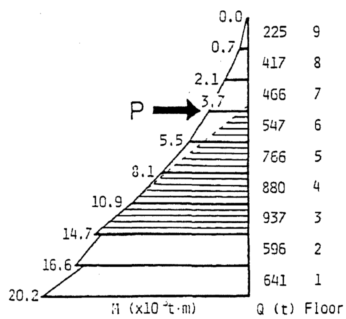

Fig.3 Moment Diagram of the East Side Shear Wall Obtained from Response Analysis

Table 1 Mechanical Characteristics of Materials

Concrete	Fc (kg/cm^2)	Fsp (kg/cm^2)
28 Days	285	27
ST-1*	291	27
ST-2*	293	24

* : at time of testing
Fc : Compressive Strength
Fsp : Splitting Strength

Steel	f_y (kg/cm^2)	f_m (kg/cm^2)
D6	3563	5672
3.2 φ	2183	3235
2.2 φ	3000	4433

f_y : Yielding Stress
f_m : Maximum Stress

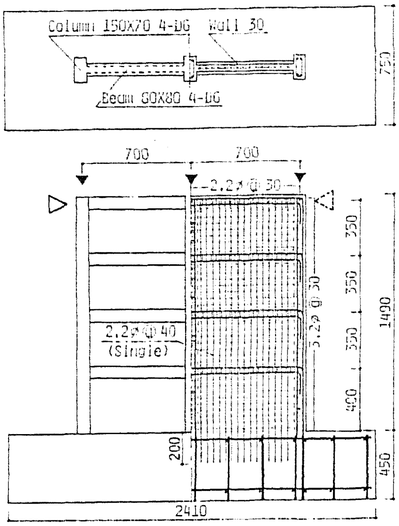

Fig.4 Test Specimen

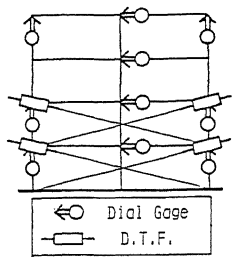

Fig.6 Instrumentation

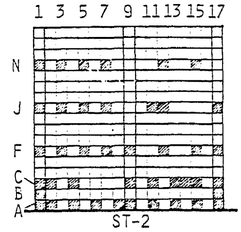

Fig.7 Grid for Measurement of Crack Width (Hatched Grid)

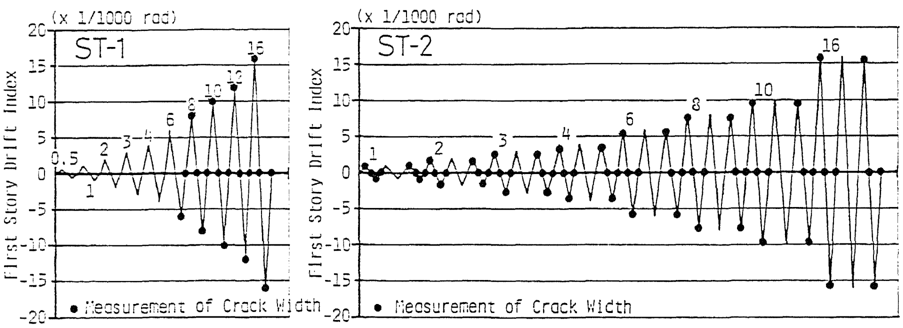

Fig.5 Loading Program

Table 2 Comparison of Specimen Strengths

Specimen		Flexural Crack cQf (t)	Shear Crack cQs1 (t)	Shear Crack cQs2 (t)	Shear Crack cQs3 (t)	Flexural Strength uQf1 (t)	Flexural Strength uQf2 (t)	Shear Strength uQs (t)
Computed		8.11	13.83	14.23	8.44	15.23	11.19	21.28
Experimented	ST-1	4.52	7.33			17.79		——
	ST-2	5.00	6.58			18.62		——
Exp./Comp.	ST-1	0.56	0.53	0.52	0.87	1.18	1.61	——
	ST-2	0.62	0.48	0.46	0.78	1.22	1.66	——

cQf =(1.8√Fc+N/Ae)Ze/h (Ref.2)
cQs1=t·Ie√(cσt+σo cσt)/Smax (Ref.2)
cQs2=0.1t·l·Fc
cQs3=Aw(0.043Pg(%)+0.051)Fc (Ref.3)
uQf1=(at·σcy·l+0.5Σ(aw·σy)l+0.5N l)/h (Ref.4)
uQf2=(0.9at·σcy·L+0.4aw·σy·L+0.5N·L(1-N/b·D·Fc))/h (Ref.2)
uQs =(0.0679Pte^0.23(Fc+180)/√(M/QL+0.12)+2.7√(Pwh·σy+0.1σo))be·j (Ref.2)

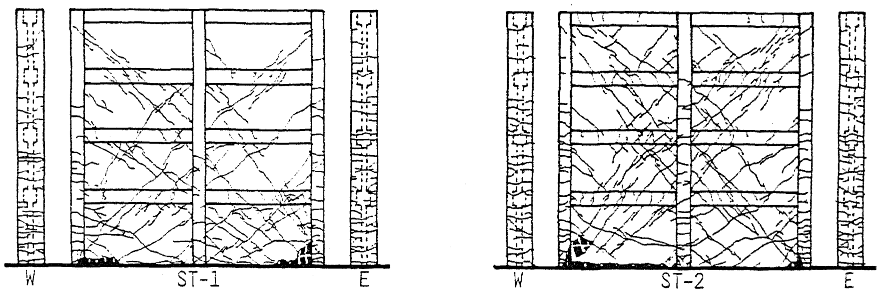

Fig.8 Final Crack Patterns of Specimens at 16/1000

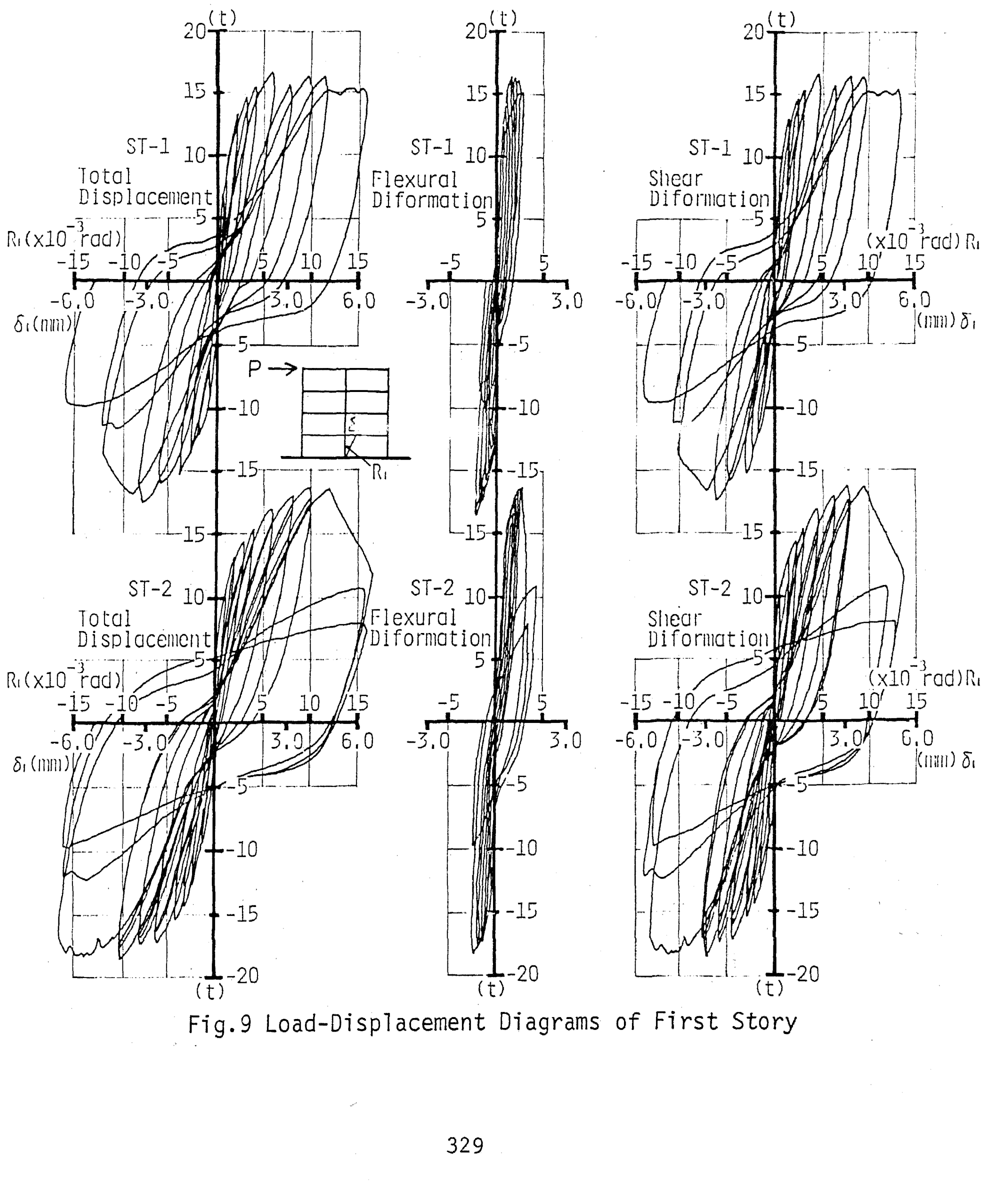

Fig.9 Load-Displacement Diagrams of First Story

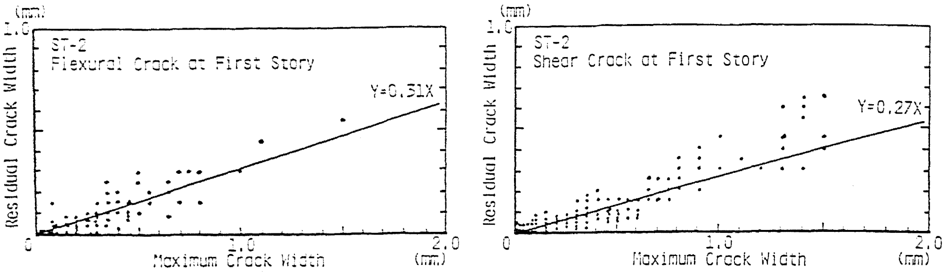

Fig.10 Residual Crack Width vs. Maximum Crack Width at First Story

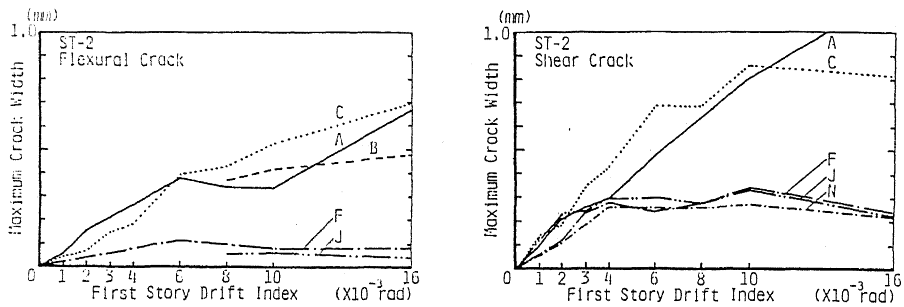

Fig.11 Average Maximum Crack Width vs. First Story Drift Index

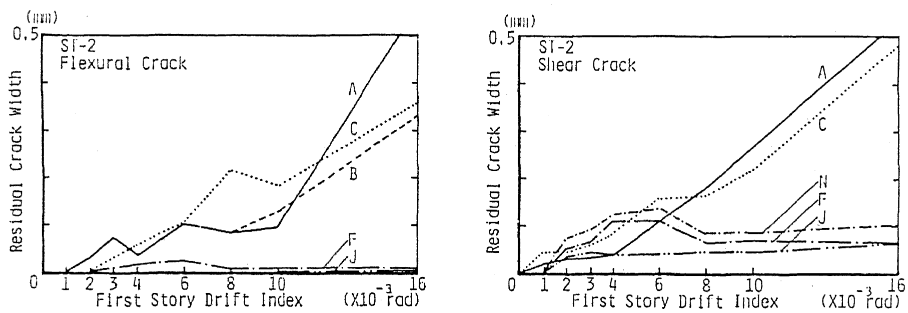

Fig.12 Average Residual Crack Width vs. First Story Drift Index

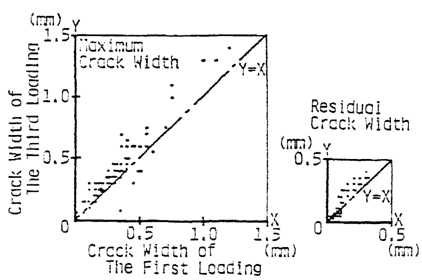

Fig.13 Effect of Cyclic Loading on Crack Width at 6/1000 (ST-2)

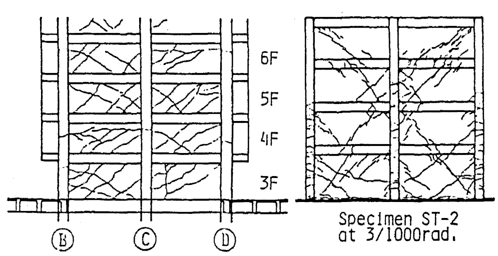

Fig.14 Comparison of Crack Patterns for the Actual Shear Wall and Specimen