Behavior of Shear Wall Using Various Yield Strength of Rebar
Part 2: Parameter Study Using Nonlinear F.E.M.

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1. INTRODUCTION

In Part 1, the effect of yield strength of rebars to the shear characteristic of shear wall was investigated. In this paper the effect of yield strength of rebars is examined by elasto-plastic F.E.M. analysis for other parameters which were not used in the experiments. The applicability of the experimental results was considered by these analyses. The other parameters studied here are the shape (cylindrical wall), the product of reinforcement ratio and the yield strength of rebar ($p_s{}' \cdot \sigma_y$=1.8 MPa), and the shear span to length ratio(M/QD=0.4).

2. OUTLINE OF ANALYSIS

As this research was mainly carried out for considering reinforcement of web, the analysis was targeted on two-dimensional F.E.M. analysis by using detailed model of web and briefly taking into account the effect of flange (1). However, in the analysis of cylindrical wall, three-dimensional analysis (layered model) was carried out with consideration for out-of-plane bending moment. The concrete used in the finite element model was considered as a 4-point-contact isoparametric element and assumed to have the stress-strain relationship shown in Fig.-1. The rebars were considered as a plane element with a uniform cross-section which had only an axial rigidity in each element and had the stress-strain relationship shown in Fig.-2.

Analyses were carried out with monotonic loading.

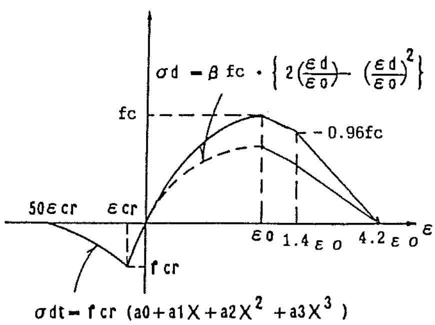

Fig.-1 Stress- Strain Curve of Concrete

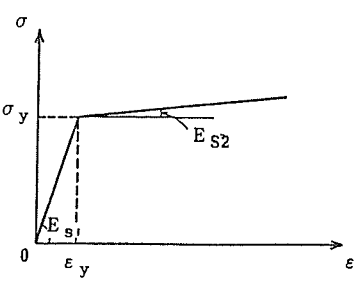

Fig.-2 Uniaxial Stress-Strain Curve of Steel

3.PARAMETER

In the experiment, the yield strengths of rebar were set at 300 MPa,400 MPa, and 500 MPa. In this analysis, two types of yield strength, 300 MPa and 500 MPa, were used and comparison was carried out on the element which had the same product of reinforcement ratio and the yield strength of rebar. A chart of parameters is shown in Table-1. The standard specimens were 36M8 series in experiments. Simulation analyses were carried out on the standard specimens (36M8 series) to examine the applicability of the analysis. In accordance with the experiments, specimens with the smaller product of reinforcement ratio and the yield strength of rebar were referred to as 18M8-30 and 18M8-50, of which number 18 indicates this product and -30 or -50 means yield strength. A numerical number 4 in symbols of specimens distinguishes the smaller shear span to length ratio (M/QD=0.4) as 36M4-30 and 36M4-50, and the cylindrical wall series are distinguished as SW-30 and SW-50 as well.

4.ANALYTICAL MODEL

Analytical model is shown in Fig.-3 ~Fig.-5. Fig.-3 shows the finite element idealization of 36M8 series (Simulation analysis) and 18M8 series. Fig.-4 shows the finite element idealization of 36M4 series. In both Fig.-3 and Fig.-4 it is idealized that 45cm width concrete in flanges is effective and that all vertical rebars are effective. And the axial stress is assumed as σ_0=2.0 MPa like in the experiment. Fig.-5 shows the finite element idealization of cylindrical wall, SW-30,SW-50. Table-2 shows the material properties used in the analysis.

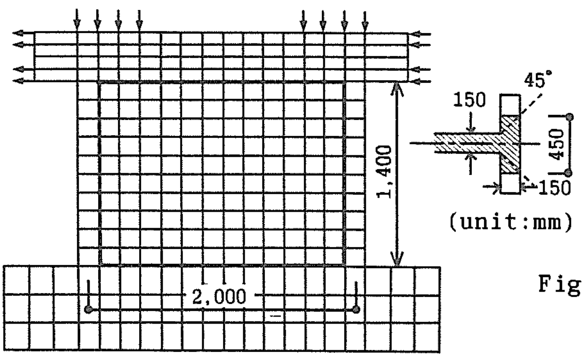

Fig.-3 Finite Element Idealization (M/Q・D=0. 8)

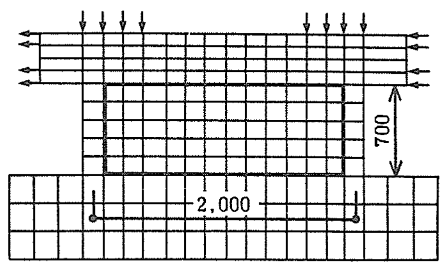

Fig.-4 Finite Element Idealization (M/Q・D=0. 4)

(unit:mm)

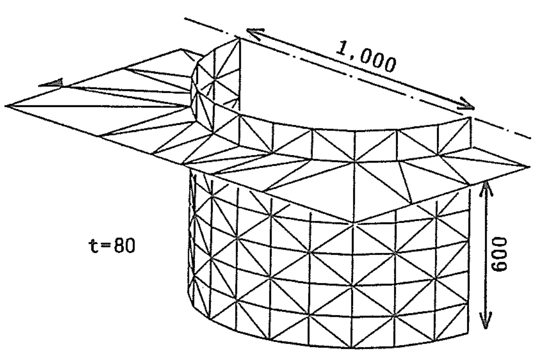

Fig.-5 Finite Element Idealization (Cylindrical Wall)

Table-1 Analytical Specimen Parameters

Analysis	Steel Grade		
	SD30 (300MPa)	SD40 (400MPa)	SD50 (500MPa)
36M8 Series (Simulation Analysis)	○	○	○
Cylindrical Wall * S W ($p_s \cdot {}_s\sigma_y$=3. 6)	○	——	○
1 8 M 8 ($p_s \cdot {}_s\sigma_y$=1. 8, M/Q・D=0. 8)	○	——	○
3 6 M 4 ($p_s \cdot {}_s\sigma_y$=3. 6, M/Q・D=0. 4)	○	——	○

* non Axial Load

p_s :Vertical and Horizontal Steel Content per Unit Wall Area

${}_s\sigma_y$:Yield Strength of Shear Reinforcement

M/Q・D:Shear Span to length Ratio

18M8-30
- Grade of rebar, SD30(specified fy=300 Mpa)
- M/QD=0.8(0.4)
- Fc=32.4 Mpa
- $p_s \cdot {}_s\sigma_y$=1.8(3.6) Mpa

Table-2 Material Properties

Specimen	Concrete			Reinforcement	
	Compressive strength fc(MPa)	Tensil *2 strength ft(MPa)	Young's Modulus Ec ($\times 10^4$ MPa)	Yield Strength ${}_s\sigma_y$ (MPa)	Young's Modulus Es ($\times 10^5$ MPa)
36M8-30 *1	39.3	2.07	2.41	296	1.97
36M8-40 *1	38.8	2.06	2.41	422	1.90
36M8-50 *1	37.5	2.02	2.33	528	1.96
SW-30 18M8-30 36M4-30	32.4	1.88	2.10	300	2.10
SW-50 18M8-50 36M4-50	32.4	1.88	2.10	500	2.10

*1) Test Result

*2) $ft=0.33\sqrt{fc}$

5.RESULT OF ANALYSIS

1)Simulation Analysis (36M8 series)

Fig.-6 shows the relationship between the shear force and the deformation obtained through the results of experiments and analysis of 36M8 series. The analysis shows slightly high rigidity, but it turned out to be as successful simulation on initial shear crack, the maximum strength and other related.

Fig.-7 shows the comparison of final crack patterns obtained from the experiment for 36M8-50 and the one from the analysis. It shows that cracks were generated and crushing of concrete started at similar position. Fig.-8 shows the comparison of the strain distribution in longuitudinal and transverse rebars at the rotation R=4/1000 obtained from the experiment and analysis of 36M8-50. It shows that similar strain was generated at each point. The above results shows that the analysis simulates the experiments very well. Thus the applicability of the F.E.M. model was confirmed. Fig.-9 shows the principal stress distribution at the rotation R=4/1000 as a result of analysis on 36M8-50.

2)Analysis of Cylindrical Wall(SW-30,SW-50)

The analysis is examined on the cylindrical wall which is one of the major earthquake resistance elememts of the nuclear power plant building and not yet tested. Fig.-10 shows the relationship between the shear force and the deformation. SW-30 shows the order of rebar yielding in the longitudinal rebars at the low portion, the longitudinal rebars at the central portion and the transverse rebars of the central portion in sequence, and finally, the concrete as crushed by shear force of 0.73 MN. SW-50 went through the same process of SW-30. SW-50 failed at the crush of the concrete with shear force of 0.71 MN. The deformation of these two showed approximately the same at the maximum load. However, SW-50 with less amount of rebars, deformed more than SW-30 with larger amount of rebar before the maximum load.

3)Analysis of $p_s \cdot {}_s\sigma_y$=1.8MPa (18M8-30,18M8-50)

The analysis was conducted for the case of $p_s \cdot {}_s\sigma_y$=1.8MPa which is more smaller than 2.4 MPa as the product of reinforcement ratio and the yield strength of rebar($p_s \cdot {}_s\sigma_y$) as examined by the experiment. Fig.-11 shows the relationship between the shear force and the deformation. Both 18M8-30 and 18M8-50 showed similar relationship between the shear force and the deformation and the maximum strength became similar showing 1.44 MN and 1.40 MN. Fig.-12 shows the distribution of $\varepsilon/\varepsilon_y$ (the strain divided by the yield strain) of the both longitudinal and transverse rebars to indicate normalized steel strain at Q=1.37 MN in comparison of 18M8-30 and 18M8-50. The longitudinal rebars at the foot portion yielded in 18M-30 and 18M8-50 and they were plasticized considerably. It was found that both resisted similar exterior force. The value of $\varepsilon/\varepsilon_y$ was almost the same on other positions, so it was found that rebars showed similar resistance against similar shear force. The result shows that if the product of reinforcement ratio in wall and the yield strength of rebar stay the same, the same characteristics can be obtained even when the product is lowered.

4)Analysis of M/QD=0.4(36M4-30,36M4-50)

In the nuclear power plants, there are many shear walls about M/QD=0.4, which is smaller than M/QD=0.8 or 0.6 obtained in the experiment. Therefore, the analysis was done on the lower shear wall of M/QD=0.4. Fig.-13 shows the relationship between the shear force and the deformation. 36M4-30 showed a slightly higher rigidity than 36M4-50 from near Q=1.5 MN. This depended on the amount of the reinforcement ratio and is on the same trend with the experimental results. The failure mechanism was the same in both 36M4-30 and 36M4-50. Finally, the concrete was crushed in lower position at the web. The maximum strengths were 2.77 MN for 36M4-30 and 2.66 MN for 36M8-50. It was found that both are almost similar. Fig.-14 shows the distribution of $\varepsilon/\varepsilon_y$ of the both longitudinal and transverse rebars at Q=2.5MN in comparison with 36M4-30 and 36M4-50. The value of $\varepsilon/\varepsilon_y$ is almost the same at any position and it is found that the rebars showed a similar resistance against the same shear force. At Q=2.55 MN near the maximum strength, the strain of rebars was small because of the small shear span to length ratio. A portion of the strain of rebars reached the yield strain. Therefore, it may be said that if the product of reinforcement ratio in the wall and the yield strength of rebar stay the same, the same characteristics can be obtained, keeping the product of the two the same and the yield strength of rebars kept under 500 MPa, even when the shear span to length ratio is small (M/QD=0.4).

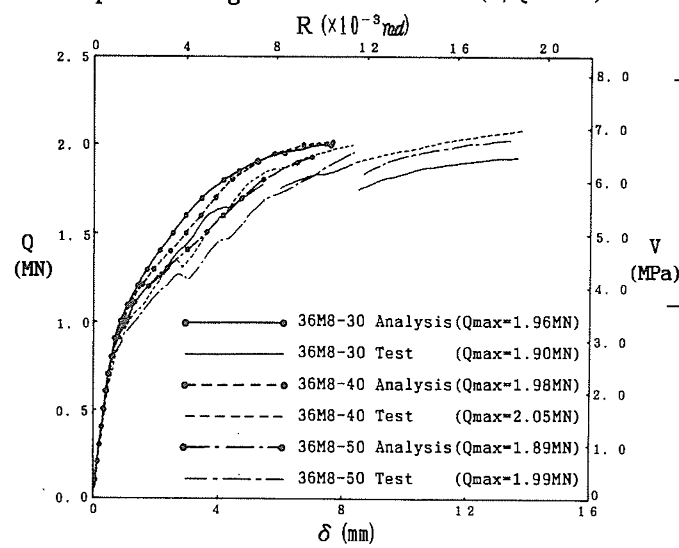

Fig.-6 Shear Force-Deflection Relationship (38M8 Simulation Analysis)

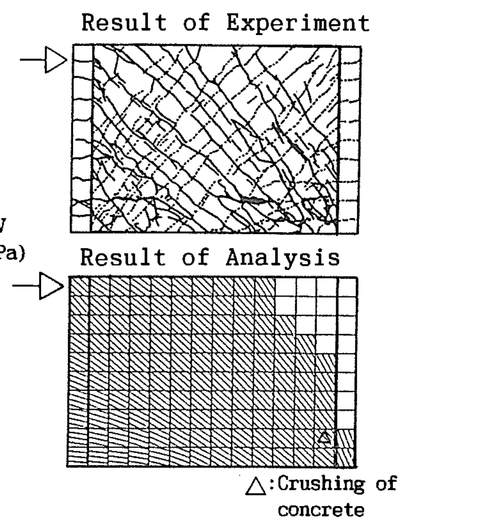

Fig.-7 Crack Patterns(36M8-50)

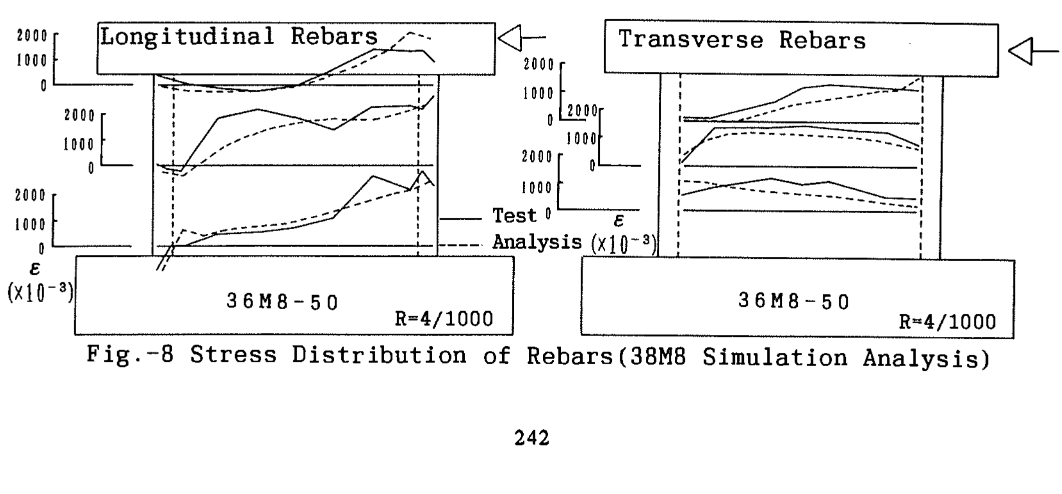

Fig.-8 Stress Distribution of Rebars(38M8 Simulation Analysis)

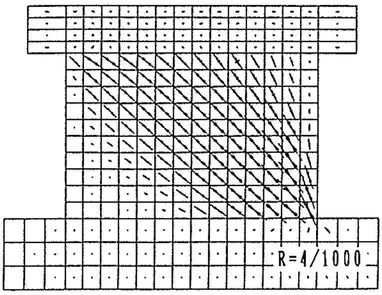

Fig.-9 Principal Stress of Specimen (Analysis)

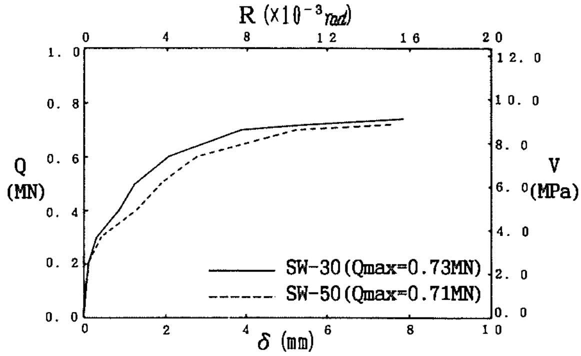

Fig.-10 Shear Force-Deflection Relationship (Cylindrical Wall Analysis)

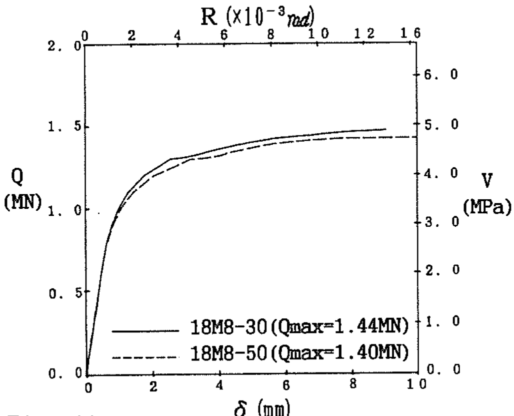

Fig.-11 Shear Force-Deflection Relationship (18M8-series Analysis)

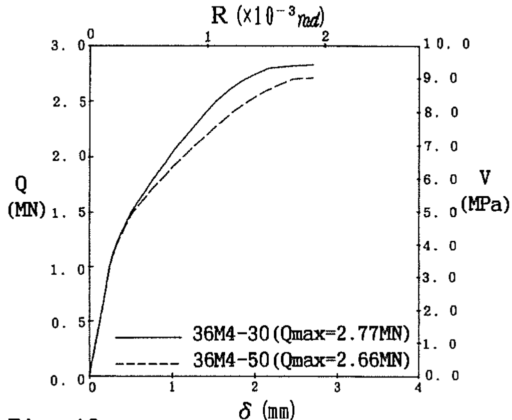

Fig.-13 Shear Force-Deflection Relationship (36M4-series Analysis)

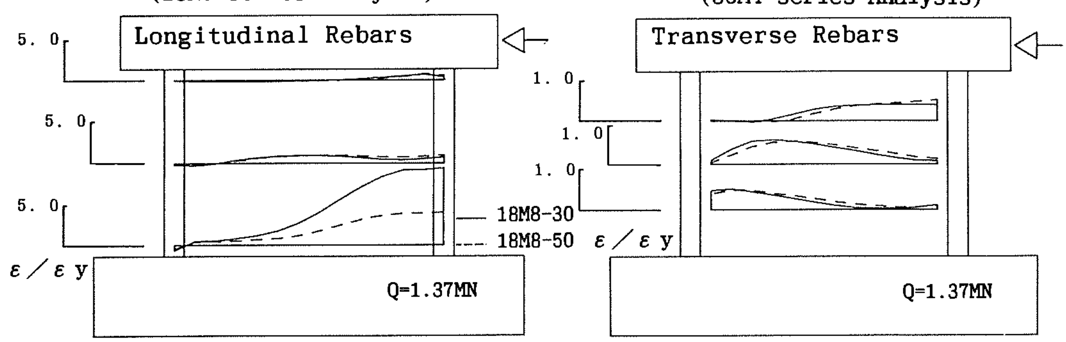

Fig.-12 Stress Distribution of Rebars(18M8-series Analysis)

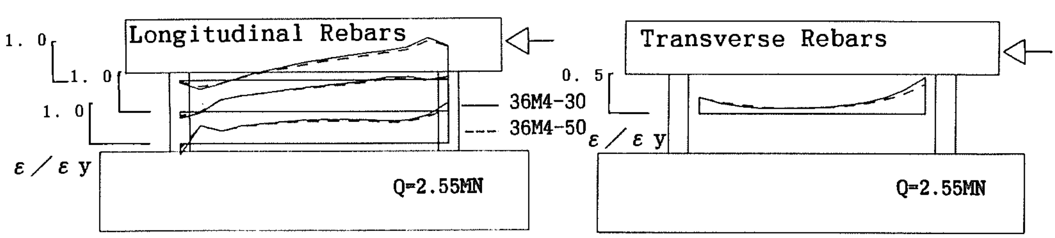

Fig.-14 Stress Distribution of Rebars(36M4-series Analysis)

6.CONCLUSION

1)These F.E.M. model analyses adequately simulated the result of experiment and applicability of the analysis was well determined.

2)In comparison with the result of the experiment (38M8 series) the analysis showed that the maximum strength declined when the product of reinforcement ratio and the yield strength of rebar was decreased, and that the maximum strength indicated a trend to increase when the shear span to length ratio was decreased.

3)It was determined that when the yield strength of rebar is kept below 500 MPa and the product of reinforcement ratio in the wall and the yield strength of rebar stay the same, the combination of the two may bring the same shear response even when the shear wall had different shapes, I-shaped or cylindrical.

4)Two cases, that were not examined in the experiment were analyzed by using F.E.M.. Either of these cases was the small product of reinforcement ratio and the yield strength of rebars($p_s \cdot {}_s\sigma_y$ =18 MPa). Another was the small shear span to length ratio (M/QD=0.4). These results showed that if the product of reinforcement ratio in the wall and the yield strength of rebar stay the same, the same shear characteristics can be obtained keeping the product of two the same and the yield strength of rebars kept under 500 MPa.

From the foregoing consideration, it was confirmed from the elasto-plastic F.E.M. analysis that a various combination of the reinforcement ratio and the yield strength of rebar can be used in designing, disregarding the slight difference in effect over shear characteristics of shear wall by the shape or the amount of reinforcement, keeping the product of the two the same and the yield strength of rebars kept under 500 MPa.

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REFERENCE

(1)Inoue,N. Koshika,N. and Suzuki,N."Analysis of Shear Wall Based on Collins Panel Test" Finite Element Analysis of Reinforced Concrete Structures, Proceedings of Seminar Sponsored by Japan Society for Promotion of Science/U.S. National Science Foundation, Tokyo, Japan, May 1985, Published by ASCE, pp288-299