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A study on plate anchor detailing systems of shear re-bar

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ABSTRACT: For shell walls and base slabs in reactor buildings of nuclear power plants, besides a large amount of main bars, numerous shear re-bars have been employed to resist to out-of-plane force. As a result of that design, detailing work involving shear re-bar is extremely involved. For example, the employed rebar anchor method differs from the ordinary methods, in which an end of shear rebar with 135-degrees hook or with anchor plate type and another re-bar end with 90-degrees hook are used. However the structural characteristics in members using shear re-bar of the bolt-mounted anchor plate have not yet been examined.

A test was performed to confirm the effects of anchor methods for shear re-bars on shearing behavior of members. This paper describes the test plan, methods and results. A cross section of the reactor building is shown in Figure 1.

1 TEST PLAN

1.1 PREPARATIONS FOR SPECIMEN AND TEST

Research was carried out on the anchor work method using nut and plate anchor at the end of the screw deformed bar for design of the specimen prior to the test. Then the design for the test specimen was executed. As a principal parameter, various shapes of anchor are shown in Figure 2. In order to know the basic characteristics in shear re-bar using a anchor plate, a pulling out analysis was conducted with axis symmetrical non-linear finite element analysis to confirm the capability of the plate anchor. Analytical models of the anchor plate bolt type and taper bolt type are shown in Figure 3. The analytical results are shown in Figure 4.

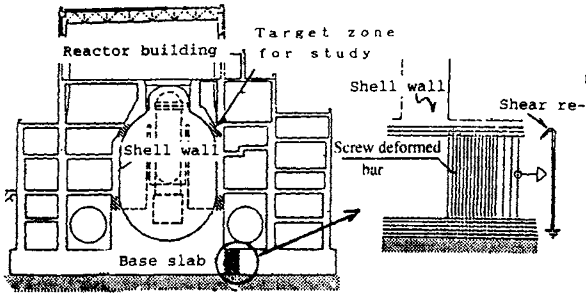

Fig.1 Section of the reactor building

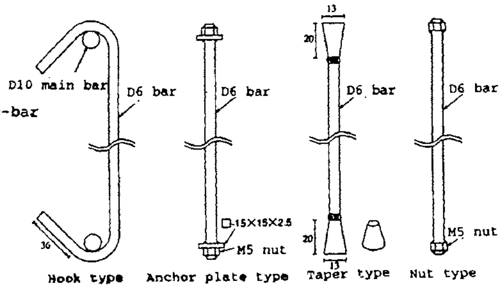

Fig. 2 Shapes of the shear re-bar end

1.2 SPECIMEN

The evaluation zone of the specimen was selected from a reduced model of the shell wall, with a thickness of 0.3m (1/6 scale), and a width of 0.6m which was derived from the precious data for pulling out strength evaluation zone (approximately double of the thickness) in the anchor bolt, and a length of 0.6m, which was modeled as stress status in the actual shell wall (shear span ratio = 1.18). The total length of the specimen was approximately 4m, which was decided by the size of the loading apparatus. The size and shape of the specimen are shown in Figure 5.

The types of the specimen are listed in Table 1. Seven units were used in the beam model specimen, including the specimen B1 of ordinary shear re-bar with 135-degrees hook, the specimen A1 to A4 of the anchor plate mounted at both ends, and the specimen KA1 of taper type. The amount of longitudinal bars in the specimen A4 was modeled on an actual plant, which had a re-bar ratio of 1/2 compared with the other 6 specimens. Ends of shear re-bar were placed on the same layer as the most outer longitudinal bars in the specimen A2, whereas for the specimen A3, the layer of the end was equal to the second layer main bar. All specimens excluding the specimen A1 had transversal re-bar confining in both sides of the specimen.

Figure 6 shows the bar detailing of the KA1 specimen, which indicates a typical example for the tapered anchorage portion. For the main bar, the A4 specimen had a 3- layered re-bar arrangement (Pt=0.84%) with both an upper and lower end of 6-D10, and other specimens had each 3-layered detailing of 12-D10. The shear re-bar ratio is 0.64% (6-D6 pitch 50). The transversal re-bar was detailed in 6 lines for A4 with 6-D10, and for others with 12-D10. The properties of concrete and steel bars used for those specimen are described in Table 2 and 3.

1.3 LOADING AND MEASUREMENT

Monotonic cycle loading was applied to the specimen so as to simulate the stress condition in the target zone of the actual plant. A hydraulic jack was used for the inverse symmetric shear-flexure loading method. The test was carried out by controlling the determination of the specimen and the shear cracking occurred in cycles of 1 mm and 2 mm, the main bar yielded cycle of 4 mm, finally failure occurred in the fourth cycle.

The outline of the loading apparatus is shown in Figure 7. Displacement (vertical displacement at the loading point and specimen center), relative displacement in the evaluation zone (in the direction of horizontal/vertical axis and diagonal), and strain of steel bars (48 locations in a unit) were recorded.

2 TEST RESULTS

2.1 LOAD-DISPLACEMENT RELATIONSHIP

Comparison of load-displacement relationships among the plate anchor type specimens as well as that of the different anchor types are shown in Figures 8 and 9, respectively.

Among those anchor plate types, acceptable ductility and high strength were found in the A2 specimen, which had transversal re-bars and ordinary anchorage. Although the A1 specimen which had no transversal re-bar indicated secondary high values in maximum strength, however, which also indicated large reduction in strength after maximum strength. Whereas the A3 which had transversal re-bar and short and ordinary anchor indicated small reduction in strength after maximum strength despite of lower value of the maximum strength than that of types without transversal re-bars. Consequently it was found that existence of the transversal re-bar could effect on a reduction in strength after maximum strength, and the anchor length had an effect on maximum strength.

For the specimen A4, enough stable curve was found without a reduction in strength. Another comparison is adequately shown in Figure 9 for each anchor types. For maximum strength, excluding the nut type (KC) of 69.1 tons, other specimens indicated as nearly equal to the levels of 73 to 75 tons. As for ductility, anchor plate type (A2) and taper type (KA1) indicated the reduction in strength to the extent of 50 mm of the relative displacement. The nut and hook type (B) indicated no reduction in strength after maximum strength. The degree of the reduction was larger in the hook type than the nut type.

2.2 DEFORMATION MODE

With the exception of the A4 specimen which indicated acceptable ductility with flexure yielding, the deformation properties of other specimens are examined below.

1. OUTLINE OF DEFORMATION PROPERTIES: All layers of the longitudinal bar yielded in each specimen, and the maximum strengths exceeded to the calculated flexural strength at the time when the outer most layered main bar yielded. The shear re-bar yielded in all layers to the extent of the maximum strength.
2. SEPARATION OF DEFORMATION: After the section was divided into 2 zones (see Figure 10), each relative displacement was measured on horizontal, vertical, and diagonal directions so as to calculate shear deformation angle, principal strain, and principal direction (each average in 2 zones was derived). The occupied ratio by shear deformation in total relative deformation was shown in Figure 11. A circled mark indicates the deformation at maximum strength. For the A1 and A3, the deformation after the maximum strength was occupied by shear deformation, so they were thought to be shear failure mode. For other specimens, the ratios of shear deformation were approximately 60%, and shear deformation increased after the maximum strength to the extent of the shear failure. However, for A2 and KA1 specimen, the shear deformation gradually increased after the maximum strength, and they were thought to be the flexural failure mode.

2.3 ULTIMATE FAILURE CONDITION

Figure 12. shows a comparison of the final crack condition among various anchor methods. As the distribution of diagonal cracks were comparatively similar among both types of the anchor plate and taper type. The growth of the cracks was also homogeneous, and the width of the flexural cracks was large. So both types of the anchor plate and taper indicated acceptable ductile behavior. Whereas for the hook type (B), shear cracks occurred along with diagonal lines and bond split cracks occurred along with main bar of upper surface were prominent, which progressed and caused the failure. For the nut type, growth of shear cracks of 2 to 3 lines was prominent as well. Therefore, the radical reduction in strength after maximum strength was found in the hook type and the nut type anchor.

2.4 COMPARISON WITH CALCULATIONS OF VARIOUS STRENGTH

Comparison between experimental values and calculations for flexural cracking strengths are shown in Table 5. Formula (1) was selected from the standards of the Architectural Institute of Japan. The test values were relatively consistent with the calculations, excluding the specimen A3 and A4 .

For various shear cracking strengths, Table 6 shows the comparison between experimental values and calculations. Data were selected from the standards of AIJ (results from the formula (2)) and from the results of the formula (3). The experimental values for A1, A3, and A4 specimens, were multiplied by 0.8 for those calculations, however for other specimens, the experimental values almost all agreed with the calculations. Also consistent degree was the approximately equal levels in those formulas.

The maximum strength by comparison with the calculations were shown in Table 7. For formula (4), average shear strength of $Q_{su,mean}$ was used. The experimental values were comparatively consisted with the calculations in A4 specimen. However for other specimens, those experimental values exceeded from 5% to 28% against the corresponding calculations.

For other specimens except for A4, which failed due to acceptable bond properties, the flexural strength were examined. By use of the measurement data regarding main bar strain, the distance from centroid of compression to centroid of tension in the section J_e was counted backward. Also the distance from centroid of compression to centroid of tension in member of J_s ((7/8)d, d: distance of 25.5 cm) which was adopted in the flexural strength calculating formula as shown in (5); $M=a_t \times f_t \times J_s$ (a_t: the sectional area of tensile re-bar, f_t: yielding strength of the main bar), was calculated and the both distances were shown in Table 4. Although Je of A3 specimen was slightly smaller than Js. However for the KC and A1, the J_e was almost consistent with J_s. The J_e of B, A2, and KA1 were slightly larger than J_s. Flexural strength derived from the formula (5), in which J_s of Table 4 used was 68.8 tf. Maximum flexural strength of the specimen A3 was smaller than the calculations shown in (5). For other specimens, the maximum flexural strength could be estimated by use of the calculation formula shown in (5). For the hook type specimen B, and for the anchor plate attached A2 specimen which had ordinary anchor length, and for the taper anchor, each flexural strength derived from the formula were indicated in the conservative zone as shown in (5).

It was found that the both strength of flexural cracking and shear cracking could be estimated through those calculations, excluding A3 and A4 specimens. And maximum strength also could be estimated through the formula for the flexural strength.

3 CONCLUSION

The test results are described below.

1) For the anchor plate, it was found that the transversal re-bar effected on the reductions in strength after maximum strength, the anchor length had an effect on maximum strength.
2) Among the various types, the anchor plate and taper types indicated acceptable capabilities of strength and ductility.
3) Each strength could be approximately estimated through the corresponding formula.

As described above, the anchor plate type, which is one of the end anchor methods for out-of-plane shear re-bars, was determined to have the equivalent to or more capability than that of the hook type. And the newly developed taper anchor plate was found to have the capability equivalent to that of the plate anchor type. Also it was found that anchor plate type and nut type which have a short anchor length, were indicated to have lower maximum strength and larger reductions in strength, therefore, they were determined to be undesirable.

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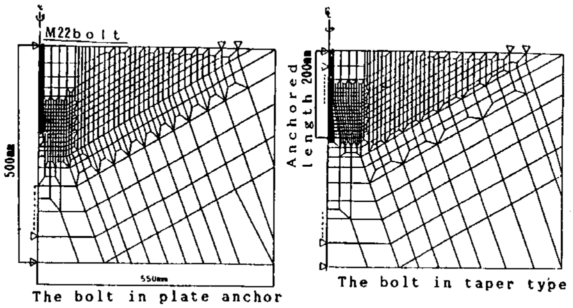

Fig. 3 Analytical models for pulling out simulation of plate anchor

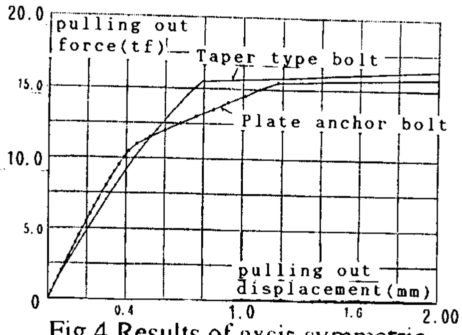

Fig.4 Results of axsis symmetric non-linear FEM analysis

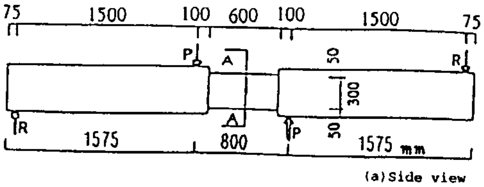

Fig. 5 Size and shapes of specimen

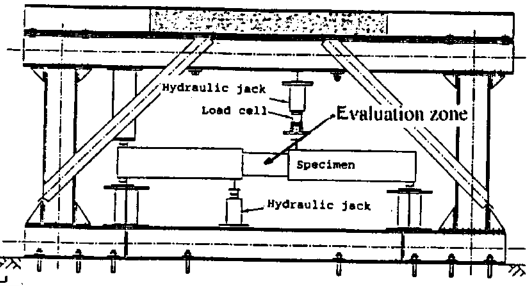

Fig. 7 Outline of loading apparatus

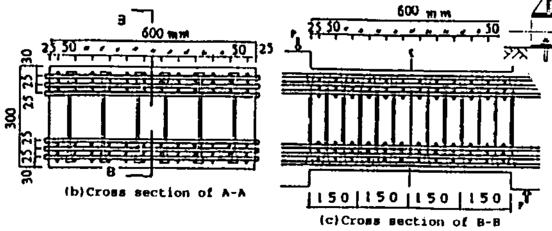

Fig. 6 Re-bar arrangement of specimen

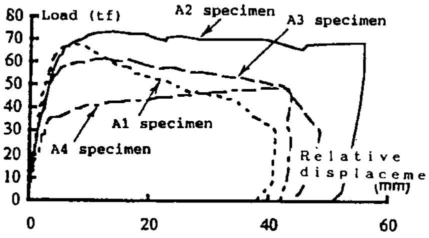

Fig. 8 Comparison of load-deformation relationship in the plate anchor

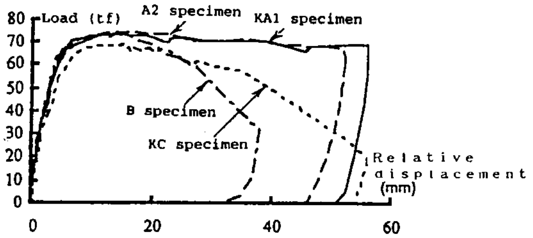

Fig. 9 Comparison of load-deformation relationship in different anchor types

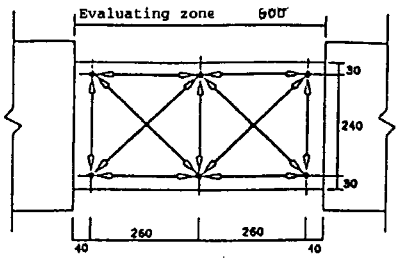

Fig. 10 Location of displacement measurement

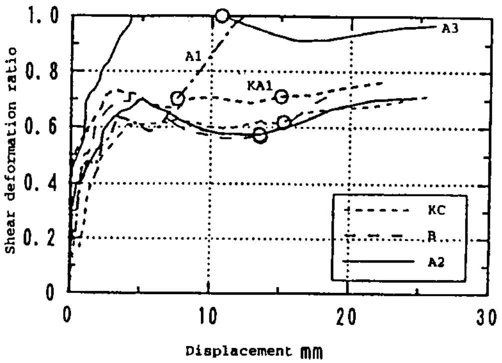

Fig.11 Shear deformation ratio to overall deformation

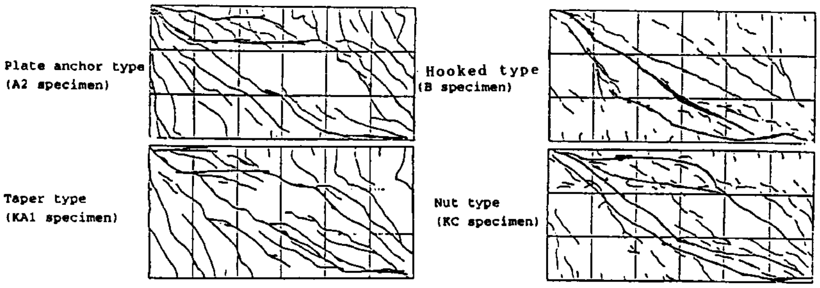

Fig. 12 Final failure conditions

Table 1. Specimen chart

Test series (Pt %)		For shear mode (1.68%)			actual plant (0.84%)
Transversal re-bar		Not installed	Installed		
Anchor length		Ordinary		Short	Ordinary
method	Hook type		B		
	Anchor plate	A 1	A 2	A 3	A 4
	New taper type		KA1		
	Nut type		K C		

Table.2 Test results of the concrete

Age (days)	Sealed curing		
	Compressive strength (kg/cm^2)	Elastic modulus (10^5 kg/cm^2)	Splitting strength (kg/cm^2)
57^{*2}	350	2.41	26.2

*2 At the beginning of the test (1MPa=10.2kg/cm^2)

Table.3 Results of the tension test on the steel bar

Re-bar	Location for use	Yielding point (kg/cm^2)	Tensile strength (kg/cm^2)	Young's modulus (10^6 kg/cm^2)	Yielding strain (μ)
D6	Shear re-bar	3720	4940	1.88	1980
D10	Principal bar Cross binding bar	3620	5170	1.86	1940

Table.4 Distance from centroid of compression to centroid of tension in member at maximum strength

Je counted backward with test						Formula (5)
KC	B	KA1	A2	A1	A3	J s
22.2	23.0	23.8	23.7	22.8	20.6	22.3 cm

Table 5. Comparison with calculations on the flexural crack strength

Specimen	Test	Formula (1)	Test/Cal.
A1	14.0	13.9	1.01
A2	14.6	13.9	1.05
A3	10.1	13.9	0.73
A4	9.9	12.0	0.83
B	15.2	13.9	1.09
KA1	15.6	13.9	1.12
KC	16.0	13.9	1.15

(Unit : tf)

Table 6. Comparison with calculations on the shear crack strength

Specimen	Test	Formula (2)	Test/Cal.	Formula (3)	Test/Cal.
A1	20.6	25.7	0.80	25.0	0.82
A2	25.5	25.7	0.99	25.0	1.02
A3	18.7	25.7	0.73	25.0	0.75
A4	17.9	25.7	0.70	25.0	0.72
B	25.9	25.7	1.01	25.0	1.04
KA1	26.1	25.7	1.02	25.0	1.04
KC	25.3	25.7	0.98	25.0	1.01

(Unit : tf)

Table 7. Comparison with calculations on the maximum strength

Specimen	Test	Formula (5)	Test/Cal.	Formula (4)	Test/Cal.
A1	69.4	68.8	1.01	59.4	1.17
A2	73.2	68.8	1.06	59.4	1.23
A3	62.1	68.8	0.90	59.4	1.05
A4	49.3	34.4	1.43	53.2	0.93
B	73.5	68.8	1.07	59.4	1.24
KA1	76.0	68.8	1.10	59.4	1.28
KC	69.1	68.8	1.00	59.4	1.16

(Unit : tf)

Formula (1) : $Q_c = 1.8\sqrt{Fc}Z_e / a$

Formula (2) : $Q_{sc} = \dfrac{Kc(Fc+500)0.085}{\frac{M}{Qd}+1.7} \times b \times j$

Formula (3) : $Q_{sc} = \sqrt{\sqrt{Fc}(\sqrt{Fc}+\sigma)} \times b \times j$

Formula (4) : $Q_{su,mean} = \{\dfrac{0.068\,p_t^{0.23}(Fc+180)}{M/(Qd)+0.12} + 2.7\sqrt{p_w \cdot \sigma_{wy}}\} \times b \times j$

Formula (5) : $M = a_t \times f_t \times J_s$

Fc: Compressive strength of concrete

Ze: Section modulus of the beam considering steel bar

a: Shear span b: Beam width

j_s: Distance from centroid of compression to centroid of tension in member

d: Effective depth of beam

p_t: Tensile re-bar ratio

p_w: Shear re-bar ratio

σ_{wy}: Tensile strength of shear re-bar

M/ Qd : Shear span ratio