A Research on the Mechanical Property, Work Efficiency and Structural Characteristics of Heavyweight Concrete

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1 INTRODUCTION

Generally walls and slabs are thickened to improve the shielding ability of normal concrete in the buildings in nuclear power plants. On the other hand, the decrease of thickness of the members and the decrease of building size can be expected by the adoption of heavyweight concrete. But there are little principal structural members such as shear walls with heavyweight concrete. Therefore the data relating to mechanical properties and construction method are not sufficient.

This study has been carried out to investigate the properties and the structural characteristics of heavyweight concrete and to establish the construction method.

2 AGGREGATE AND CONCRETE PROPERTIES

2.1 SELECTION OF AGGREGATE

In Japan, we use only imported iron ores as the raw material for steel because of both the lack of resources and high cost of mining. As a point of departure, coarse and fine aggregate was selected for the study, investigating imported iron ore. The particle ore of magnetite from Chile as a fine aggregate and the mass ore of hematite from Australia as a coarse aggregate were selected for this study, because their quality was excellent and the import quantity of them was stable.

2.2 AGGREGATE PROPERTIES

Table 1 shows the results of property test. They were tested complying with JIS and JASS5, standards in Japan. The fine aggregate had sufficiently good qualities except for the amount of material passing standard sieve 74 μm and the amount of clay contained in the aggregate. The test results of the coarse aggregate satisfied the regulated values except for the amount of material passing the sieve. Because the material passing the sieve and the clay consisted almost entirely of iron powder, it is considered that they didn't have a bad influence on the concrete properties. S and SO_3 content was less than the regulated value in JIS-A5011.

Figure 1 shows the grain size distribution of the aggregate. Both fine and coarse aggregate exceeded the limit of standard grain size distribution in JIS. The fine aggregate was used without grain adjusting. The coarse aggregate was used after grain adjusting shown in Fig. 1.

2.3 PROPERTIES OF HEAVYWEIGHT CONCRETE

Table 2 shows materials and proportioning conditions of the heavyweight concrete used

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in the test. Using a high quality water reducing agent, the unit quantity of water in concrete was adjusted to 160 kg/m^3 in case of slump 5 cm, and 180 kg/m^3 in case of 12 cm. Table 3 shows the concrete proportioning.

Table 4 shows properties of the fresh concrete, drying shrincage value and thermal properties of hardened concrete. All specimens got objective value of slump and air content. The maximum bleeding quantity was 0.28 cm^3/cm^2. The results of the drying shrincage test were within the limits of 0.037 $\sim$0.058%. They satisfied the objective value of high durability concrete (0.3 cm^3/cm^2, 0.06 %) regulated in JASS5. Thermal properties of heavyweight concrete were almost equal to the ones of normal concrete.

Figure 2 shows the compressive strength - water-cement ratio relation in case of slump 12 cm. The compressive strength increased smoothly until a material age of 180 days.

Figure 3 shows the static elastic modulus - compressive strength relation. The experimental formula (1) was derived from these results.

Figure 4 shows the results of dry bulk density test. All values of dry bulk density were above 3.4 t/m^3.

3 PUMPING TEST

3.1 TEST PROCEDURE

A pumping test was carried out with the two kinds of concrete proportioning shown in Table 5. One had ordinary Portland cement and the other Portland fly-ash cement. The aggregate was used as it was without grain adjusting.

Figure 5 shows pipe arrangement. The pipe had a 5 inch diameter and was a total of 125 m long. The pump was piston style. Its logical pump out pressure was 82.6 kgf/cm^2. The pump out pressure, pump out volume and the pressure distribution in pipes were measured.

3.2 TEST RESULTS

The pressure loss per 1 m of lateral pipe was calculated from the test results. Figure 6 shows it and logical pump out volume relation. The relation of normal concrete in Fig.6 is taken from Recommendation for Practice of Concrete Pumping. Figure 7 shows the maximum lateral transport distance and the logical pump out volume. The pressure loss of heavyweight concrete in the pipe was 2.6 $\sim$ 3 times as large as one of normal concrete. But, from Fig.7, it is considerd that the lateral transport of 300 m was possible with logical pump out volume of 20 m^3/h.

4 PLACING TEST

4.1 TEST PROCEDURE

The heavyweight concrete was placed in the wall specimen shown in Fig 8. Its thickness was 1.1 m, width 5 m and height 3 m. The concrete was placed in two parts with a 30 minute interval. Each height was 1.5 m. The proportioning of the concrete is shown in Table 5 as "B". Deformed bars with a nominal diameter of 38 mm were arranged in vertical and horizontal directions in double layers. The principal measurements were the distribution of the specific gravity along height by core test and filling grade by ultrasonic propagation velocity test.

4.2 TEST RESULTS

The slump of the heavyweight concrete placed in the wall specimen was 12 cm. The air content was 2.0 %, the weight of unit volume 3.56 t/m^3. They were within the range of the original plan.

Figure 9 shows the specific gravity at an age of 28 days. They were measured with core test specimen (ϕ15×30cm) from the wall specimen. The mean specific gravity was 3.62 t/m³, being larger than the value of fresh concrete, and the standard deviation 0.028 t/m³. The difference of the mean specific gravity between upper and lower part was inspected by Japaneses code JIS-Z9049 with the result being no significant difference.

It was confirmed that the uniformity of specific gravity could be achieved with two times placing of 1.5 m height and a total of 3 m height.

Figure 10 shows the ultrasonic propagation velocity in thickness direction. The mean was 3.78 km/s and the standard deviation 0.053 km/s. Inspecting them with the same method as Chung's, only one place in the top had lower value than $V-1.96\sigma$. Then, there was no probability of defect in the wall.

The results of this test shows that heavyweight concrete can be placed in the same way as normal concrete.

5 THE STATIC LOADING TEST OF SHEAR WALL SPECIMENS

5.1 TEST PROCEDURE

Figure 11 shows the shape of specimens, and Fig.12 shows the arrangement of rebars of specimen No.1 as an example. Table 6 shows the arrangement of rebars of each specimens. The amount of reinforcement was given differently to each of specimens, and the other elements were equally given.

Each specimen consisted of a test part, a top slab and a bottom slab. Test parts, that had H-shaped cross sections, were constructed with heavyweight concrete which had similar aggregate to the mechanical property test, but with the maximum diameter of aggregate being 10 mm. Table 7 shows the material properties of heavyweight concrete that was used in the test part. The yield stress of rebars arranged in the test part was 4160 kgf/cm².

Figure 13 shows the loading setup. The bottom slab of specimen was fixed on the test slab with prestressing steel bars. Then, the lateral load was applied to the top slab using four actuaters which were fixed to the abutment test wall. The axial load was also applied using two oil jacks and was kept constant (20 kgf/cm²) during alternation of the lateral load.

5.2 TEST RESULTS

Figure 14 shows lateral load - lateral deflection relation of specimen No.1. The lateral deflection was measured at the center bottom of the top slab. The hysteresis loop of the large deflection cycle had lower stiffness in small deflection and higher in large deflection. This is one of the characteristics of the specimens that have short shear span, and specimen No.2 showed similar characteristics.

Table 8 shows test results. "24M8-40" and "36M8-40" are specimens made with the normal concrete in a past investigation which was carried out with a similar process to this test. The shape and making method of specimens was also similar. The "24" and "36" in each specimens' name shows the amount of reinforcement ($Ps \cdot s\sigma y$). The amount of reinforcement of "24M8-40" was almost equal to "No.1" and "36M8-40" to "No.2".

The test results with heavyweight concrete specimens in this investigation didn't show much lower values than the ones with normal concrete except for the bending crack strength of specimen No.1. This effect is possibly attributable to prestress from drying shrinkage. Most importantly, the bending crack sterength didn't affect the hysteresis loop.

Figure 15 and 16 shows the deflection envelopes of four specimens. In both cases No.1 and No.2, the stiffnesses on the way from shear crack point to maximum load point were slightly larger than in the case with normal concrete specimens. The reason of it was considered that the elastic modulus of heavyweight concrete was larger than the one of normal concrete.

6 CONCLUSIONS

i) The heavyweight concrete made with the particle ore of magnetite from Chile and the mass ore of hematite from Australia had no problem of the properties, i.e. specific gravity, strength, etc. Therefore, selected aggregates in this investigation have sufficient properties to be used in heavyweight concrete.
ii) The pressure loss of heavyweight concrete in pipes when it was pumped was larger than that of normal concrete, but, it's sufficiently possible to place heavyweight concrete using concrete pump, and to get homogeneous concrete with two parts of 1.5m in height giving the total 3m.
iii) The results of static shear wall test with heavyweight concrete were almost equal to ones with normal concrete. Therefore, in the range of this investigation, the structural properties of shear wall with heavyweight concrete can be considered to be the same as normal concrete with the exception of stiffness.
iv) As stated above, mechanical properties, performance for construction work and structural properties of heavyweight concrete are by no means inferior to ones of normal concrete.

This paper is a part of joint research "Investigation and Research into Heavyweight Concrete", carried out by the cooperation of ten electric power companies (The Tokyo, The Hokkaido, Tohoku, The Chubu, Hokuriku, The Kansai, Chugoku, The Shikoku, The Kyushu, The Japan Atomic) and Japan Nuclear Fuel Service Company.

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Table 1 Aggregate Properties

	Absolute Dry Specific Gravity	Coeffcient of Water Absorption (%)	Ratio of Absolute Volume (%)	Passing Sieve Test (%)	Clay Volume (%)	Organic Impuri-ties	Chloride (%)	Fineness Modulus
F.A.	4.66	0.42	74.2	9.0	6.1	pass	0.009	3.23
C.A.	4.19	2.95	57.3	2.1	0.2	—	—	7.32

	Chemical contents (%)							
	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	S	SO_3
F.A.	4.45	1.00	62.44	28.21	1.84	1.31	0.07	0.10
C.A.	3.19	0.52	94.09	0.39	0.02	0.03	0.16	0.04

F.A. : Fine Aggregate (Particle Ore of Magnetite from Chile)
C.A. : Coarse Aggregate (Mass Ore of Hematite from Australia)

Table 2 Proportioning Conditions

	Proportioning Conditions
Cement	Ordinary Portland Cement, Portland Fly-ash Cement
Fine Aggregate	Magnetite from Chile
Coarse Aggregate	Hematite from Australia
Admixture	High Quality Water Reducing Agent
Water-Cement Ratio	45 % , 50 % , 55 %
Slump	5 cm , 12 cm
Air Content	2 %

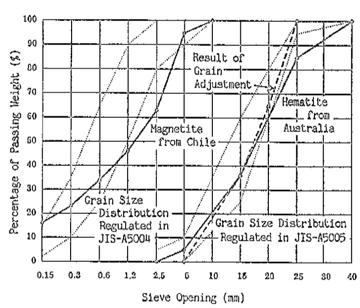

Fig. 1 Grain Size Distribution

Table 3 Concrete Proportioning

Cement	Slump (cm)	Air Content (%)	Water Cement Ratio (%)	Sand Percentage (%)	Unit Quantity of Water (kg/m³)	Absolute Volume (l/m³): Cement	Absolute Volume (l/m³): Fine Aggregate	Absolute Volume (l/m³): Coarse Aggregate	Saturated Surfaced-dried weight (kg/m³): Cement	Saturated Surfaced-dried weight (kg/m³): Fine Aggregate	Saturated Surfaced-dried weight (kg/m³): Coarse Aggregate	Admixture (kg/m³)
Ordinary	5	2	45	44.0	160	113	311	396	355	1453	1639	2840
Portland	↑	↑	50	45.0	↑	102	323	395	320	1510	1636	2560
Cement	↑	↑	55	46.0	↑	92	335	393	291	1563	1627	2328
	12	↑	45	47.0	180	127	316	357	400	1477	1477	2800
	↑	↑	50	48.0	↑	114	329	357	360	1537	1476	2520
	↑	↑	55	49.0	↑	104	341	355	327	1593	1470	2289
Portland	5	2	45	43.0	160	120	301	339	356	1405	1652	4272
Fly-ash	↑	↑	50	44.0	↑	108	313	399	320	1463	1651	3840
Cement	↑	↑	55	45.0	↑	98	325	397	291	1517	1643	3492
	12	↑	45	44.8	180	135	298	367	400	1391	1520	4000
	↑	↑	50	45.8	↑	122	311	368	360	1451	1522	3600
	↑	↑	55	46.8	↑	111	323	367	327	1507	1518	3270

Table 4 Concrete Properties

Cement	Slump (cm)	Water Cement Ratio (%)	Propeties of Fresh Concrete: Slump (cm)	Propeties of Fresh Concrete: Air Content (%)	Propeties of Fresh Concrete: Weight of Unit Volume (kg/l)	Propeties of Fresh Concrete: Bleeding (cm³/cm²)	Drying Shrincage (%)	Thermal Properties: Thermal Conductivity (kcal/mh°C)	Thermal Properties: Thermal Diffusivity (m²/h)	Thermal Properties: Coefficient of Thermal Expansion (×10⁻⁶/°C)
Ordinary	5	45	5.0	1.6	3.735	0.07	0.045	—	—	—
Portland	↑	50	5.9	2.0	3.749	0.14	0.044	—	—	—
Cement	↑	55	5.9	1.7	3.759	0.20	0.042	—	—	—
	12	45	11.5	1.7	3.662	0.10	0.053	—	—	—
	↑	50	11.5	1.5	3.689	0.17	0.053	1.97	0.0031	8.24
	↑	55	12.2	1.4	3.679	0.19	0.054	—	—	—
Portland	5	45	4.1	1.5	3.690	0.10	0.040	—	—	—
Fly-ash	↑	50	4.5	1.2	3.701	0.14	0.045	—	—	—
Cement	↑	55	4.0	1.3	3.756	0.20	0.037	—	—	—
	12	45	11.4	1.6	3.617	0.14	0.051	—	—	—
	↑	50	12.0	1.2	3.684	0.22	0.058	1.74	0.0030	7.26
	↑	55	11.1	1.4	3.669	0.28	0.047	—	—	—

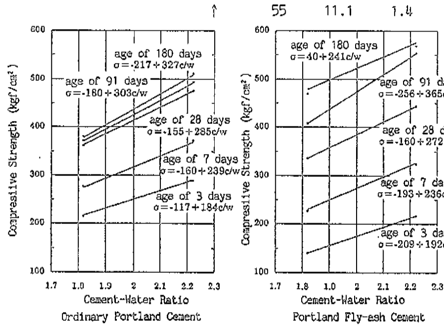

Fig. 2 Compressive Strength - Water-Cement Ratio Relation

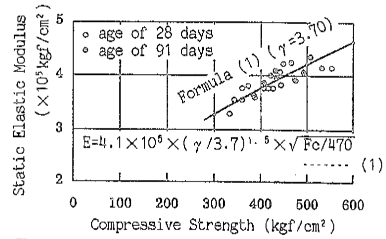

Fig. 3 Elastic Modulus - Compressive Strength Relation

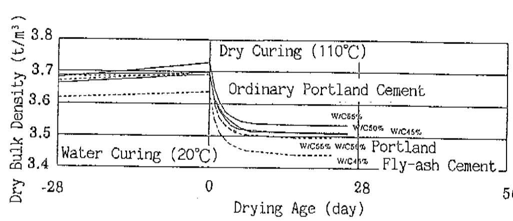

Fig. 4 Dry Bulk Density

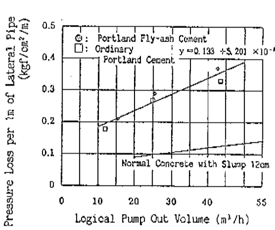

Fig. 6 Pressure Loss - Logical Pump Out Volume Relation

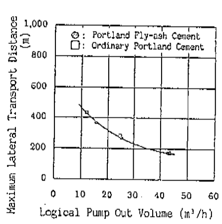

Fig. 7 Mximum Transport Distance - Logical Pump Out Volume Relation

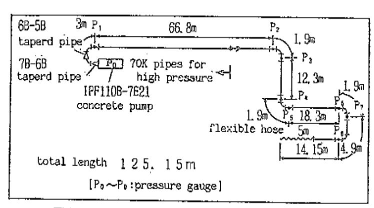

Fig. 5 Pipe Arrangement

Table 5 Concrete Proportioning

	Cement	Slump (cm)	Air Content (%)	Water Cement Ratio (%)	Sand Percentage (%)	Unit Quantity of Water (kg/m³)	Saturated Surface-dried Weight (kg/m³): Cement	Saturated Surface-dried Weight (kg/m³): Fine Agregate	Saturated Surface-dried Weight (kg/m³): Coarse Aggregate	Admixture (kg/m³)
A	Ordinary Portland Cement	12	2	55	49.0	180	327	1586	1480	2616
B	Portland Fly-ash Cement	↑	↑	↑	46.8	↑	↑	1502	1530	3597

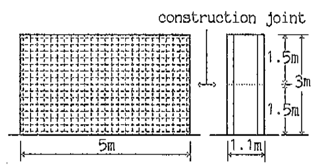

Fig. 8 Wall Specimen

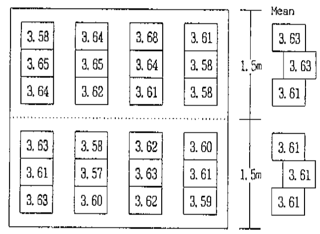

Fig. 9 Specific Gravity

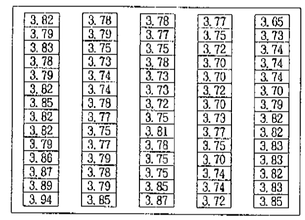

Fig. 10 Ultrasonic Propagation Velocity

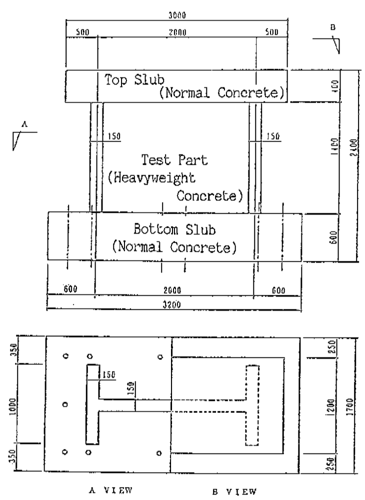

Fig. 11 Specimen of the Static Loading Test

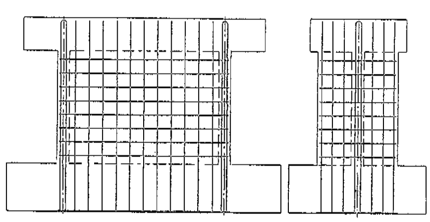

Fig. 12 Arrangement of Rebars (No.1)

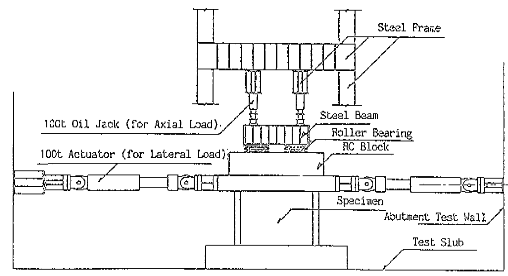

Fig. 13 Loading Setup

Table 6 Arrangement of Rebars

Specimen	Reinforcement Ratio × Yield Stress Ps・sσy (kgf/cm²)	Reinforcement Ratio (%)	Yield Stress (kgf/cm²)	Arrangement of Rebars (in double layers)
No.1	23.3	0.56	4160	D10-@170mm
No.2	35.8	0.86	↑	D10-@110mm

D10 : Deformed Bar with a Nominal Diameter of 10 mm

Table 7 Concrete Properties

Specimen	Slump (cm)	Air Content (%)	Compressive Strength (kgf/cm²)	Tensile Strangth (kgf/cm²)	Weight of Unit Volume (tonf/m³)
No.1	16.0	2.9	366	8.8	3.58
No.2	15.0	2.4	348	26.1	3.58

Table 8 Test Results

		No.1	(24M8-40)	No.2	(36M8-40)
Ps・sσy	(kgf/cm²)	23.3	(25.4)	35.8	(37.8)
Ps	(%)	0.56	(0.57)	0.86	(0.85)
sσy	(kgf/cm²)	4160	(4300)	4160	(4300)
Es	(×10⁵kgf/cm²)	1.96	(1.90)	1.96	(1.90)
cσB	(kgf/cm²)	366	(365)	348	(396)
τu	(kgf/cm²)	59.8	(58.9)	69.3	(69.6)
Ru	(×1/1000)	8.3	(6.0)	9.4	(10.0)
τcB	(kgf/cm²)	12.8	(17.7)	23.6	(19.6)
τcs	(kgf/cm²)	42.3	(36.1)	40.4	(32.6)
τy	(kgf/cm²)	53.6	(57.7)	58.6	(62.1)

Ps : Reinforcement Ratio
sσy: Yield Stress of Rebar
Es : Elastic Modulus of Rebar
cσB: Compressive Strength of Concrete
τu : Ultimate Shear Stress
Ru : Ultimate Rotation Angle
τcB : Shear Stress at Bending Cracking
τcs : Shear Stress at Shear Cracking
τy : Shear Stress at Yielding of Vertical Rebar in Flange

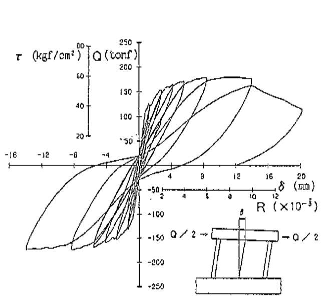

Fig. 14 Load - Deflection Relation (No.1)

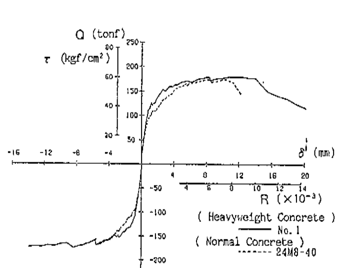

Fig. 15 Deflection Envelopes

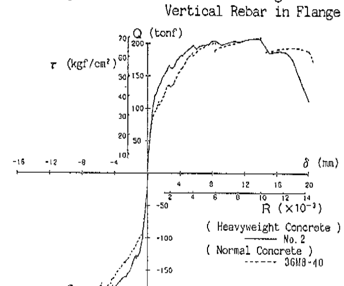

Fig. 16 Deflection Envelopes