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Autor: Matzumoto, Yoshiji / Fukuzawa, Kimio / Endo, Hiroshi

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Manufacture and Behaviour of Hollow Composite Members

Fabrication et comportement d'éléments composites creux

Herstellung und Eigenschaften von hohlen Verbundbauelementen

YOSHIJI MATZUMOTO
Professor
University of Tokyo
Tokyo, Japan

KIMIO FUKUZAWA
Research Engineer

HIROSHI ENDO
Research Engineer

Nippon Concrete Industries Co., Ltd.
Tokyo, Japan

1. Introduction

The use of hollow composite members consisting of relatively thin circular or rectangular steel tubes lined with concrete compacted by centrifugal force is conceivable as a means of economically improving the strength and ductility of precast concrete members. This will not only make manufacturing easier but should also handling easier due to a lightening in weight comparing to concrete filled steel tubes.

Hollow composite members are now used mainly as foundation piles, and wide utilization in bridge piers and columns and beams of buildings is looked forward to.

This paper discusses methods of manufacturing hollow composite members with high-strength concrete along with the structural behaviour of such members when subjected to bending.

2. Specimens and Test Procedure

2.1 Specimens

There are three structural types of hollow composite members, which may be cylindrical or rectangular in section, namely, 1) steel tube lined with concrete (Type I), 2) steel tube with reinforcement placed in the axial direction and lined with concrete (Type II), 3) steel tube with prestressing reinforcement lined with concrete and with prestress transferred after hardening of concrete (Type III). Comparison were made of the three structural types with specimens of hollow cylindrical section and in addition concrete filled steel tubes and hollow prestressed concrete members were tested as illustrated in Fig. 1.

The members were 4 m long and about 30 cm in diameter, and measured dimensions are shown in Table 1. The principal test variables in the investigation were as follows; 1) wall thickness of hollow composite emmbers; 2) thickness of steel tube; 3) compressive strength of concrete; 4)bond properties between concrete and steel tube.

Axially welded mild steel tube were used in the investigation. The tensile and yield strengths of steel tube are reported Table 1. Round steel bar whose diameter 13 mm was used and its tensile and yield strengths were 4,340 kg/cm^2 and 3,150 kg/cm^2 respectevly. Prestressing wire whose diameter 7 mm was used and its tensile and 0.2 % proof strengths were 16,500 kg/cm^2 and 14,800 kg/cm^2 respecitively.

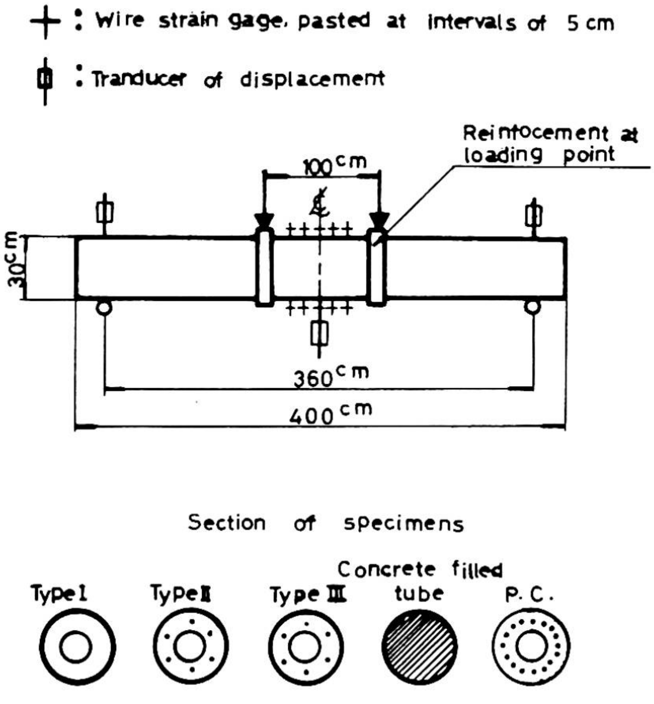

Fig.1 Specimen and gage arrangement

Normal portland cement and expansive component were used. A water-reducing agent whose main component was sodium salt of β-naphthalene sulfonic acid-formaldehyde condensate was used. Crushed stone whose maximum size was 20 mm and river sand were used as aggregates.

The base mix of concrete was as follows: water-cement ratio

Table 1 Specimens and test results

Specimen	Type of Specimen	Type of concrete	Dimension: Outer diameter mm	Dimension: Wall thickness mm	Steel tube: Wall thickness mm	Steel tube: Yield strength kg/cm^2	Steel tube: Tensile strength kg/cm^2	Concrete: Comp. strength kg/cm^2	Ultimate bending strength: Observed tm	Ultimate bending strength: Calculated tm	Ultimate bending strength: Observed / Calculated
A	I	Expansive	298	28	3.15	3,220	4.620	844	12.08	13.21	0.91
B	I	Expansive	297	41	3.17	3,220	4,620	844	13.03	13.96	0.93
C	I	Expansive	296	58	3.19	3,220	4,620	1,024	13.88	14.21	0.98
D	Filled tube	Expansive	297	—	3.10	3,220	4.620	823	13.07	13.52	0.97
E	I	Expansive	298	60	3.13	3,220	4,620	458	13.26	12.39	1.07
F	Filled tube	Normal	297	—	3.18	3,220	4.620	426	11.44	11.45	1.00
G 2)	I	Expansive	297	68	3.12	3,220	4,620	1,072	8.78	14.28	0.60
H-1	I	Normal	297	64	3.19	3,220	4.620	1.072	14.17	14.38	0.99
H-2	I	Normal	297	69	3.18	3,220	4.620	1,050	13.65	14.37	0.95
I 3)	I	Expansive	299	61	2.92	2,160	3,640	980	10.95	10.33	1.06
J 3)	I	Expansive	298	61	2.84	2,160	3,640	981	10.60	10.40	1.01
K	I	Expansive	297	59	1.36	2,830	3,730	940	6.23	6.46	0.96
L	I	Expansive	297	61	2.26	2,030	3,550	940	7.61	7.79	0.98
M	I	Expansive	297	61	4.46	3,040	3,870	947	15.21	16.51	0.92
N	I	Expansive	299	71	6.35	2,850	4,840	947	28.34	26.50	1.07
O	II	Expansive	297	64	3.18	3,220	4,630	929	16.97	18.50	0.92
P	II	Expansive	298	61	3.19	3,220	4,620	924	16.77	17.25	0.97
Q	III	Expansive	298	61	3.20	3,220	4,620	1,034	17.03	17.49	0.97
R	P.C.	Normal	302	58	—	—	—	1,002	10.92	10.30	1.06
S	P.C.	Normal	301	62	—	—	—	1,002	4.68	4.65	1.01
T-1	I	Normal	296	61	4.05	2,960	3,730	1,071	16.40	16.02	1.02
T-2	I	Normal	296	63	4.04	3,040	2,820	1,018	16.30	16.10	1.01
U	I	Expansive	296	70	4.06	2,950	3,740	1,128	16.70	16.85	0.99

Note: 1) All specimens were autoclaved but F. 2) Paraffin was coated about 2mm inside of steel tube of G. 3) Chequered plate was used for I and J. Rugged face was out side for I's tube and was inside for J's tube.

0.32, sand-aggregate ratio 42 %, cement content 404 kg/cm^2, content of expansive components 26 kg/m^3, water-reducing admixture 1.6 % wt. of cement, slump 12 cm. The water-cement ratio fell to approximately 0.27 by the time the centrifugal compaction had been completed. The compressive strength was about 900 kg/cm^2 after autoclaving. Concrete strengths at the time of testing are reported for each member in Table 1 as an average of three 20 x 30 cm centrifugally compacted hollow cylinders which was autoclaved in the form.

Specimens were manufactured following process:

1) Steel tube or steel tube with reinforcement or prestressing reinforcement placed in the axial direction was set in the form.
2) Concrete was placed in the steel tube using concrete pump and centrifugal compaction is performed for 7 minutes. The maximum speed was 1,090 r.p.m..
3) Curing by atmospheric pressure steam at a maximum temperature 50 °C was carried out for about 12 hours.
4) Members were stripped at the next day. Prestress was introduced into concrete and steel tube in the case of type III.
5) Stripped member was cured by high-pressure steam for 9 hours at maximum pressure at 10 atm. (180 °C).

2.2 Test Procedure

All specimens were supported on rollers at 3.6 m centers and were loaded at two points 0.5 m either side of the midspan, as shown in Fig.1. The ultimate load and load-deflection chracteristics were observed. In addition longitudinal and transverse strain of steel tube were recorded thoughout the test. The arrangement of gages is shown in Fig.1. The wire strain gages and strain meter which were able to measure great strain to 10 % were used in the test. Outer face of specimens were reinforced for 10 cm long at loading point, in order to prevent from the falling of concrete by shearing force.

3. Test Results

Typical load-deflection diagrams of hollow composite members are illustrated in Fig.2. It was verified that the properly made hollow composite member irrespective of type has greater ductility than the prestressed concrete member and that

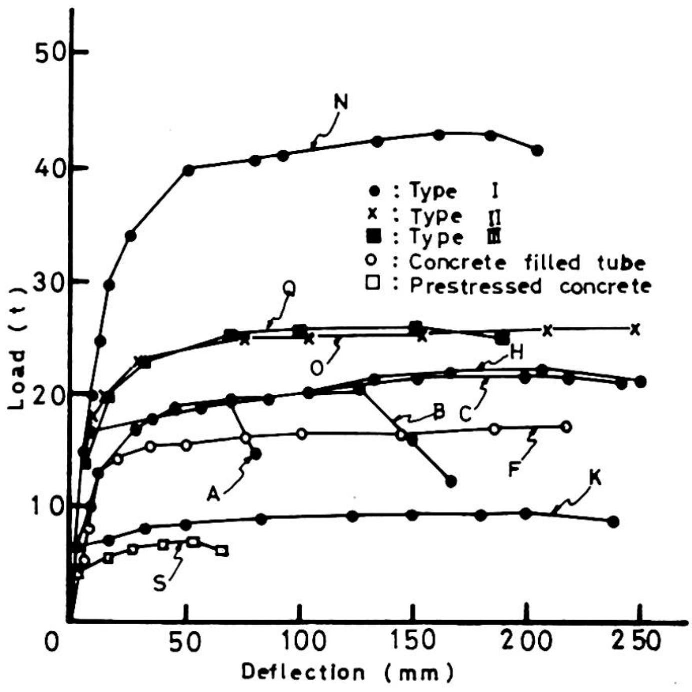

Fig. 2 Load – deflection diagram

structural behavour of hollow composite member was equal to that of concrete filled steel tube. The inside view of tested member is shown in Fig.3. It is shown in this figure that the concrete at compressive zone was completely failed and that the concrete at tension zone developed many cracks and that concrete was not thrusted out to the inside of the member. In case of the member whose wall thickness was thin, concrete at compressive zone was thrusted out into the inside, so that it had not so much ductility.

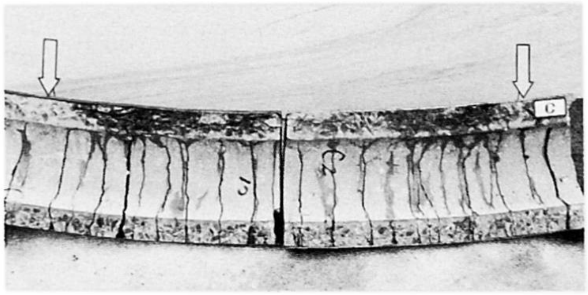

Fig. 3 Inside view of tested specimen

It is conceivable that complete interaction takes place between the steel and the concrete in the case of hollow composite member lined with normal concrete. This is thought to be because even if there is no bond between steel tube and concrete, when the member is deformed due to external force, the concrete is restrained by the steel tube and frictional force is produced between the two, which acts as an apparent bond.

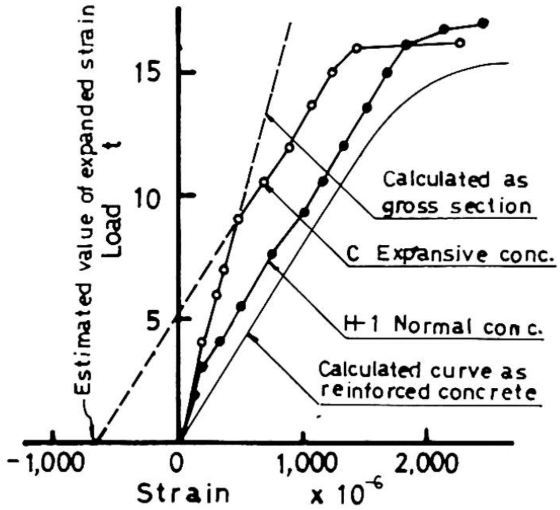

Fig.4 Load-strain diagram

By using expansive concrete the deflection in the elastic range will be improved. This is because chemical prestress is induced in the member as shown in Fig.4. The chemical prestress induced in the specimen C is estimated about 92 kg/cm².

Fig.5 shows the relation between longitudinal strain and ratio of transverse strain and longitudinal strain. The ratio at compression side shows neary fixed value till the longitudinal strain is 1,000 x 10^{-6}, but it increases remarkably when the longitudinal strain exceeds 1,000 x 10^{-6}. This is thought to be because the concrete at the compression zone is failed and steel is expanded by the concrete.

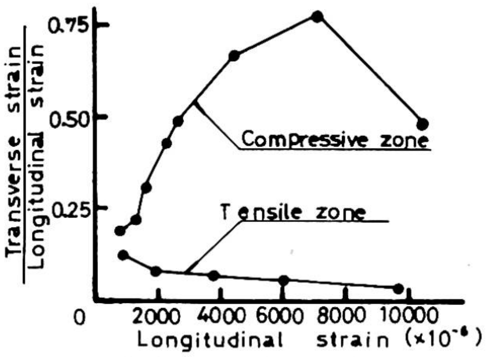

Fig.5 Relation between longitudinal strain and $\frac{\text{transverse strain}}{\text{longitudinal strain}}$

At the tension side, the ratio decreases as the longitudinal strain increases. The value is smaller than the poisson's ratio of steel. This shows that the steel tube is expanded by concrete also at the tension side.

The typical computed load-strain curves are shown in Fig.7 assuming as follows:

1) The concrete has no tensile strength;

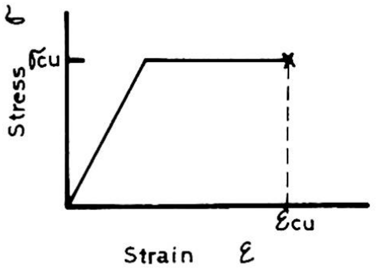

Fig.6 Assumed stress-strain relationship for concrete

2) The stress-strain relationship of concrete under compression is assumed as Fig.6;
3) Uniaxial state of stress for the steel is assumed. And the observed stress-strain relationship is used;
4) Plain section remain plain after bending.

Fig.7 shows that the observed compressive fiber strain was more than 10,000 x 10^{-6} and that the calculated and observed compressive and tensile fiber strain were roughly equal. Fig.8 shows the relation between ultimate bending strength calculated using the four assumptions and observed ultimate bending strength. The ultimate compressive fiber strain was used 10,000 x 10^{-6} for the hollow composite members and 3,000 x 10^{-6} for the prestressed concrete members.

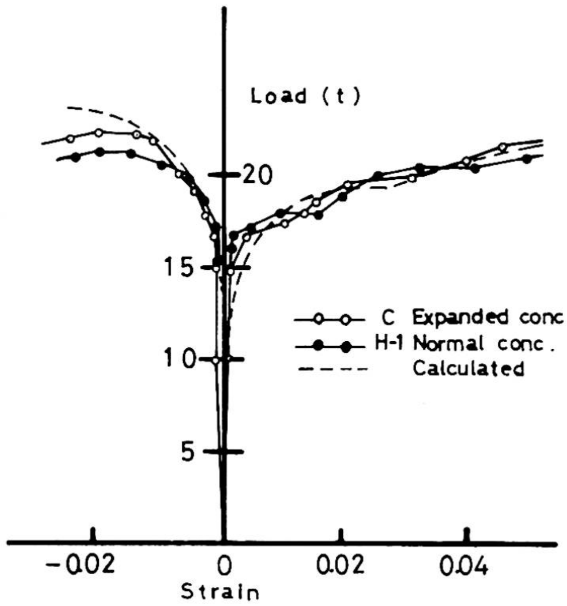

Fig. 7 Load—strain curve

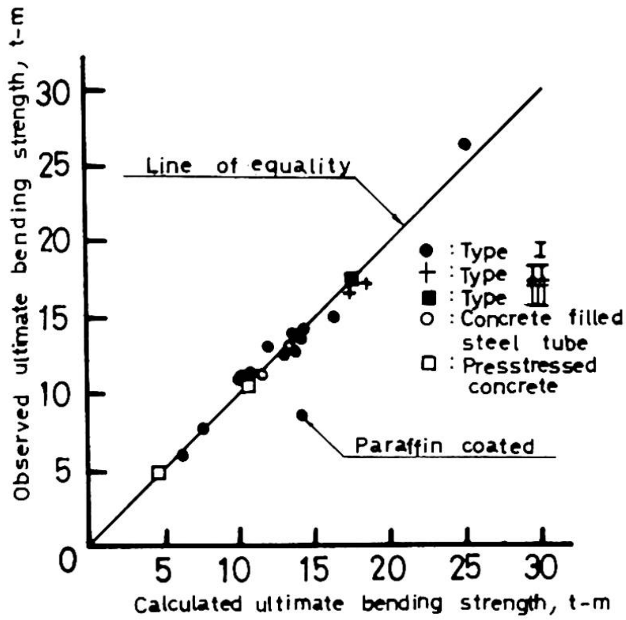

Fig 8 Relation between observed and calculated value of ultimate bending strength

4) Conclusions

The structural behaviour of this type of member indicated by the experiments may be summarized as follows:

1) It was verified that the hollow composite member has a high bending strength and great ductility, and this is thought to be due to the prevention of buckling of the steel tube, to the continuance of the united action of the concrete with the steel even when the internal concrete in the compression zone had become greatly deformed by the restraint of the steel tube and arch action, and to the fact that concrete in the

tension zone did not spall even after crack development.

2) Complete interaction takes place between the concrete and the steel tube of hollow composite member, lined with normal concrete without treating the inside of steel tube. The use of expansive concrete in the hollow composite members introduces chemical prestress to the concrete and improves the structural behaviour of the members at the elastic range.

3) The ultimate bending strength of this type of member could be calculated ignoring the tensile strength of concrete, assuming that the section would at all times maintain a plane, and that the maximum compressive fiber strain is 10,000 x 10^{-6}.

SUMMARY

It was verified that hollow composite members consisting of relatively thin circular steel tubes lined with concrete compacted by centrifugal force has a high bending strength and great ductility. The ultimate bending strength of this type of member could be calculated ignoring the tensile strength of concrete, assuming that the section would at all times maintain plane, and that the maximum compressive fiber strain is 10^{-5}.

RESUME

Il a été vérifié que les éléments composites creux formés d'un tube circulaire en acier mince revêtu de béton compacté par centrifugation, ont une grande résistance à la flexion, et une haute ductilité. L'effort à la flexion maximum pour ce genre d'éléments, peut être calculé sans tenir compte de la résistance à la rupture du béton, en supposant que la section reste tout le temps plane et que l'effort maximum de compression dans la fibre est égal à 10^{-5}.

ZUSAMMENFASSUNG

Die hier behandelten hohlen Verbundbauelemente bestehen aus einem Stahlrohr verhältnismässig kleiner Wanddicke und Beton, welches auf die Innenseite des Rohrs durch Schleudern aufgebracht wird. Es wurde nachgewiesen, dass diese Bauelemente eine grosse Biegefestigkeit und Duktilität besitzen. Ihr Bruchmoment kann unter Vernachlässigung der Betonzugfestigkeit unter der Voraussetzung ebenbleibender Querschnitte und einer maximalen Druckstauchung von 10^{-5} rechnerisch ermittelt werden.