KAWASAKI STEEL TECHNICAL REPORT
No.17 (October 1987)

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This study deals with the applicability of a newly developed pipe, which has spiral ribs on its inner surface, thereby making it a composite structure. Mechanical properties of the composite pipe were investigated through push-out, compression and bending tests. Main conclusions obtained are as follows:

(1) Bond stress can satisfy the ordinarily required value for the composite pipe having ribs more than 8 mm high.

(2) Nominal bond stress increases steadily with increasing the number of ribs.

(3) Structural member made of spiral ribbed pipes and concrete can be designed and used as a fully integrated body.

1 Introduction

The concept of steel-concrete combination for the use of structural member is not new, with many actual achievements seen in civil engineering fields. Its demand came to see marked rise following a series of events; one was the revision in 1974 made by Architectural Institute of Japan (AIJ) to the design rule for the foundation of building, stipulating that a pile should share the horizontal load applied to the structure. Another was many ruptures occurred to the top of foundation RC and PC piles caused by earthquakes happened in the offshore of Miyagi Prefecture (Japan) in 1978, and still another was the law-enforcement in 1983 of new aseismatic design method to building piles.

In the case of a general composite pile which uses the expansive admixture, bonding resistance between steel pipe and concrete is maintained by the expansive force working at the inner wall of the pipe. Problems are a high cost of the expansive admixture, and its yet unknown aging properties. A composite structure, which uses the dowel as the mechanical fastner of steel and concrete, is popular in the civil engineering field in Japan[1,2]; therefore, the realization of this type of composite pipe is highly expected.

This research intends to develop a new and improved manufacturing process of the composite pipe with which spiral ribs are welded to the inner surface of the pipe at the time of pipe manufacture and will discuss adequate shapes, sizes, and pitches of the rib through structural tests. Furthermore, the utility of the composite pipe tentatively manufactured with commercial production equipment will also be investigated. This type of composite pipe facilitates the control of the height and the pitch of the rib, and can be supplied at lower cost than ordinary types.

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2 Model Specimen

STK 41 steel pipe of 600 mmϕ × 9 mm$t$ and SS41 steel ribs of 9 mmϕ round bar and 9 mm × 9 mm square bar were used as model specimen. **Tables 1 and 2** show the mechanical properties and the chemical compositions, respectively. The pitch of the rib was chosen to be of two types; one, 812 mm which corresponds to the width of the steel plate for the spiral pipe, and the other, a half size, namely, 406 mm. The rib was spirally cold-formed and fillet-welded at both sides by SMAW (shield metal arc welding). A size of the fillet was 4 mm. Stud bolts, which are popularly used as the dowel for the composite structures, were used for several specimens (shown as mark "J" in Table 2) in order to compare the structural behavior with spiral-ribbed composite pipes. Schematic view of these specimens are shown in **Photo 1**.

Table 1 Mechanical properties and chemical composition of pipe

Mechanical properties			Chemical composition (wt %)				
YP (MPa)	*TS* (MPa)	*El* (%)	C	Si	Mn	P	S
275	461	41	0.16	0.18	0.57	0.014	0.016

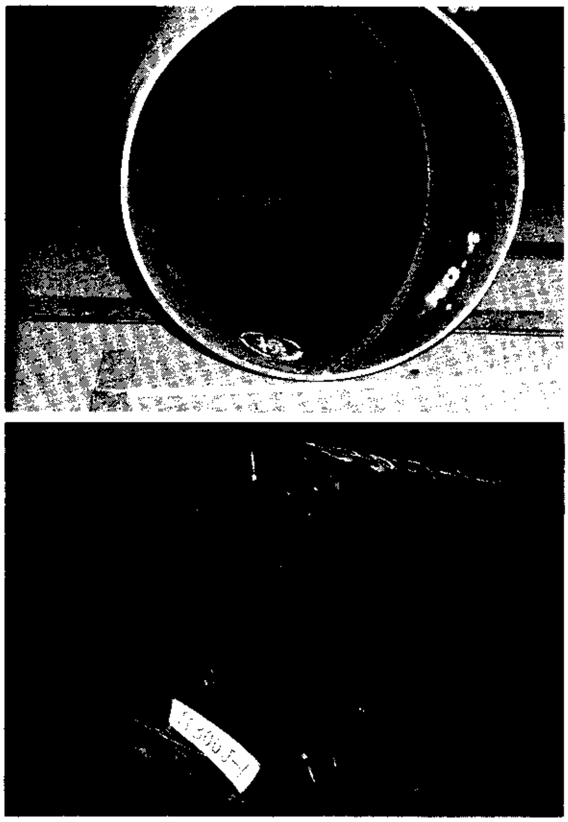
Table 2 Specimens used

Test	Specimen	Concrete		Rib			
		Strength (MPa)	Young's modulus (GPa)	Lining (cm)	Figure	Dimension (mm)	Pitch (mm)
Push out	S300FN	29.1	19.2	filled in			
	S300FS-1	29.1	19.2	9	Square	9×9	812
	S300FR-2	29.1	19.2	9	Round	9 ϕ	406
	S800LN	70.3	37.5	9			
	S500LS-1	43.3	27.9	9	Square	9×9	812
	S500LS-2	43.3	27.9	9	Square	9×9	406
	S500LR-1	43.3	27.9	9	Round	9 ϕ	812
	S500LR-2	43.3	27.9	9	Round	9 ϕ	406
	S500LJ-1	43.3	27.9	9	Stud	13 ϕ×60	270
	S500LJ-2	43.3	27.9	9	Stud	13 ϕ×60	170
Compression	CPR-2*				Round	9 ϕ	406
	CPS-2*				Square	9×9	406
	C500LS-2	43.3	27.9	9	Square	9×9	406
	C500LR-2	43.3	27.9	9	Round	9 ϕ	406
	C500LJ-2	43.3	27.9	9	Stud	13 ϕ×60	170
	C300FN	29.9	19.7	filled in			
	C800LN	81.3	38.1	9			
Bending	BPR-2*				Round	9 ϕ	406
	BPS-2*				Square	9×9	406
	B500LS-2	43.3	27.9	9	Square	9×9	406
	B500LR-2	43.3	27.9	9	Round	9 ϕ	406
	B500LJ-2	43.3	27.9	9	Stud	13 ϕ×60	170
	B300FN	29.9	19.7	filled in			
	B800LN	81.3	38.1	9			

* Without concrete

a

b



(a) Pipe with spiral rib
(b) Pipe with stud bolts

Photo 1 Schematic view of pipes with spiral rib and stud bolts

Three strength levels 30, 50, and 80 MPa were adopted for the concrete. The 30-MPa level corresponds to the concrete which is cast at the construction site, and the concrete was filled up in the pipe. The 50- and 80-MPa levels were lined 90 mm thick to the spiral-ribbed pipes and the ordinary spiral pipes, respectively. The expansive admixture was mixed to the latter specimens which correspond to the popularly marketing composite pile. The expansive admixture was not used for the 30- and 50-MPa level concrete.

3 Push-out Test

The design rule for the composite pipe, specified by

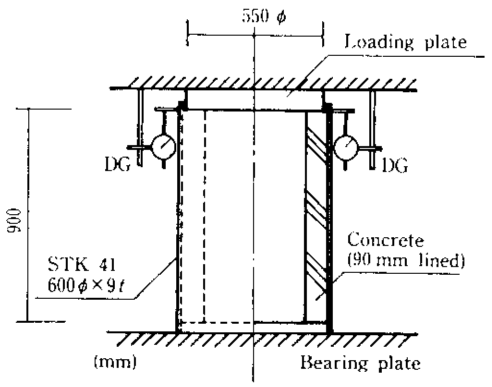


Fig. 1 Push-out testing apparatus

Table 3 Bond stresses obtained from the push-out tests

Specimen	Collapse load (kN)		Nominal bond stress (MPa)	Ratio to 800 LN	Ratio to allowable stress*
	Average	Standard deviation			
S300FN	1 689	263.7	1.03	0.62	4.67
S300FS-1	4 200	20.4	2.55	1.53	11.5
S300FR-2	5 132	83.5	3.12	1.87	14.1
S800LN	2 788	274.3	1.67	1.00	7.56
S500LS-1	5 401	128.0	3.29	1.97	14.9
S500LS-2	6 407	233.0	3.89	2.34	17.6
S500LR-1	5 374	68.6	3.27	1.96	14.8
S500LR-2	6 051	648.1	3.68	2.21	16.7
S500LJ-1	3 586	109.3	2.18	1.31	9.87
S500LJ-2	6 407	304.0	3.89	2.34	17.6

* Specified in "Specification for calculation of composite tube structures"[2]

AIJ, adopts the allowable bond stress between pipe and concrete to a constant value, 0.15 MPa, which is considerably low, independent of the strength of concrete.[3] This value is assumed to have been determined reflecting the fear that the bond stress tends to be scattered or lowered in the case of the ordinary casting, especially of the site casting, because cast concrete is easily shrinked at the hardening stage and the inner surface of the pipe tends to be stained by mud or oil. The composite pipe dealt in this study makes a contrast with the ordinary case stated above, since the stable higher bond stress which acts as a kind of a mechanically combining force can be expected between spiral rib and concrete.

Bond stresses were investigated through simple push-out tests using a 9.8-MN structural testing machine and the equipment as shown in **Fig. 1**. Relative slippage between the pipe and the concrete was measured as the relative deformation of a pipe to the loading plate as shown in Fig. 1.

Table 3 shows collapse loads obtained by the push-out tests. Three specimens for each test series, or totally 30 specimens were tested. The bond stress 4.7 times the allowable stress specified by AIJ was obtained for S 300 FN series, to which a concrete having strength slightly higher than ordinary one was used. In this study, pipes were cleaned by hand grinder before concrete placing so that such a high bond stress could be obtained under an adequate control of the pipe surface.

S 500 LJ-1 and 2 adopted a kind of a dowel, named stud-bolt. This is commonly used for the composite structures in order to obtain the stable bond stress, and the spiral-ribbed composite pipe, which adopted square or round shaped rib, showed almost the same strength as the stud-bolted one. Therefore, it is concluded that the spiral-ribbed pipe is useful enough for the composite structures.

S 800 LN was the same as a popularly used composite pile authorized by the Ministry of Construction, and all the specimens except S 300 FN, which had no rib and no expansive admixture in concrete, showed bond strength higher than S 800 LN. It can be said, therefore, that in ensuring the nominal bond stress between concrete and steel, mechanical resistance given by the rib is superior to the frictional and bonding resistance given by the expansive admixture. **Photos 2** and **3** indicate the concrete surface of the spiral-ribbed type (S 300 FR-2) and the ordinary type (S 800 LN), respectively, after push-out tests. It is clear that the collapse of the former was determined by the crush of the concrete kept in touch with the rib, and the latter by the slip of the concrete. Therefore, the nominal bond stress is assumed to be increased by the dense distribution of the rib.

Within the scope of the subject test the difference of the rib configuration did not affect the bond stress; therefore, it is assumed that round rib has the same bond strength as the square rib when the height of the rib is equal to each other. The nominal bond strength of the spiral-ribbed composite pipe can be calculated by the following equation.

$$\sigma_s = \frac{1}{A_P}(\sigma_f A_P + \sigma_b A_R) \quad \cdots\cdots\cdots\cdots\cdots (1)$$

where, σ_s: Nominal bond strength

σ_f: Bond strength expected at the inner surface of the pipe

σ_b: Bearing strength expected at the rib

A_P: Area of inner surface of the pipe

A_R: Bearing area of the rib = Height × Total length of the rib

Assuming that σ_f in Eq. (1) is constant and has no relations with ultimate strength of the concrete, σ_b of each spiral-ribbed composite pipe can be calculated as

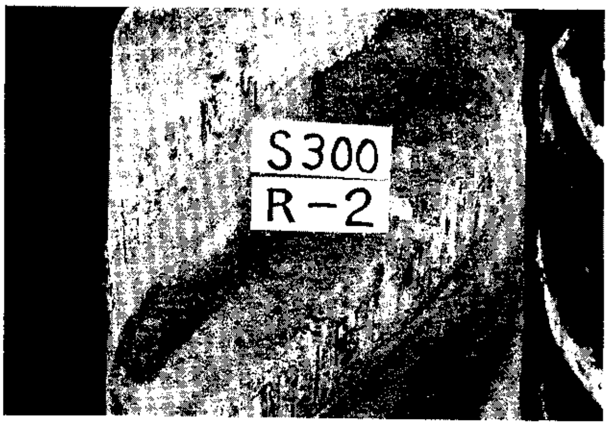


Photo 2 Crushed concrete at the rib after push-out test (S 300 FR-2)

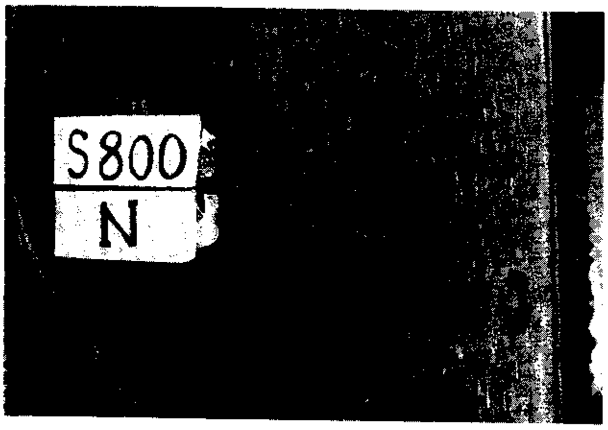


Photo 3 Slippage of concrete after push-out for ordinarily used type (S 800 LN)

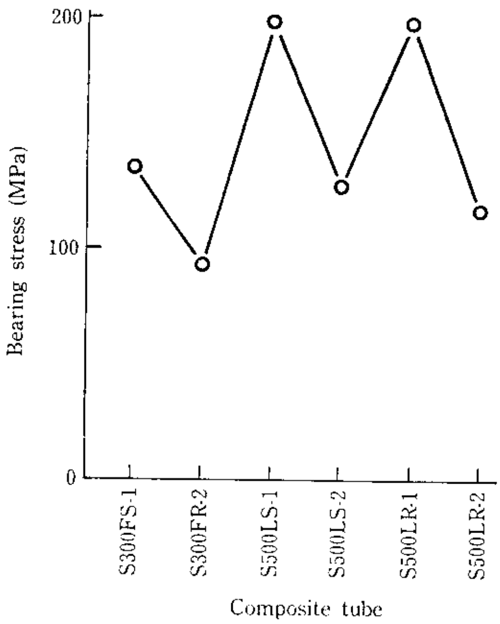


Fig. 2 Bearing stresses of composite tubes

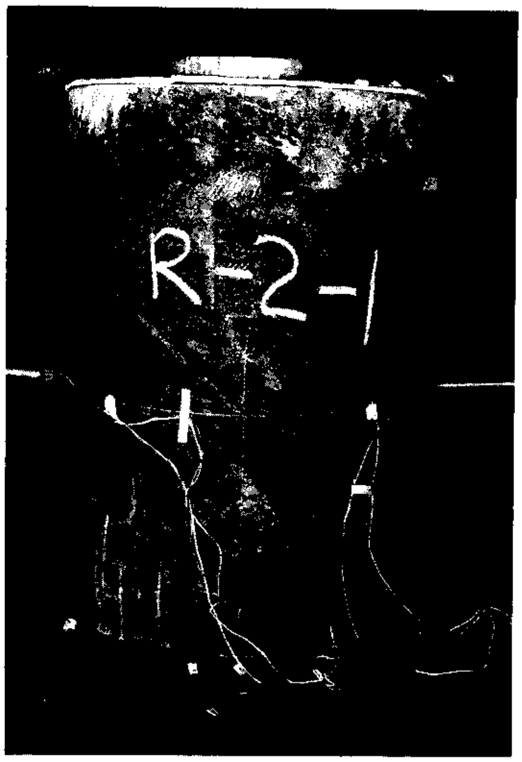


Photo 4 Local buckling of steel at the rib

shown in **Fig. 2**. It is derived from this figure that σ_b is dependent on the number of the rib, and has no relations with the concrete stregnth as σ_f. It is not clear, however, that this phenomenon would arise generally, because the ultimate strength of a spiral-ribbed composite pipe could also be dependent on the radial local buckling of the pipe at the rib, as shown in **Photo 4**, as it is dependent on the crush of the concrete at the rib. Namely, σ_b can be increased with an improvement of the pipe strength which restrains the concrete deformation. In any case, σ_b would be expected to be high around 100 MPa and exceed the concrete strength fairly well.

4 Column Strength

Compression load was simply added to the stub column specimen using a 29.4-MN structural testing machine. The column length was 3 000 mm long, and the loading was made untill failure occurred after arranging loading points so that longitudinal strains of four points at mid span of the pipe would fall in the range of $\pm 10\%$ of the mean value. High strength plaster was put into both edges of the specimen in order to give equal strains to the pipe and the concrete.

Test results are shown in **Table 4**. Calculated values show good accordance with test results of both maximum strength and initial rigidity of the column. Maximum strengths were calculated by the following

Table 4 Strength of composite column

Specimen	Collapse load			Stiffness			P_y *3 (kN)	D_{max} *5/ D_y *4
	exp.*1 (kN)	cal.*2 (kN)	exp./cal.	exp.*1 (kN/mm)	cal.*2 (kN/mm)	exp./cal.		
CPR-2	5 413	4 962	1.09	981	1 147	0.85	4 305	7.0
CPS-2	5 472	4 962	1.10	1 010	1 147	0.88	4 344	7.2
C500R-2	14 220	11 219	1.27	2 501	2 481	1.01	11 376	1.7
C500S-2	15 200	11 219	1.36	2 667	2 481	1.08	11 895	1.7
C500J-2	12 621	11 219	1.13	2 177	2 481	0.89	9 414	2.4
C300FN	16 279	13 435	1.21	2 903	3 011	0.96	12 866	3.2
C800LN	18 142	16 691	1.09	2 618	2 981	0.88	15 691	1.2

*1 Test results
*2 Calculated values
*3 P_y: Yield load obtained by general yield method
*4 D_y: Displacement obtained at P_y
*5 D_{max}: Displacement obtained at collapse load

equation.

$$P_{max} = A_s\sigma_s + A_c\sigma_c \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

where, A_s: Sectional area of the pipe
A_c: Sectional area of the concrete
σ_s: Buckling strength of steel pipe
σ_c: Concrete strength

Strengths of tube columns (CPR-2, CPS-2 in Table 4) were calculated by Kato's method[4] which treats the local buckling of tube columns after yield strength, and in this case, the stiffening effect of the rib was not considered.

Structural elements, which should endure earthquakes and wind forces, are required to be tough. The toughness of the structural member is generally represented as a capability of deformation (D_{max}/D_y in Table 4), and $D_{max}/D_y \risingdotseq 3$ is obtained for the ordinary RC structural member.

In this study, R, S, and J of C 500 series and C 800 LN were resulted in $D_{max}/D_y < 3$. They were concrete-lined composite pipes at the inner surface, and it is considered that the resistance for the expansion, namely, the resistance for the tension at this free surface was smaller than that of filled-in type. In case of filled-in type (C 300 FN), $D_{max}/D_y \risingdotseq 3.2$ was obtained. Compared with the lined type, the toughness was in the order of J > R = S > N, so it is concluded that the spiral-ribbed type is tougher than the expansion admixture-added type.

5 Simple Bending Test

Specimens, which had a span of 6 000 mm and supported by rollers at both ends, were loaded equally and gradually at two mid-points (span 2 000 mm) until they reached failure. Displacements and strain distributions were measured at several loading stages. **Figure 3** indicates the obtained load-displacement at mid-span of the specimen relationships. Results show almost the same stiffness for the composite pipe except B 300 FN, which is of concrete filled-in type. Lines which correspond to stiffnesses of specimens are the calculated values, assuming that whole section of the concrete is effective. It is clear from these results that in the case of composite pipes, the tension-side concrete was restrained by the rib or the expansion admixture (800 LN), preventing the crack extension of the concrete in the elastic range of the steel, thus maintaining high rigidity at the initial stage of bending. In other words, it is concluded that the structural behavior of the composite pipe, which is spirally ribbed or adopts the expansion admixture, can be estimated practically by the use of real Young's modulus ratio of steel to concrete and assuming that the whole section of the concrete is effective for the stiffness of the pipe.

On the other hand, the concrete filled-in type showed a slightly larger deformation than ribbed or admixture-added type. This is considered attributable to the fact that the type in which concrete was simply filled in the pipe has the same bond strength as in general RC structures, so the crack tends to occur to the tension-side concrete at a relatively initial loading stage, thus interrupting an effective functioning of the whole cross-section against bending.

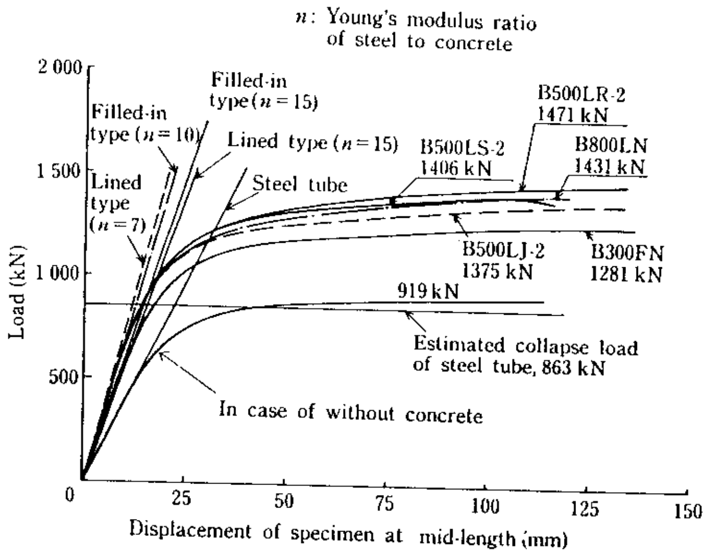


Fig. 3 Bending test results

6 Trial Manufacture of the Spiral-Ribbed Composite Pipe

6.1 Manufacture of the Spiral-Ribbed Pipe

Since the conclusion was obtained through structural tests including push-out tests that the configuration of the rib does not affect the bond strength, the round bar of 8 mmϕ was adopted for the trial manufacture because of the utility such as the followings: (1) Materials for ribs are easily available, (2) a feeder which supplies the rib is simple, (3) welding can be conducted automatically. Manufactured pipe was STK 41, 600 mmϕ × 9 mm$t$, and lined with concrete 90 mm thick as the same condition stated before.

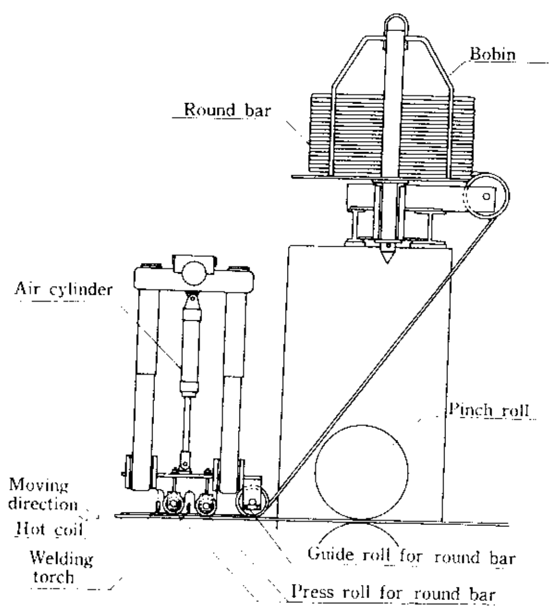


Fig. 4 Manufacturing process of "Spiral ribbed pipe"

Connecting process of the rib is shown in **Fig. 4**; a round bar is supplied continuously between a guide roll and a pinch roll, and then pressed and welded to the steel plate by the use of the press roll and GMAW (gas metal arc welding: CO_2 gas shielded). The rib is connected to the steel plate at the front of the forming press of the spiral pipe.

6.2 Bond Strength of the Trial Manufactured Composite Pipe

Spiral-ribbed pipes were manufactured by the equipment described above. An example of the manufactured pipe is shown in Photo 1(a). The used steel coil was KPH 42 shown in **Table 5** and the round bar was 8-mmϕ annealed type. Two pipes each 6 000 mm long were manufactured. One was welded at the both sides of the rib, and the other is welded at only one side of the rib. The welding condition is shown in **Table 6**.

The bonding strength of the composite pipe was investigated by push-out tests as shown in Fig. 1. In this test, a high strength concrete of 85.1 MPa and no expansive admixture was adopted.

Test results shown in **Table 7** indicate no clear effect of

Table 5 Properties of coil used for manufacturing test of "spiral ribbed pipe"

Coil	Size (mm)	Mechanical properties			Chemical composition (wt %)				
		YP (MPa)	*TS* (MPa)	*El* (%)	C	Si	Mn	P	S
KPH 42	9 *t* × 1 305 *W*	294	481	37	0.16	0.20	0.61	0.025	0.014

Table 6 Conditions of rib welding

Welding	Consumables	Current (A)	Voltage (V)	Velocity (cm/min)
GMAW	KC-50, 1.2 mmϕ, CO_2 gas shielded (20 l/min)	220	33	120

Table 7 Bond stresses obtained for manufacturing test specimens

No. of specimen	Strength of concrete (MPa)	Bearing area of rib (cm²)	Collapse load (kN)	σ_b*1 (MPa)	σ_s*2 (MPa)	Rib welding
800 S-1	85.1	104.4	3 697	186.9	2.25	One side
800 S-2	85.1	104.4	3 707	187.9	2.26	One side
800 S-3	85.1	104.4	3 746	191.6	2.28	One side
800 W-1	85.1	104.4	3 677	185.1	2.24	Both sides
800 W-2	85.1	104.4	3 717	188.8	2.26	Both sides
800 W-3	85.1	104.4	3 815	198.2	2.31	Both sides
		Average	3 727	189.8	2.27	
		Standard deviation	44.1	4.27	0.025	

*1 Bearing stress
*2 Nominal bond stress

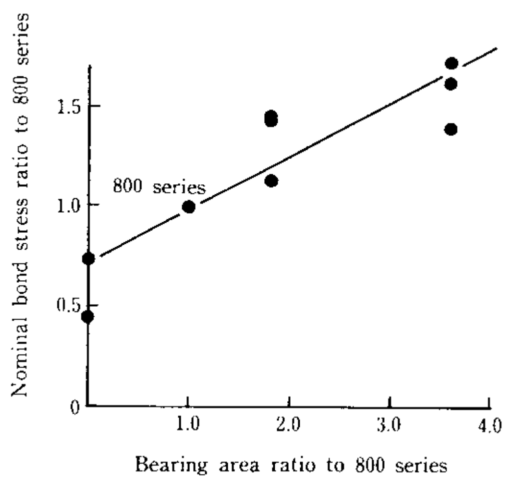


Fig. 5 Nominal bond stress vs. bearing area

the welding process on the bond strength. It is therefore concluded that the welding for the only one side of the rib is sufficient for practical uses.

Figure 5 summarizes the relationships between the bearing area of the rib and the nominal maximum bond strength detected from Tables 3 and 7. It is clear from this figure that the nominal bond strength increases as an increase of the bearing area. Conversely, bearing area which satisfies the required bond strength of the rib can be derived from this relationship.

7 Conclusions

Through pre-studies on the structural properties of the composite pipe, in which the bond strength between steel and concrete was increased by the use of spiral rib connected to the inner surface of the steel pipe, and trial manufacturing, the following conclusions are obtained:

(1) Sufficient bond strength can be obtained by a minimum of 8-mm height of the rib. The configuration of the rib does not affect the strength under this condition.

(2) In the case of the pipe of less than 600 mmϕ, only one rib welded to the center of the steel width is enough to ensure practical bond stress requirements.

(3) It is enough to weld only one side of the rib for the practical use of the composite pipe.

(4) The bond strength increases as the number of the rib increases.

(5) Spiral-ribbed composite pipes can be designed based on the assumption that the concrete is connected firmly to the steel, to form a concrete-steel unity function.

The above conclusions obtained for the structural properties were investigated only for the pipe of 600 mmϕ × 9 mm*t*. Therefore, follow-up surveys on the pipe dimensions would be necessary in order to generalize these conclusions, and the relationship between the strength of the concrete and the effect of the rib should also be clarified.

Though several details remain still unknown, it is clear that the spiral-ribbed composite pipe has structural properties superior to those of the one with expansive admixture.

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1) Japan Road Association: "Specifications for Highway Bridges," (1983), 130–133, [Maruzen]
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4) B. Kato, H. Akiyama, and H. Suzuki: "Inelastic Local Buckling of Steel Circular Tubes under Pure Compression," *Trans. Architectural Inst. Japan*, No. 204 (1973), 9–17