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Concrete-filled Rectangular Hollow Sections with Inner Ribs

Sections rectangulaires creuses à nervures intérieures remplies de béton

Betongefüllte rechteckige Stahlhohlprofile mit inneren Rippen

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SUMMARY

This paper deals with the concrete-filled Rectangular Hollow Sections with inner ribs which are developed to improve the bond stress capacity. In order to make full use of the generalized superposed strength of steel-concrete composite members, the steel and concrete components need to behave with the same neutral axis. This is confirmed by the theory of the limit analysis and the results of the beam-column tests. Furthermore, a new type building system which uses the Rectangular Hollow Sections with inner ribs is introduced.

RÉSUMÉ

Cet article traite des sections rectangulaires creuses à nervures intérieures remplies de béton, qui ont été développées pour améliorer la contrainte d'adhérence. Afin d'utiliser complètement la résistance superposée équivalente des éléments mixtes acier-béton, il est nécessaire que les deux composants acier et béton aient le même axe neutre. Cela est confirmé par la théorie de l'analyse à l'état limite et par les résultats d'essais effectués sur le dispositif poutre-poteau. Cette étude présente en outre un nouveau système de bâtiment utilisant les sections rectangulaires creuses à nervures intérieures.

ZUSAMMENFASSUNG

Dieser Aufsatz behandelt betongefüllte rechteckige Stahlhohlprofile mit innenliegende Rippen zur Verbesserung der Verbundspannungen. Um beide Werkstoffe im Verbund voll auszunützen, müssen deren Neutralachsen zusammenfallen. Dies wird durch Traglastbetrachtungen und Versuche an Stützen und Riegeln bestätigt. Weiter wird ein Hochbausystem vorgestellt, welches diese Verbundbauteile verwendet.

1. INTRODUCTION

Concrete-filled tubular (CFT) structure are recently taken worthy notice in Japan, because of not only its excellent structural and fire resistant characteristics, but also its advantage in construction works. However, the following problems are pointed out which should be gotten over for the CFT structure to be spread over many buildings.

(1)For example in the usual beam-to-column connection shown in Fig.1, it is said that the concrete unfilled portion exists especially under the diaphragms. In this problem, there is no reliable inspection and also repair methods.

(2)There is a question about the stress transfer mechanism from beams to filled concrete. In the case that the beam forces are designed to be transferred in terms of bond stress between inner surface of steel tube and filled concrete, the bond strength is quite small and uncertain of value for a long time. This question leads the one on necessary condition of the generalized superposed strength (GSS) theory which is the theoretical base of structural design of CFT columns.

To over come above mentioned problems, the author developed the rectangular hollow section (RHS) with inner ribs for the CFT columns as shown in Fig.2 which is produced by roll forming or press forming process using hot-rolled steel plate with checkered typed ribs. The RHS with inner ribs improves the bond stress capacity due to mechanical resistance of the ribs and filled concrete. The inner ribs of CFT columns have following main three roles.

(1)It gives the satisfactory condition for the GSS by complete achievement of stress transfer from beams to filled-concrete within beam-to-column connections.

(2)It can increasingly emphasize the advantages in construction works of CFT structures by being used at the column bases, column joints and beam-to-column connections.

(3)It improves the plastic deformation capacity of the structure, and then gives the reasonable limitation of width-thickness ratio of the RHS.

Pushing-out typed bond stress capacity tests shown in Fig.3 were done in which the parameters were the width-thickness ratio of the RHS (B/t) and the concrete compressive strength (Fc). The experimental bond strength (τbmax) formula was obtained already as shown in Fig.4 which is also based on the fracture theory of concrete [1]. Thus the bond strength of RHS with inner ribs is 0.3~0.6 kN/cm^2 which is larger than the one of RHS with flat surface by approximately one-digit, and

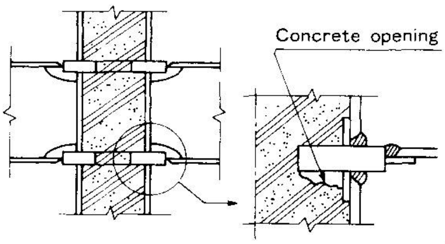


Fig.1 Imperfect concrete filling

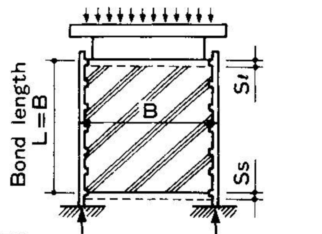


Fig.3 Scheme of bond strength test

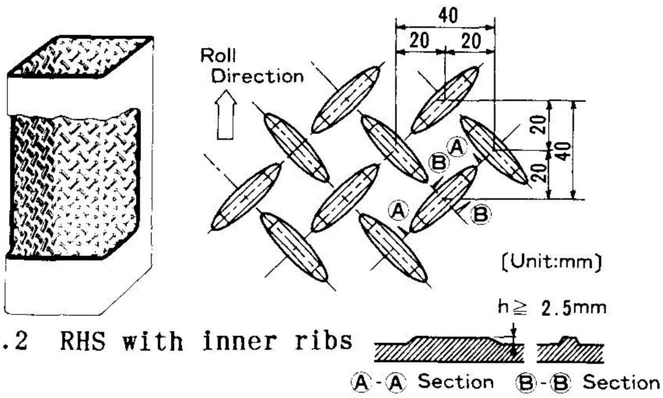


Fig.2 RHS with inner ribs

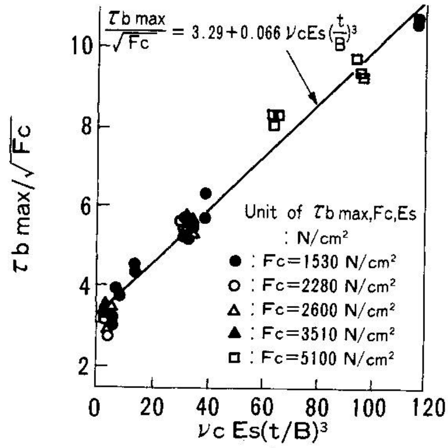


Fig.4 Bond strength τbmax

can be estimated with the experimental formula. In this paper, the author describes the technical significance and roles of the RHS with inner ribs.

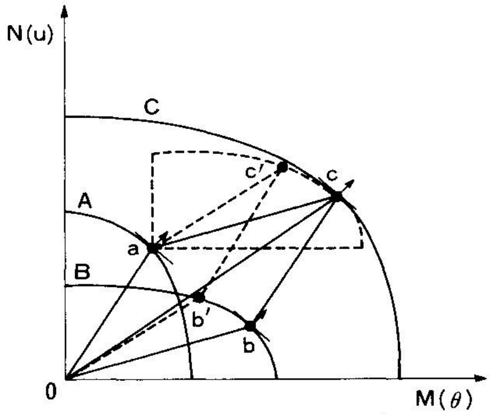


Fig.5 Yield surface and GSS

2. NECESSARY CONDITION OF THE GSS THEORY

Structural design of steel-concrete composite structures has been based on the GSS theory which deals with the plastic strength of the section [2,3].

We discuss about the relation between the superposed strength and the slip behavior of composite section. Let us assume the section S composed of components SA and SB yield surfaces of which are A and B as shown in Fig.5. In this case, the yield surfaces are drawn with the co-ordinate axis of axial force (N) and bending moment (M). Superposing the plastic strength of A and B means the vector sum of Oa and Ob which are stress points on the yield surfaces. The most outside locus of this vector sum is nothing but the envelop curve resulting from moving of the origin of B along the yield surface A. THis envelop curve C in Fig.5 obviously corresponds to the locus of c obtained as the vector sum of a and b which have parallel tangent at each yield surface. On the contrary, if the tangent at another point b' is not parallel to the tangent at point a, the vector sum point c' is evidently plotted inside of C. Namely the point c on the superposed envelop curve is the vector sum of the points which have same slope of tangent at each yield surface A and B. The same slope of tangent leads the same normal slope, then the directions of plastic flow of each section are same. In the case of composite sections under axial force and bending moment, this means that the each component sections have same ratios of axial deformation (u) to rotation (θ), and then behave with the same neutral axis. In this instance only, the plastic strength of the section is equal to the GSS. In other word, in order to make full use of the GSS of composite members, the component sections should behave with the satisfactory condition of the Bernoulli's Beams. Namely in the case of CFT columns, the slip behavior between the steel tube and filled-concrete must not be caused. This is the first role of the inner ribs of the RHS.

3. BEAM-COLUMN TESTS

Bending and shear experiments of the CFT columns under constant axial load are performed to confirm the above mentioned necessary condition

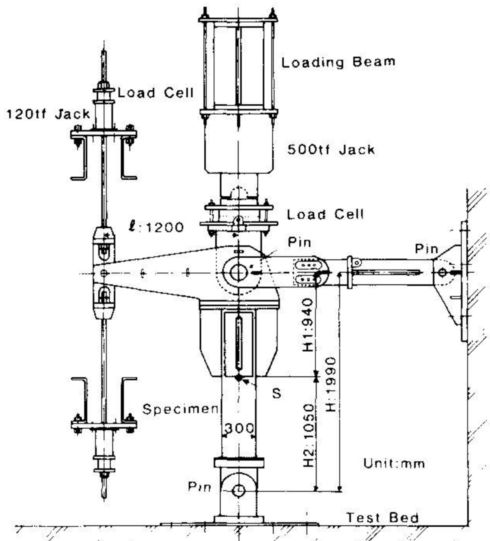
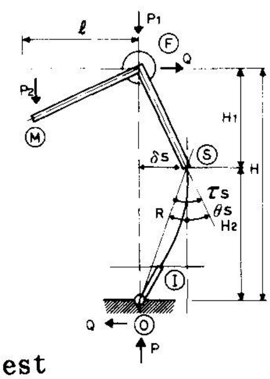


Fig.6 Scheme of Beam-Column test



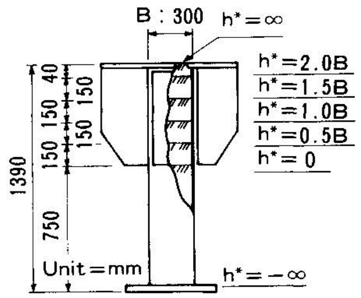


Fig.7 Development length (h*)

Table 2 Mechanical properties of the RHS

Kind of square tube	σy (kN/cm²)	σu (kN/cm²)	EL (%)
R50 (t= 6 mm) R.H.S.With inner ribs	38.9	45.0	37.2
F50 (t= 6 mm) R.H.S.With flat surface	37.7	44.1	37.9

σy : yield strength
σu : ultimate strength
EL : elongation

Table 3 Mechanical properties of the concrete

Concrete age (Weeks)	Fc (kN/cm²)	σt (kN/cm²)	Ec (×10³kN/cm²)	νc
4	2.28	0.26	2.01	0.19
8	2.71			
11	2.98			

Fc : Compressive strength
σt : tensile strength
Ec : Young's modulus
νc : Poisson's ratio

Table 1 Specimens of Beam-Column tests

	B/t (t)	50 (6 mm)			Remarks
	n	0.0	0.25	0.5	
h*	−∞		R50SHQ		B : Width of square tube(300mm) t : Thichness of square tube n : Axial force ratio n=P/No No=σy·As+Fc·Ac h* : Development length for anchorage
	0		R5000Q		
	0.5B		R5005Q		
	1.0B		R5010Q		
	1.5B	R5015NC	R5015QC F5015QC	R5015HC	
	2.0B		R5020Q R5020QC	R5020H	Naming rule: R5015HC R:With inner ribs / F:Without ribs 50···B/t=50 h*=1.5B N···n=0 / Q···n=0.25 / H···n=0.5 C:Cyclically loaded
	∞		R5099Q F5099Q R5099QC F5099QC		

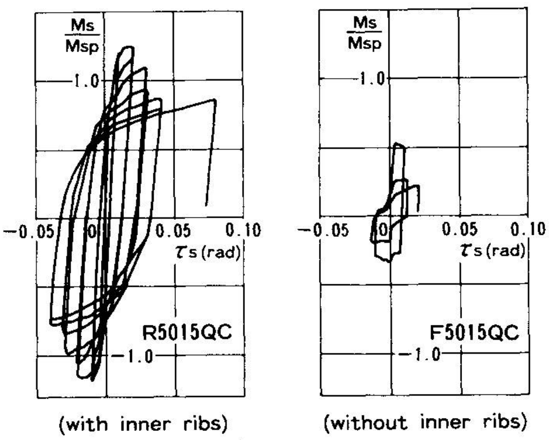


Fig.8 Ms-τs relations

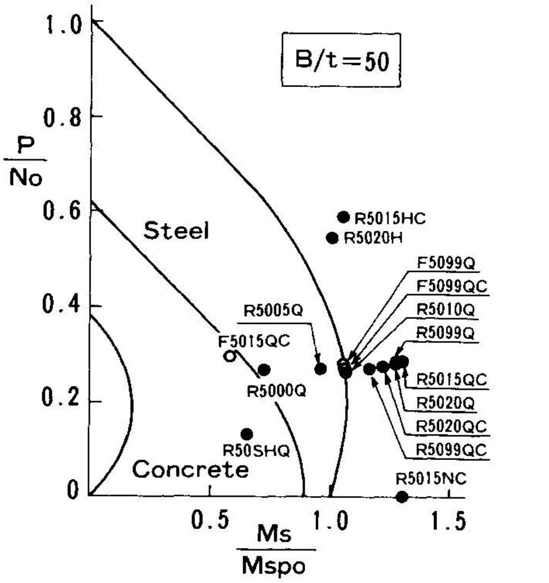


Fig.9 Load carrying capacity interaction

of the GSS theory. Scheme of the tests, the deformation figure and the list of the specimens are shown in Fig.6 and Table 1. The bending moment (Ms) at point Ⓢ and the tangential rotation (τs) which roughly corresponds to the story deformation angle are adopted as the main load-deformation relation. The main parameter is the development length (h*), that is, the height of filled concrete shown in Fig.7 which is adopted to evaluate the stress transfer mechanism and the effects of bond strength on the strength and deformation capacity of the CFT columns. Table 2,3 show the mechanical properties of RHS and concrete used in the experiments. As the loading order, the axial load (P1) is imposed first. After that, the bending and shear are given by P2, getting control over P1 for the axial force of the specimen (P) to keep constant. The examples of the load-deformation relations are shown in Fig.8 in which the bending moment is normalized by the GSS (Msp) given in Ref. [4]. In N-M interaction in Fig.9, maximum strength of the specimens are plotted as well as the GSS curve in which the bending moment is normalized by the GSS in the case without the axial load (Mspo). This figure indicates that the maximum strength becomes large in proportion as h* is long in the case of RHS with inner ribs. The strength reaches the GSS if h* equal to the column with (B), and meets to some value of strength if h* is over 1.5B. This strength is recognized as the maximum strength of the CFT column in the case that the bond strength capacity is sufficiently enough. Namely if h* is over 1.5B which is roughly appropriate

as height of beams, the RHS with inner ribs can transfer the forces which correspond to concrete strength to filled concrete by the bond stress capacity. Bond strength distribution of CFT columns can not be explained explicitly even now in the case under bending moment. If we estimate under the assumption that the stress transfer is performed in compression and tension side separately by respective bond strength, the working bond strength (τb) equal to $B^2 \cdot Fc/(4B \cdot 1.5B)=0.4$ kN/cm^2. This bond strength is recognized to be within the bond capacity shown in Fig.4.
The results of the beam-column tests can explain the relation between stress transfer capacity in beam-to-column connection and member strength. If the development length is not enough, the GSS of CFT column can not be obtained. This result was implied also by the frame tests [5].

4. NEW BUILDING SYSTEM

As the advantages of improving the bond stress capacity by inner ribs, the utilization in the member connection such as column joint, column base and beam-to-column connection is available. Here the author introduces the improvement of the column joint and column base of CFT columns shown schematically in Fig.10,11. In both connections, the stress transfer of steel members is accomplished by the bond strength between ribs of the RHS and grouted high strength non-shrink mortar. Inspection of bond strength is to be done with the aid of the bond strength formula in Fig.4 [6]. In many cases, the full strength design of connection is available under the condition that the development length (L) is $(1.5\sim2.0)B\ell$.
The new building system which was developed by using previously mentioned column and connections is illustrated in Fig.12. In this system, most of construction works including the concrete filling into the RHS can be done in the steel shop, then the welding work is not needed in the construction field. The orders of steel works in the field are as followings. (1) erection of the columns (2) laying of girders and beams (3) laying of deck plates (4) plumbing of frame (5) tightening of connection H.T. bolts (6) mortal grouting in column base and column joint.
By using this system, many skillful works in the field can be in little need and the construction term can be reduced into about half as much as one of the usual construction method.

5. CONCLUSION

(1)In order to make clear the stress transfer mechanism which is important

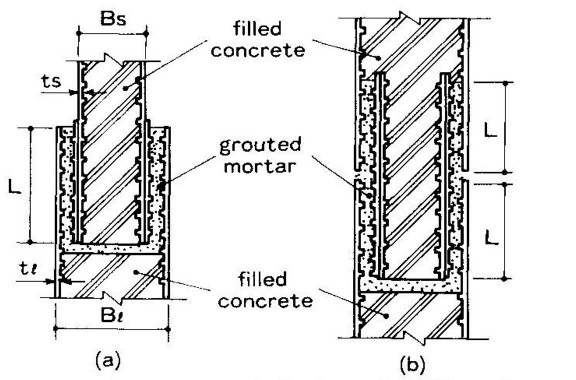


Fig.10 New type joints of CFT columns

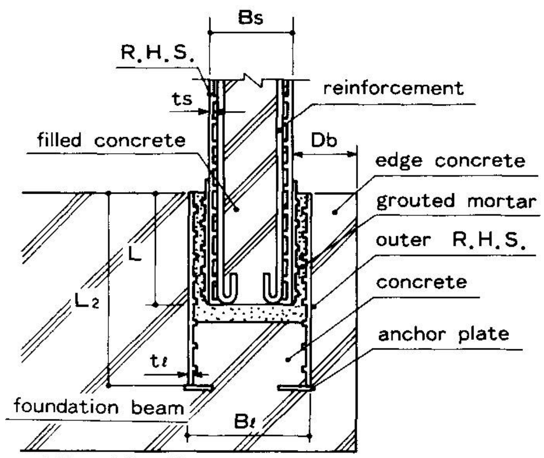


Fig.11 New type column base

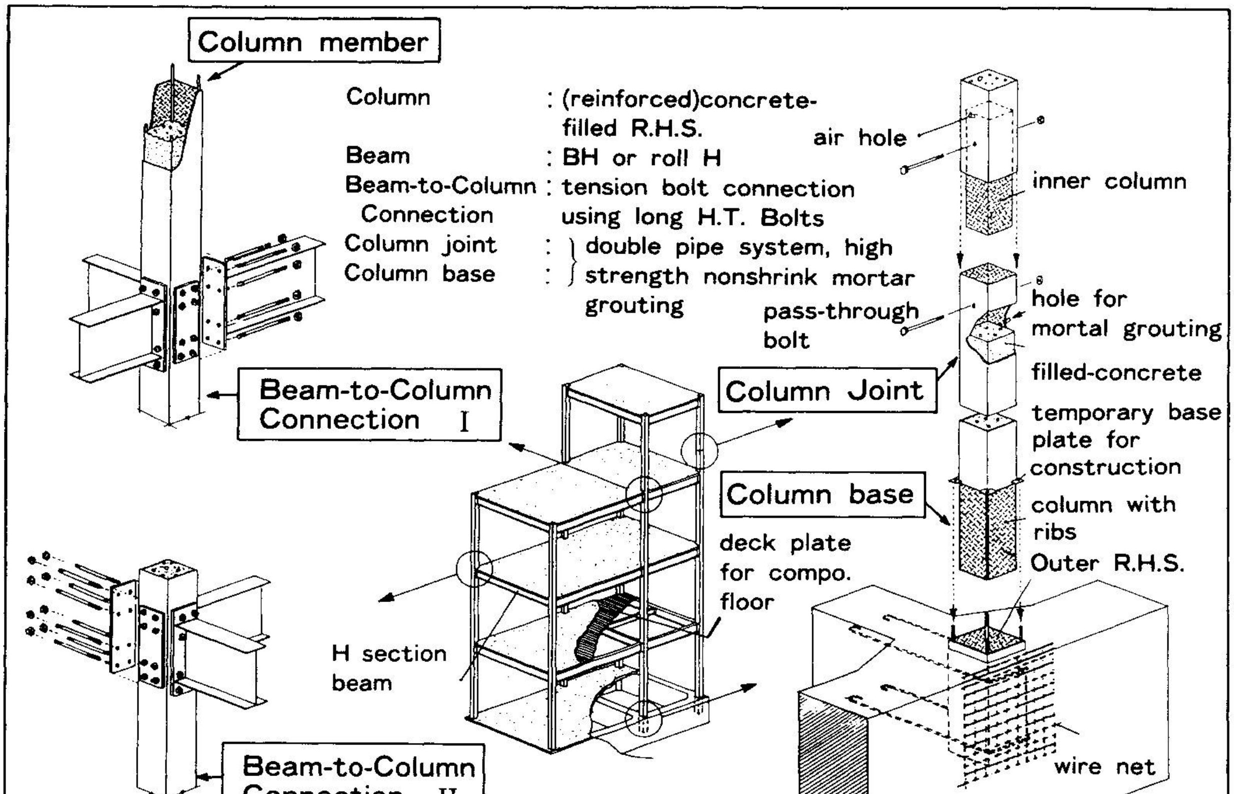


Fig.12 New typed building system

problem in the beam-to-column connection of the CFT columns, the RHS with inner ribs is developed.

(2)The GSS theory and the results of the beam-column tests indicate that the slip behavior between the RHS and filled concrete must not exist. This is the first role of the large bond strength given by the inner ribs.

(3) The new type column joint and column base systems which utilize the large bond strength of the RHS are introduced. These systems are very helpful in the construction works.

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