Composite structures of concrete and steel plate

Autor(en): **Takeuchi, Hirokazu / Okamura, Hajime**

Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **55 (1987)**

PDF erstellt am: **29.04.2024**

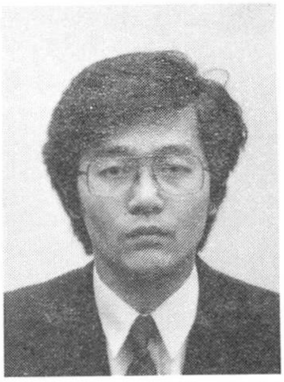
Persistenter Link: https://doi.org/10.5169/seals-42764

Composite Structure of Concrete and Steel Plate

Structure composite en béton et tôle d'acier

Verbundbauteile aus Beton und Stahlplatten

Hirokazu TAKEUCHI
Civil Engineer
Ishikawajimaharima Heavy Ind.
Tokyo, Japan



Hirokazu Takeuchi, born in 1954, received his M.E. degree from Waseda University in 1980. He has been engaged in research and design of concrete and steel structures at Ishikawajimaharima Heavy Ind., Ltd.

Hajime OKAMURA
Professor
University of Tokyo
Tokyo, Japan

Hajime Okamura, born in 1938, received his Dr. Eng. degree from the University of Tokyo in 1966. He is a professor of civil engineering at the University of Tokyo.

SUMMARY
The composite structure of concrete and steel plate without reinforcing bar has various advantages compared with reinforced concrete. The steel plate, which acts also as the formwork, resists external forces together with the concrete. The rib used as the stiffener to ensure the rigidity of formwork acts as the shear connector. Use of a flanged rib improves the integrity of the concrete and steel plate. Experiments with composite beams using ribs as shear connectors revealed some fundamental factors relating to rib shape and rib arrangement in design of composite structure member, the results of which are presented.

RÉSUMÉ
La structure composite en béton et tôle d'acier, sans barres d'armature, présente quelques avantages par rapport au béton armé. La tôle d'acier, qui agit aussi comme coffrage, résiste aux forces extérieures en collaboration avec le béton. La nervure, utilisée comme raidisseur pour assurer la rigidité du coffrage, agit aussi comme goujon. L'emploi d'une aile nervurée améliore le comportement de l'élément mixte. Des expériences réalisées avec des poutres composites utilisant les nervures comme goujons ont montré l'importance fondamentale de l'emplacement et de la forme de ces nervures. Les résultats en sont présentés.

ZUSAMMENFASSUNG
Verbundbauteile bestehend aus einer Stahlplatte und unbewehrtem Beton haben verschiedene Vorteile gegenüber normal bewehrten Stahlbetonbauteilen. Die Stahlplatte dient auch als Schalung. Die aufgeschweissten Steifer geben der Stahlplatte eine grössere Steifigkeit für ihre Funktion als Schalung und dienen gleichzeitig als Schubdübel im Verbund mit dem Beton. Die Verwendung von Rippen mit Flansch verbessert das Verbundverhalten. Versuche mit solchen Trägern zeigten die fundamentale Bedeutung von Rippenanordnung und Rippenform auf. Die Ergebnisse dieser Versuche werden besprochen.

1. INTRODUCTION

In Japan, with the increase in urban population and to make better use of space, need of expanding cities toward coast or even to offshore, enlarging the unit of construction, and building larger structures by demolishing old ones. On the other hand, in the case of construction work in and around the city, not only usual safety and non-interference of urban lives are required but, especially in Japan, lack of on-site preparation area has become a matter of grave concern.

From these points of view, as well as the development of new efficient construction methods, the development and plans of new type structures have increased. For instance, lately, the submerged sewage treatment plant of reinforced concrete structure was constructed by improving the former technique of the submerged tunnel. The erection of steel parts and the concrete casting of bottom slab were carried out at a shipyard, and after flooding, the concrete of wall and top slab was cast with the body floating. The caisson thus completed was towed by tugboats from the shipyard to the project site, and was placed on the previously built seabed foundation.

The composite structure of concrete and steel plate concerned in this paper has various advantages and problems that are not seen in the reinforced concrete structure or the steel structure, as shown in Table 1. These advantages should make this kind of composite particularly suited for the following structures : (1) offshore structures, submerged structures, or bridge slabs, (2) tanks, vessels, or containers that needed tightness, and (3) structures carrying huge loads.

The greatest advantage of the composite structure over reinforced concrete is that the steel plate itself acts as the formwork, whose rigidity is further reinforced by the ribs, which act not only as shear connectors but also as stiffeners. All these combined make the structure economical.

The authors have carried out experiments on the composite beam using rib as the shear connector to create a composite action between concrete and steel plate. Also, some fundamental considerations related to rib shape and rib arrangement in design of composite structure member are presented.

2. DESIGN PROCEDURE

The design procedure of composite structure is shown in Fig. 1. Firstly, the steel shell (steel plate thickness, dimension and arrangement of stiffeners and web plates, etc.), is designed against the construction load, which consists in the external load, including the load from unhardened concrete, and the dead load. Of course, the construction load depends on the construction method. Nextly, the composite functions are reviewed with regard to the efficacy of compositioning, the efficiencies of stiffeners and the total strength against the service loads the composite is expected to carry, and the durability.

Should any of these be judged unsatisfactory, the design work is re-started from the steel shell designing again.

Table 1 Advantages and problems of composite structure compared with reinforced concrete structure

	Advantages		Problems
Construction	1. Formworks are not necessary. 2. Steel shell can be manufactured in a factory. 3. Bar arrangement is not necessary. 4. Concrete can be cast at the sea.	*Economy *Safety *High accuracy *Short of construction term *Reduction of land for construction	1. Stiffeners(ribs) are necessary to ensure the the rigidity of steel shell, making it rather difficult to fill up the space under the stiffener with concrete. 2. Calculation of stresses operating during construction is complicated. *Residual stress due to construction work must be considered as the permanent stress. *The order of concrete casting must be planned carefully.
Serviceability	1. The outer steel plate ensures the tightness 2. Concrete cover is not necessary. 3. Concrete does not fall off.	*Economy *Safety *Lightweight	1. There is possibility of increased deflection. 2. Buckling of the compression plate. 3. Corrosion of steel plate (durability).
Strength and Structural Behavior	1. High toughness with the sandwich type structure. 2. Concrete is confined by the steel plate.		1. The design of proper shape and arrangement of the stiffener (ribs) as shear connector is difficult. 2. The design method of the imperfect composite structure has not been established. 3. Influences of creep and shrinkage of concrete are not well known.

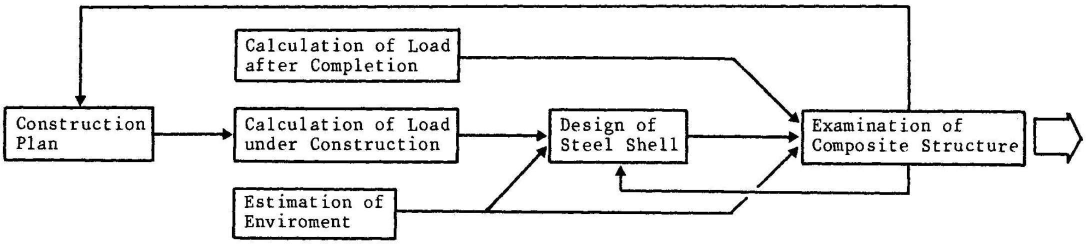


Fig. 1 Design Procedure

3. CONDITION FOR COMPOSITE FUNCTION AND STRUCTURAL BEHAVIOR

3.1 Shape and arrangement of rib

Since the shear is transferred between concrete and steel in the composite structure by the shear connector, the shape and the arrangement of shear connectors affect significantly the composite action. Since the stresses around the shear connector generally are highly concentrated, local copmressional failure or cracking of concrete may be likely. Therefore, it is realized that the shear strength may deteriorate markedly if the shape or arrangement of the shear connector is not correct.

3.1.1 Consideration on rib height for the composite action

Rib height should be greater than the largest aggregate in the concrete, and the compressive stress on the concrete enclosed in a rib should be smaller than the bearing strength.

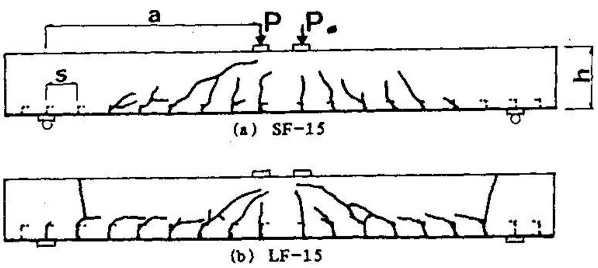
In the case that ribs are anchored in the tension zone of concrete, the rib height has no effect on the strength of the member as a whole and on the composite function (Fig. 2). But, when the rib height is too small, the concrete enclosed in a rib will fail under the bearing stress, and ribs will not work as the shear connector.

To demonstrate an extreme case, an experiment was carried out on a composite beam made up of concrete and checkered plate. The result obtained was that the beam failed simultaneously with occurrence of bending crack, and the concrete in contact with the checkered plate was pulverized at the places of stress concentration.

3.1.2 Necessity of rib-flange

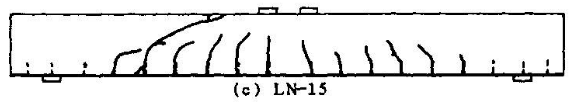
The rib-flange is necessary for the rib to act as the shear connector. In general, the flange width should be larger than the size of the greatest aggregate.

The shear connector should prevent the separation of concrete and steel plate, besides transferring the shearing force between them. If there is no flange on the rib, the bending crack from the top of rib is liable to occur early, and this bending crack will induce the diagonal tension crack in concrete (Fig. 2). From the experiments, the static shear strengths of beams with flanged ribs were higher than those of beams with unflanged ribs. On the other hand, however, the rib-flange is liable to induce almost horizontal cracks at the top of the flange, degrading the composite characteristic. And, when these horizontal cracks are linked together, the member will collapse (Fig. 2). Since the crack pattern is different with or without the rib-flange, the designer must judge which crack pattern is more harmful to the structure.



(a) SF-15

(b) LF-15



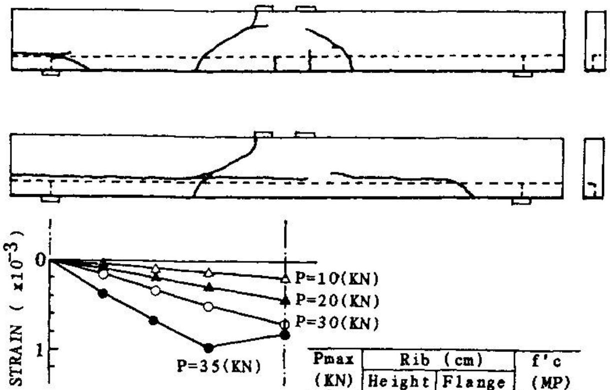
(c) LN-15

Specimen	Pmax (KN)	Rib (cm) Height	Flange	Space	a (cm)	h (cm)	f'c (MP)
SF-15	26.5	4.0	4.0	15.0	105	30	21.6
LF-15	29.4	7.5	4.0	15.0	105	30	22.1
LN-15	26.4	7.5	0	15.0	105	30	22.2

Fig.2 Effects of Rib height and Rib-flange on the strength and composite action

3.1.3 Effects of longitudinal rib

If the longitudinal rib has a proper flange, it functions as an excellent shear connector. However, as shown in Fig. 3, on account of tensile stress acting between concrete and rib-flange, it will give rise to a continuous weak plane along the rib-flange. When a crack propagates along this plane, the rib will lose its power.



Pmax (KN)	Rib (cm) Height	Flange	f'c (MP)
35.6	7.5	4.0	21.8

Fig. 3 Connection effects of longitudinal rib

3.1.4 Cares to be exercised on using longitudinal rib with transverse rib

If the longitudinal rib and the transverse rib are used together, concrete will be subjected to tensile forces from both the longitudinal and the transverse rib flanges. Therefore, their heights should not be the same, and the difference between the two need to be larger than the size of the greatest aggregate.

3.1.5 Shear reinforcement effects of transverse rib

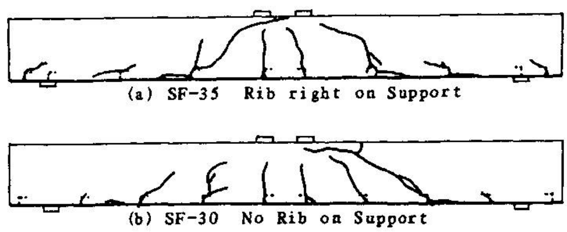
If the transverse ribs with flange are anchored in compressive zone of concrete, or the compression plate and the tension plate are connected by the transverse ribs (web), these ribs act as shear reinforcements as well as shear connectors. The shear mechanism in the member is like that in the truss action in which diagonal compressive struts equilibrate with transverse tensile ribs. Therefore, shear strength of this type of member is determined by the compressive strength of concrete or the tensile strength of transverse rib.

3.1.6 Shear reinforcement effects of longitudinal rib

If the longitudinal ribs with flange are anchored in compressive zone, or the compression plate and the tension plate are connected by the longitudinal ribs (web), these ribs also act as shear reinforcements. Vertical tensile stress in the rib varies like that of shear reinforcement (stirrup) of reinforced concrete with load increasing. But, in the case of longitudinal rib, the rib should carry the shear force (stress) from tension plate. Therefore, at the time of calculating the shear strength of longitudinal rib (Vs), the width of rib should be considered in assessing the influence of shear stress.

3.1.7 Effects of location and arrangement of transverse rib

In the case of large shear span members, the shear strength is equal to the diagonal tension crack load. And, in the composite member, cracking occurs from the top of all ribs. Therefore, when ribs are located so that the crack pattern is similar to that of reinforced concrete, the shear strength is equal to that of the reinforced concrete. As shown in Fig. 2, however, in the case the rib spacing is too short, the almost horizontal cracks are linked together easily, and the



Specimen	Pmax (KN)	Rib (cm) Height	Flange	Space	f'c (MP)
SF-35	35.2	7.5	4.0	35.0	25.4
SF-30	27.8	7.5	4.0	30.0	20.8

Fig. 4 Effects of rib arrangement on shear strength

composite action is lost early. On the other hand, in the case there exist a rib right on a support and few ribs are inside the shear span, compressive struts are formed in concrete from underneath of the load points to the supports, and the shear strength becomes larger than that of reinforced concrete, because the diagonal crack does not occur easily (Fig. 4). The mechanism of force transfer in this case is like in the tied-arch action with the concrete acting as the arch rib and the steel plate as the tie. But, as shown in 3.2, the deflection of member will be larger than that of reinforced concrete.

3.2 Deformation behavior

Deflection of composite member has been calculated by modifying the beam theory by rib spacing.

The bending stiffness of composite member under concentrated load will be $1/(1+s/a)$ as large as that calculated from the beam theory on the reinforced concrete (Fig. 5). Where, s is the rib space, and a the shear span.

From the experiments, the bond stress between concrete and steel plate becomes zero just about the time the flexure crack occur, and the axial strain of steel plate between two ribs becomes the same. Based on experimental results, the axial strain of steel plate can be assumed to be the solid line in Fig. 6 . The average (total) strain of steel plate in shear span is $(1+s/a)$ times the broken line value (perfect composite). Therefore, the deflection of this composite type member shall be $(1+s/a)$ as large as the perfect composite.

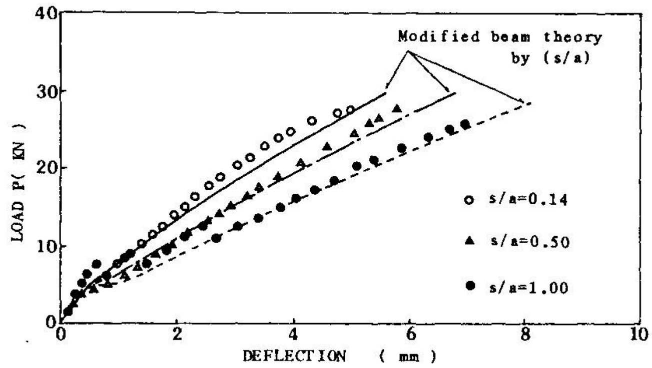


Fig. 5 Load - Deflection curve of composite beam

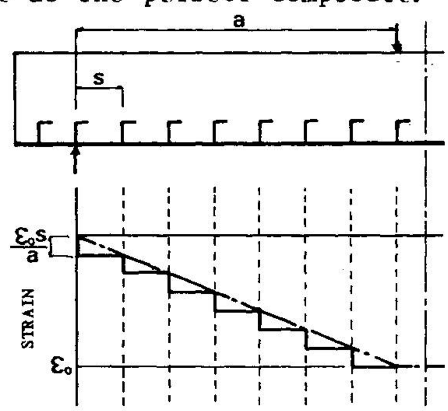


Fig. 6 Axial strain distribution of steel plate

REFERENCES

[1]. ISHIOKA,J. and HASHIMOTO,K. , Experimental Study on Shear Connector for Steel-Concrete Composite Beam Loading on Shear Span Around 3d. Proceedings of Symposium on Research and Application of Composite Constructions, Japan Society of Civil Engineers, Sept.1986 (in Japanese)

[2]. MATSUISHI,M., NISHIMAKI,K., TAKESHITA,H., IWATA,S. and SUHARA,T., On The Strength of Composite Steel-Concrete Structure of a Sandwich System (1st and 2nd Reports). The Hitachi Zosen Technical Review. Vol.38,Sept.1977 and Vol.39, March 1978

[3]. SENNA,H.,TAKEUCHI,H. and UEDA,T.,The Influences of Rib shape in the Shear Transfer Mechanism between Concrete and Steel Plate. Abstracts of 41th Congress, Japan Society of Civil Engineers, Vol.5, 1986 (in Japanese)

[4]. ACI Committee 435, Deflection of Reinforced Concrete Flexural Members. Journal of ACI, June 1966