

FUNDAMENTAL STUDY ON CONSTRUCTION SYSTEMS FOR COMPLETE REUSE USING UHPFRC BLOCKS

Hiroshi Ito (1), Tomoya Nishiwaki (1), Sukmin Kwon (1) and Takatune Kikuta (2)

(1) Department of Architecture and Building Science, Tohoku University, Sendai, Japan

(2) Department of Architecture, Nippon Institute of Technology, Saitama, Japan

Abstract

Reused construction systems are economical and environmentally friendly. However, such systems have not been developed yet for a practical stage. A reason for this situation is the bonding stress transmission method, such as welding in steel structures or adhesion between rebar and concrete in RC structures, is primarily used to connect members, and such method makes their reuse difficult. Therefore, we propose novel construction systems for “Complete Reuse using Ultra high performance-hybrid Fibre reinforced cement-based composites Blocks” (CR-UFB) that could be applied for a “jigsaw puzzle structure” because its high durability and high mechanical properties. In contrast to conventional designs, our system may enable buildings to consist only of an unbonded connection such a jigsaw puzzle without the need for reinforcing materials such as rebar, mortar or adhesives. As the first step, we experimentally investigated the mechanical properties in the connections and opened up the possibilities of the CR-UFB.

Résumé

La réutilisation de matériaux de construction est économiquement et écologiquement intéressante, cependant, le développement à grande échelle est difficile. En effet, la principale difficulté réside dans le traitement des éléments de liaison, indispensable à la transmission des efforts, telles que les soudures pour les structures en acier ou l'adhérence entre le béton et les armatures pour les structures en béton armé. Par conséquent, nous proposons un nouveau type de système constructif permettant une réutilisation complète du béton ultra haute performance fibré (CR-UFB). Cette technique peut être appliquée aux blocs de béton crantés appelés "Jigsaw Puzzle Structure" grâce à ses capacités de résistances mécaniques et de durabilité. Par opposition aux conceptions conventionnelles, notre système permet la construction de bâtiments constitués uniquement de blocs "jigsaw puzzle" sans nécessité de matières de renfort tel que des armatures, du mortier ou de la colle. Comme première approche, nous avons travaillé les propriétés mécaniques aux liaisons, et élargi le champ des CR-UFB.

1. INTRODUCTION

It is expected that the future population of Japan will rapidly decrease. The trends and forecasts of the total population of Japan are shown in Fig. 1 [1]. On the basis of moderate estimates, the population in the year 2011 is expected to decline to 65 % in the year 2105.

On the other hand, the life cycle cost (LCC) of buildings comprises mainly running expenses, including operation and maintenance costs, rather than initial costs. Therefore, when considering long-term building use in such a region, in addition to maintenance and longer life, one of effective options to reduce LCC is a reduction method of floor area to match the expected decrease in the number of inhabitants. In such case, only the involvement of complete reuse technologies, which do not require new materials, will make it possible to minimize the cost and environmental impact even in case of large-scale reconstructions that require a change of the existing structure. Shifu et al. [2] simulated and compared the LCC of a complete reuse structure which consists of the prototype of construction systems we propose, with that of a conventional building, in which a large-scale repair and reconstruction was carried out 40 and 90 years later respectively. Assuming a complete reuse building, where the reconstruction was performed within 30 years, the future building costs were calculated while taking into account changes in the operating costs that may be reduced by reduction of the floor area and state-of-the-art technology in a reconstruction period. The simulation results from the building to 100 years are shown in Fig. 2.

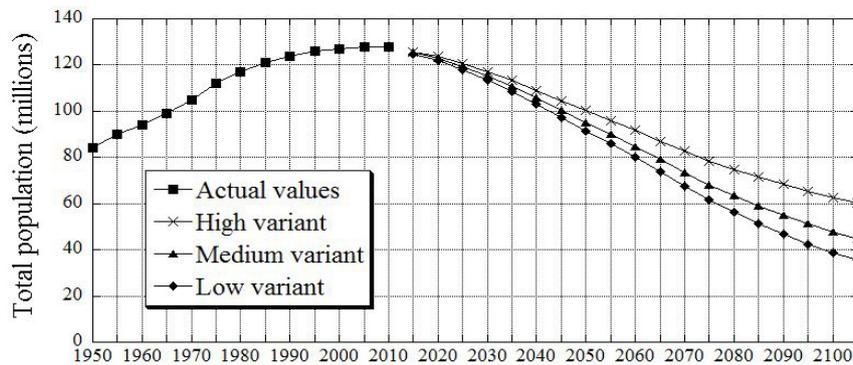


Figure 1: Expected variation in the total population of Japan [1]

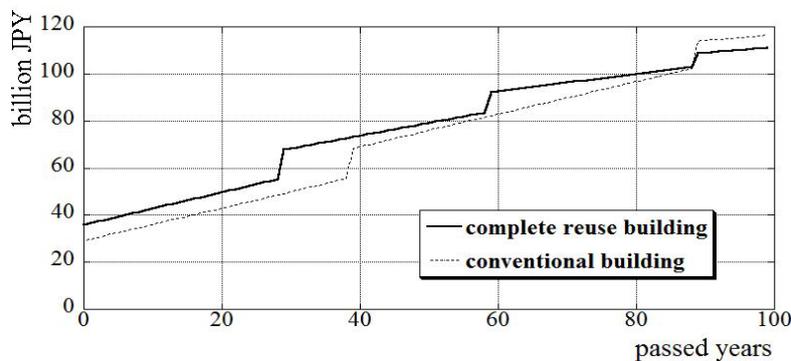


Figure 2: LCC calculation results [2]

From this figure, a cost saving of 9% is possible among 100 years in case that the total floor area of the building is reduced to match the population decline. It means that the introduction of renewable construction systems, which consider reuse in the system during the design process, can lead to a cost reduction and environmental impact [3]. In the process, the ease of separation of connections is particularly important. Conventionally, a bonding stress transmission method, such as welding in steel structures or adhesion between rebar and concrete in RC structures, is primarily used to connect members, and such method makes their reuse difficult. For this reason, we carried out a basic study to establish novel construction systems which consist of an unbonded method in connections. As the first step, fundamental experiments were performed to investigate the mechanical properties of the connections when Ultra High Performance-Hybrid Fibre Reinforced Cement-based Composites, hereafter UHP-HFRCC, was applied to a “jigsaw puzzle structure”.

2. PROPOSAL OF A NOVEL CONSTRUCTION SYSTEM

As mentioned above, only the construction systems that enable easy separation of connections will make it possible to minimize the cost and environmental impact irrespective of the way of the reconstruction/retrofitting. Because of that, we propose novel construction systems for “Complete Reuse using UHP-HFRCC Blocks”, hereafter CR-UFB, which consists of an unbonded method of connections. As indicated by the result of the uniaxial tensile test of UHP-HFRCC (Fig. 3), it has a high strength of approximately 20 MPa even under uniaxial tensile stress, and its mechanical properties are also known to include a high toughness based on its strain hardening behaviour and multiple cracking by means of the multi-level-reinforcement system, or the synergy effects of fibre cocktail [4]. Consequently, while the tensile strength is the same level as the compressive strength of normal concrete, this material is expected to suppress brittle fracture.

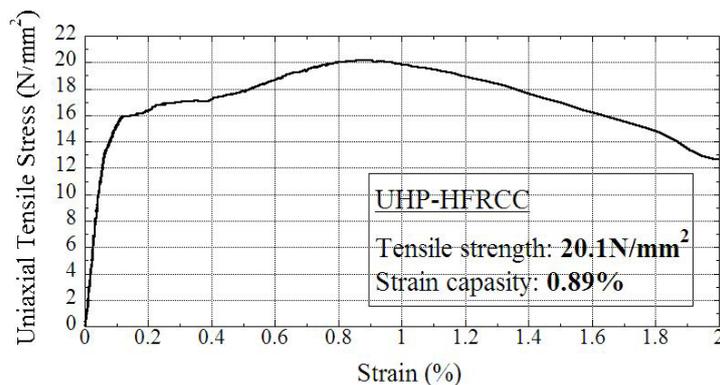


Figure 3: Uniaxial tensile response of UHP-HFRCC [4]

In contrast to contemporary earthquake-resistant designs such as RC structures or reinforced masonry, it is expected to bear not only compressive stress but also tensile stress. Therefore, if this material is built in construction systems, it is conceivable that structures can be built more simply using a few kinds of members without the need for steel reinforcement or mortar binder. Moreover, because the life expectancy of the block is not determined by the corrosion of reinforcing bars, it is also effective from the viewpoint of the durability of structures.

Figure 4 shows a conceptual diagram of block masonry using UHP-HFRCC which is applied to a jigsaw puzzle structure.

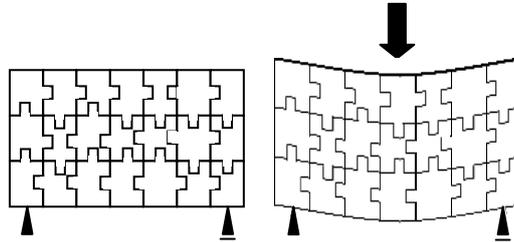


Figure 4: Conceptual diagram of block masonry [5]

CR-UFB can resist tensile force and shear force (seismic loads) without bolt anchorage or reinforcing bar. In this study, three different shapes of specimens were studied (Fig. 5). These blocks in a member may be easily removable and exchangeable because of the unbonded connections when they are damaged. It means that reconstruction could be possible from the existing structure. From this point of view, applying CR-UFB in a structure might reduce the input resource and waste when the reconstruction is carried out.

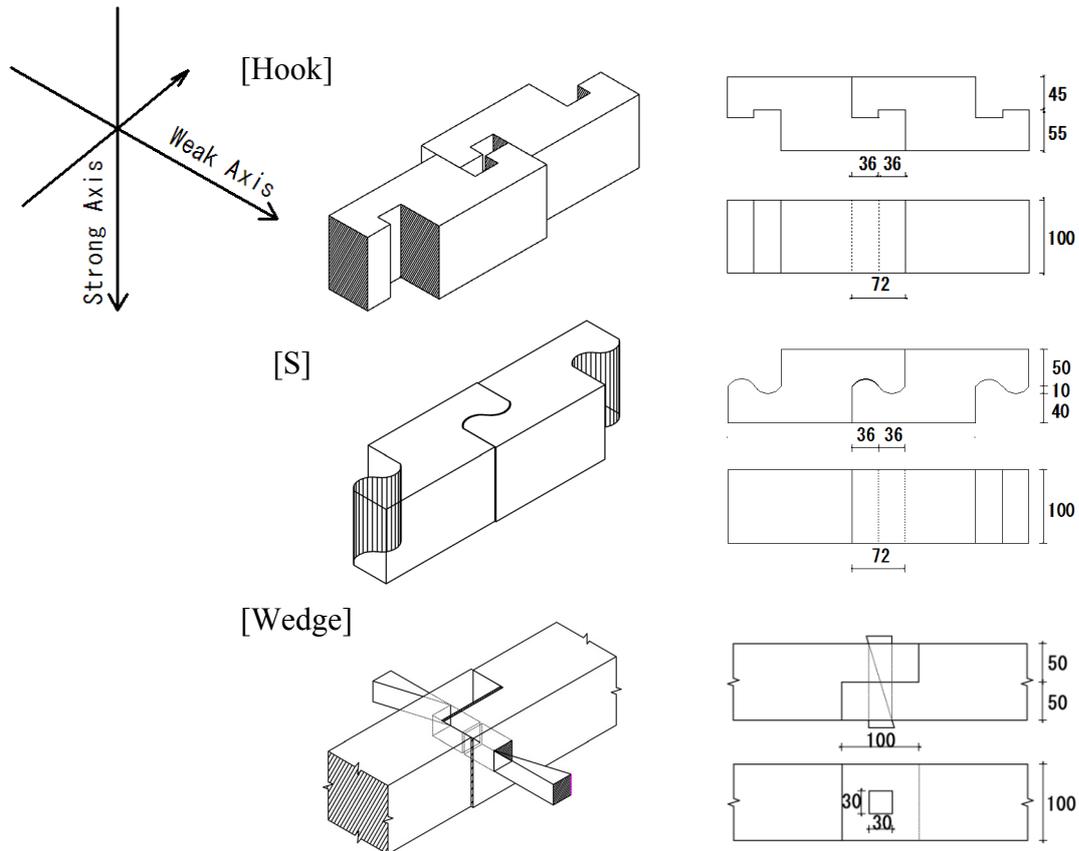


Figure 5: Three types of block specimen

3. MECHANICAL PROPERTIES OF UHP-HFRCC BLOCKS

3.1 Outline of experiments

As the most basic consideration of the CR-UFB, we tested UHP-HFRCC blocks in a simple beam member configuration which have an unbonded connection method. Fundamental experiments were carried out in order to confirm mechanical properties of the connections with three kinds of blocks. The geometry of the specimens is shown in Fig. 5. Bending tests were performed using the simplified connections and a UHP-HFRCC prism (Non-joint) in the direction of both strong and weak axes (Fig. 5). In order to observe the pure bending properties in the connections of the block specimens, four-point bending tests based on JIS A 1106 (based on ISO 1920-4) were performed (Fig. 6). A displacement gauge was placed at the centre between fulcrums, and the deflection was measured. The mix proportion of the employed UHP-FRCC and its mechanical properties are presented in Table 1 [4]. With regard to curing, after removal of the mould on day 1, steam curing (90 °C, 24 h) was performed, after which the steam curing was performed in moist air until the tests were executed on day 7.

Table 1: Mix design and mechanical properties of UHP-HFRCC [4]

W/B Wt.%	SFC/B Wt.%	S/B Wt.%	Wo/B Wt.%	SP/B Wt.%	OL Vol.%	HDR Vol.%	Uniaxial tensile strain %	Uniaxial tensile strength MPa
16	100	35	13	1.7	1	2	0.89	20.1

Note: B: binder, SFC: pre-mixed cement, S: sand, Wo: wollastonite,
 SP: superplasticizer, OL: straight-steel-fibre (L: 6 mm, D: 160 µm),
 HDR: hooked-steel-fibre (L: 30 mm, D: 380 µm)

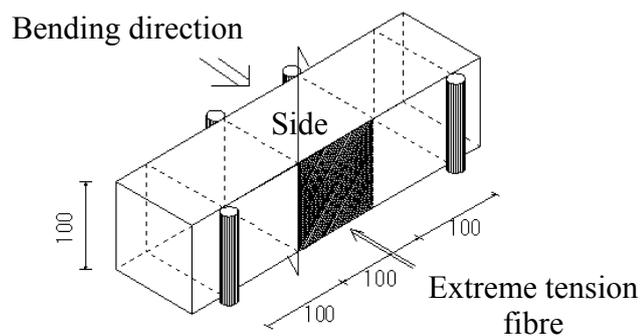


Figure 6: The test set-up for the four-point bending

3.2 Results and discussion

The relationship between load and deflection obtained from the bending test is presented in Fig. 7, which were calculated by averaging the stress values of each curve at the same strain level. The Fig. 7 (b) is focused on block series (only connections) in the Fig. 7 (a). The maximum load and initial stiffness in the connections are shown in Table 2. The initial stiffness was calculated as the slope for deflections between the 0-0.1 mm.

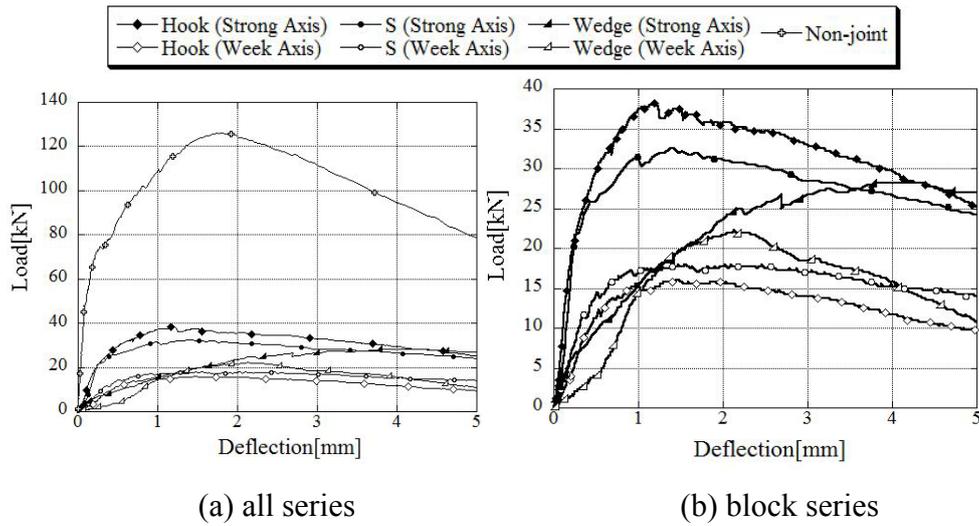


Figure 7: Relationship between load and displacement

Table 2: Test results

Connection form	Max load (kN) (L)	(L/L _N *)	Initial stiffness (kN/mm) (S)	(S/S _N *)
Hook (Strong Axis)	38.2	0.304	75	0.127
Hook (Weak Axis)	16.0	0.127	20	0.034
S (Strong Axis)	32.5	0.258	49	0.083
S (Weak Axis)	18.0	0.143	30	0.051
Wedge (Strong Axis)	28.2	0.224	34	0.058
Wedge (Weak Axis)	22.2	0.177	8	0.014
Non-joint	125.9*	1	591*	1

*L_N, S_N: Maximum load and Initial stiffness of Non-joint are fixed as the basis.

Although there were variations in the ductility performance of each specimen, all series showed a ductile behaviour with hardening for a deflection of at least 1 mm. Fig. 8 shows the relationship between the maximum load and the minimum section modulus of a single block. A linear relationship was observed, however, there is no influence of the connection shape.

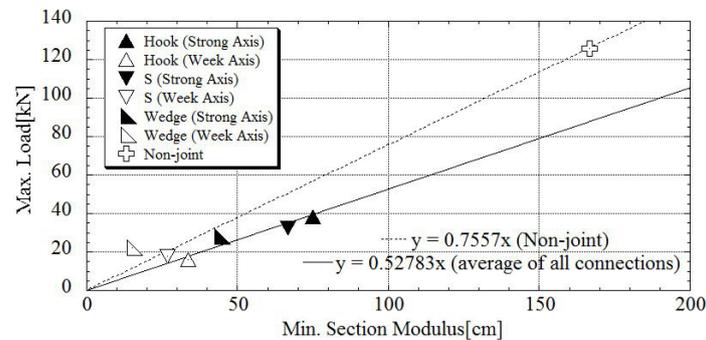


Figure 8: Relationship between maximum load and minimum section modulus of a single block

In this study, the clearance was defined as the distance of the spacing between blocks and measured with a vernier calliper. From Fig. 9, there is a general tendency for the initial stiffness to be inversely proportional to the magnitude of the clearance between members when it is distinguished between the strong and the weak axis direction.

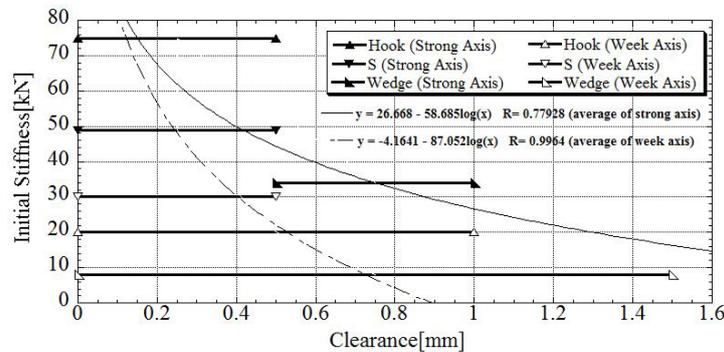


Figure 9: Relationship between initial stiffness and size of clearance between the members

Table 3 shows the observed crack patterns. It is clear that the maximum load was determined by the tensile stress at the bottom of the connection because the main crack was due to internal forces at there. The decline in strength for Non-joints may be due to the variation in the section, or because the tensile stress is concentrated at the extreme tension fibre of the connection bottom.

Table 3: Crack pattern

	Hook and S	Wedge
Side		
Extreme tension fibre		

From the above discussion, it can be confirmed that the maximum bending strength in the connections of the UHP-HFRCC blocks depend on the minimum section modulus of each single block, and the initial stiffness is influenced mainly by the clearance.

4. CONCLUSIONS

In order to realize completely reused construction systems, we proposed novel construction systems, CR-UFB, which consists of an unbonded stress transmission method of connections. As the first step, fundamental experiments were performed to investigate the mechanical properties of the connections when UHP-HFRCC was applied to a jigsaw puzzle structure. Without reinforcing materials, all series showed a ductile behaviour with a deflection hardening until a deflection of at least 1 mm, therefore, the potentiality of that system was presented. In the future, changes in the performance requirements of a building due to changes in social conditions and technological innovation are expected to occur frequently. From this point of view, the CR-UFB is considered to be a type of system that is suitable for sound material-cycle that can respond to changes in society.

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