The Development and the Structural Behavior of a New Type Hybrid Concrete Filled Fiber-Glass Reinforced Plastic Pile

Développement et comportement structural d'un nouveau type de béton hybride rempli de fibre de verre renforcé par pile plastique

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ABSTRACT: Concrete and reinforced Concrete are the most frequently used material due to the superior strength, durability and affordability. But Concrete and reinforced Concrete are weak in a adverse external environment. Especially, corrosion and damage from sea water cause the serious durability deterioration on marine structures, such as piles. To avoid corrosion of steel and degradation of the durability of concrete, repair and reinforcement are needed. Fiber-glass Reinforced Plastic(FRP) material is widely used because of the excellent corrosion resistance, fatigue resistance, light weight. In the study, in order to enhance the durability and constructability of the pile foundation, a FRP pile is developed and its applicability considering construction is discussed. To improve the axial and transverse load carrying capacities longitudinal reinforcement is also needed additionally, and hence a new type hybrid Concrete Filled FRP Pile (HCFFP) is suggested. A new type HCFFP which is composed of pultruded FRP, filament winding FRP, and concrete filled inside of the FRP tube is proposed to improve compressive strength as well as flexural strength of the HCFFP. This paper studied compression structure behavior of Concrete Filled FRP Pile(CFFP) by using uniaxial compression test about CFFP. The load-strain relation of CFFP is compared with result from finite element analysis program, as well, gained the properties of FRP Pile and analyzed existing document relating to the study about CFFP. This paper proved the confinement effect comparing between FRP Pile and CFFP. Prediction model for the strength and load-strain relation of CFFP is suggested. Also, we present the results on experimental investigations pertaining to the structural behavior of HCFFP which is suggested in order to mitigate the problems associated with the concrete filled steel-concrete composite pile (CFSP) and the concrete filled fiber reinforced plastic pile (CFFP).

RÉSUMÉ : Les bétons concrets et renforcés sont les matériaux utilisés les plus fréquemment à cause de la force supérieure, la durabilité et l'abordabilité. Mais, les bétons concrets et renforés sont faibles dans un environnement externe défavorable. Particulièrement, la corrosion et le dommage de l'eau de mer causent la détérioration sérieuse de la durabilité sur des structures marines, par example, piles. Pour éviter la corrosion de l'acier et la dégradation de la durabilité du béton, la réparation et la renforcé sont nécessaires. Le matériel plastique renforcé en fibre-verre (en anglais, Fiber-glass Reinforced Plastic, FRP) est utilisé largement à cause de sa résistance excellente contre la corrosion et la fatigue, et son poids léger. Dan cette étude, afin d'améliorer la durabilité et la constructabilité de la fondation en piles, une pile en FRP est dévelopé et son applicabilité sur la construction en site est discutée. Pour améliorer la charge axiale et transverale qui transporte les capacités du renforcement logitudinal est composé du FRP est nécessaire plus, et donc un béton de nouveau type hybride remplie en pile FRP (HCFFP) est suggéré. Un nouveau type de HCFFP, qui est composé par le FRP pultrudé, le filament enroulant par FRP et le béton rempli à l'interieur d'un tube FRP, est proposé pour améliorer la force compressible et la force flextionnelle du HCFFP. Cet article présente le comportement compressible structural du béton rempli par FRP piles (en anglais, Concrete Filled FRP Pile, CFFP) en utilisant un essaie de compression uniaxiale sur CFFP. La relation entre la charge et la tension de CFFP est comparée avec des resultats obtenus de l'analyse de la méthode des éléments finis, les propriétés deu pile FRP, et l'analyse des documents existant relative à des études sur CFFP. Cet article prouve l'éffet de la détention comparant entrée le pile FRP et CFFP. Le modèle de prédiction pour la force et la relation entre la charge et la tension de CFFP est suggeré. En outre, nous présentons les résultats sur les investigations expérimentales concernant le comportment structural de HCFFP qui est proposé afin d'atténuer les problèmes associés au béton rempli par le pile composite de l'acier et le béton (en anglais, concrete filled steel-concrete composite pile, CFSP) et le béton rempli par pile plastique renforcé en fibre.

KEYWORDS: hybrid concrete filled FRP pile, FRP, fiber-glass reinforced plastic, pile, laboratory test

1 INTRODUCTION.

Due to the advantageous mechanical properties of the fiber reinforced polymeric plastics (FRP), their application in the construction industries is ever increasing trend, as a substitute of structural steel which is highly vulnerable under hazardous environmental condition (i.e., corrosion, humidity, etc.).

As a fundamental structural element, pile is constructed to transfer loads from superstructure to foundation. In general, since the pile foundation is constructed in the soil and/or underwater, it is difficult to maintain against the damages relating to corrosion. Moreover, it is even more difficult to estimate its durability. Accordingly, the requirement to be satisfied in the design of pile foundation is diversified. In recent years, as a new construction material in the pile foundation industries, fiber reinforced polymeric plastic (FRP) pile has been developed because it has a superior corrosion resistance, fatigue resistance, high specific strength/stiffness, etc. Therefore, such mechanical and physical properties can be used to mitigate the problems associated with the use of conventional construction materials.

When the reinforced concrete compression member (e.g., reinforced concrete pile) is wrapped with the fiber reinforced plastic, the axial load carrying capacity of the pile is increased due to the confinement provided by the fiber reinforced plastic. Such an effort to develop efficient concrete Column wrapped with FRP has been continued from the early of 20th century.

Hybrid FRP-concrete composite pile (HCFFP) is consisted of pultruded FRP unit module, filament winding FRP which is in the outside of mandrel composed of circular shaped assembly of pultruded FRP unit modules, and concrete which is casted inside of the circular tube shaped hybrid FRP circular tube as shown in Figure 1. Therefore, pultruded FRP can increase the flexural load carrying capacity, and the filament winding FRP tube and concrete filled inside of it can increase the axial load carrying capacity.

In this study, in order to use as the pile for foundation construction, we estimated the structural performance of HCFFP through the uniaxial compression tests. Mechanical properties of the FRP material are investigated. Based on the reviews of previous research results and the experimental studies conducted in this study, equation for predicting the ultimate axial compressive strength of the HCFFP is suggested.

1 HYBRID FRP-CONCRETE COMPOSITE COMPRESSION MEMBER

In this study, improved HCFFP system, an exterior filament winding FRP layer component and an interior pultruded FRP with concrete, is proposed as shown in Figure 1.

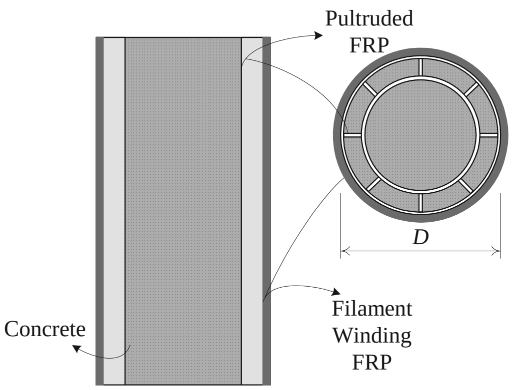


Figure 1 Hybrid FRP-concrete composite pile (HCFFP).

The exterior layer consists of a multilayer filament winding FRP. The interior reinforced concrete consists of pultruded FRP and concrete. Filament winding FRP may have various cross-sectional dimensions to satisfy the structural design requirements. A cylindrical concrete core is located in the filament winding FRP and pultruded FRP, where the interior pultruded FRP and the exterior filament winding FRP provide axial and circumferential reinforcement, respectively, for the concrete core.

The specimens of HCFFP members, which are the FRP circular tubes that had been manufactured by filament winding and pultrusion processes are shown in Figures 2 and 3, respectively. Filament winding process is surfaces of revolution, such as pipes, cylinders, and spheres. In filament winding, continuous reinforcements, such as roving, are wound onto a mandrel until the surface is covered and the required thickness is achieved. Pultrusion is a continuous manufacturing process used to manufacture constant cross section shapes with unlimited length. Pultrusion is a cost effective process because it achieves direct conversion of continuous fibers and resin into a finished part. The fibers are continuously impregnated and pulled through a heated die, where they are shaped and cured.

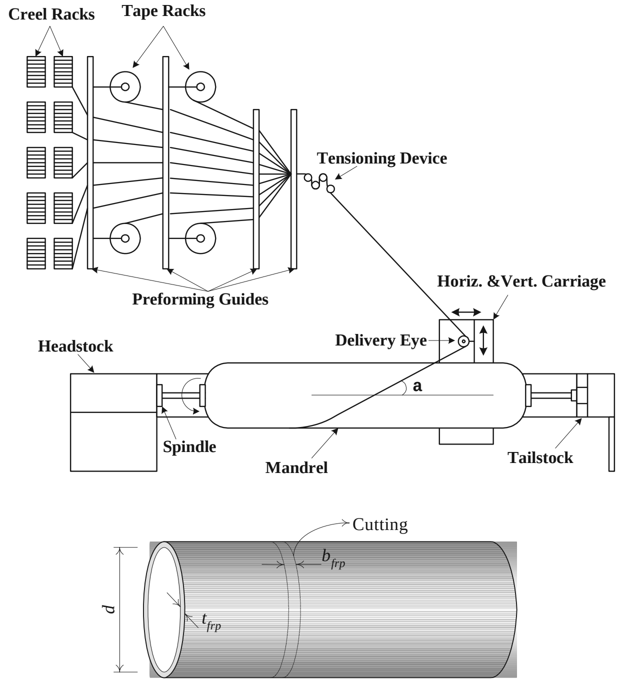


Figure 2 Manufacture of the filament winding FRP specimen.

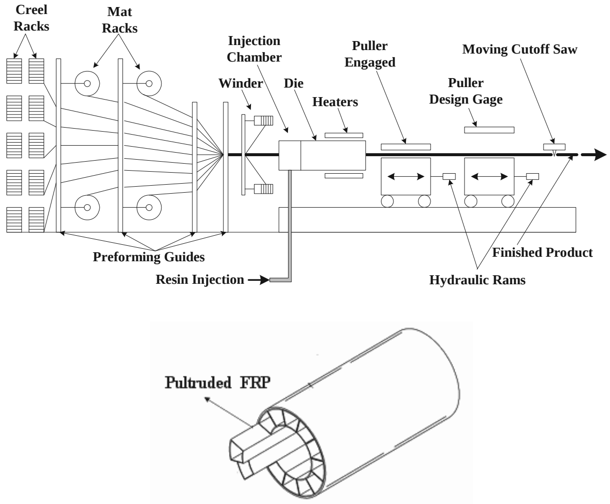


Figure 3 Manufacture of the pultruded FRP specimen.

2 LABORATORY TEST RESULTS

2.1 *Mechanical Properties of Materials*

Dimension of the filament winding FRP tube and pultruded FRP specimens are given in Table 1. A glass-fiber and a polyester resin were used to manufacture the FRP. Compressive strength of concrete was obtained from the uniaxial compression tests at the age of 28 days. Material properties tests of the filament winding FRP tube were split disk and compressive tests and pultruded FRP were tensile test. The split disk test of the FRP specimens was carried out at the Structures Laboratory in Hongik University, Korea. A total of 9 specimens were tested for the split disk test and the compressive test, respectively. A total of 9 specimens are tested, 3 for 3 tests, as given in Table 1.

The failure load, the ultimate strength, and the modulus of elasticity are determined and summarized as shown in Table 2, respectively. One of the failure modes of a tested specimen is also shown in Figure 4.

Table 1. Dimension of the FRP tube specimen

Classification		Number of specimen	Thickness (mm)	Width (mm)
Filament winding FRP	Split disk test	3	2.8	30
		3	4.2	
		3	5.6	
	Compressive test	3	2.8	L= 600 D= 300
		3	4.2	
		3	5.6	
Pultruded FRP	Tensile test of inner arc	3	3.9	25.3
	Tensile test of outer arc	3	3.7	28.5
	Tensile test of rib	3	3.1	24.7

Table 2. Test results

Classification		Thick ness (mm)	Failure load (kN)	Ultimate Strength (MPa)	Modulus of elasticity (MPa)
Filament winding FRP	Split disk test	2.8	62.3	294.6	22.2
		4.2	112.7	326.9	23.3
		5.6	157.7	318.8	22.6
	Compressive test	2.8	254.9	194.1	N/A
		4.2	507.4	258.2	N/A
		5.6	647.1	247.5	N/A
Pultruded FRP	Tensile test of inner arc	3.9	25.6	260.1	22.4
	Tensile test of outer arc	3.7	22.8	214.2	27.9
	Tensile test of rib	3.1	29.8	387.4	31.4

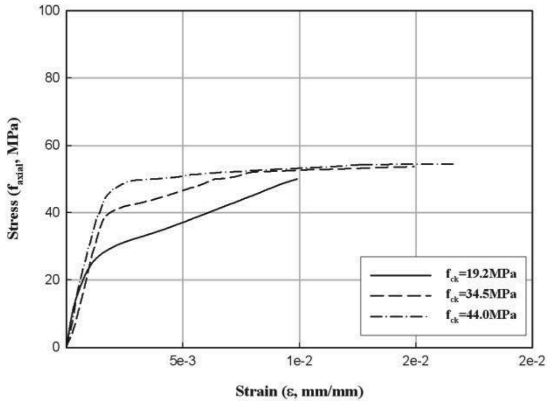
Figure 4 Failure mode.

The mechanical properties were determined from the experiments conducted by changing the thickness. In the test, three sets of tests with different thickness and each set consists of three specimens are prepared. Specimens were taken from the FRP tube and the properties were, then, calculated by averaging the results obtained from the split-disk test, compression test, and tensile test. From the tests result, it can be observed that the mechanical properties for the FRP tube specimens were almost similar. In the specimen preparation three different compressive strengths of concrete, i. e., 19.2MPa, 34.5MPa, and 44.0MPa, are used and the strength of concrete at the age of 28 days was measured by tests.

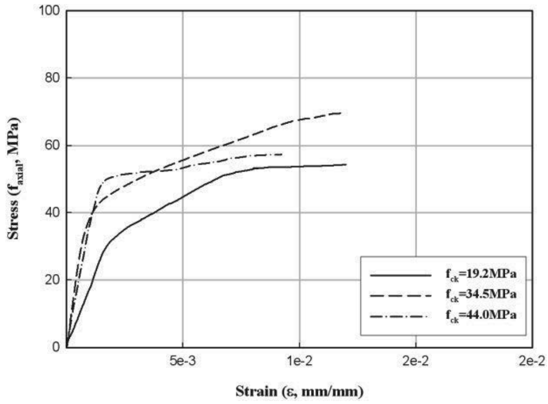
2.2 *Uniaxial Compression Tests of HCFFP*

For estimating the compressive strength of HCFFP, uniaxial compression tests on HCFFP members are conducted. It was observed that the HCFFP specimens are finally failed after the rupture of filament winding FRP. From the experiment, load versus displacement at the upper part of a loading plate and the load versus strain measured at the middle of the specimen are obtained. The axial stress versus axial strain of confined concrete specimen is shown in Figure 5.

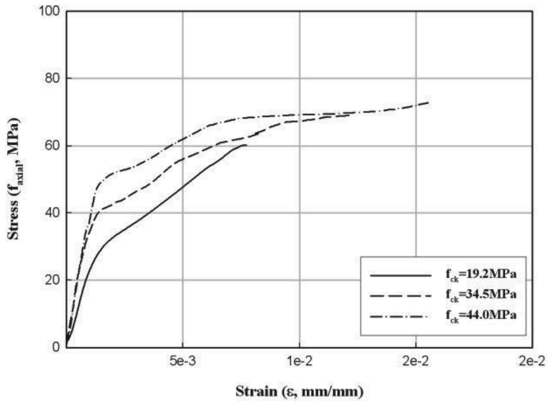
It can be observed that the uniaxial compressive strength of HCFFP is increased if the concrete strength and the thickness of exterior filament winding FRP tube is increased. This tendency is also similar to that of existing CFFP member used currently in practice.



(a) 2.8mm FFRP



(b) 4.2mm FFRP



(c) 5.6mm FFRP

Figure 5 Axial stress-strain relationship of HCFFP specimen.

2.3 *Flexural Test of HCFFP*

For estimating the flexural strength of HCFFP, flexural tests on HCFFP members are conducted. A total of 9 specimens, 3 sets of test with 3 specimens for each set, were tested under four-point bending loads as shown in Figure 6. In the test, specimens with 3 different filament winding thicknesses, i.e., 2.8mm, 4.2mm, and 5.6mm, are used. It was observed that the HCFFP specimens are finally failed after the rupture of filament winding FRP. From the experiment, load versus displacement measured at the middle and quarter points of span length of the specimen is obtained.

It was observed that the moment estimated at failure of the HCFFP specimens is almost similar regardless of the differences in the thickness of exterior filament winding FRP tube. Moreover, the flexural moment versus vertical deflection at the time of cracking initiation of the specimen surface is shown in Figure 7.

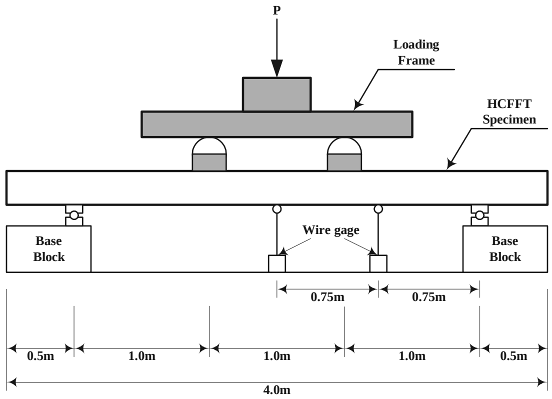


Figure 6 Loading and measurement location of HCFFP specimen.

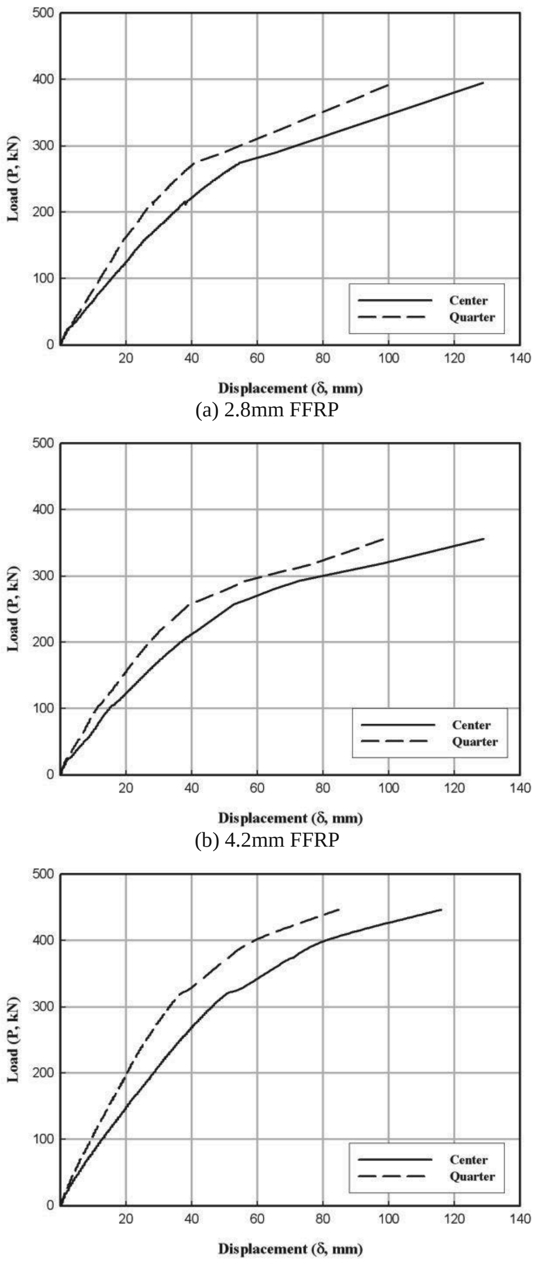


Figure 7 Moment-deflection relationship.

3 CONCLUSIONS

In this paper, we presented the structural behavior of HCFFP specimens under compression and flexure. The improvements of the load carrying capacity of HCFFP members compared with CFFP, based on the experimental investigations, are discussed. As expected, load carrying capacity of HCFFP member is increased if the confining pressure and core concrete strength are increased. In addition, the equations for predicting the compressive and flexure strengths of the HCFFP member are proposed. The results obtained by the analytical study are compared with the average experimental results. It was also provided that HCFFP member is suitable to apply as the structural member by performing the comparison with the strength of CFFP member.

For the future study, structural performance of the connection between the segments of HCFFP, and constructability of HCFFP pile should be explored and eventually its applicability in the construction field should be evaluated.

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5 REFERENCES

An, D.J. 2011. *Structural Characteristics of Hybrid FRP-Concrete Composite Piles.* Ph.D. Thesis, Hongik University, Seoul, Korea.

Choi, J.W., Joo, H.J., Nam, J.H., and Yoon, S.J. 2010. Development of the Hybrid CFFT Pile. *Journal of the Korean Society for Advanced Composite Structures* 1 (2), 20-28.

Shin, K.Y. 2010. *Estimation of Load Carrying Capacity of Hybrid FRP-Concrete Composite Pile.* Ph.D. Thesis, Hongik University, Seoul, Korea.