AN EVALUATION ON THE EFFECTIVE FLEXURAL RIGIDITY OF RC SLABS STRENGTHENED WITH CFRP SHEET AND GSP PLATE

Shim Jae-Joong[1], **Song Seul-Ki**[2], **Oh Min-Ho**[3], **Cui-Jie**[4], **Park Sun-Kyu**[5]

[1] Graduate student, Sungkyunkwan University, Suwan City, Kyung-gi, Korea
[2] Graduate student, Sungkyunkwan University, Suwan City, Kyung-gi, Korea
[3] Graduate student, Sungkyunkwan University, Suwan City, Kyung-gi, Korea
[4] Graduate student, Sungkyunkwan University, Suwon City, Kyung-gi, Korea
[5] Professor Sungkyunkwan University, Suwan City, Kyung-gi, Korea
Correspond to jjsim85@skku.edu

ABSTRACT: Since improved capacity for RC bridges has been required due to deterioration or increase in traffic, the deflection of cracked reinforced concrete slabs need to be reconsidered. Strengthening is known as the better way to improve capacity of bridges than reconstructing. In this paper, Fiber Reinforced Plastic (FRP) was introduced as one of the best strengthening methods for civil structures. The structures strengthened with FRPs can improve the strengthening capacity and serviceability. Therefore, CFRP sheet and Glass Fiber-Steel Composite Plate (GSP) in this research were used for strengthening slabs of RC bridges. Experimental data from the strengthening will be helpful to better understand the effect of the strengthening and effective flexural rigidity.

Keywords: CFRP sheet, GSP, Effective flexural rigidity

1. INTRODUCTION

Usually, reinforced concrete (RC) structures undergo degradation of performance over time. Especially, in case of the bridge, as present traffic density gets increased more than that of past and weight of transit gets increased, related structures needs to be improved. Since Fiber Reinforced Polymer (FRP) was developed, which is 10 times lighter in weight and stronger in tensile strength than iron bar, FRP has been widely used as a strengthening method for reinforced concrete (RC) structures. FRP reinforced structures show a new failure mode such as found from the existing iron and concrete structure. Also, although FRP material as well as iron bar is used for the structure, there's no practical standard for effective flexural stiffness. In this study, the effective flexural rigidity of the RC slabs externally bonded with Carbon Reinforced Polymer (CFRP) and Glass Steel Plate (GSP) was estimated through flexural experiment. In addition, the effective flexural rigidity was compared with the existing design code and a suggested equation.

2. THEORETICAL BACKGROUND

Effective flexural rigidity of the RC structures is evaluated as shown in Fig. 1 by using Branson's equation, Eq (1).

When Ma is greater than Mcr in Eq (1), Ie is applied and Ig is applied as the maximum moment of inertia.

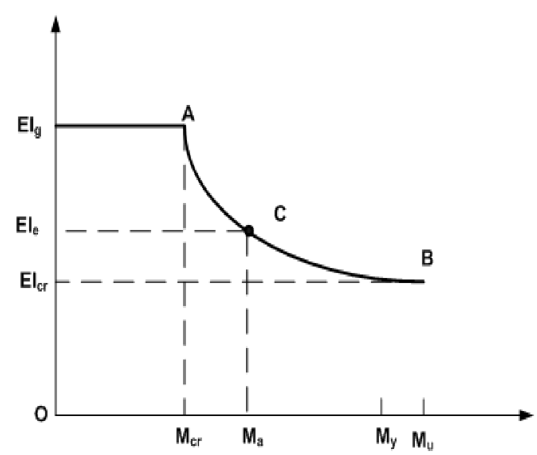


Fig. 1 Effective flexural rigidity by Branson

Since FRP material was developed, researches on estimation of flexural rigidity of RC structures using FRP materials have been conducted. Bartholomew suggested that 5th order equation yields more accurate result for evaluation on flexural rigidity of RC structures strengthened with FRPs than that of Branson's Equation.

ACI 440.1R-03 adopts a design standard such as the below expression (3) for the estimation of flex rigidity for RC structure strengthened with FRPs.

$$\beta = \alpha\left(\frac{E_F}{E_S} + 1\right)$$

where, β is a reduction coefficient according to FRP material, 'E_F' and 'E_S' are the modulus of elasticity of FRP and iron bar, and 'α' is a cohesion coefficient and 0.5 is suggested to be used.

3. EXPERIMENT

In this study, Fig. 2 shows that 5 slabs was made. Each slab has a section of 700×250mm and length of 2500mm. For tension and compression rebars, H13 rebars were located as shown in Fig. 2.The variables considered in this experiment were the types and amount of reinforcing material. As shown in Fig 3, CFRP sheets and GSP plate were strengthened with the length of 2,000mm. The amount of strengthening was 77% and 147% respectively of the specified compressive strength of concrete. Loading rate is 1mm per minute in 3-point load by using UTM (Universal Testing Machine)

4. EXPERIMENTAL RESULT

In order to evaluate effective flexural rigidity, effective moment of inertia can be calculated by using Eq. (4). By using Bartholomew's method, ACI 318 and ACI 440.1R-03, the effective moment of inertia was compared.

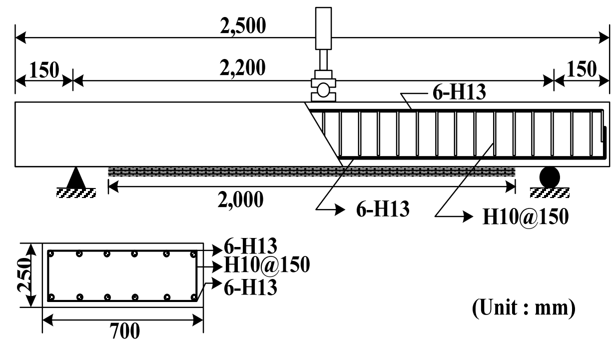


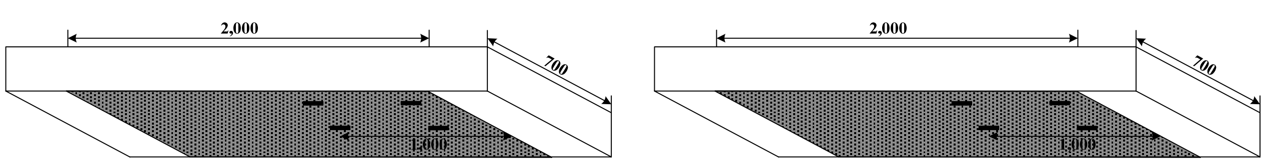
Fig. 2 The longitudinal and the cross sections

Table 1 The name and the variable

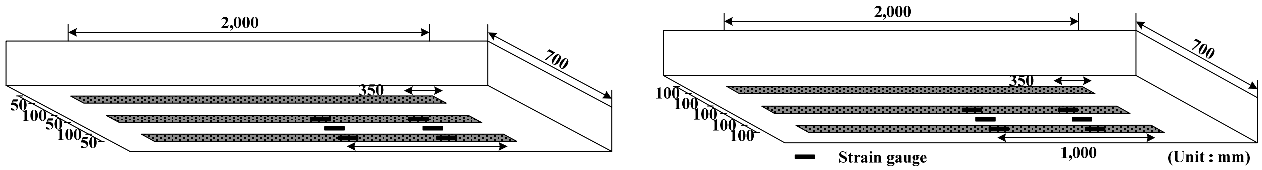
Name of specimen	Kind of strengthened material	Amount of strengthening (%)
Control	–	–
CFS77	CFRP sheet	77%
CFS147	CFRP sheet	147%
GSP77	GSP	77%
GSP147	GSP	147%

To estimate the effective flexural rigidity, the effective moment of inertia was estimated compared regarding 60~70% of the design strength RC slabs strengthened with FRPs as a service load.

As shown in Fig.4 and table 2, the equations suggested by ACI318, Bartholomew and ACI440.1R-03 did not estimate the effective flexural rigidity of the RC slabs strengthened with FRPs. When the equation suggested by Bartholomew was applied to CFS77, the maximum error of 26% occurred. In addition, applying the equations suggested by ACI318 and ACI 440.1R-03 yielded the maximum error of 19% and 18% respectively. For the average error, 15.4%, 10.8% and 10.2% were yielded by applying Bartholomew's equation, ACI318 and ACI 440.1R-03 respectively**.**



(a) CFS77 (b) CFS147

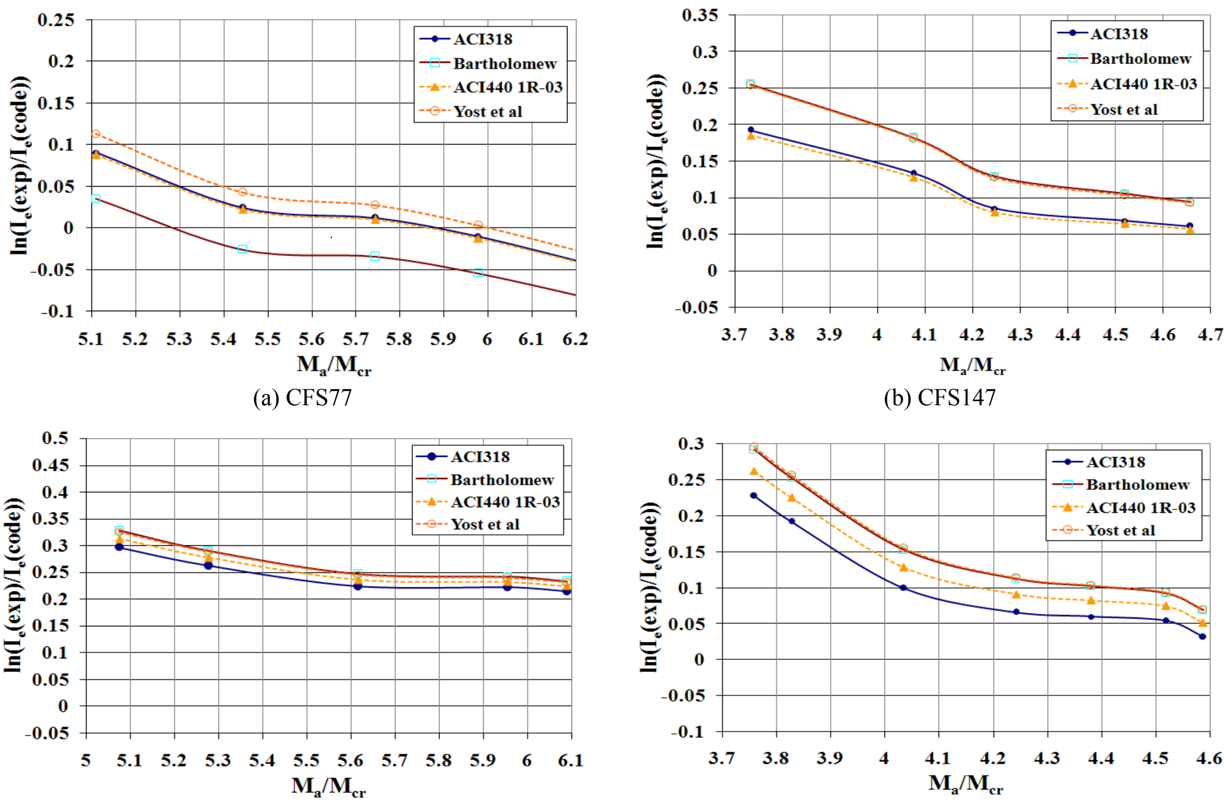


(c) GSP77 (d) GSP147

Fig. 3 The strengthened specimens

Table 2 The error between theory and experiment

Name of specimen	Average error (%)			Maximum error (%)		
	ACI318	Bartholomew	ACI440.1R-03	ACI318	Bartholomew	ACI440.1R-03
CFS77	10.8	15.4	10.2	19	26	18
CFS147	4	4.8	4	9	8	9
GSP77	11.3	15.6	13.3	23	29	27
GSP147	23.8	26.8	25.6	29	33	32



(a) CFS77 (b) CFS147

(c) GSP77 (d) GSP147

Fig. 4 The effective moment of inertia of service load

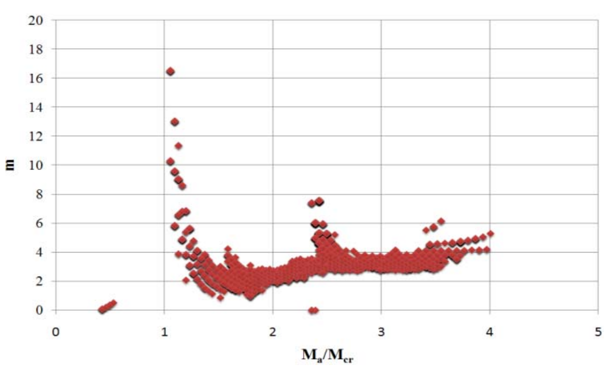
In case of CFS147, maximum of 8% occurred for Bartholomew, 9% was done for ACI318 and 9% for ACI 440.1R-03. In case of average error, 4.8% occurred for Bartholomew and 4% for ACI 318 and ACI 440.1R-03. For GSP77, maximum error of 29% occurred when Bartholomew's equation was applied. The errors of 23% and 27% were yielded by using the equations of ACI318 and ACI 440.1R-03 respectively. In case of average error, 15.6% occurred for Bartholomew, 11.3% for ACI 318 and 13.3% for ACI 440.1R-03.

In case of GSP147, maximum of 33% occurred for Bartholomew, 29% was done for ACI318 and 32% for ACI 440.1R-03. In case of average error, 26.8% occurred for Bartholomew, 23.8% for ACI 318 and 25.6% for ACI 440.1R-03.

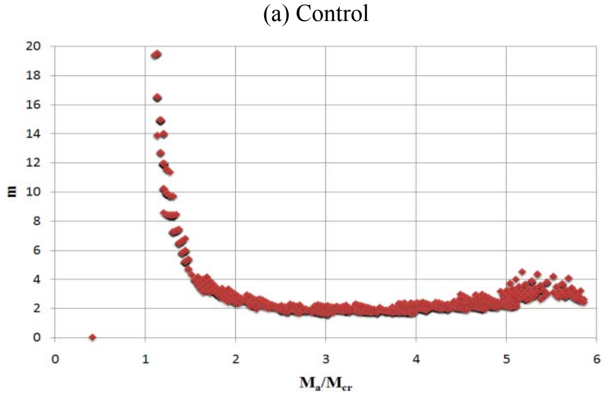
5. ANALYSIS RESULTS OF EXPERIMENT

In order to find precise value of effective flexural rigidity of the slabs external strengthened with FRPs, a variable, m was calculated by using Eq. (6). The variable m was calculated to yield the minimum error between the experimental results and analysis. The estimated variable of m was shown in Fig. 5. As the value of M_a/M_{cr} increases, the variable of m was converged to a certain value.

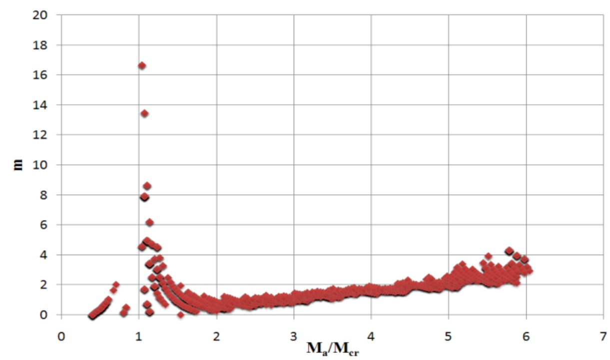
Under the range of a service load, the average value of m was calculated by using Eq. (6). In control specimen, value of the m is estimated at 3.03. It shows similar behavior of a cubic order equation suggested by Branson which is used to design code in Korea and USA. In specimen external strengthened with FRPs, however, an average of the variable m is estimated differently than behavior of a cubic order equation in ordinary RC structures. In the result of test by each slab, 2.16 was presented for CFS77, 2.58 was done for CFS147, 2.25 for GSP77 and 1.54 for GSP 147. Hence, those results shows different tendency from the existing Branson's expression. The comparison result of the value acquired from a new order was presented, 'm' which was applied to each slab through analyzing the result of test to the value acquired from the existing expressions to solve any value at Table 3~6.



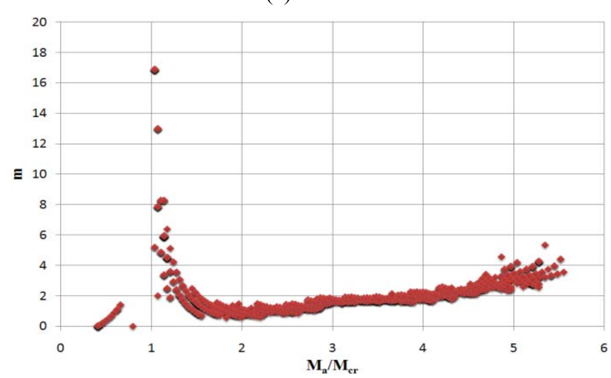
(a) Control



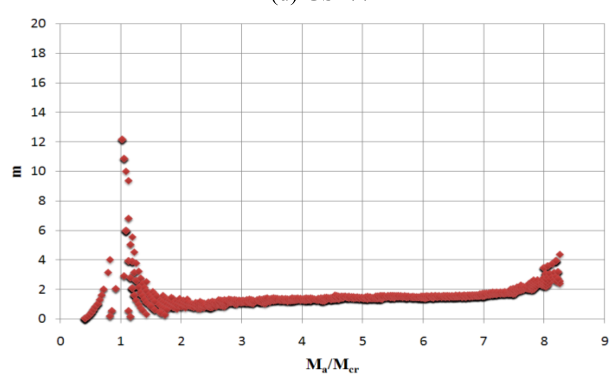
(b) CFS77



(c) CFS147



(d) GSP77



(e) GSP147

Fig. 5 Variation of the power m with M_a/M_{cr} ratio and type of specimen

According to the results of CFS77, when substituting 2.16 for a cubic order of equation, that is Eq, (5), a maximum error is yielded 7%, an average error is 3%. It presented more exact prediction because these results show a maximum error is decreased 11% and an average error is decreased 7%. In case 2.58 as an order is applied to CFS147, the maximum and average error were presented as 7% and 3.4%, respectively. These values showed 1% in maximum error and 0.6% in average error less than that of the existing suggestive expressions, so more exact expectation is possible. In case 2.25 as an order is applied to GSP77, the maximum and average error were presented as 12% and 4.7%, respectively. These values showed 11% in maximum error and 6.6% in average error less than that of the existing suggestive expressions, so more exact expectation is possible. In case 1.54 as an order is applied to GSP147, the maximum and average error was presented as 2% and 1.2%, respectively. These values showed 33% in maximum error and 22.6% in average error less than that of the existing suggestive expressions, so more exact expectation is possible.

Table 3 Test results and analysis of slabs CFS77

Total load	M_a/M_{cr}	△ (mm)	I_{exp}/I_{code}			
			m=2.16	ACI318	Bartholomew	ACI440.1R-03
106.82	2.73	3.4	1.07	1.21	1.29	1.2
116.62	4.07	4	1.02	1.14	1.2	1.14
121.52	4.24	4.4	0.99	1.08	1.14	1.08
129.36	4.52	4.8	0.98	1.07	1.11	1.06
133.28	5.65	5	0.97	1.06	1.09	1.06

Table 4 Test results and analysis of slabs CFS147

Total load	M_a/M_{cr}	△ (mm)	I_{exp}/I_{code}			
			m=2.58	ACI318	Bartholomew	ACI440.1R-03
149.94	5.1	4.9	1.07	1.09	1.12	1.09
159.74	5.44	5.6	1	1.02	1.04	1.02
168.56	5.74	6	0.99	1.01	1.03	1.01
175.42	5.98	6.4	0.97	0.98	1	0.98

Table 5 Test results and analysis of slabs GSP77

Total load	M_a/M_{cr}	△ (mm)	I_{exp}/I_{code}			
			m=2.25	ACI318	Bartholomew	ACI440.1R-03
106.82	3.76	3.4	1.12	1.25	1.34	1.3
108.78	3.83	3.6	1.09	1.21	1.29	1.25
114.66	4.03	4.2	1	1.10	1.16	1.13
120.54	4.24	4.6	0.98	1.07	1.12	1.09
124.46	4.38	4.8	0.98	1.06	1.11	1.09
128.38	4.52	5	0.97	1.06	1.09	1.08

Table 6 Test results and analysis of slabs GSP147

Total load	M_a/M_{cr}	△ (mm)	I_{exp}/I_{code}			
			m=1.54	ACI318	Bartholomew	ACI440.1R-03
147	5.07	5	1.02	1.35	1.39	1.37
152.88	5.28	5.4	1	1.3	1.34	1.32
162.68	5.62	6	0.98	1.25	1.28	1.27
172.48	5.96	6.4	0.99	1.25	1.27	1.27
176.4	6.09	6.6	0.99	1.24	1.26	1.25

6. CONCLUSIONS

To estimate the effective flexural stiffness with the outer FRP reinforced member, which is widely used reinforcing method, next result was acquired through the test result, making use of the outer FRP sheet and GSP.

1) In case analyzing it with the existing suggestive expressions for the outer FRP reinforced testee, the average error of the effective flexural stiffness showed the value more than 10%.

2) In case assuming reversely the order that certain exact behavior is expectable through the test result, 'Control=3.03' means the similar value to that of the existing expression. On the other hand, more exact behavior is expectable in case of applying CFS77=2.16, CFS147=2.58, GSP77=2.25 and GSP147=1.54.

3) In case applying 'm', a value which was acquired through the test result, comparing to the average error was more than 10% at the working load area where the existing suggestive expressions were applied, it was found that the average error could decreased more than 5%.

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