- Technical Paper -

FUNDAMENTAL PULLOUT EXPERIMENTS ON JOINTS OF PRECAST SLABS IN BRIDGES USING CFRP STRAND

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ABSTRACT

The paper presents an experimental fundamental study on joint of precast slab in bridge with Carbon Fiber Reinforced Plastics Strand (CFRP strand) application. A series of pullout tests were conducted with various specimens and the different setup. Finally, a method how to use CFRP strand at joint part were proposed to improve the bond capacity between concrete and CFRP strand, reduce the width of the joint, keep high durability of the structure. Besides, the suitability of CFRP strand reinforcing for the pre-cast concrete deck was confirmed.

Keywords: Carbon Fiber Reinforced Plastics Strand (CFRP Strand), pullout, joint, precast slab

1. INTRODUCTION

Fiber Reinforced Plastic (FRP) was known as a new material in the application for the concrete structures [1] , especially in bridge constructions from 1993. FRP can be used as the main material, such as tendons, piers, beam, and decks in 355 bridges around the world until 2011 [2], [3]. In Japan, the concept of using FRP in bridges was studied and discussed enthusiastically from late 1980's to 1990's [4]

Carbon Fiber Reinforced Plastics strand (CFRP strand) has more benefits than conventional steel. They have the lightweight (about 1/5 weight of steel strands), the high corrosion resistance, non- magnetic interact, the low linear expansion (the coefficient of linear expansion is about 1/20 of the steel), the high tensile strength, the high tensile modulus, the high tensile fatigue performance, the low relaxation loss and flexibility [5]. With the outstanding features, they were applied as a reinforced material for more than 140 structures in Japan [6]. Moreover, the durability of the prestressed concrete bridge using CFRP strand has been confirmed after more than 23 years through harsh environmental conditions [6], [7]. In the past, the higher price of CFRP strand was a barrier for the application in the actual constructions. However, nowadays CFRP strand has advantages not only in performance but also in economy because the cost was considered in the whole of construction life cycle contained maintenance cost [8]. Therefore, CFRP strand had more attention in the alternative application for general steel on the bridge deck, especially the bridges constructed in the corrosive environment [9] [10].

On the other hand, the using of precast slabs take advantage of saving the time of bridge construction. However, the drawback of this technology is the in-situ joint, which is required the shortest possible width, the high durability of structure, saving the time, and saving the cost of labor.

The bond between concrete and reinforced steel will control the complexity and width of the joint. When D19 is reinforced for pre-cast slabs, the width of the in-situ joint with the lap-splice method will around 600 mm. Besides, CFRP strand has bond strength to concrete of 7.23MPa [5] which is as twice as ordinary PC steel wire. It is also obvious from the past experiment that bond strength is corresponding to 40Ø in the case of normal adhesion. In this study, there was a relationship between the joint width and the embedment length of CFRP strand in joint (see Fig. 1). Hence, a series of pullout experiment was conducted with the proposed embedment length and verified the performance for each embedment length. The aim of the experiments was to improve the bond capacity between concrete and CFRP strand, reduce the joint width to around 300 mm and keep high durability of the structure when CFRP strand was applied in slabs. Three main experimental studies were carried out and useful results have been finally shown.

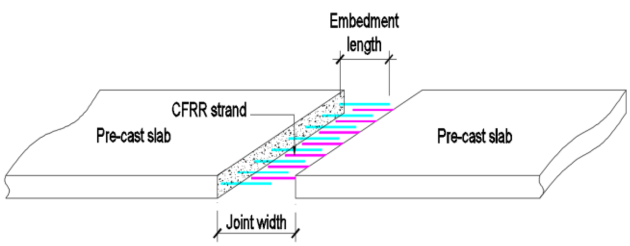

Fig. 1 The in-situ joint of pre-cast slabs reinforced by CFRP strand

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2. THE EXPERIMENT

2.1 The outline of experiment

The test was conducted according to the method in conformity with JSCE-G503-2013[11]. Fig. 2 shows the outline of the pullout experiment by the universal test machine (Shimadzu corporation UH-1000kN) and the detailed installation process for the experiment at the laboratory. Measurement devices, the displacement meter (Tokyo Sokki Kenkuyjo Co., Ltd CDP5) and the load cell (Tokyo Sokki Kenkuyjo Co., Ltd CLC-300KNA) were used to measure the displacement of the tip of CFRP strand and the loading force.

2.2 Concrete

Concrete was mixed with fly ash, and designed for standard strength of 50N/mm2. The compound is shown in Table 1. The two specimen sizes in cross-section were set to 75mm x 75mm in the first experiment and 150mm x 150mm for the second and third experiment as shown in Fig.3.

2.3 CFRP strand diameter

Diameters of the reinforcing bar D16 or D19 were generally used for the reinforced concrete slab. Besides, the tensile strength of CFRP strand has about five times that of ordinary steel reinforcement so the diameter corresponding to CFRP strand was 10.5 mm. However, to escape the excessive crack width in the high strength region and balance the strength due to the decrease of the embedment length in the joint, the diameter of 12.5 mm and 15.2 mm were selected and investigated with CFRP strand. Table 2 shows the standard specification of CFRP strand.

Table 1 Standard specification of compounding used CFRP Strand

Slump (kg)	Air content (%)	Gmax (mm)	W/B (%)	W (kg)	B (kg)	EX (kg)
18	4.5	13	35	165	471.4	20
C (kg)	FA 15 (kg)	s/A	Fine aggregate (kg)	Coarse aggregate (kg)	AE (kg)	Anti-foaming Agent (kg)
383.7	67.7	0.41	736.9	1060.5	3.3	14.1

Here, EX: Expansion material for concrete
C: Early - strength Portland cement
FA 15: Fly ash (subtraction rate 15%)
B=C+EX+FA
s/A: Fine aggregate ratio
AE: High- performance ae water reducing agent

Table 2 Standard specification of CFRP Strand

Shape of section	Designations	Diameter (mm)	Effective cross-sectional area (mm^2)	Guaranteed capacity (kN)	Nominal mass density (g/m)	Tensile elastic modulus (kN/mm^2)
	1x7 Φ12.5	12.5	76	184	145	155
Stranded wire 7	1x7 Φ15.2	15.2	115.6	270	221	155

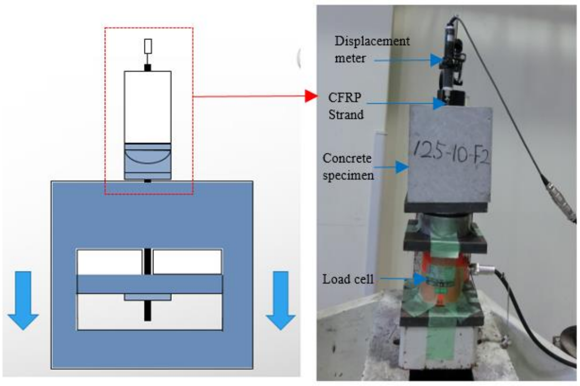
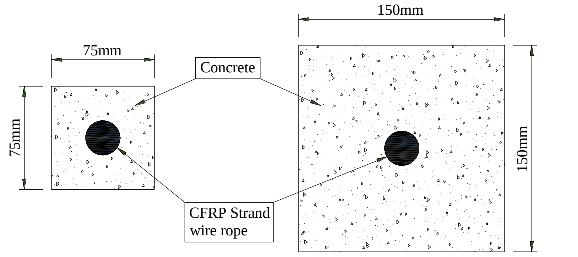


Fig. 2 Outline of experiment and detail setup



a) Fist experiment b) Second, third experiment

Fig.3 Cross-section size of the first, second, and third experiment

a) S type b) N type c) F type

Fig.4 Three types of CFRP strand in the joint part

2.4 Embedment length in joint part

Regarding the purpose of reducing the joint width, the embedment length was chosen in the relationship with CFRP strand diameter including 10Ø, 15Ø, and 20Ø as shown in Table 3. In addition, the length of tuft body in the first and second experiment was 10Ø.

2.5 Method using CFRP strand in joint part

Three methods using CFRP strand in the joint of slabs is shown in Fig.4. In addition to the method using the straight-ordinary CFRP strand (S type), two methods using the untwisted CFRP strand with no filling inside tuft body (N type) and filling inside tuft body (F type) were used to improve the adhesion. In order to compensate for insufficient load-bearing capacity due to the shorter joint and shorter embedment length, the method was expected that the diameter was partially increased by untwisting and the stiffness of tuft body by filling inside was increased. In the absence of any treatment, the concrete filling inside the tuft body was uncertain as Fa type. N type simulates incomplete filling of concrete and the polyurethane foam was put inside of N type, CFRP strand could be shrunk. Fb type fills pre-filled mortar with no risk of insufficient filling.

Totally sixties specimens were prepared for the series of pullout experiment in term of the difference of the cross-section of concrete, the embedment length, the CFRP strand diameter, and the method using CFRP in the joint part.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 The first experiment.

Fig.5 shows the failure situation of specimens in the first experiment. Here, as an example, the name "12.5-10-S" means diameter 12.5 mm - embedment length to diameter ratio 10 - method of using CFRP in the joint part: S type. Most of the failure of the specimens due to concrete splitting except for the specimen of (Φ15.2-10Ø-N), and it was impossible to judge which shape of CFRP strand has the stronger adhesive strength. Fig.6 shows the relationship between the embedment length and the maximum load for each diameter of CFRP strand in the first experiment. Maximum load of all cases of the experiment was smaller than 110kN. This value was significantly lower than the guaranteed capacity of CFRP strand with diameter Φ12.5 mm (at 184kN). It was obvious that concrete was damaged sooner than the pullout of CFRP strand and the accurate of the adhesive strength could not be measured. The cross-section area of concrete was not enough for the aim of this experiment.

3.2 The second experiment

After the first experiment, the second series of experiment was conducted by considering the effect of the specimen sizes of concrete to the bond-failure mode of joint. In this series, the cross-section size of the specimen was changed to 150mm x 150mm as shown in Fig.3. It was expected that the specimens of F series could have the highest bond capacity so the number of specimens in the second test was two pieces for each diameter and each embedment length respectively to

Table 3 List of specimen number

Diameter (mm)	Embedment length (mm)	The number of specimens S series	N series	F series in first test	F series in second test	Total number of the first test	Total number of the second test
Φ12.5	125mm(10∅)	1	1	1	2	3	4
	188mm(15∅)	1	1	1	2	3	4
	250mm(20∅)	1	1	1	2	3	4
	Total number of test	3	3	3	6	9	12
Φ15.2	152mm(10∅)	1	1	1	2	3	4
	228mm(15∅)	1	1	1	2	3	4
	304mm(20∅)	1	1	1	2	3	4
	Total number of test	3	3	3	6	9	12

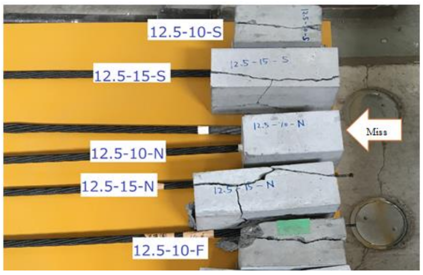
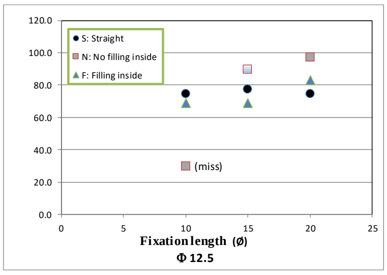
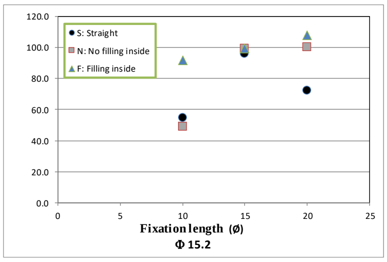


Fig.5 Specimens after the first experiment

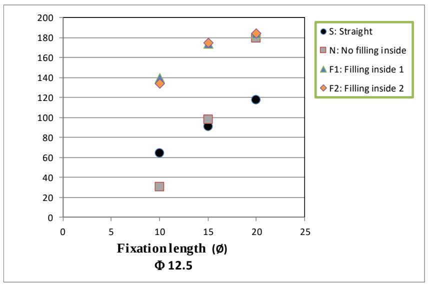


a) Φ12.5 mm

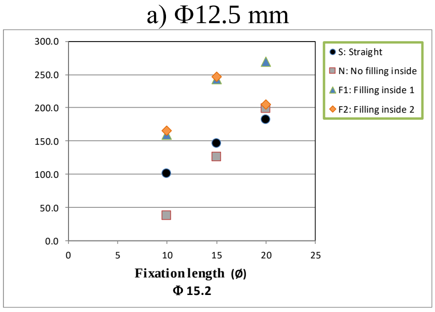


b) Φ15.2 mm

Fig.6 Relationship between embedment length, diameter and maximum load in the first experiment



a) Φ12.5 mm



b) Φ15.2 mm

Fig. 7 Relationship between embedment length, diameter and maximum load in the second experiment improve the accuracy of the data. (See Table 3)

The failure mode of this series test in S type and N type was the pullout mode of CFRP strand. In the series of F type, the results were similar with embedment lengths to diameter ratio (10Ø, 15Ø) but there was a small difference in the result of specimens (20Ø) with the concrete of the (Φ15.2-20Ø-F2) specimen broken.

Fig.7 shows the relationship between the maximum load and the embedment lengths in both of diameters. The maximum load monotonically increased when the embedment length of CFRP strand increased. When the diameter of CFRP strand was larger, the applied load was also larger in all series. In addition, F series had the highest bond capacity as expected, compared with S series and N series in the group having the same diameter and the embedment length. The applied load of (Φ15.2-15Ø-F) specimens were around 40% greater than the value of (Φ15.2-15Ø-S) specimen and of (Φ15.2-15Ø-N) specimen. Furthermore, three F-series specimens namely (Φ12.5-20Ø-F1), (Φ12.5-20Ø-F2) and (Φ15.2-20Ø-F1) did not fail when the load passed the guaranteed capacity of CFRP strand, reached at 184.2 kN, 184.8 kN, and 270 kN, respectively.

On the other hand, it was necessary to concern the (Φ15.2-20Ø-F2) specimen, which was a broken at lower load than the breaking load of CFRP strand. From the observation of the status of specimens after the test, some reasons could be considered. Firstly, the length of tuft body of CFRP strand, which was filled with the concrete, was shorter than other specimens. Secondly, the concrete was not filled well inside the tuft body of CFRP strand, which seemed to be slightly thinner than other specimens were.

3.3 The third experiment

Based on the consideration the results of the second experiment, an additional test-the third experiment was conducted to focus on the F type in order to pursue a more efficient shape in term of function and cost. Besides, the experiment also investigated the influence of the length of the tuft body and the method to fill inside the tuft body of CFRP strand on the adhesive strength.

The specimens with the CFRP strand diameter Φ15.2mm, concrete cross-section of 150mm x 150mm and embedment length to diameter ratio (15Ø) were set to F type. In addition to the length of tuft body (10Ø), which was used in the first and second experiment, two lengths (9Ø, 11Ø) were also selected to the third experiment. Fig.8 shows three lengths of the tuft body of the CFRP strand. In this test, F type was divided into two series. Namely, Fa series have no special internal filling inside and Fb series have polymer cement mortar as an internal filling.

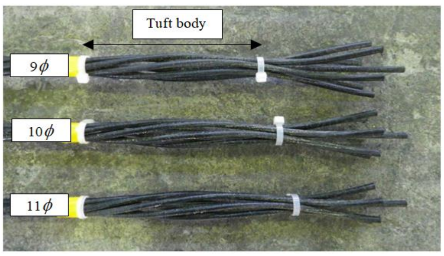
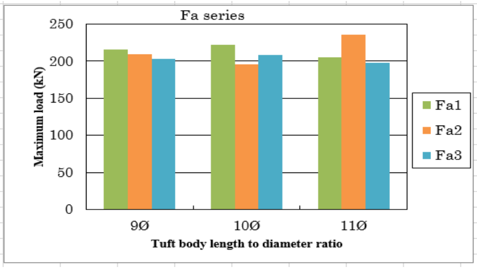


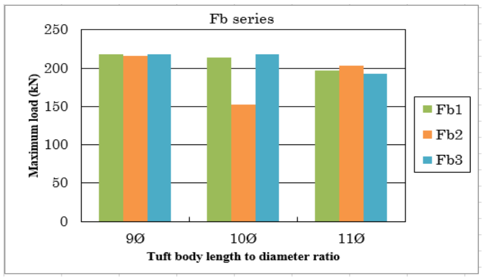
Fig. 8 Three lengths of the CFRP strand tuft body before filling

The results of eighteen specimens after the third experiment are shown in the Fig.9. The average load of three specimens with the same tuft body length among groups was approximately 210kN, of which the variation was small. The difference between a maximum and a minimum load was within 2kN in the Fb group with the tuft-body length of 9Ø. It seems that the bond capacity did not significantly depend on the tuft body length of CFRP strand.

The biggest difference came from the Fb group with the tuft-body length of 10Ø. One of the specimens of (10Ø-Fb) was broken down at a lower load than those of the others. From the situation of the specimen after experiment shown in Fig.10, it could be seen that most of the polymer cement mortar in tuft body did not remain inside of the (10Ø-Fb-1) and the (10Ø-Fb-3) specimen. In the contrast, almost polymer cement mortar of the (10Ø-Fb-2) specimen remained in CFRP strand. It may be that the filling situation of the (10Ø-Fb-2) specimen



(a) Fa series



(b) Fb series

Fig. 9 Relationship between the tuft body length and maximum load

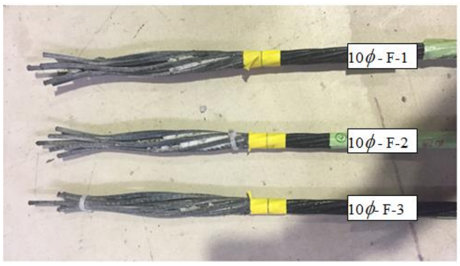
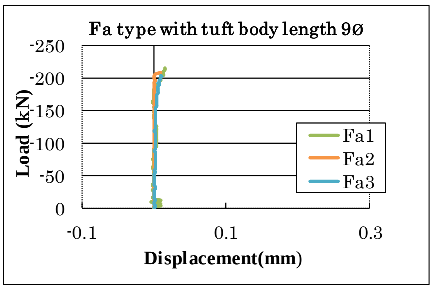


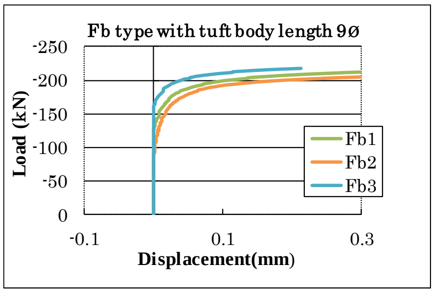
Fig. 10 The situation of specimens (10∅-Fb) after experiment

differed from others and polymer cement mortar inside the (10Ø-Fb-2) specimen has strong strength. As result, concrete near the root of tuft body could not stand with this load and broken down with a low load.

The load-displacement relationship diagrams of the both (9Ø-Fa) and (9Ø-Fb) series is shown in Fig.11. As can be seen that in any of the lengths of tuft body, the Fb series had more displacement than that of Fa series.

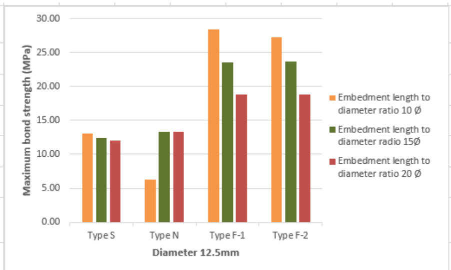


a) Fa series
(No special internal filling inside tuft body)

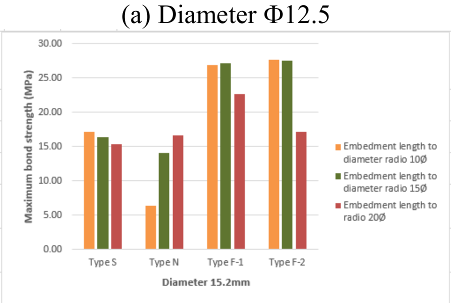


b) Fb series
(Polymer cement mortar filled in tuft body)

Fig. 11 The load-displacement relationship of two types CFRP strand with the same tuft body length 9Ø



(a) Diameter Φ12.5



(b) Diameter Φ15.2

Fig. 12 Relationship among average bond strength and several parameters

This phenomenon may be due to the tuft body pre-filled with cement mortar, which was more certain and the tuff body's stiffness was also higher than in the case filling by concrete. Therefore, the adhesion between the surface of the concrete and the CFCC strand in the joint was better. Furthermore, the stiffness of tuff body pre-filled with cement mortar was reduced by the shrinkage of CFRP so this method made the pullout of CFRP strand slowly.

4. PARAMETERS FOR DISCUSSION

To investigate and evaluate the influence of some factors on the bond strength, this section was added to study based on the results of the second experiment.

The bond strength was generally calculated by the following equation and the results shown in Fig.12.

$$\tau = \frac{F}{\pi \phi L} \qquad (1)$$

where,

τ is average bond strength (MPa),
F is pullout load,
ϕ is CFRP strand diameter,
L is the embedment length make it

4.1 The diameter of CFRP strand

In previous studies, average bond strength between concrete and FRP decreases when the diameter of rebar increases. Several reasons are considered. The bleeding of the water in the concrete would made contact force between concrete and FRP bar lower [12]. The embedment length requires longer suiting with larger diameter but greater embedment length reduces the bond strength. Sometimes, Poisson ratio and shear stiffness are also influence factors [13].

The second experiment produced the result that significantly disagreed with the previous studies. Herein, the diameter was larger, the applied load was larger in all series. The result from Fig. 12 shows that more than 80% couple specimens with the same embedment length, the average bond strength in the diameter of 15.2 mm higher than that in the diameter of 12.5 mm

4.2 The embedment length of CFRP strand

The embedment length plays an important role in bond strength of FRP bar and concrete. The bond strength reduces when embedment length rises [13], [14]. The results of the specimens using CFRP strand with straight-S type and filling inside tuft body-F type in the same diameter group almost agreed with the previous studies. This decrease among three embedment lengths with the same diameter was slight in S type but it was remarkable in F type. In contrast to those, N type - no filling inside tuft body had higher bond strength in the case longer embedment length

4.3 The method using CFRP strand in joint part

Outer surface has a remarkable influence on bond strength when the failures did not occur in the concrete. Some authors had worked with S type-straight outer surface. In 1989, it was reported that the bond strength of experiment with diameter of 12.5 mm and concrete strength 47.6 MPa was 7.23MPa [5]. This value was 9.5 MPa and 13 MPa in the research of Tepfers in 1992 corresponding to 47.3 MPa and 44.4 MPa of concrete strength, respectively and 12.5 mm in diameter [15]. Likewise, the bond strength of S type in this study fluctuated from 12.03 MPa to 17.10 MPa depending on the diameter and the embedment length. It is not much different in the bond strength when using CFRP strand with N type. However, the value of F type was two-fold that of S type, it peaked at 27.54MPa corresponding to (Φ12.5-15Ø-F2) specimen.

5. CONCLUSIONS

From the above results and discussions, the conclusions are summarized as follows.

(1) The outcome of the method using three types of CFRP strand in joint part was shown. As expected, the method using F type-filling inside tuft body was the best choice which provided the highest bond strength among three types with the same conditions.

(2) In F series of the second experiment, the applied load in the case of the embedment length of 20Ø reached the value that was higher than ultimate load of CFRP strand standard. From these results, it is necessary to study with more investment for the method using F type for joint part in design, manufacture, and application.

(3) Comparing about ultimate load, the ratio of ultimate load to the breaking force of CFRP strand, and the embedment length, F type with diameter of 15.2 mm and the embedment length of 15Ø (228 mm) would be a great combination for actual bridge.

(4) One of the purposes of the experiment was to clarify the minimum possible width of the joint. It was confirmed that when slabs using CFRP strand with the diameter of 15.2 mm, the embedded length of CFRP strand in joint of 15∅ and F type was selected, the joint width was improved.

(5) From the result of the series in third test, no remarkable change was observed in the bond capacity with whatever the length of the tuft body. However, the bond capacity may be depended on the method and material to fill in the tuft body of CFRP strand, which should be considered more.

(6) With the generally calculation by formula (1), an increase in the diameter of CFRP strand was accompanied by a rise in bond strength. In S type and F type, the longer embedment length maked lower bond strength. Nevertheless, this trend was opposite in N type-no filling inside. Formula (1) should study to add new parameters for accuracy in this case.

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