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USING CARBON FIBER STRIPS IN JOINTS STRENGTHING OF BOX SEGMENTAL SELF-COMPACTING CONCRETE BEAMS

*** Ahmed H. Hashim[1]** **Dr. Waleed A. Wrayosh[2]**

1) PhD. Student in Civil Engineering Department, Mustansiriayh University, Baghdad, Iraq.
2) Assist prof. Dr. in Civil Engineering Department, Mustansiriayh University, Baghdad, Iraq.

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Abstract: The main objective of this research is to study the effect of carbon fibers used to strengthen the joints of the box segmental beams. For this research, four beams were produced and tested. One of these beams, monolithically, was cast as a reference beam and the three others were segmental beams. All beams were produced with Self-Compact Concrete (SCC) and box cross section. Each segmental beam consisted of three precast concrete segments were connected by post tensioning tendons. The three segmental beams have same characteristics, but different in joint types between the segments. The types of joints used were (dried , epoxied and dried strengthen by CFRP sheets). All beams were tested under static two point loads up to failure. For each test, deflections at mid-span location were recorded for each (5kN). Also, first cracking, mode of failure and ultimate loads values were recorded as well as the concrete surface strains at the specified locations for both loadings.

Keywords: *box segmental specimens, segments, joint positions, dry joints, epoxy joint,* CFRP sheets.

1. Introduction

Segmental prestressed concrete box beam bridges have become the adopted construction method for many high elevation projects in recently [1] and it was classified within achievements the most important in engineering region in the last three decades. It is recognized today in all countries and particularly in the United States as a safe, practical and economical construction method [2].

There are many useful aspects of the segmental bridges construction, where by this method quality of concrete can be controlled during casting , mitigate construction efforts, decrease in construction time, and reduce environmental inconvenience comparison with the traditional technology[3].

The segmental construction is different than that of the monolithic construction, where the segmental bridge consists of small precast units usually called segments which can be connected of some by post-tensioning technique. The precast segments can be manufactured in a casting factory or yard and then transported to the final position by various launching equipment. The prestressing may then be used to achieve the assembly and to provide the structural strength The segmental beam is beam fabricated by numbers of segments which are assembled with some to form the specimen. Joints between the segments have different types that may dry, epoxy or key joint.

* Corresponding Author: alarejiahmed968@gmail.com

Choosing of any type of joint, greatly, depends on the system conditions that it will be used. [8]

Segmental box girders, for example of segmental beams, can be widely used for several positive aspects one of them their load carrying whether the bending moments are positive or negative and their torsional stiffness in addition to economy, where segmental box specimens are more equate for longer girders and larger decks. Mainly, behavior of segmental girders is controlled by the resistance mechanism of the segments joints. The applied shear force is resisted by components of the interface friction of the joint and the strength of the shear keys, if exited, (see Figure (1-3)). Two joint types were, commonly used in these are dry and epoxied joint types. In epoxied type the segments are pasted by epoxy resin. This resin works on occupancy the gaps between the joint faces, leading to increase resistance ability for shear stresses, but applying this type of joint needs more time and efforts which is leads to increase the time of construction.

In case of dry joint type, the segments are collected some of them directly without any binder in between. Dry type of joints was, widely, adopted because of the facilities in construction of this method and, as a result, the time of construction will be reduced. There are many tests to various types of joint were carried out to evaluate shear capacity of the joints. [9]

Some guides were provided by (AASHTO) for the segmental construction. These guides include some formulas deal with estimation of shear capacities of single and multi-keys dry type of joints. [10].

2. Experimental Program

2.1. Model Cross Section

This study consists of four specimens one of them was produced monolithically to consider as a reference and the others were segmental specimens. Each segmental specimen was fabricated with three (700 mm length) precast concrete segments by using post tensioning technique. The total length of each specimen is (2100mm) and box section with total dimensions (300mm×300mm) and hollow (140mm×140mm). The hollow section was adopted for all beam length except (200mm) from each ends. All segments were reinforced with four steel bars of Φ 10 mm for bending and with Φ 8 mm @ 120 mm c/c for stirrups,Figure1.

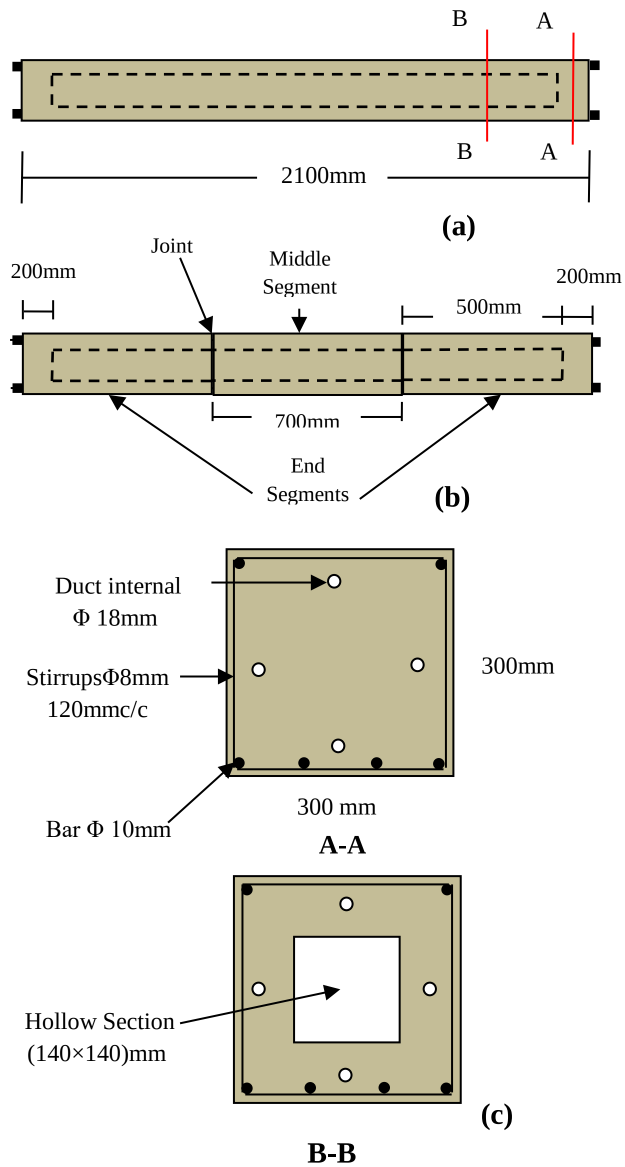

Figure1. Monolithic Specimen (a), Segmental Specimen (b) Cross Section A-A and B-B (c)

2.2Design of Joints

Each segmental specimen was fabricated with three precast concrete segments assembled by using post-tensioning internal tendons. Mechanism of connecting between the segments at the joint positions and adjacent sides' compatibility of the joints was the focus of this study, therefore; three types of joint were adopted to evaluate flexural behavior of segmental specimens under bending stresses, as illustrated in Table 1.

Table 1 . General description of joint positions

Beams*	Description of Joint
RB2	Monolithic (No joints)
SB5	Dried joint
SB6	Epoxied joint
SB7	Dried joint strengthen by CFRP sheets

***These beams were selected from a large number of specimens of a thesis.

2.2.1 Dried Joint Type

This type of joint was applied for segmental beam SB5.There were no details in procedure to form segmental beam with dry joint. The procedure was limited to cleaning the joint faces before assembling the segments by post tensioning tendons without any binder materials, Figure 2.

Figure 2. Dried joint for Beam SB5

2.2.2 Epoxied Joint Type

This type of joint was applied for segmental beam SB6. This type had more details in procedure than dry joint, this procedure can be summarized by the three following steps:-

1-Before post tensioning operation the faces of the segments ends are cleaned from dust and impurities.

2- After preparing epoxy resin, Directly, spread it on the faces of the joints to specified thickness ensures the side faces adhesion well.

3- During few minutes, after spreading the resin on joint faces, tendons are inserted through the ducts and post tensioning operation is started, Figure 3.

Figure 3. Epoxied Joint for Beam SB6

2.2.3 Dry joint Strengthen by CFRP sheets.

Beam SB7 was formed with this type of joint. The different feature between this type and epoxied joint type is that epoxied joint leads to create a tensile strength of the interfaces of the joint, while this type leads to bond the extreme surfaces of concrete adjacent to the joint position together and enhance joint resistance to the bending tensile stress.

Procedure of this type can be clarified the following steps:-

1- After the completion of the post tensioning process and forming segmental specimen with dry joint, the side area of concrete adjacent to the joint in width of 300mm (150mm from the joint position of each side) is cleaned from dust very well.

2- After limiting the required area for strengthening and preparing epoxy resin, directly, spread it on the limited area of the four side faces of the specimen.

3- Placing the first layer of CFRP sheets on the epoxied area and repeating same procedure for other layers. In this study two layers were adopted, Figure 4.

Figure 4. Dry Joint Strengthen by CFRP sheets

The epoxy resin, which was used in preparing each of epoxied and CFRP sheets joints, was one of products with 2 structural adhesive binders high modulus and strength under name Sikadure-31 DW, Figure 5.

Figure 5.Sikadure-31 Epoxy Resin

2.3 Materials

Ordinary Portland cement of 53 grade corresponding to (ASTM type I) was used throughout the investigation. The locally available crushed gravel with a size of (5-12) mm was used as coarse aggregate. The locally available clean river sand was used as a fine aggregate according to the specifications. ViscoCrete 5930-L superplastizer was added to mixing materials in order to improve its workability. Silica fume and Limestone powder with specified quantities were added to improve mechanical properties of concrete. Self-Compact Concrete (SCC) type was used to produce all specimens of this study by using materials above with coarse and fine aggregate properties and mixing proportions as shown in Tables 2,3 and 4, respectively.

Table 2. Grading and sulfate content of Coarse Aggregate

Sieve Size	Coarse Aggregate Passing%	Iraqi Specification Limits No. 45/1984
19mm	100	(%)
14 mm	99	100
10mm	93	90-100
5mm	12	50-85
SO_3	0.034	0-10

Table 3. Grading and Sulfate Content of Fine Aggregate

Sieve Size	Coarse Aggregate Passing %	Iraqi Specification Limits No. 45/1984
10 mm	100	100
4.75 mm	94	90-100
2.36 mm	85	75-100
1.18 mm	76	55-90
600 µm	65	35-59
300 µm	40	8-30
150 µm	12	0-10
SO_3	0.343	Less than 0.5%

Table 4 . Mixing proportion per cubic meter

Materials	*Quantities*
Cement	470 kg/m^3
Fine Agg.	750 kg/m^3
Coarse Agg	900 kg/m^3
Silica Fume	23 kg/m^3 of cement weight
Powder	130 kg/m^3
ViscoCrete	2.45 % of total volume
w/c	0.39

2.3.1 Properties of Materials for Self-Compact Concrete:

Self- Compacting Concrete is characterized by filling ability, passing ability and resistance to segregation. Many different methods have been developed to characterize the properties of SCC. No single method hasbeen found until date, which characterizes all the relevant workabilityaspects, and hence, each mix has been tested by more than one test method or the different workability parameters.

Five tests were carried out to assess the flow, filling and passing abilities of this type of concrete as follows:-

a- The Slump Flow Test

this test was used to assess the horizontal free flow of SCC in the absence of obstructions. On lifting the slump cone, filled with concrete, the concrete flows. The average diameter of the concrete circle is a measure for the filling ability of the concrete. The time T_{50cm} is a secondary indication of flow. It measures the time taken in seconds from the instant the cone is lifted to the instant when horizontal flow reaches diameter of 500mm, Figure 6.

Figure 6. Slump Flow Test

b- The J Ring Test.

This test was used to determine the passing ability of the SCC. The equipment of the test consists of a rectangular section open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar as shown in Figure 7. After raising the cone and allow the concrete to flow out freely, the final diameter of the concrete in two perpendicular directions was measured, in additional to measure the difference in height between the concrete just inside the bars and that outside the bars.

Figure 7. J Ring Test

c- The V-funnel Test.

The flow ability of the fresh concrete has been tested with this test, whereby the flow time is measured, Figure 7.The funnel is filled with about 12 liters of concrete and the time taken for it to flow through the apparatus is measured. Further, T_{5min} is also measured with V-funnel, which indicates the tendency for segregation, wherein the funnel can be refilled with concrete and left for 5 minutes to settle.

Figure 8. V-funnel Test

d- The L- Box Test.

the passing ability was determined by using this test ,Figure 8, the vertical section of the L-Box is filled with concrete, and then the gate lifted to let the concrete flow into the horizontal section. The height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (H2/H1). This is an indication of passing ability.The specified requisite is the ratio between the heights of the concrete at each end or blocking ratio to be ≥ 0.8.

Figure 9. L- Box Test

e- The U-Box Test.

This another test to assess the passing ability of SCC. in this test, the vertical section of the box was filled with the concrete sample and leaved it stand for 1 minute then sliding gate was lifted to allow the concrete to flow out into the other section of the box. The limitation of this test was the difference in the heights H1 and H2 of the concrete in the two vertical sections of the box, Figure 10.

Figure 10. U- Box Test

The obtained results of fresh concrete tests and the standard limits these tests are listed in Table 5.

Table 5. Results of Test Methods for SCC

Tests	Acceptable Values of Tests	Results of Tests
Slump Flow	$D_a \geq 650$mm	$D_a = 735$mm
	T_{50} (3-7) Sec.	T_{50}=4.45 Sec.
J Ring	$D_a \geq 650$mm	$D_a = 653$mm
L-Box	H2/H1≥ 0.80	H2/H1=0.94
V-Funnel	Flow Time≤ 10 Sec.	12 Sec.
U-Box	H1-H2≈0	H1-H2=4cm

2.4 Post-Tensioning Procedure

After precast concrete segments had been cured for 28 days under outdoor atmospheric curing condition they were subjected to prestressing forces to form the segmental specimen by using four tendons in each specimen. P.V.C ducts with internal diameter (18 mm) and external diameter (20mm) were embedded in concrete bodies to accommodate the post- tensioning strands after concrete hardening. Pre-stressing strands were seven-wire 12.7 mm in diameter, with cross-sectional area of 92.6 mm^2 , 0.1 % proof yield and ultimate strengths of 1570 MPa and 1860 MPa respectively.Post-tensioning operation was done in three stages to stretch each tendon to 250 bar which equivalent to 100.5 kN. Pre-stressing anchor heads and wedges were fixed to all tendons stressing ends. A (10mm) steel plate of dimensions (10×10cm) was used at each end of tendon as bearing plates. All the beams were post tensioned straightly with four tendons according to ACI 318-14 requirements.

2.5 Testing

2.5.1 Testing Setup

The tests were performed in the Structures Laboratory in Civil Engineering of Mustansiriyah University. All the specimens were tested under four-point bending test as shown in Figure 11.

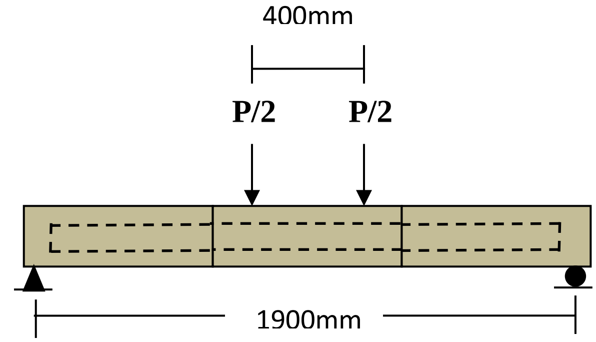

Figure 11. Loading arrangement

2.5.2 Instrumentation

Measurements recorded during each test included applied loads, beam deflections and strains.

1. Two strain gages were placed on the lower and upper sides of mid span position of the specimens for measuring the maximum concrete strains in tension and compression.
2. Dial gauge with (0.01mm) accuracy dial gauge and of (30mm) range was installed at mid span underneath the bottom face of the test specimens to measure the vertical deflections.

2.5.3 Testing procedure

The loading was applied slowly at small increments of about (5 kN) intervals. The deflections and strains were recorded. Once cracking of concrete was observed (first crack), the load was recorded. The tests were continued up to failure where the ultimate load was recorded.

4. Results And Discussions

4.1 Deflection results

The test results are listed in Table 6 and load-deflection relationships of the results are illustrated in Figure 12.

Table 6: The Results of all beams

Spe.	Load (kN)		Pcr/	Pu/	Δ_{cr}	Δ_{cr}/
	Pcr	Pu	(Pcr)c	(Pu)c	(mm)	$(\Delta_{cr})_c$
RP2	198	348	1.00	1.00	2.12	1.00
SB5	113	227	0.57	0.65	2.03	0.96
SB6	138	248	0.70	0.71	2.11	0.99
SB7	123	235	0.63	0.68	2.30	1.08

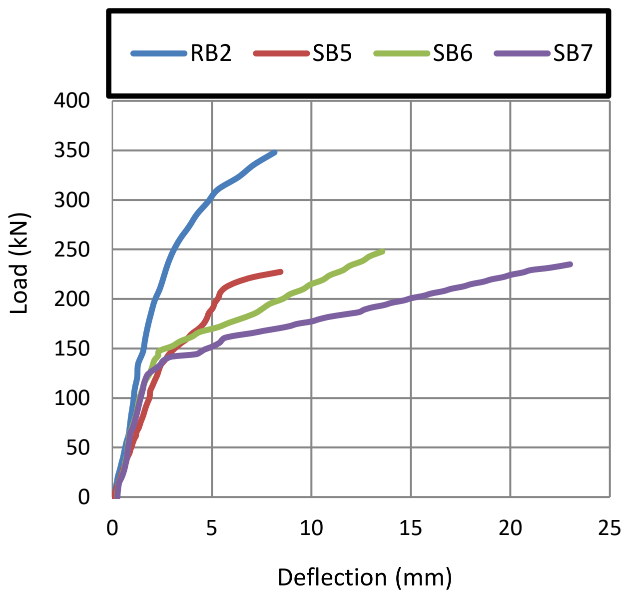

Figure 12. Load- Deflection Relationship for all beams

From fourth and fifth columns of Table 6, the segmental specimens revealed lower elastic stage than of the monolithic beam by about (37-43)% and lower bending strength by about (29-35)%.This can be attributed the continuation of the longitudinal reinforcement and concrete along the span of the monolithic specimen, while the longitudinal reinforcement and concrete are cut off at the joint position of the segmental specimens.

In this study, the deflection measurements at the first loadings (**Δ_{cr}**) instead of that at the ultimate loads (**Δ_u**) because that the plastic behavior of the specimens at the ultimate loading stage cannot give reasonable recordings of deflection.

From the deflection results, It was found that the deflection radios of the segmental specimens have ranged between (0.96-1.08) of that of the monolithic specimen. When taking into account that these ratios were recorded under first loadings lower than that of the monolithic specimen by about (30 to 43) %. In other words, the segmental specimens have shown lower stiffness (higher deflection) than that of the monolithic specimen.

From Table (6), taking into account the differences in elastic limits of the tested segmental specimens, dry joint specimen (SB5) behaved in stiffness lower than other specimens because the low resistance of the joint position against the bending stress of loading.

Using CFRP sheets had a clear effect in improving the joint strength of specimen (SB7), where it had deflection about (2.3mm) at first crack loading about (123kN), while dry joint specimen (SB5) had deflection about (2.03mm) in lower first crack loading about (113kN).

In comparison with CFRP sheets (SB7), epoxied joint specimen (SB6) had the better behavior, where it recorded about (2.11mm) at higher first crack loading (138kN).

4.2 Mode of failure

In general, the monolithic specimen (RB2) had a different mode of failure in comparison with the segmental specimens, where it revealed a failure in flexural while all segmental specimens had failed with concrete crushing at the upper side

of the joint position. The failure of monolithic specimen occurred with tensile cracks initiated from the bottom and when the load increased further cracks moved farther upward as shown in figure13.

Figure 13. Crack Pattern for specimen RB2

For the dry joint specimen (SB5), it was observed that the failure starting with opening of the lower side of joint (tensile zone) ending with crushing of concrete of the upper side (compression zone). This can be explained as follows;

At dry joint, concrete has no contribution in mechanism resistance against the bending tensile stress caused by the loading, therefore; when the bending tensile stress exceeds the axial compressive stress of the post tentioning tendons, the joint will open. With the progress of loading up to the ultimate load, the opening width of joint will increase leading to generate a compressive stress higher than compressive strength of the concrete of the upper side of joint causing crushing of this side, Figure 14.

Figure 14. Crack Pattern for specimen SB5

For comparison with the failure mode of dry joint, the epoxied joint specimen (SB6) had higher strength than the dry joint by about (22)%, this can be attributed to the great effect of the epoxy resistance. Improvement in joint strength SB6 can be observed from the failure mode that occurred in the plane of concrete adjacent to the epoxy layer instead of opening the joint plane, Figure 15.

Figure 15. Crack Pattern for specimens SB6

Similar effect of the epoxy joint it was observed of the dry joint strengthens by CFRP sheets of specimen (SB7).

Connection both concrete sides adjacent to the joint together by CFRP sheets with epoxy resin enhanced the joint resistance against to the tensile stress of the applied loading.

The failure mode of this type of joint, as shown in figure (16), occurred in the plane of concrete adjacent to the edge of carbon fiber layer.

Figure 16. Crack Pattern for specimens SB7

Improvement in resistance of both epoxy joint and the joint strengthen by CFRP sheets was not limited to the tensile stress, but reflected to the resistance of the compressive stress at the upper side of the joints. On the other hand, it was found, from Table (6), that specimen SB7 behaved in stiffness higher than dry joint specimen, lower than epoxied joint specimen.

4.3 Strain results

The test results of strains versus first crack loadings are listed in Table 7 and illustrated in figures 17 and 18.

Table 7. Strain results of the tested specimens

Spe.	Pcr	Pcr/ (Pcr)c %	ε_{tcr} $\times10^{-6}$	ε_{ccr} $\times10^{-6}$	$\varepsilon_{tcr}/(\varepsilon_{tcr})_c$ %	$\varepsilon_{ccr}/(\varepsilon_{ccr})_c$ %
RP2	198	1.00	177	-236	100	100
SB5	113	0.57	385	-373	218	158
SB6	138	0.70	333	-390	188	165
SB7	123	0.63	333	-448	188	189

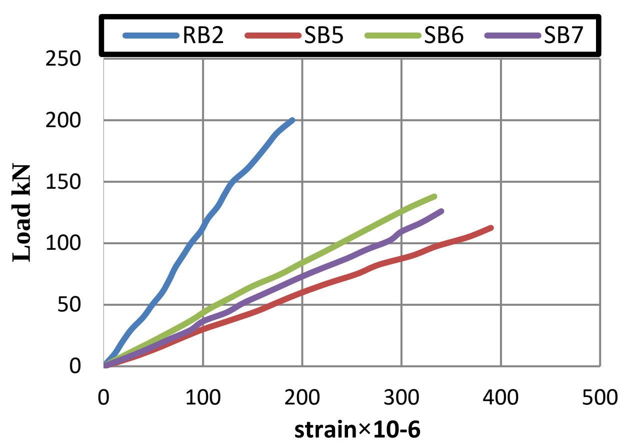

Figure 17.Load- tensile strain relationship

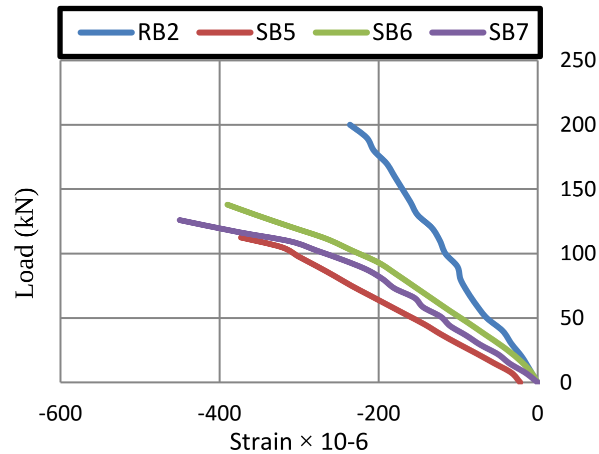

Figure 18. Load- compressive strain relationship

From Table 7, it was found that the segmental specimens had tensile and compressive strains higher than that of the monolithic specimen and lower limits in elastic stages.

Because of the low strength of dry joint against the bending tensile stress, the dry joint specimen (SB5) recorded strain in tension about (118)% higher than the corresponding strain of the monolithic specimen (RB2) at the lowest value of first crack loading which was (113kN).

Specimen with epoxied joint (SB6) behaved in better manner to the bending stresses than the dry joint specimen SB5, this can attributed to that adhesion interior concrete faces of the joint by using epoxy resin enhanced the axial compressive stress of the prestressing tendons (*T*po) applied on the entire cross section of the specimen, therefore; the strains recorded by the specimen SB2 were lower compared to that of the dry joint specimen SB5.

From Table 7, strengthen dry joint between segments by using CFRP sheets, which was used to produce specimen SB7, enhanced the joint resistance of the joint against the bending tensile stress, therefore; it recorded reduction in tensile and compressive strains about 7% and 34% in comparison with that of dry joint specimen SB5.

On the other hand, mechanism of strengthen dry joint by carbon fib CFRP sheets had an effect approximated to that used of epoxied joint type on tension zone, where specimen SB7 recorded tensile strain about 100% that of epoxied joint, but it had lower effect on compression zone.

5. Conclusions

Based on the test results and observations the following conclusions can be drawn:

1. Strengthen dry joint by CFRP sheets led to increase stiffness of the segmental specimen under bending moment in comparison with that of dry joint type by about 22%.
2. Strengthen dry joint by CFRP sheets led to enhance joint resistance of the concrete adjacent to the joint position against both tensile and compressive bending stresses by about 23% and 5%, respectively.
3. The failure of dry joint occurs in the segment interface, while the failure of joint strengthen by CFRP sheets, develops in the concrete adjacent to the segment interface.
4. Strengthen dry joint by CFRP sheets has a significant effect on the improvement of the flexural behavior in effect less than of epoxied joint.

Conflict of interest

There are not conflicts to declare.

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