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Behavior of RC Continuous Spliced One-Way Slab with Four Types of Concrete in Splice Regions

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Abstract

This paper sheds light on the behavior of reinforced concrete RC spliced one-way slab OWS in the case of using four types of concrete in the splice region in addition to the non-spliced specimen. Five specimens have been used, one cast as a monolithic unit for comparative and four consisting of three precast members and two splice regions with (normal concrete NC, high strength concrete HSC, slurry infiltrated fiber reinforced concrete SIFCON, and reactive powder concrete RPC). The whole dimensions of specimens are 2130mm length, 600mm width, and 100mm thickness. The parameters that have been studied which first flexural cracks, ultimate load, max deflection, longitudinal concrete strain and failure mode in addition to calculating a new index called ductility index which represented the capacity of ductility after failure, in which proportions to the deflection at ultimate load and flexural cracking load. The results from the investigation test shows that in the case of using RPC and SIFCON in the splice region, there is a convergence in increasing value of ultimate load and deflection. While no improvement in specimens' behavior with NC and HSC in the splice region.

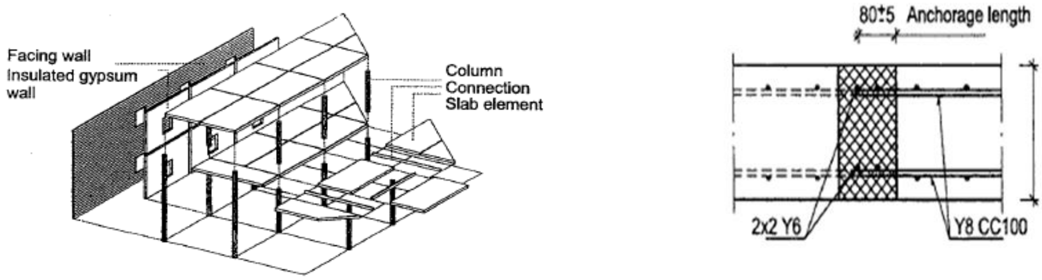
Keywords: Splice region, slab, continuous support, one way, and ductility

1. Introduction

The improvement in construction in the last decades made construction organizations research new methods in construction to achieve high quality, faster construction, and increased service life of the structure. So found the precast construction technique achieved these requirements in addition to the ability to reduce thickness which leads to a reduction in died load of the structure and reducing the cost of construction.

The method spliced reinforced concrete one-way slab was a type of precast construction technique. This technique contains joint cast in situ to connect several members transversely and longitudinally to make the slab in case of a large span. This happened as using full dimension precast members to form the slab has been caused difficulty in translation and lifted the members to locations. So that this technique has been used in the construction of bridge decks and buildings with more than five floors.

The first form of a slab containing precast members connected by joint appeared at Aalborg University in 1995 by using members with 2.9*5.9m connected by joint of ultra-high-strength fiber reinforced concrete UHS FRC as shown in Figure 1. This technique is again used in 1998 at the same university after that begin planning to build hospital [1].



(A) **(B)**

Figure 1 A) Sketch of new building and B) Details of joint [1].

In 2003, the Canadian transport organization used the precast panels connected by a joint of UHPC concrete to repair damaged bridge deck in CN overhead bridge that completed service life without completed closing of bridge and this method used especially in the cities which have problems with heavy traffic [2]. After that, this method has been used to replace two damaged bridge decks in the United States in the summer of 2009. One was the bridge located on route 31 and the other was one of the route 23 bridges as shown in Figure 2[3].

Because the joint connected to the precast members is the weakest point in the specimens, is preferred to use joints from ultra-high performance concrete and reinforced bars extended from precast members to strengthen the connection. Arafa et al. (2016) [4] used joint width of 220mm from UHP FRC concrete that has a compressive strength equal to 170MPa to connect two precast members as shown in Figure 3. When applying load, the results showed that the joint resisted the appearance of early cracks at the negative moment region. The joint region remained undamaged after failure and also a continuous specimen without failure in the bond between precast parts and joint cast on-site with increasing stress till failure.

(A) **(B)**

Figure 2 A) Longitudinal joint in route 31 bridge and B) Transverse joint in route 23 bridge [3].

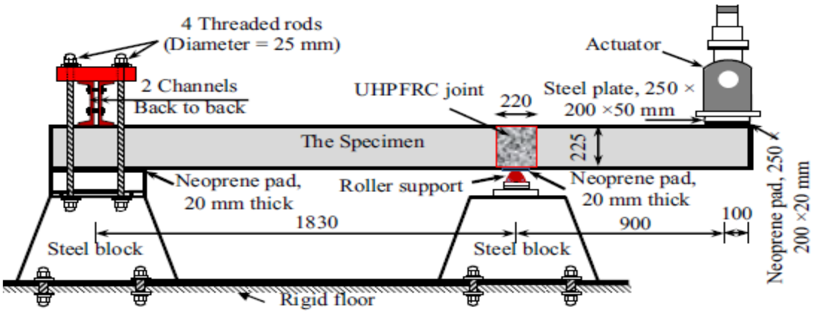


Figure 3 Details of specimen dimensions and support [4].

Bae JH [5] studied the behavior of three specimens two with joint and one without joint for comparative with UHPC specimen have a compressive strength equal to 120MPa as shown in Figure 4. The ultimate load increased at specimens with joint equal to 66% and 74% compared with the specimen without joint. The failure was a flexural failure with the crushing of concrete at the compression zone.

Figure 4 Stages of casting precast and joint [5].

The innovative dovetail joint from UHPC was used to connect two precast panels by using seven specimens studied by Qi, Jianan et al. (2020)[6] with different treatments (steel wire mesh, epoxy resin, and without treated), two shapes of reinforced bars expanded from precast members (U-shaped and straight shaped), two types of UHPC, and prestressing level. The experimental results showed that the used steel-wire-mesh enhanced performance by increasing ultimate load and ductility while the joint materials have not affected the performance of specimens. But, using straight bars make the performance brittle due to insufficient length. The flexural behavior is enhanced in the case of using a prestressing level.

This paper demonstrated the performance of reinforced concrete one-way slab with and without splice region in case of using continuous support by studying the effects of the concrete of splice region on the load-deflection curve, ductility, longitudinal concrete strain, ultimate load, and failure mode.

2. Experimental Work

2.1 Types of Concrete

Four types of concrete have been used in the present study to show the effect of concrete types in the splice region on the behavior of the RC one-way slab. All types of concrete have been prepared by using ordinary Portland cement type Crystal from Al-Najaf Ashraf. In NC and HSC has been used normal sand and coarse aggregate with a max size of 12.5mm. The RPC and SIFCON have been prepared by using very fine sand passed through sieve 600-μm and steel fiber (micro steel fiber of 13mm length in RPC mixture and hook-ended fiber of 35mm length in SIFCON) as shown in Table 1. The concrete mixture has been obtained after several trials to meet the standard compressive strength for each type as shown in Table 2.

MasterRoc MS610 is the silica fume that is used in the installation of the RPC mixture. Table 3 includes the properties of silica fume [7]. Hyperplast (PC200) is also used in the installation of HSC, RPC, and SIFCON. Hyperplast (PC200) properties are shown in Table 4. The used materials are satisfying the ASTM C494, Type A, and G [8]. Epoxy resin (Quickmast 108) has been used to connect precast members to the splice region and its properties are shown in Table 5 agreeing the specification ASTM C881, Type II, Grade2, Class C [9].

Table 1 Properties of steel fibers.

description	Hook-end steel fibers	Micro steel fibers
Length (mm)	35	13
Diameter (mm)	0.55	0.2
Aspect ratio	65	65
Density (kg/m3)	7850	7830
Tensile strength (MPa)	1100	2300
Modulus of Elasticity (Gpa)	210	200

Table 2 Percentage mixing for each type of concrete.

Concrete type	Cement Kg	Sand Kg	Gravel Kg	Silica fume Kg	Water L	PC200 Kg/m^3.	Steel Fiber %
NC	573	687	840	-	217	-	-
HSC	600	660	960	-	168	4.56	-
RPC	850	980	-	150	197	22	2
SIFCON	885	885	-	-	247.8	11	6

Table 3 MasterRoc MS610 properties.

property	Test result
Color	grey
Density (Kg/l)	0.55-0.7
Chloride content	>0.1%

Table 4 Hyperplast PC200 properties.

Property	value
Form	liquid
Color	Light yellow
Relative Density(Kg/lt)	1.03-1.07
Boiling point (°C)	>100
Freezing	-3
Dosage	(0.5-2.5)litter/100 kg cementations materials

Table 5 Quickmast 108 properties.

Property	data
Mixture color	Green
Mixed density (gm/cm^3)	1.2∓0.1
Compressive yield strength MPa	≥ 50 @ 7 days
Bond strength (slant shear) MPa	≥ 10 @ 14 days
Water absorption	≤ 0.2 %

2.2 Preparation of Reinforced Concrete One-Way Slab

A wood mold with inside dimensions representing the entire dimension of the slab was prepared, resulting in a one-way slab in accordance with ACI 318-19 [10]. In spliced samples, cork has been used to represent the splice region based on its dimensions, as shown in Figures 5 and 6 and Table 6. The splice region position was approximately at the inflexion point of the moments, and the length was achieved by extending the longitudinal bar from precast members according to the development length in ACI 318-19[10]. The goal of using cork in addition to epoxy resin was to make the side of precast panels rough to increase connection with the splice region.

The two meshes of reinforced bars at the top and bottom of the samples were represented by 5Ø10mm bars in the longitudinal direction and 11Ø6mm bars in the transverse direction. The yield strength from the tensile test at bars Ø10 and Ø6 was 501 MPa and 402 MPa, respectively, which is acceptable according to ASTM A-615-05 [11].

All precast members were made in the Al-Ibrahimia factory from normal concrete NC, and the specimens were vibrated by a table vibrator to remove any voids in the concrete before being covered in nylon to reduce moisture loss at an early age. After 28 days of curing the precast members, we started preparing the splice region by removing the cork adhesive insides of the precast members with an iron brush and painting the sides with epoxy resin to strengthen the bond. The concrete was mixed with a 0.1 m3 mixer to make the mixture homogeneous before being poured into the splice region. Except for the sample with RPC in the splice region, which was cured for the first three days at 60 C and the remaining 25 days at normal temperature, as shown in Figure 7, all samples were cured at normal temperature.

Table 6 Details of continuous supports reinforced concrete one-way slabs with and without splice region.

	Symbol of slabs	**Splice region**	
		Length mm	**Type of concrete**
Continuous support slabs	CSS-R	-	-
	CSS-2N	200	NC
	CSS-2H	200	HSC
	CSS-2R	200	RPC with 2% steel fiber
	CSS-2S	200	SIFCON with 6% steel fiber

CSS-R: the reference slab (non-spliced sample), CSS-2N: spliced slab with NC in splice region, CSS-2H: spliced slab with HSC in splice region, CSS-2S: spliced slab with SIFCON in splice region, and CSS-2R: spliced slab with RPC insplice region.

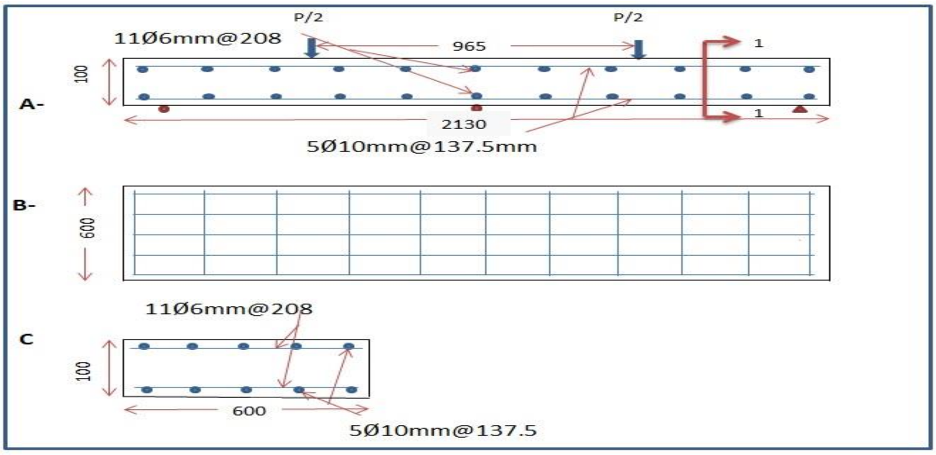


Figure 5 Details of reference specimen A) Side view, B) Top view, and C) Section1-1.

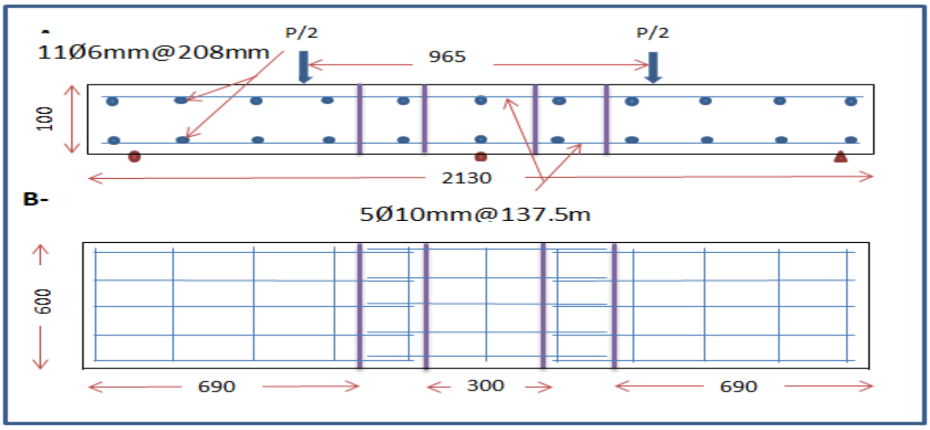


Figure 6: Details of spliced specimen: A) Side view and B) Top view.

(A) **(B)**

Figure 7 A) Curing of specimens at normal temperature and B) Curing of specimen with RPC in the splice region.

2.3 Testing Instruments

The specimens were tested using the universal machine at the University of Karbala/structure materials laboratory after curing and painting with white paint to easily show visible cracks. The test included increasing the load until failure. The incremental load was 5KN up to 150 KN and 3KN up to failure.

The support was built with three I-sections with a height of 25cm, as shown in Figure 8, welded on the girder and then welded on the machine test. This support was designed to make it easier to see the crack propagation at the bottom face.

Three LVDTs (linear variable differential transformers) were used to measure deflection in the mid slab, mid splice, and under load. In addition, the strain was measured in concrete at the bottom face in two locations: the mid slab and the mid splice.

Figure 8 Support fixed on the girder.

3. Results and Discussions

3.1 Mechanical Properties

The mechanical properties were measured for each type of concrete which represented the compressive strength test by using three cubes (100*100*100) and the splitting tensile strength by using three-cylinder (100*200)mm. The values of different types of concrete are displayed in Table 7.

Table 7 Mechanical properties for precast member and the splice region concrete.

Concrete Type	fcu MPa	$f'c$ MPa	Splitting Tensile Strength MPa
NC	40.12	31.59	3.23
HSC	55.32	44.92	4.15
RPC	100.05	90	13.31
SIFCON	78.8	70.9	12.85
NC for precast	43.9	34.12	3.67

fcu: Cubic compressive strength (MPa) and $f'c$: Cylinder compressive strength (MPa).

Table 7 demonstrated that compressive strength was increased when steel fiber was used due to the ability of steel fiber to resist the appearance of cracks, growth, and increased width with the increasing load so that the percentage of increased in case of RPC and SIFCON was 163.77 and 107.8 percent from NC and 100.3 and 57.8 percent from HSC. When compressive strength was increased, the splitting tensile strength increased as well, but by a smaller amount because the cracks distributed easily through the tensile load. Even though SIFCON has 6% steel fiber and RPC has 2% steel fiber, RPC has a 3.58 percent increase in splitting tensile strength. This increased in relation to RPC mixture components, the high tensile strength of micro steel fiber compared to hook-ended fiber, and also in relation to the edge phenomenon between the mold and the interface of the cylinder that occurred with SIFCON, which causes a higher percentage of fiber at the center than from the edges [12].

3.2 Performance of Specimens

The results of five specimens are shown in Table 8 when three supports are used and the load is acted along the width of the specimen at the center of each span.

Table 8 Results of continuous one-way slab with and without the splice region.

Slab Symbol	Pcr		Splice Crack KN	Ultimate load		Δp %	Ductility Index	Type of failure
	Pcr KN	Δcr mm		Pu KN	Δu mm			
CSS-R	35	3.6	40	225.3	13.52	0	3.76	Direct Shear
CSS-2N	38	2	52	184.63	8.58	-18.05	4.29	Direct shear
CSS-2H	27	1.67	58	197.21	8.93	-12.47	5.34	Direct shear
CSS-2S	40	1.81	74	250.41	13.09	11.14	7.23	Direct shear
CSS-2R	58	1.93	94	250.55	13.02	11.2	6.74	Direct shear

Pcr and Δcr: load and deflection at first flexural crack and Pu and Δu : load and deflection at ultimate load.

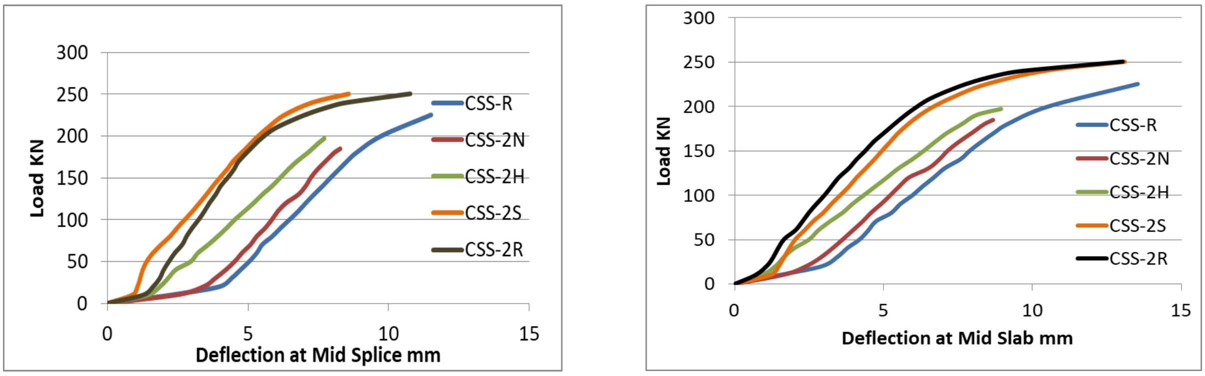
Ductility index= Δu/ Δcr

3.2.1 Load-Deflection Curve

When compared to the non-spliced specimen, the deflection in the spliced sample with NC, HSC, RPC, and SIFCON decreased by (36.5, 33.9, 3.7, and 3.18) percent at the mid slab and by (28.1, 33.01, 6.5, and 25.4) percent at the mid splice. This is related to the extended bars from the top and bottom to the splice region. Reduced deflection occurred despite increased ultimate load when RPC and SIFCON were used in the splice region related to the steel fiber in the mixture and improved mechanical properties for these types of concrete.

Allowable deflection is 5.36mm, and the load at this deflection is 83.73KN at the non-spliced specimen. When compared to the non-spliced specimen, the allowable deflection load at the splice region of spliced specimens with NC, HSC, RPC, and SIFCON increased by (7.45, 51.35, 115.2, and 97.6)%, respectively. Also, when compared to the non-spliced specimen, ductility increased by

(14.09, 42, 92.2, and 79.2)%, respectively, and this increment was related to the smaller deflection at mid slab in spliced specimens, as shown in Figure 9.



(A) (B)

Figure 9 Load-deflection curve at A) Deflection at mid splice and B) Deflection at mid slab.

3.2.2 Cracks and Failure Mode

With increasing load, several types of cracks appeared at the bottom and sides of specimens, including flexural cracks, diagonal cracks, and splice cracks (between the splice region and precast members). Flexural cracks appeared on the top face at about 38% of the ultimate load. The failure mode in the reference specimen was direct shear with reinforcement yielding. When compared to the reference sample, the ultimate load when using NC and HSC in the splice region decreased by 18.05% and 12.47 %, respectively, resulting in brittle failure with damage in the splice region, as shown in Figure 10. While the ultimate load has been increased by (11.14 and 11.2) percent when using SIFCON and RPC in the splice region when compared to the reference specimen, the failure is more ductile and stiffer with reinforcement yielding and this is related to steel fiber which resists increasing the number of cracks, expansion and crack width with increasing load.

3.2.3 Longitudinal Concrete Strain

The concrete strain at the early stage was increased in both positions (mid splice and mid slab) in the specimen without the splice region and in the specimen with NC in the splice region. While using HSC, SIFCON, and RPC, the splice region was very close to zero until the appearance of cracks and the beginning stage of increasing crack width with increasing load. This causes an increase in strain, which in some cases is greater than the ultimate strain, as shown in Figure 11, so that reading is ignored. Because of the greater deformation at mid slab than at mid splice, the longitudinal concrete strain at mid slab was greater than at mid splice.

Figure 10 Failure mode in continuous support one-way slab.

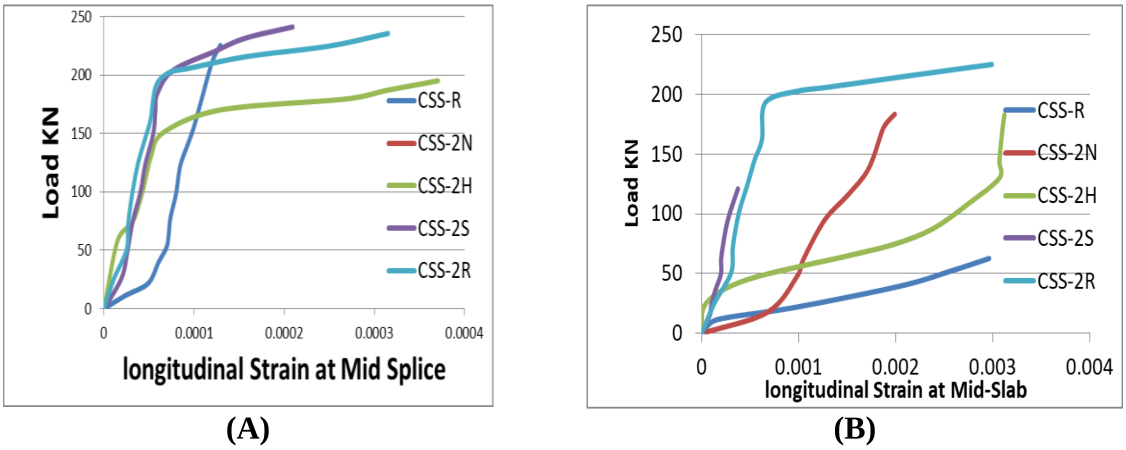
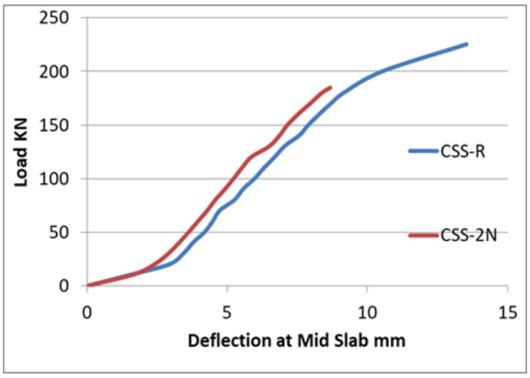


Figure 11 Longitudinal concrete strain at: A) Mid splice and B) Mid slab.

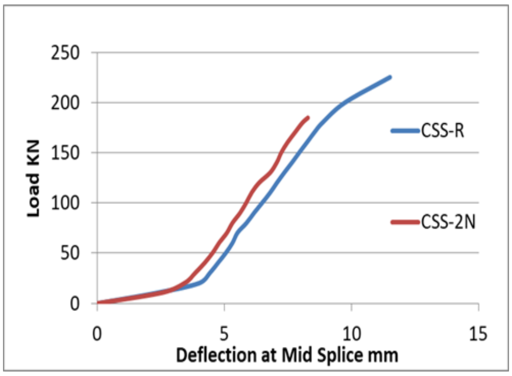
4. Parameters Study

4.1 Effect of Splicing Technique

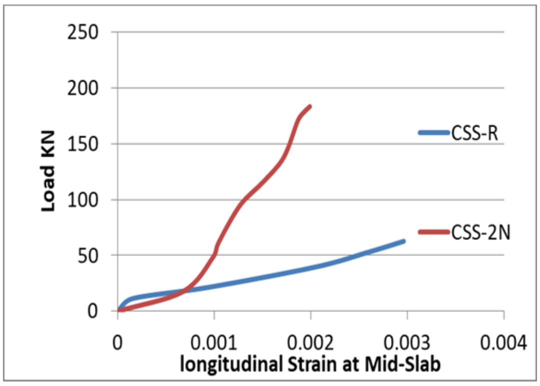
To investigate the effect of splice region on the performance of RC one-way slab, normal concrete NC was used in the splice region. With a length of 200mm, the splice region was taken at the inflexion point. When compared to the reference specimen without the splice region, the failure was changed to brittle failure with damage at the splice region, and the ultimate load was reduced by 18.05 percent. Furthermore, the allowable deflection load increased by 7.45 percent because the deflection of the splicing specimen with NC in the splice region at mid slab was less than the reference specimen, resulting in a 14 percent increase in ductility compared to the reference specimen, as shown in Figure 12.



(A)



(B)



(C)

Figure 12 The relationship between load-deflection and load-strain: A) deflection at mid slab, B) Deflection at mid splice, and C) Longitudinal strain at mid slab.

4.2 Effect of Types of Concrete in the Splice Region

Instead of NC, three types of concrete were used in the splice region. In the case of using HSC in the splice region CSS-2H, the ultimate load increased by 6.8 percent and deflection increased by 4.07 percent at the mid slab and decreased by 6.77 percent at mid splice compared to CSS-2N, while the allowable deflection load and ductility increased by 40.85 and 24.47 percent, respectively, owing to lower deflection at the early stage at CSS-2H.

While the performance of a splicing specimen with SIFCON in the splice region is roughly comparable to that of a splicing specimen with RPC in terms of ultimate load and maximum deflection, as shown in Table 7, When compared to specimens with NC in the splice region, the ultimate load increased by 35.6 percent for SIFCON and 35.7 percent for RPC. As shown in Figure 12, the maximum deflection in specimens CSS-2S and CSS-2R increased compared to the specimen with NC at the splice region, but the allowable deflection load increased by 83.9 percent for specimen with SIFCON and 100.2 percent for specimen with RPC compared to the specimen with NC in the splice region. This performance improvement is due to steel fiber's ability to resist the appearance and growth of cracks, as well as its high resistance to tensile strength for RPC and SIFCON when compared to normal concrete.

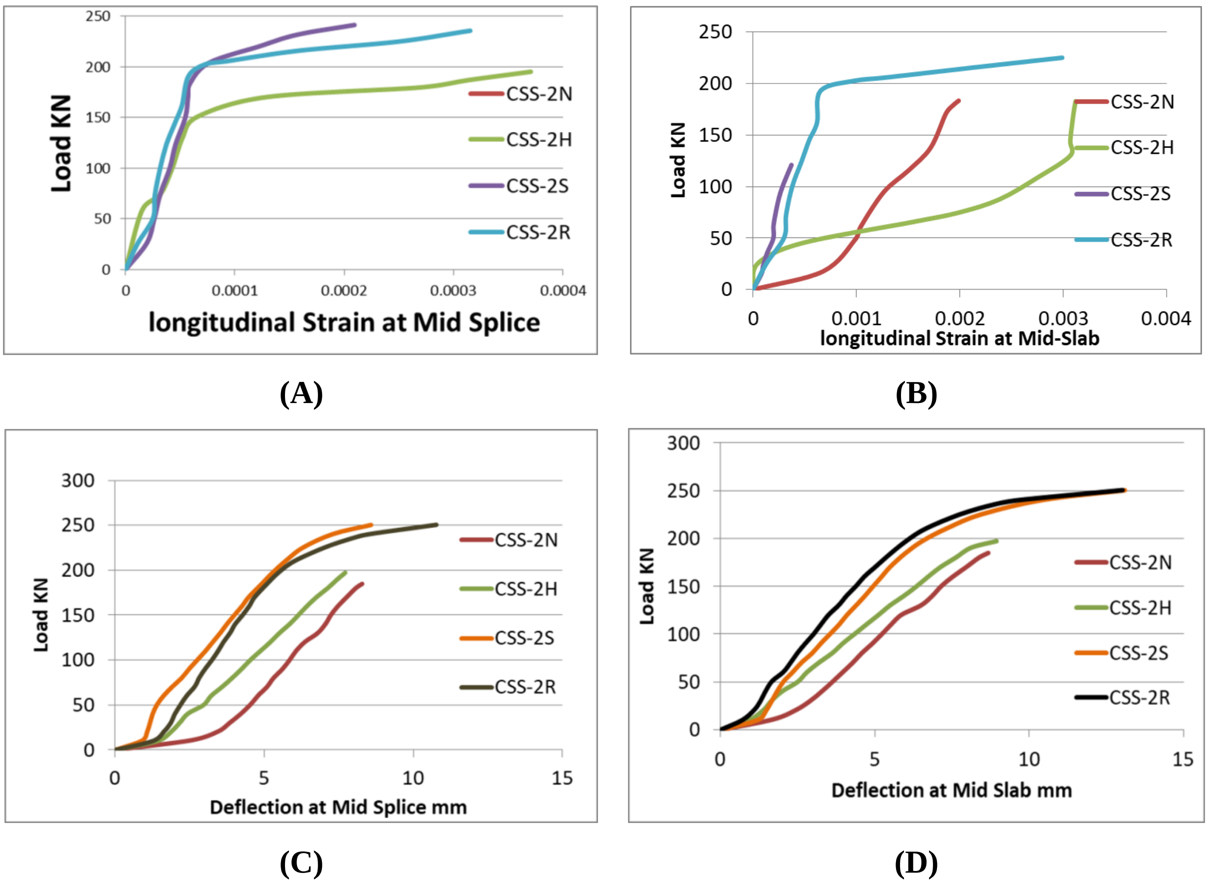


Figure 13 Load-deflection and load-strain at :A) Longitudinal strain at mid splice, B) Longitudinal strain at mid slab, C) Deflection at mid splice, and D) Deflection at mid slab.

5. Conclusion

Several conclusions were obtained from the experimental test in the present study:

1. The use of NC and HSC in the splice region reduced the performance of the specimens by 18.05 and 12.47 percent, respectively, when compared to the reference specimen. The failure was caused by direct shear with damage in the splice region.
2. The deflection at the mid slab and mid splice in spliced samples with NC, HSC, RPC, and SIFCON decreased by 36.5, 33.9, 3.7, and 3.18 percent, respectively, at the mid slab and by 28.1, 33.01, 6.5, and 25.4 percent, respectively, at the mid splice. This is related to the bars that extend from the top and bottom of the precast panels to the splice region, as well as the strength of the concrete used in the splice region.
3. When spliced specimens were compared to reference specimens, their ductility increased, which was attributed to a smaller deflection at the mid slab.
4. The use of SIFCON and RPC in the splice region increases the ultimate load by 11.14 and 11.2 percent, respectively, when compared to the reference specimen. Furthermore, the failure was direct shear with reinforcement yielding without damage in the splice region.
5. The best performance was obtained when RPC was used in the splice region because it provided a high ultimate load with a small deflection. Also, because of the high cost of steel fiber, RPC is less expensive than SIFCON.

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سلوك الانحناء في حالة الدعم المستمر للبلاطة الخرسانية المسلحة احادية الاتجاة والمرتبطة بوصلات خرسانية مع استخدام أربعة أنواع من الخرسانة في منطقة الوصلات

الخلاصة: *يلقى هذا البحث الضوء على سلوك الخرسانة المسلحة للبلاطة احادية الاتجاة والمقسمة الى الواح مربوطة بواسطة وصلات خرسانية باستخدام عدة انواع من الخرسانة فى منطقة الوصلات. تم استخدام خمس عينات ، واحدة مصبوبة كوحدة واحدة للمقارنة وأربعة مكونة من ثلاثة أعضاء سابقة الصب ووصلتين ربط باستخدام الخرسانة العادية NC ، الخرسانة عالية القوة HSC ، الخرسانة المسلحة بالألياف SIFCON ، وخرسانة المساحيق الفعالة RPC فى منطقة الوصلات. وكانت الأبعاد الكاملة للعينات طولها 2130 مم وعرضها 600 مم وسمكها 100 مم. المعلمات التى تم دراستها وهى حمل أول شق ، الحمل النهائى ، أقصى انحراف ، إنفعال الخرسانة الطولى ووضع الفشل بالإضافة إلى حساب مؤشر جديد يسمى مؤشر الليونة والذى يمثل قدرة الليونة للعينات بعد الفشل ، حيث تكون مساوية الى النسبة بين الانحراف عند الحمل النهائى الى الانحراف عند حمل اول شق. تظهر نتائج الاختبار التجريبى أنه فى حالة استخدام RPC و SIFCON فى منطقة الوصلات ، هناك تقارب فى زيادة قيمة الحمل النهائى والانحراف النهائى. بينما لا يوجد تحسن فى سلوك العينات مع NC و HSC فى منطقة الوصلات .*