Experimental study on the behaviours of spliced reinforced concrete girders strengthened with NSM CFRP bars

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Abstract. This paper presents the results of an experimental investigation of spliced and non-spliced reinforced concrete girders strengthened with near surface mounted (NSM) CFRP bars. Six reinforced concrete girder specimens were tested, divided into two groups according to their support condition: simply supported and continuous. Each group thus contained three girders; one girder of each group was single segment without splicing, as a control for comparison purposes. The second girder was spliced in three precast segments without strengthening, and the third girder of each group was spliced in three precast segments strengthened with NSM CFRP bars at the bottom surfaces of the two splice regions. The main variables studied were support conditions, presence of the splicing technique, and strengthening with NSM CFRP bars. The strengthening of spliced girders was achieved by using two bars of 6 mm diameter CFRP in the longitudinal direction. The results for the simply supported group showed that this strengthening resulted in an increase in ultimate load of 11.25%, as compared with that seen in the spliced girder without strengthening, and of 5.4% when compared with the control girder. This strengthening method also reduced the maximum deflection by about 23%. The results also showed that strengthening the continuous girder resulted in an increase in ultimate load by 3.76% compared to the spliced girder without strengthening, and the maximum mid-span deflection was reduced by 8.7%. It was also found that the ultimate load of the control girder was greater than that of the strengthened girder by 2.54%. These results indicate that strengthening with NSM CFRP was more effective within the simply supported group than in the continuous group.

Keywords: Spliced Girders, Simply Supported Girder, Continuous Girder, NSM CFRP Bars

1. Introduction
In recent years, splicing girders has been adopted as a technique to provide significantly increased span ranges for precast concrete girders. This technique offers a solution for the problem of transportation, particularly the movement from the plant to the site of a project by a segment, especially for long span girders, and can accelerate the construction of bridges taking into account the reduced cost [1]. Spliced girders are included one or more of the joints through which the segments are linked together in order to obtain the total length of the girder. One of the oldest bridges using this method was the Bridge of Klickitat County in Washington, which was built in 1954 in three equal precast segments, which were linked together to obtain the total span of 28 m. Many bridges have since been built using the spliced girders method, with clear spans reaching up to about 76 m, as in the Highland view bridge in Florida, which was constructed in 1994.
2. Background

This section will describe some of the previous research related to spliced girders in order to outline the stages of development of this method.

[2] studied a splicing method that depended on the continuity provided by pretensioned wire extending from the end of segments. A mechanical connector was used for strand splicing, and this method was implemented at interior supports to provide continuity between adjacent bridge spans without the need for continuous posttensioning. Two equal precast segments of 3 m were spliced together, and the load was applied at location of the splice area. The results showed that ultimate load reached 1,375 kN while the estimated capacity was 1,600 kN.

[3] presented an experimental and theoretical study of the behaviours of spliced and non-spliced reinforced concrete girders. The test was applied to sixteen specimens with rectangular cross-sectional areas. Half of the girders were without splicing while the other half were each spliced from three precast segments. The experimental and theoretical variables included loading conditions, location of splice region, number of posttensioning tendons, depth of girder, length of the span, and the effect of pretensioning. The theoretical study included an analysis of tested girders using three-dimensional finite element (ANAYS) computer programming. The results showed that the ultimate load of spliced girders was generally less than that of non-spliced by 12% to 17%. It was also found that increasing the area of pretensioned tendons by 50 to 100% led to an increase in the maximum strength of 11 to 16%, and a decrease in deflection of 8 to 14%.

[4] presented spliced holed-web posttensioned concrete girders. The experimental study used the two girder specimens with a total length of 50 m, and height of 2 m. One of these specimens was cast monolithically, while the other consisted of five 10 m segments for each one and spliced together with epoxy joints. Testing was applied using a two-point concentrated load, and the results showed that the model bridge structure exceeded the design requirements.

[5] presented experimental and numerical studies on the behaviours of spliced reinforced concrete girders strengthened by carbon fibre reinforcement polymer (CFRP) laminates in different forms and directions. The variables studied included the length and location of splice region, loading arrangements, support conditions, and effect of using internal stirrups; however, the main variable was the strengthening of the region of splice using CFRP laminates. The specimens comprised 19 reinforced concrete beams distributed according to type of support in two groups. The first group was simply supported and consisted of 11 beams, while the other group was of 8 continuous beams. One beam from each group was the reference beam (without splice) and the others were spliced. All beams were rectangular section with dimensions of 250 mm depth, 150 mm width, and 2,000 mm length. The results of this study showed that strengthening of the splice region using a 45° inclined form of CFRP was more effective than using longitudinal and transfer forms. It was also found that the longitudinal strengthening of simply supported spliced girders led to an increase in the ultimate load by 42 of 77%; the deflection was decreased by 10 to 22%, while the ultimate load for the inclined condition of continuous girder was increased by 47 to 74% as compared with the continuous spliced girder without strengthening. The ratio between ultimate loads of spliced and non-spliced girders ranged from 0.94 to 1.11 as a result of strengthening with CFRP laminates at a 45° inclination.

3. Experimental Program

3.1. Description of the Tested Specimens

Six reinforced concrete girders were used in the experimental programme for the current study. Two of these girders were cast as single segments to act as a reference for comparison purposes, while the others were spliced from three precast segments using hooked dowels at 90° and a cast-in-place (CIP) splice region. All tested girders had the same total length of 2,800 mm and cross-sectional area of 150 mm width, and 230 mm height. Based on type of support, the girders were divided into two groups: simply supported girders and continuous girders.
3.1.1. **Simply supported girders group.**

This group included three reinforced concrete girders with equal total lengths of 2800 mm; one of these girders was retained without splicing as a control while the others were spliced girders of three precast segments. The flexural steel reinforcement included two bars of 12 mm diameter at the bottom of the cross sectional area of the girder to meet bending moment requirements, along with two bars of 8 mm diameter at the top of cross section of the area to act as supporting stirrups; shear reinforcement was provided by 6 mm diameter bars distributed at a distance of 100 mm spacing along the girder length. The control girder was designed according to the ACI 318 M-11 Code [6] to ensure flexural failure. Hooked dowels of 90⁰, and CIP concrete in the splice region were used for all spliced girders. The length of the splice regions was equal to the development length, following the requirements of the ACI-318 M-11 Code [6]. The differences between the simply supported girders were as follows:

- **SSG-R**: This girder consisted of one segment with total length of 2,800 mm, utilised for comparison purposes as shown in Figure 1.
- **SSG-1**: This girder consisted of three precast segments linked together at two splice regions of 300 mm length to obtain the total length of 2,800 mm. The strengthening method with CFRP bars was not applied for this girder, as shown in Figure 2.
- **SSG-5**: This girder was similar to SSG-1, but a strengthening method using NSM CFRP bars was applied to this girder using two bars of 6 mm diameter at the bottom face of each splice region to study the effect of this strengthening method, as shown in Figure 3.

![Figure 1. Details of simply supported reference girder (SSG-R)](image1)

![Figure 2. Details of simply supported girder (SSG-1)](image2)
3.1.2. Continuous girders group.

This group also consisted of three reinforced concrete girders with the same total length as the simply supported group. One of these girders was also without splicing as a control, while the others were spliced girders with three precast segments at the inflection points of zero moment. The flexural steel reinforcement included two bars of 12 mm diameter at the bottom, in addition to the same amount at the top of each section. The shear reinforcement was provided by 6 mm diameter bars distributed at 80 mm spacing along the girder length. The control girder was designed according to the ACI 318 M-11 Code [6] to satisfy flexural failure. Hooked dowels of 90° and CIP concrete at the splice region were also used for all spliced girders in this group, and the same length of spliced region, 300 mm was used, as this was equal to the development length as designed according to the requirements of the ACI-318 Code [6]. The differences between the continuous girders were as follows:

❖ **CG-R**: This girder consisted of one segment, utilised for comparison purposes as shown in Figure 4.
❖ **CG-1**: This girder consisted of three precast segments linked together at two splice regions of 300 mm length. The strengthening method using CFRP bars was not applied to this girder, as shown in Figure 5.
❖ **CG-5**: This girder was similar to CG-1, with the strengthening method using NSM CFRP bars conducted using two bars of 6 mm diameter at the bottom face of each splice region, as shown in Figure 6.
Figure 4. Details of reference continuous girder (CG-R)

Figure 5. Details of continuous spliced girder without NSM strengthening (CG-1)

Figure 6. Details of continuous spliced girder with NSM strengthening (CG-5)
3.2. Material Properties:

3.2.1. Cement

The type of cement used in the experimental work was Aljisir Portland cement (type V) sulphate resistant cement. This type is produced in Iraq by a Karbala factory and is acceptable according to the limits of Iraqi Specification No. 5/1984 [7].

3.2.2. Fine aggregate (Sand)

Al-Akhaidher natural sand with a maximum particle size of 4.75 mm was used to create a normal concrete mix. The results of grading and its chemical properties showed that this type of sand complied with Iraqi Specification No. 45/1984 [8].

3.2.3. Coarse aggregate (Gravel)

Local gravel with a maximum particle size of 19 mm was used in this experimental work. The gravel was sprayed with water to remove dust, then left to dry in the air before use. Test results for the coarse aggregate showed that it was acceptable according to Iraqi Specification No. 45/1984 [8].

3.2.4. Mixing water

Tap water was used for mixing and curing of all concrete samples and girders.

3.2.5. Steel reinforcement

Three sizes of deformed bars, made in the Ukrainian, of 6, 8, and 12 mm diameter were used in the concrete girders. Three samples of each size were tested under the effect of tensile force. The yield and ultimate stresses for these bars are illustrated in Table 1. These results conform to ASTM A-615-05 [9].

| Bar size (mm) | Actual diameter (mm) | Yield stress (MPa) | Ultimate stress (MPa) |
|--------------|----------------------|-------------------|----------------------|
| Φ 6          | 5.62                 | 510.4             | 540.5                |
| Φ 8          | 7.74                 | 592.9             | 659.9                |
| Φ 12         | 11.89                | 636.2             | 706.8                |

3.2.6. Carbon fibre reinforcement polymer (CFRP) bars

Aslan 200 CFRP bars with a nominal diameter of 6 mm sand coating were used for the NSM strengthening method in the experimental work. Table 2 shows properties of these as supplied by the manufacturer. The test results agreed with the standard specifications of ASTM D 7205 [10].

| Property                              | Test result | Specification limits     |
|--------------------------------------|-------------|--------------------------|
| Tensile strength (MPa)               | 3176        | 2068 (minimum).          |
| Modulus of Elasticity (GPa)          | 254         | 124 (minimum).           |
| Ultimate strain                      | 0.017       | 0.017 (minimum).         |
3.2.7. *Epoxy adhesive properties*
Two types of epoxy were used in the experimental programme:

3.2.7.1. *Epoxy resin bonding agent*
To provide structural bonding of new to existing concrete, Sikadur®-32 LP was used. Due to the high tensile strength of this epoxy type as compared with concrete, it is most suitable for bonding, and a mixing ratio of A:B=2:1 by volume or weight was adopted as suggested by the manufacturer. Table 3 presents the mechanical properties of this adhesive.

| Property                   | Sikadur®-32 |
|----------------------------|-------------|
| Compressive strength       | 60-70 (MPa) |
| Tensile strength           | 18-20 (MPa) |
| Flexural strength          | 30-35 (MPa) |
| Bond strength to concrete  | 2.5-3.0 (MPa), (concrete failure) |
| Density                    | 1.4 kg/l    |

3.2.7.2. *Epoxy adhesive for installation (CFRP) bars*
The most common and suitable epoxy adhesive material used for installing CFRP bars in NSM strengthening methods is Sikadur®-30 LP. This consists of two components, adhesives A and B, and it depends on the combination of these two components at a mixing ratio of A:B = 3:1 by volume or weight. Table 4 shows the properties of this type of epoxy.

| Property                   | Sikadur®-30 LP |
|----------------------------|---------------|
| Compressive strength (MPa) | 90-110        |
| Tensile strength (MPa)     | 26-28         |
| Shear strength (MPa)       | 19 N/mm²~     |
| Coefficient of thermal expansion | 2.5*10⁻⁵   |
| Modulus of Elasticity (MPa)| 10000~        |

3.3 *Mixture Proportions*
Normal strength concrete was used for all precast segments and the splice regions of the tested girders. This mix consists mainly of cement, sand, gravel, and water. Several empirical mixes were tested in the laboratory before selection of the final design mixture; the final proportions selected were 1 cement: 1.2 sand: 1.4 gravel by weight; the W/C ratio was 0.4. The quantities of materials by weight per cubic meter are presented in Table 5. Mixing was carried out using a rotary mixer of 0.1 m³, and this type of concrete is cured in water in 25 °C.
Table 5. Quantities of Materials for Normal Concrete Mix

| Cement (kg/m³) | Coarse aggregate (kg/m³) | Fine aggregate (kg/m³) | Water/cement ratio |
|----------------|--------------------------|------------------------|--------------------|
| 563            | 787                      | 680                    | 0.4                |

3.4. Concrete Casting and Curing

The moulds were prepared, and the internal surfaces oiled to facilitate stripping of the mould after the concrete hardened. After mixing the material to obtain a homogenous mixture with the selected properties, the concrete was poured into the mould in three layers; subsequent compaction was provided by using an electric vibrator for few minutes. The surface was covered with nylon sheet to reduce the loss of mixing water due to dissipation and evaporation. After 24 hours, the moulds were opened, and the concrete specimens cured with water at 25 °C. The stages of casting and the curing of precast segments are illustrated in Figure 7:

Figure 7. Stages of casting and curing of precast segments
Each of spliced girders consisted of three precast segments connected together with two splice regions. In order to produce the spliced girders, the precast segments were placed into the mould in a longitudinal direction. There was a difference in lengths of the segments according to the support conditions, but the overall length remained at 2,800 mm for all girders. Figure 8 shows the splice regions of the two types of spliced girders.

![Image of spliced girders](image1)

**Figure 8.** The splice regions of spliced girders

Concrete was added in the splice region after the lateral surfaces of precast segment were painted with epoxy adhesive bonding (Sikadur® 32-LP). A nylon sheet then covered this area in order to reduce the loss of water due to evaporation. After 24 hours, the moulds were removed, and the specimens were cured at 25 °C with water for 28 days. Figure 9 shows the curing of the splice regions of spliced girders by water.

![Image of cured splice regions](image2)

**Figure 9.** Curing of splice region of spliced reinforced concrete girders
3.5. Installation Procedure of NSM CFRP Bars

The installation of CFRP bars as NSM strengthening methods in concrete girders was conducted in stages. Rectangular cross section grooves were made using a concrete cutter on the bottom faces of the girders in the region of the splices and extending 200 mm on both sides of this area. The cross section of grooves was 15 mm width and 18 mm depth. These dimensions were determined according to ACI 440.2-08 [14]. The recommended dimensions are shown in Figure 10.

![Recommended dimensions of grooves](image)

**Figure 10.** Recommended dimensions of grooves [14]

After that, the grooves were cleaned with water to remove concrete residue and dirt, dried, and then partially filled with mixed epoxy adhesive (Sikadur®-30 LP). The CFRP bars were inserted carefully into the grooves. Finally, the epoxy resin was used to completely cover the grooves, and surface levelling was conducted. Tests were performed after seven days of curing. A summary of the work stages is given in Figure 11.

![Stages of installation procedure of CFRP bars](image)

**Figure 11.** Stages of installation procedure of CFRP bars
3.6. Hardened Concrete Tests

3.6.1. Compressive strength test
The compressive strength test was conducted according to BS 1881: part 116 using cubes of dimensions 100 x 100 x 100 mm [15]. The average value of three specimens was considered to represent the concrete mixture after 28 days of water curing.

3.6.2. Splitting tensile strength test
The splitting tensile strength was tested according to the ASTM C 496 M-2004. Three cylinders of dimensions 100 x 200 mm were used [16]. The test was carried out 28 days after casting. The average value of three cylinder specimens was adopted to represent the tensile strength.

3.6.3. Flexural strength test
This test method included determination of the flexural strength (modulus of rupture) of concrete specimens according to ASTM C 292-02 [17]. The average value of three prisms of 100 x 100 x 500 mm dimensions was adopted to represent the flexural strength.

3.6.4. Modulus of elasticity test
The static modulus of elasticity test was carried out using cylinders of 100 x 200 mm dimensions according to ASTM C 496-02 [18]. The significance of this test was to examine the stress to strain relationship for concrete.

3.7. Tests Setup and Instrumentation of Girders
Both spliced and non-spliced girders were tested after curing was completed. A load was applied on each girder using a two-point concentrated load; the distance between the two points of load differed according to the support conditions. For the simply supported beams, the centre to centre span of supports was 2,600 mm, and the differences used for the spliced girders were dependent on the details of the splicing area. The load was applied using two-point concentrated loads at 400 mm distance from each side of the girder centre. For continuous girders, the load was also applied using two-point concentrated loads at 650 mm distance from each side of the girder centre. The layout of the point loads and the deflection gage for simply supported and continuous girders are illustrated in Figures 12 and 13, respectively.

Figure 12. The layout of point loads and the deflection gages for simply supported girders
The test was carried out by taking the girders to failure using a hydraulic testing machine with a 2,000 kN ultimate capacity. The increment of load was about 6 kN for simply supported beams and about 18 kN for continuous girders. Two methods were used to measure the deflection: the first was a digital gage of 0.01 mm accuracy while the second was by using an LVDT of 20 mm settlement capacity linked to a computer. The testing process is shown in Figure 14.

**Figure 13.** The layout of point loads and the deflection gages for continuous girders.

**Figure 14.** Hydraulic testing machine used on concrete girder specimens

### 4. Experimental Results

#### 4.1. Mechanical Properties of Concrete

The mechanical properties of the concrete used in the precast segments and joint regions are presented in Table 6. Each value given in this table represents the average of three samples.
Table 6. Mechanical properties of concrete

| Property          | fcu (Cubes) (MPa) | fc’ (Cylinders) (MPa) | ft (Splitting) (MPa) | fr (Flexure) (MPa) | Ec (MPa) |
|-------------------|-------------------|-----------------------|----------------------|-------------------|----------|
| Precast Segments  |                   |                       |                      |                   |          |
|                   | 40.4              | 32.16                 | 3.35                 | 4.21              | 27350    |
| Splice region     |                   |                       |                      |                   |          |
|                   | 38.5              | 30.96                 | 3.23                 | 3.39              | 25400    |

4.2. General Behaviour of Simply Supported Tested Girders Group

4.2.1. Crack pattern and failure modes

Cracks occur in the reinforced concrete girders when the tensile stress reaches the ultimate strength of the concrete. Many types of cracks appeared in girder specimens under the applied load; these cracks included flexural, diagonal, and interface cracks which appeared at the joint of the precast segments in the splice region. The results for all girders in this group, including first cracking load, ultimate load, and modes of failure are presented in Table 7.

Table 7. The first cracking load, ultimate load, and type of failure of simply supported girders

| Girder Symbols | First Flexural Crack Load (Pcr) (kN) | Ultimate Load (Pu) (kN) | Pu(i)/Pu(R)\(^a\) | Type of Failure                      |
|----------------|--------------------------------------|-------------------------|-------------------|-------------------------------------|
| SSG-R          | 21                                   | 57.4                    | 1.0               | Yielding of tension steel reinforcement |
| SSG-1          | 19                                   | 54.3                    | 0.94              | Opening the interface cracks & splitting |
| SSG-5          | 20                                   | 60.4                    | 1.05              | Flexural failure                     |

\(^a\)Pu (i): ultimate load of the considered girder, Pu(R): ultimate load of the reference girder.

It was noticed from the test that cracks started at the lower face of the girder and propagated upward, increasing in wide with the increase in the applied load. Figure 15 shows the crack patterns and modes of failure of the tested girders in the simply supported group.

Figure 15. Crack pattern at the failure stage of tested simply supported girders
The failure load of girder SSG-R, the reference girder without splicing, was recorded when the deflection began with the increase in the constant load. This failure occurred due to yielding of the tension steel reinforcement. The first flexural crack of girder SSG-1, which was the spliced girder without strengthening with NSM CFRP bars, was noticed between the two points of loading in the tension zone of the girder at a load of 19 kN; after that, interface cracks occurred at the interfaces between the precast segments and joint region at a load of 15 kN. The failure stage was recorded when the load reached about 55 kN; at this stage, the deflection increased rapidly while the load remained constant. In girder SSG-5, which was the spliced girder with strengthening with NSM CFRP bars, the first flexural crack was observed at a load of 20 kN under the point load, while interface cracks were noticed at a load of 28 kN. The girder specimen failed by flexural cracking and splitting carrying the cracks into the ends of CFRP bars at a load about 59 kN.

4.2.2. Load-deflection behaviour
The results of the experimental programme showed that the ultimate load of the spliced girders was less than that of non-spliced girder by about 6%, while the deflection was less in the non-spliced girders by 17%. Strengthening the splice region had a positive effect on the ultimate strength, load-deflection curves, and failure modes. The results of examining the strengthening technique showed that the ultimate load of the strengthened spliced girders (SSG-5) was greater than that of the spliced without strengthening (SSG-1) by 11.25%. This ratio was reduced to about 5.4% when compared with the reference girder (SSG-R).

At 50% of the ultimate load, the deflection of girder SSG-5 was found to be less than that of SSG-1 by 4.8%, while this ratio was increased to about 23% at ultimate load. Figure 16 shows load-deflection curves for all girders of this group.

![Figure 16: Load-deflection curves of simply supported girder specimens.](image)

4.3. General Behaviours of Continuous Girder Group
4.3.1. Crack patterns and failure modes
The experimental results showed that three types of cracks appeared in the continuous girder specimens under loading effects. Flexural, diagonal, and interface cracks were the most common types of cracks to occur. Flexural cracks were noticed firstly at the lower face of each span, then other cracks were observed at the upper face of the intermediate support when the load reached about 50% of the ultimate load, with some of these cracks moving diagonally. Throughout this stage, interface cracks occurred between precast
segments and the splice region. Failure types varies from one girder to another, but, most spliced girders failed by direct shear. The experimental results of crack patterns and failure modes are given in table (8).

Table 8. The first cracking load, ultimate load, and the failure type of continuous girders

| Girder Symbols | First Flexural Crack Load (Pcr) (kN) | Ultimate Load (Pu) (kN) | Pu(i)/Pu(R)* | Type of Failure |
|----------------|--------------------------------------|-------------------------|--------------|----------------|
| CG-R           | 73                                   | 283                     | 1.0          | Flexural failure |
| CG-1           | 46                                   | 266                     | 0.94         | Direct shear & splitting of concrete covers |
| CG-5           | 52                                   | 276                     | 0.975        | Rupture of CFRP bars & Splitting of concrete covers |

* Pu (i): ultimate load of the considered girder. Pu(R): ultimate load of the reference girder.

The crack patterns and the failure modes of the continuous girder group are presented in Figure 17. It was found that non-spliced girders failed due to failure in the tension steel reinforcement (control), while the spliced girders failed by splitting of the concrete covers.

Figure 17. Crack patterns at the failure stage of tested continuous girders
The splicing technique generally affects the overall performance of the spliced girders. The experimental results showed that ultimate load of the spliced girders was less than that of non-spliced girders by about 6.4%, and that failure of non-spliced girders was generally flexural failure, while the spliced girders failed by direct shear and splitting of the concrete cover. The failure type of the girders strengthened with NSM CFRP bars (CG-5) was direct shear and rupture of CFRP bars by some of concrete cover.

4.3.2. Load-deflection behaviour

The overall behaviours of the concrete girders depended greatly on the load-deflection curve under the effect of applied loads. The experimental results showed that control girder showed flexural failure (tension control) at a load of 283 kN, while the ultimate load of the spliced girder was less than that of the non-spliced girder by about 6.5%. It was also found that the deflection increased in spliced girders as compared with in non-spliced, by 32% at the ultimate load. The results also showed that ultimate load of the spliced girder without strengthening (CG-1) was less than that of strengthened girder (CG-5) by 3.76%. It was also noted that load-deflection curve was influenced by the strengthening. The deflection of girder CG-5 was found to be less than that of CG-1 by about 18.3% at the ultimate load. Figure 18 shows the effect of the splicing technique, and of strengthening with NSM CFRP bars in the splice region, on the load-deflection curves of spliced reinforced concrete girders.

5. Conclusions

Several points can be concluded from the experimental results of this study:

1. The difference in ultimate load between spliced and non-spliced girders was small, ranging between about 6% for simply supported and 6.5% for continuous girders. This small difference means that the splicing technique is an effective method to somewhat increase the span range of concrete girders while reducing the overall cost and effort.

2. It was found that strengthening the splice region using NSM CFRP bars at the bottom surface of the girder led to an increase in the ultimate load of 11.25% and 3.76% for simply supported and continuous girders, respectively, as compared with single segment girders without splicing.

3. The results indicated that the NSM CFRP bar strengthening method led to a decrease in the deflection at ultimate load of 23% and 18.3% for simply supported and continuous girders respectively when compared with the deflection of spliced girders without strengthening.
Based on these results, this strengthening method improved results for simply supported girders more than for continuous girders in terms of ultimate load and maximum deflection.

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