EXPERIMENTAL AND ANALYTICAL ANALYSIS OF PRE-STRESSED CONCRETE SPLICED GIRDER MODELS

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ABSTRACT

The present research is concerned with experimental and analytical studies of pre-stressed concrete spliced and non-spliced girder models. The test groups consisted of (16) girders of rectangular sections. Eight girders are spliced while the other eight are reference non - spliced girders. Each spliced girder is composed of three concrete segments connected by splices of ordinary reinforced concrete with hooked dowels different locations. The tested girders were of single span or continuous over intermediate supports. For single span girders two splices were used and post-tensioning was carried out for the full assembled girder. For the continuous girders pre-tensioned segments were connected by splices at quarter spans. Concentrated or uniformly distributed loads have been applied to the girders. The deflection was measured at mid-spans while the strain was measured at splice zones and at mid-spans.

Nonlinear analysis of the girders was carried out using a modified computer program. A comparison among the experimental and the analytical results for spliced and non-spliced girders was carried out to study the effects of splicing for different girders. Results have shown that at about 50% of the ultimate load which is approximately corresponds to the serviceability limit state, the deflection of the spliced girders is greater than that of the reference non-spliced girders in the range of (10%-15%) and the ultimate loads for the non-spliced girders are greater than those of the spliced girders in the range of (12%-17%).
The difference in deflection between the Finite Element and the experimental results at 50% of the ultimate load was in the range of (8%-12%). Moreover, the difference in the ultimate load between the Finite Element and the experimental results was in the range of (5%-11%).

الخلاصة

إهتم هذا البحث بالدراسة المختبرية والنظرية للروافد الخرسانية المسبقة الاجهاد (مسبقة الشد) المتكونة من قطع موصولة. تضمن البرنامج العملي عدة مجاميع شملت ستة عشر نموذجا مستطيلة المقطع. ثمانية منها ذات وصلات والثمانية المتبقية بدون وصلات لغرض المقارنة. كل رافدة من الروافد المشكلة توصيلا تتكون من ثلاث قطع خرسانية مرتبطة بوصلات ذات خرسانة اعتيادية مسلحة بقضبان معكوفة وتختلف اماكن وطريقة هذه الوصلات من رافدة الى اخرى. وتنقسم هذه الى روافد ذات فضاء واحد أي ترتكز على مسندين طرفيين واخرى مستمرة ذات اكثر من فضاء وترتكز على مساند وسطية. الروافد ذات الفضاء الواحد تحتوي على وصلتين وتم تعريضها الى عملية الإجهاد بعد التوصيل أما الروافد المستمرة فتم تشكيلها من قطع مسبقة الجهد.

الاحمال المسلطة على هذه الروافد اما ان تكون احمال مركزة في وسط كل فضاء او حمل منتظم على طول الرافدة. لقد تم قياس الهطول في منتصف طول الرافدة وكذلك تم قياس الانفعالات في المنتصف وفي منطقة الوصلات.

تم تحليل الروافد لاخطيا باستخدام برنامج تم اجراء بعض التعديلات عليه. لقد تم اجراء مقارنة بين النتائج العملية والنظرية للجسور الموصولة وغير الموصولة وقد بينت النتائج تحت تأثير 50% من الحمل الاقصى والذي يقترب من حمل حياة المنشأ الاعتيادية ان الهطول في الجسور الموصولة يزيد بنسبة (10−15%) عما هو في الجسور غير الموصولة اما الحمل الاقصى فيقل في الجسور الموصولة عما هو في غير الموصولة بنسبة (12%−17%).
لقد بينت النتائج المختبرية والنظرية تحت تأثر 50% من الحمل الاقصى ان الفرق بينهما في الهطول يتراوح بنسبة (8−12%) اما بالنسبة للحمل الاقصى فقد كان الفرق بنسبة (5−11%).

INTRODUCTION

The difficulties in the construction of long span bridges under economical aspects of time and cost have given inspiration to engineers to use segmental and/or spliced girders.

Splicing of pre-stressed precast segments can be carried out at inflection points. Usually at segment ends; dowels of ordinary rebar reinforcements are overlapped at splice zone prior to concrete casting at splice, Fig (1) .

a) Mechanically Spliced Mild Reinforcement b) Lap Spliced Mild Reinforcement

Figure (1) Cast in- Place Splice

At each splice, a temporary support is usually used, Fig. (2). This construction procedure is useful in continuous girders of spans longer than the available lengths of pre-stressed -precast girders produced in local factories.

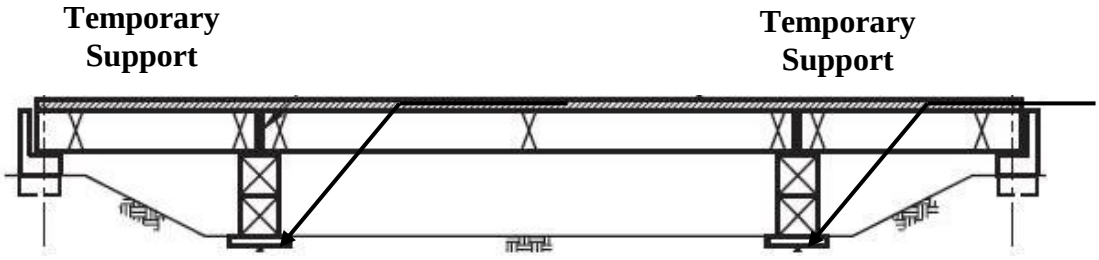

Figure (2) Temporary Support at Splice Zone.

SPLICING OF GIRDERS

The splicing of girders is used to increase the span ranges for precast pre-stressed concrete girder bridges. A spliced girder is a precast pre-stressed concrete member usually obtained by connecting pre-stressed concrete segments to obtain the required length of the bridge girder.

Splice Location

The splice for any bridge is usually located at inflection points or as determined by the requirements for bridge span. However, other considerations are also significant in determining the splice location. These other considerations include:

- Splice has lower stress limits since it generally has a lower concrete strength.
- The only pre-stressing available at the splice may be provided by the post-tensioning tendons if available.
- The use of a longer center girder segment may significantly increase the cost of transportation and increases the size of crane or cranes required for handling and erection.

Splice Width

The width of the splice depends on the duct splicing method used and on other construction requirements. However, the width of the diaphragm at the splice may also be changed if the splice width is changed, which could affect the design.

A typical splice width is 30 to 60 cm. Wider splices facilitate the placement and consolidation of concrete in the site, although the use of a diaphragm at the splice also assists in these processes. Wider splices, however, also require more field-placed concrete, and if they are cast with the deck, the placement of concrete in the larger splice and diaphragm may slow the progress of concrete placement in the deck. Wider splices also provide for more tolerance in the placement of the girders, which significantly affects the alignment and splicing of the ducts.

Splice Reinforcement

The reinforcement in the splice between girder segments is proportioned to satisfy the requirements for;

- Stress limits for the splice at the service limit state
- Shear in the splice
- The reinforcement required to satisfy shear requirements to provide a significant portion of the shear resistance. The hooked dowels or the nominal reinforcement is provided across the shear interface.

The reinforcement must be computed as part of the limiting tensile stress for the splice location. An area of reinforcement is required that resists the full tensile force in the concrete at the splice at a working stress of 0.5 fy, where fy is taken as 414 MPa, neglecting the contribution of the post-tensioning tendons crossing the splice.

The tensile force in the concrete is computed by determining the depth of tension zone at the bottom of the splice, which will be designated as x. This is accomplished using the absolute values of the computed stresses at the top and bottom of the splice. Therefore, x may be computed as (Castrodale and White 2004):

$$x = \left[f_{bot} / \left(f_{top} - f_{bot} \right) \right] h \quad \ldots(1)$$

Where:

x is the depth of tension at the bottom of the splice.

f_{bot} is the absolute value of the computed stress at the bottom of the splice.

f_{top} is the absolute value of the computed stress at the top of the splice.

h is the depth of the girder.

The tensile force, T, is then computed as the product of the average stress and the width of the bottom flange as:

$$T = f_{average}(tensile\,area) = (f_{bot}/2)[b_{bot}x] \quad \ldots(2)$$

Where:

T is the tensile force.

$f_{average}$ is the average stress.

b_{bot} is the width of bottom flange of girder.

The required area of reinforcement is computed by dividing this tensile force by the working stress of 0.5 fy to obtain:

$$A_s = T/0.5fy \quad \ldots(3)$$

where As is the area of splice reinforcement.

This area of reinforcement must be provided within the tension zone. The required length to develop a hooked bar must be computed.

As required by LRPD(Castrodale and White 2004), stirrups shall be provided in the splice with a spacing not to exceed the least of the spacing in the adjacent girder segments. The same stirrup size and detailing should be used.

The reinforcement in the splice should be detailed so that access to splicing the post-tensioning ducts will not be significantly restricted.

Duct Splicing Detail

The detail for splicing of the duct should be obtained from a supplier. The length of the coupler and other duct splice details are important factors in determining the width of the splice.

The ducts should extend approximately 7.5cm into the coupler, so they must project at least 15cm from the end of the girder segment, Fig. (3).

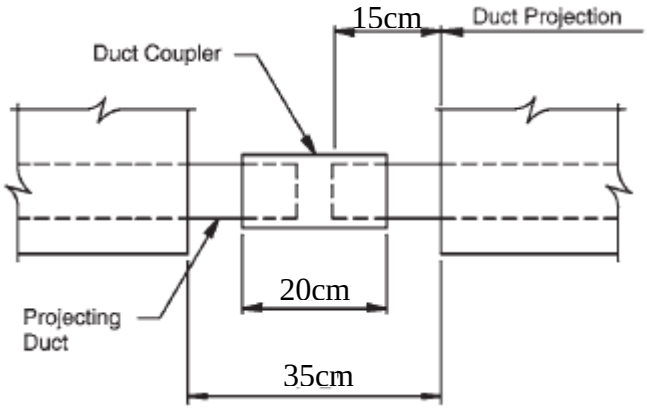

Figure (3) Schematic detail of duct splice[3]

SHEAR KEYS

Shear keys are provided in some bridges as an added factor of safety at the splice location.

TEST GIRDERS.

In this study eight spliced girders have been tested divided into three main groups. The first two groups each contains three specimens, and the third group contains two specimens.

The first group includes girders B1, B4, and B7, each having 3 pre-tensioned segments that results in a 2m length over two spans (i.e. three supports). Each is subjected to a concentrated load P at mid-span. The girder cross-sections were rectangular having dimensions of 75mm in width and depth of 160mm for B1&B7 and 140mm for B4.

The second group includes girders B2, B5, and B8 each having 3 reinforced concrete segments that results in a 4m length over one span (i.e. two supports) subjected to a uniform distributed load W over the entire span. The girder cross-section was rectangular having dimensions of (100mm) in width and total depth of (220 mm) for all girders.

The third group includes girders B3, and B6 each is of 3 pre-tensioned segments resulting in a 6m length over three spans (i.e. four supports). Each is subjected to a uniform distributed load W over the entire span. The girder cross-section was rectangular having dimensions of (100mm) in width and total depth of (220 mm) for all girders.

Figures (4, 5, and 6) shows the dimensions of the girders and reinforcement details with pre-stressing and ordinary steel. The details of cross – sectional dimensions , pre-stressing reinforcement, and ordinary reinforcement for the test girders are described in Table (1).

Eight non-spliced girders have been tested and considered as a reference to the spliced girders.

A special pre-stressing bed has been designed and fabricated for the following purposes:

(i) pre-tensioning of segments for girders B1, B4, B7, B3, and B6.

(ii) post-tensioning of three assembled ordinary reinforced concrete segments to provide girders B2 and B8.

(iii) pre or post-tensioning of reference girders.

The initial wire stress was 1000 MPa for all cases.

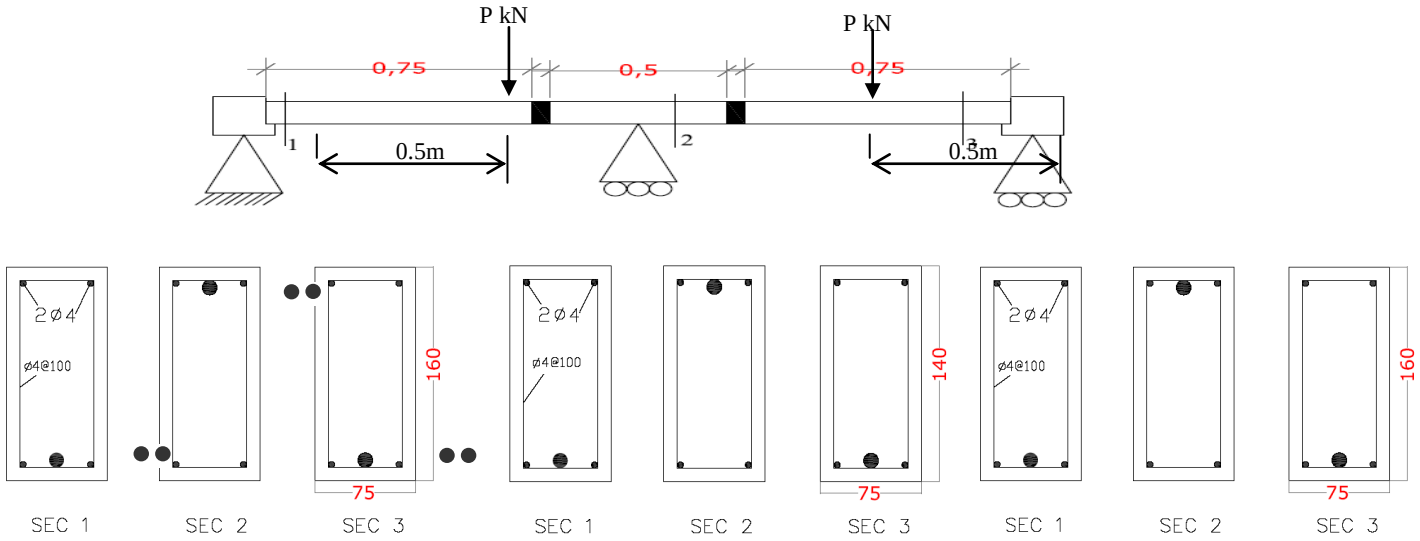

Fig. (4) Dimensions and reinforcement details of Girders (B1, B4, and B7).

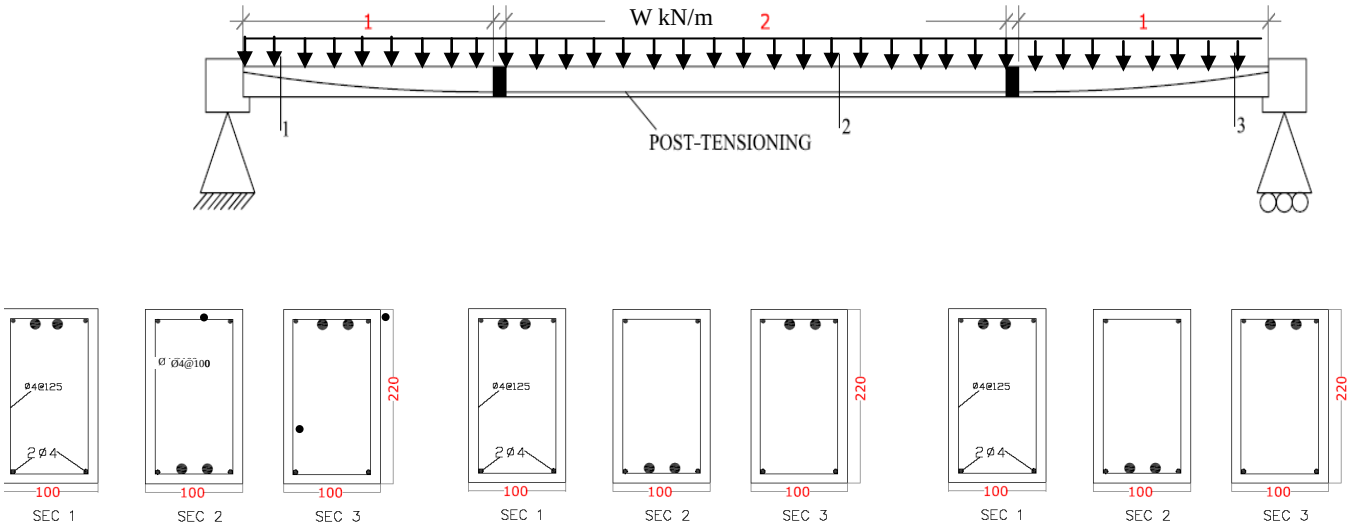

Fig. (5) Dimensions and reinforcement details of Girders (B2, B5, and B8).

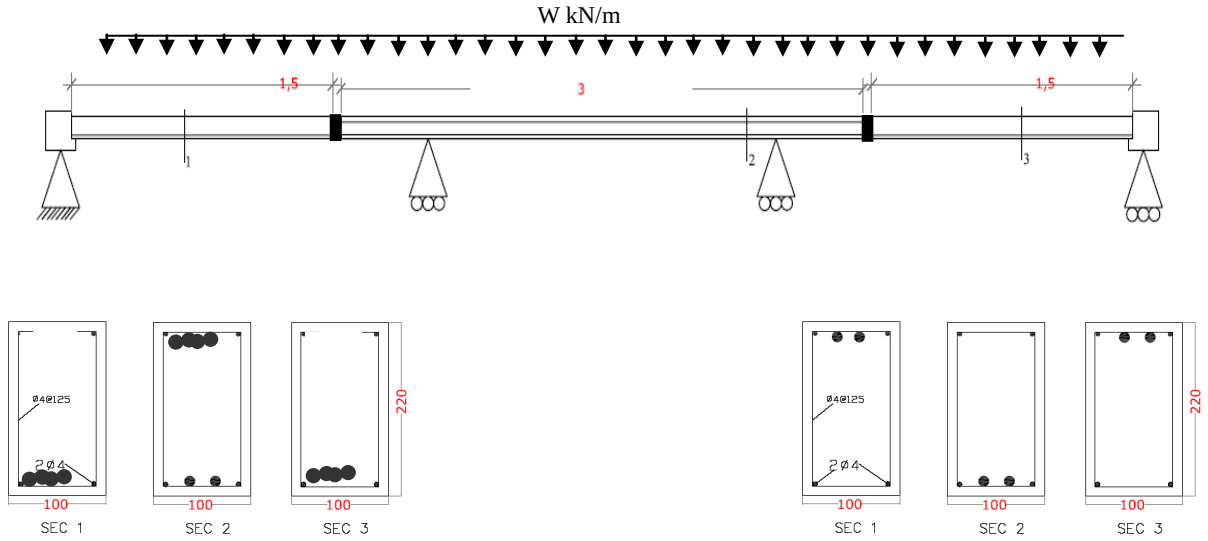

Fig. (6) Dimensions and reinforcement details of Girders (B3 and B6).

Table (1) Dimensions and reinforcement details for the first three groups.

Group No.	Beam section (mm)	Splicing method	Pre-stressing reinforcement				Ordinary reinforcement						Type of load
							Longitudinal reinforcement				Stirrups		
							Top		bottom				
			Strand No. (wire)	Area (mm^2)	f_{py} MPa	f'_c (MPa)	fy MPa	A mm^2	fy MPa	A mm^2	fy MPa	Dia mm	
G1	B1 75x160	Pre-tensioning segments spliced by ordinary R.C. splices	1	13	1570	40	480	25	480	25	480	4	Concentrated load
	B4 75x140		1	13	1570	40	480	25	480	25	480	4	
	B7 100x160		2	27	1570	40	480	25	480	25	480	4	
G2	B2 100x220	R. C. segments spliced by post-tensioning	2	27	1570	40	480	25	480	25	480	4	Uniform distributed load
	B5 100x220		2	27	1570	40	480	25	480	25	480	4	
	B8		3	40	1570	40	480	25	480	25	480	4	

	100x220												
G3	B3 100x220	Pre-tensioning segments spliced by ordinary R.C. splices	2	27	1570	40	480	25	480	25	480	4	Uniform distributed load
	B6 100x220		3	27	-	40	480	25	480	25	480	4	

f_{py} = proof yield tensile strength of pre-stressed steel

Test Results

Each spliced girder (Bi) has the same characteristics of the corresponding non-spliced girder (BiR).

The load-deflection curves of spliced girders versus that of the non-spliced girders are shown in Figures (7 to 14). Deflection of the girders was measured at mid-span for each girder by using a dial gage with travel distance of (30 mm) and accuracy of (0.01mm). Since the girder specimens are of short span the camber value of all beams was insignificant experimentally.

It is shown for different cases that the spliced girders have more deflection than that of the non-spliced girders. At about 50% of the ultimate load which corresponds to the serviceability limit state the deflection of the spliced girders is greater than that of the non-spliced girders in the range of (10%-15%). The ultimate loads for the non-spliced girders are greater than those of the spliced girders in the range of (12%-17%).

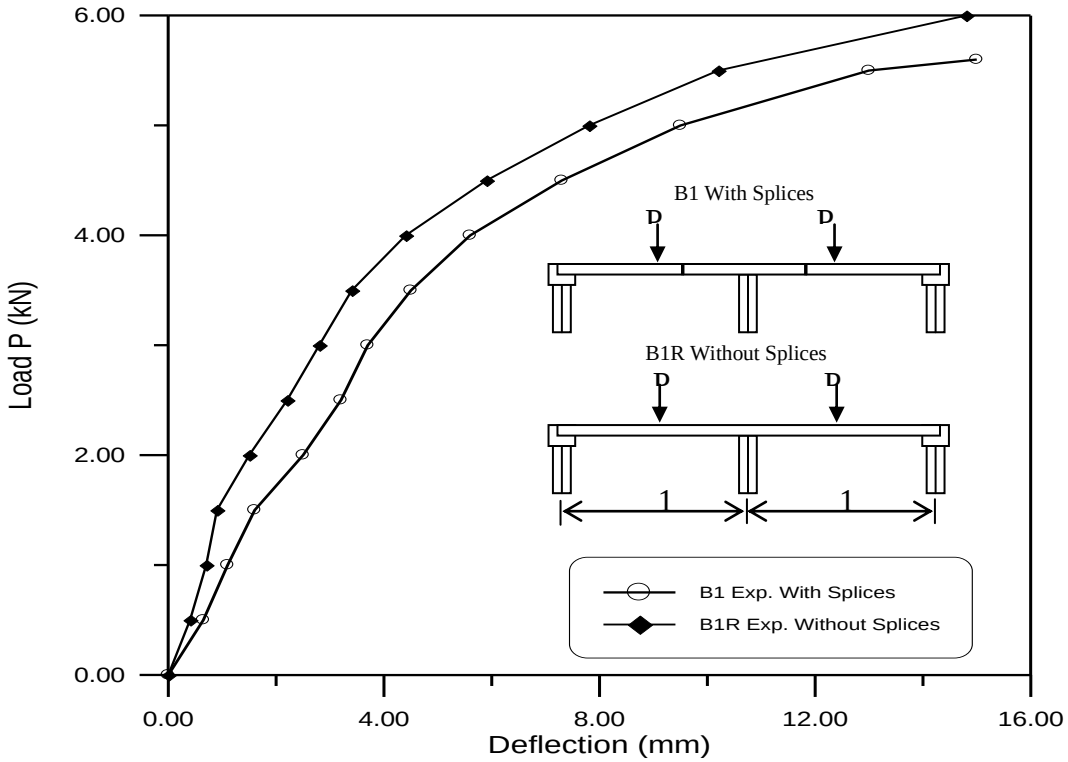

Fig.(7) Girder B1 –B1R, Load – deflection variation at mid-span considering the splicing effect.

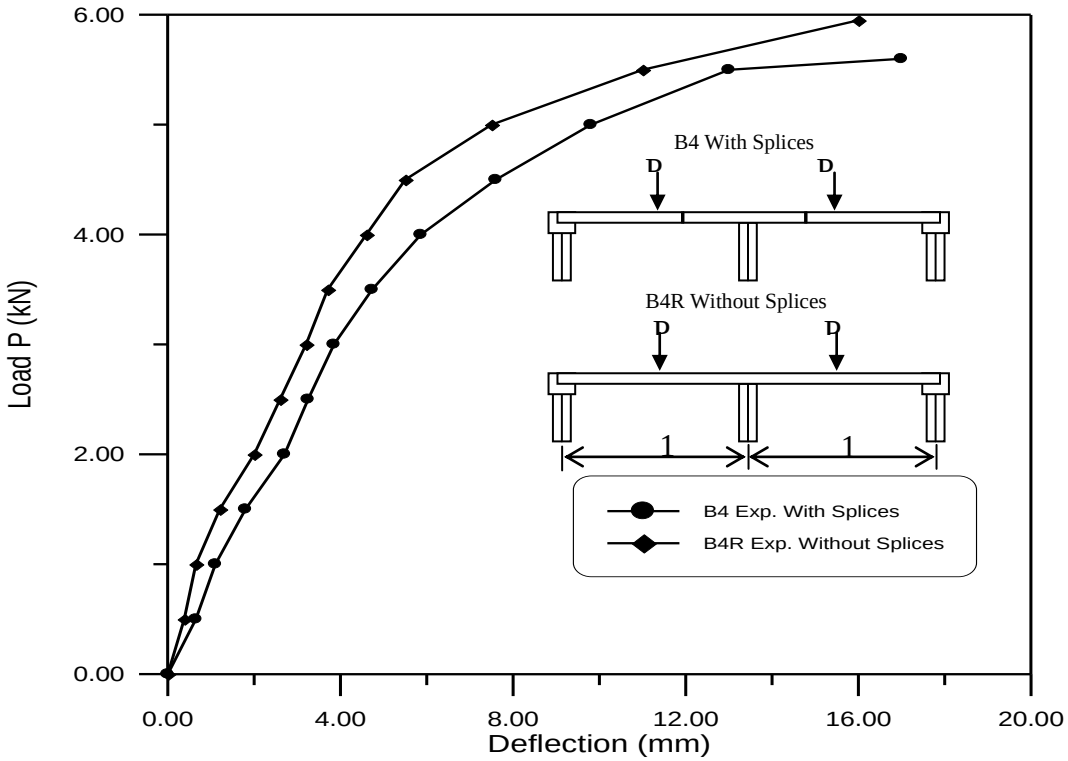

Fig.(8) Girder B4 –B4R, Load – deflection variation at mid-span considering the splicing effect.

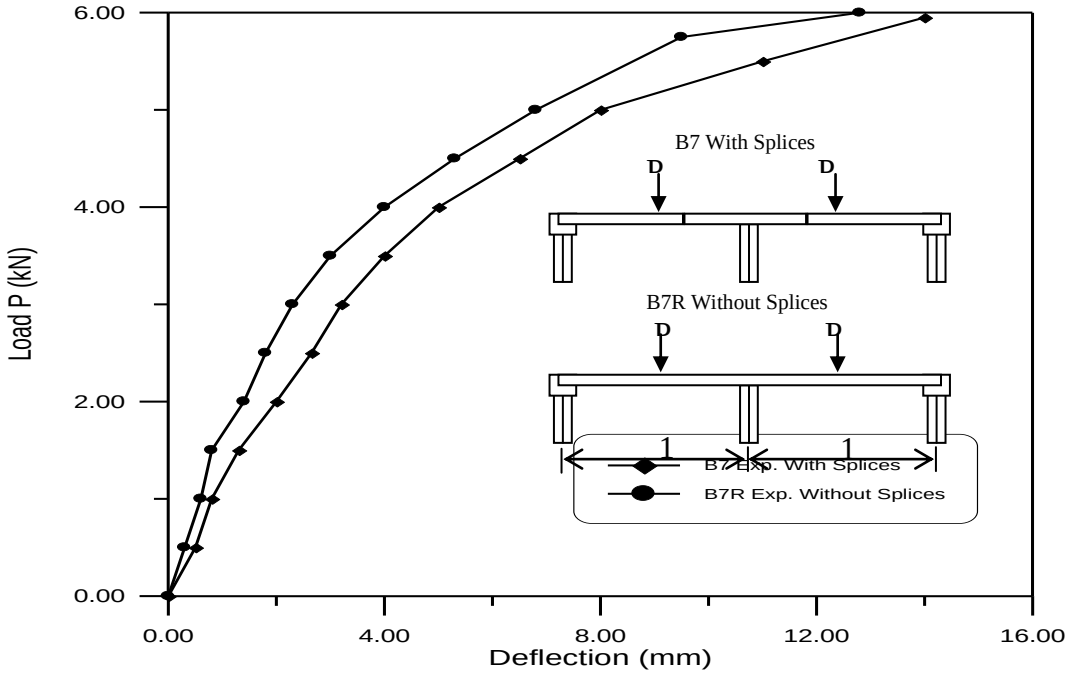

Fig.(9) Girder B7 –B7R, Load – deflection variation at mid-span considering the splicing effect.

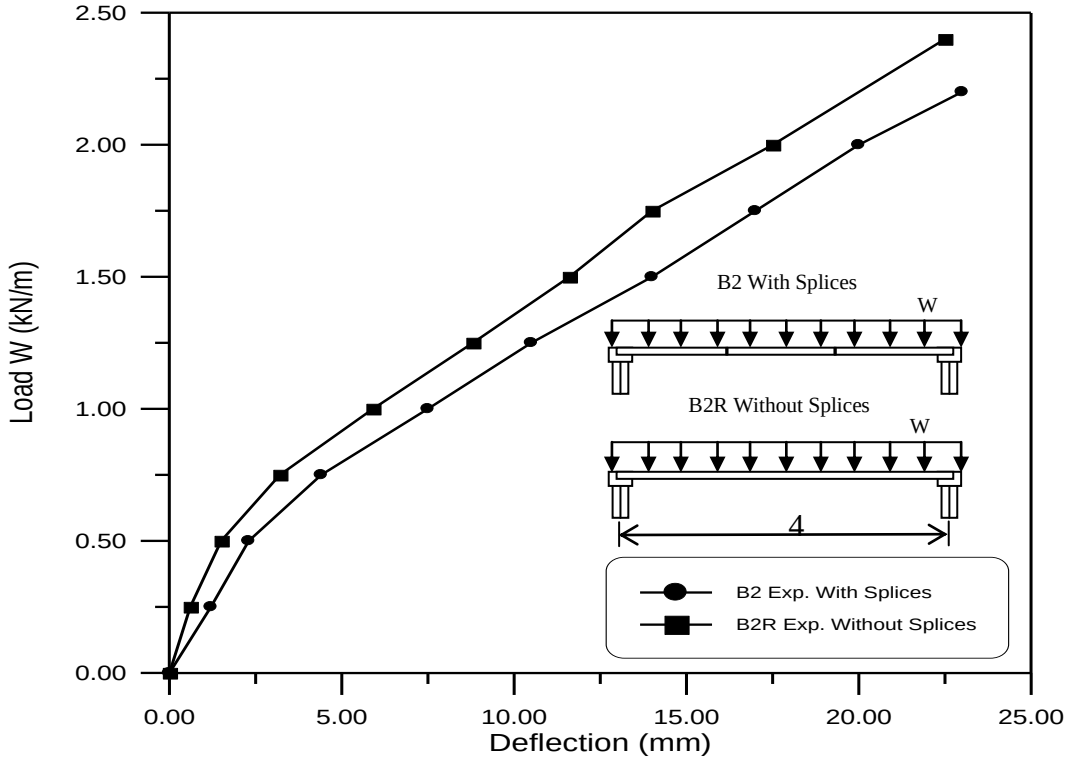

Fig.(10) Girder B2 –B2R, Load – deflection variation at mid-span considering the splicing effect.

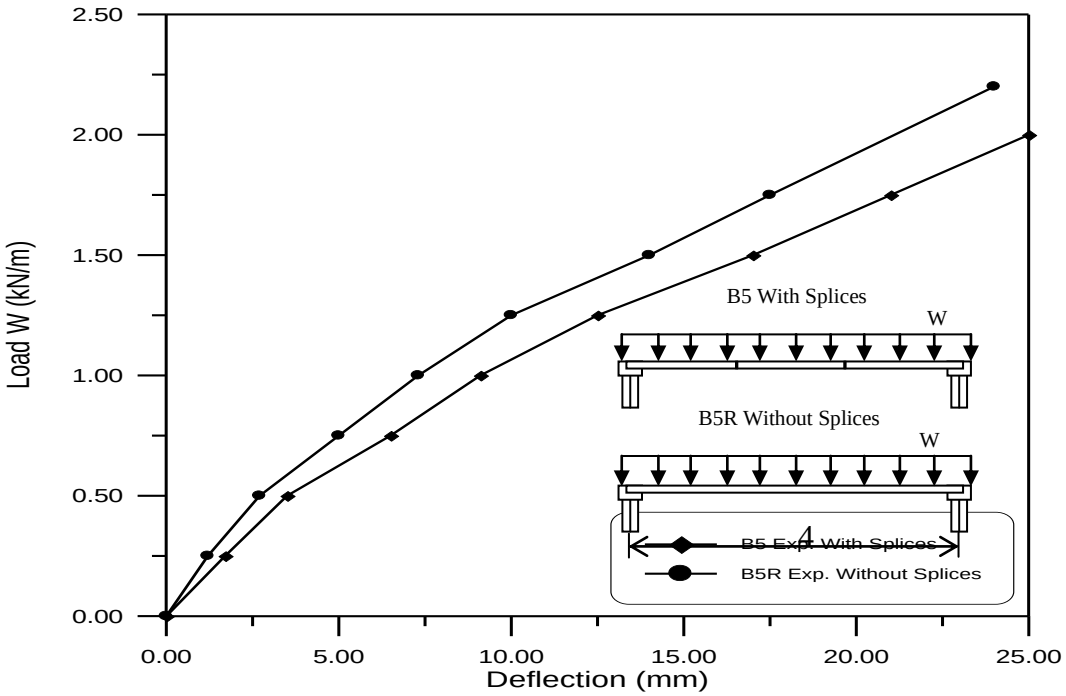

Fig.(11) Girder B5 –B5R, Load – deflection variation at mid-span considering the splicing effect.

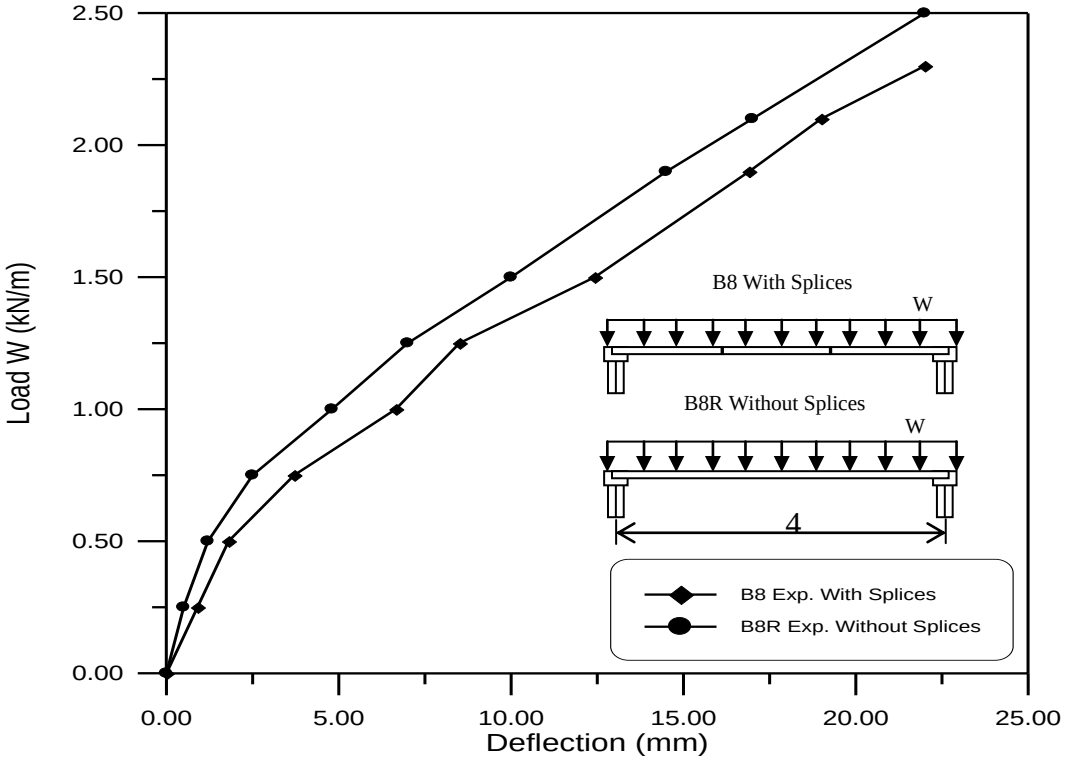

Fig.(12) Girder B8 –B8R, Load – deflection variation at mid-span considering the splicing effect.

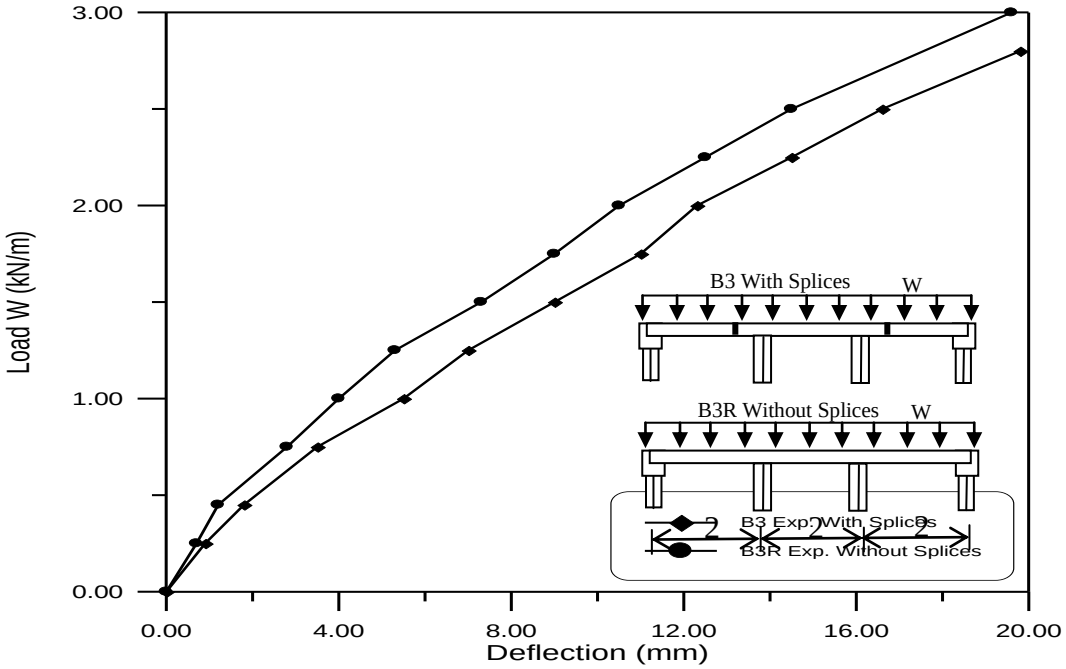

Fig.(13) Girder B3 –B3R, Load – deflection variation at mid-span considering the splicing effect.

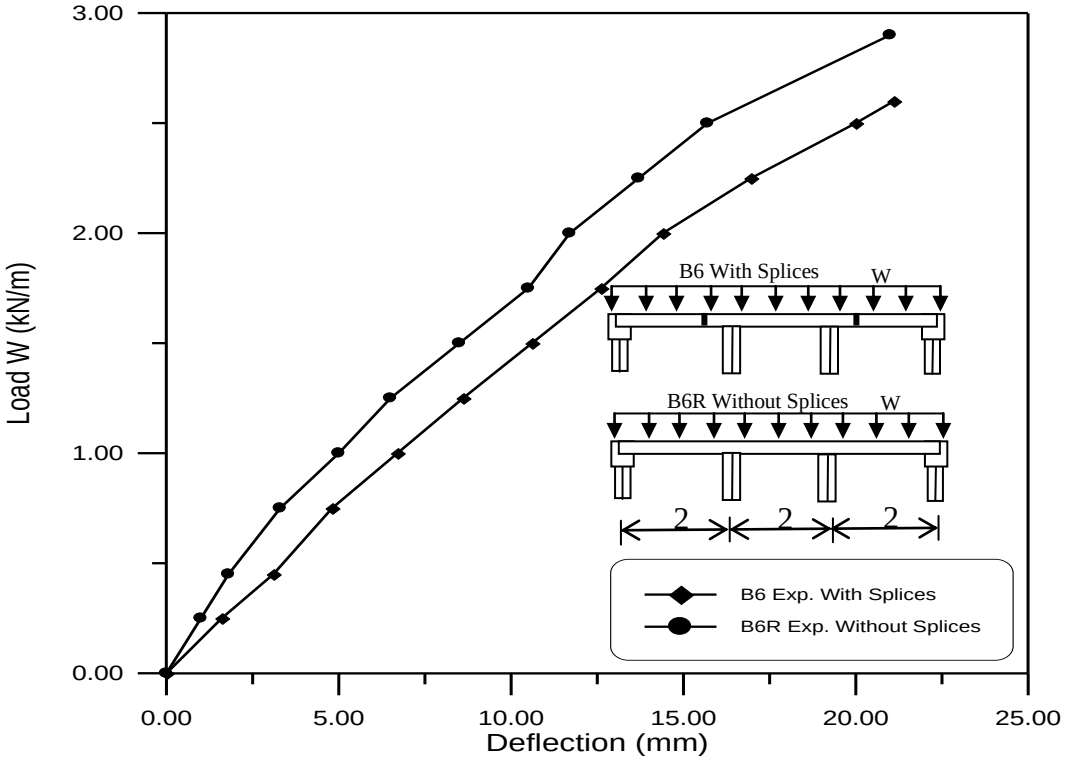

Fig.(14) Girder B6 –B6R, Load – deflection variation at mid-span considering the splicing effect.

Finite Element Analysis

The finite element analysis was carried out using a modified computer program originally developed by Al-Sharabaaf (AL-Shaarbaf 1990).

The first group of girders (B1, B4, and B7) are each of two spans and 1m length for each span and have been analyzed using the finite element method for one half of the girder discretized into 56 quadratic brick elements. The second group of girders (B2R, B5R, and B8R) and the third group (B3 and B6) are analyzed by the finite element method by taking one quarter of each specimen with 32 and 48 brick elements respectively. Fine meshes were used at mid-span for each specimen.

The longitudinal reinforcement and stirrups were simulated as embedded one dimensional elements into the brick elements and the pre-stressing tendons were idealized approximately as a series of pre-stressing steel segments each of which is straight and has initial tensioning force and a constant cross-sectional area along its length.

The finite element analysis has been carried out using the 27-point integration rule, with a force convergence tolerance of 1 %, following the modified Newton-Raphson method.

The concentrated loads for girders (B1, B4, and B7) were modeled as line loads uniformly distributed across the width of the girder and the uniformly distributed load for the other girders was modeled as groups of line loads uniformly distributed across the width of the girder (lumping procedure).

Table (2) shows the material properties, the adopted material parameters and the type of failure of these girders. The numerical load-deflection curves obtained for all girders are shown in Figs.(15 to 22). The finite element results show good agreement with the experimental results. The deflection of these girders was less than that obtained for spliced girders.

Table (2) Material properties and material parameters, and type of failure.

*** Concrete**	Group 1 (B1,B4, and B7)	Group 2 (B2,B5, and B8)	Group 3 (B3, and B6)
Elastic modulus, E_c (MPa)*	33460	29725	29500
Compressive strength, f'_c (MPa)*	40	40	41
Tensile strength, f_t (Mpa)*	3.3	3.9	3.8
Poisson's ratio, v	0.2	0.2	0.2
Compressive strain at f'_c*	0.0018	0.0018	0.0018
Ultimate compressive strain*	0.0039	0.004	0.0041
Cracking tensile strain*	0.002	0.002	0.0021
α_1	6	6	6
α_2	0.5	0.5	0.5

*** Reinforcing steel**			
Elastic modulus E_s (MPa)	200000	200000	200000
Yield stress, f_y (MPa)*	480	480	480
Ultimate strain	0.018	0.018	0.018
Yield strain	0.0018	0.0018	0.0018
*** Pre-stressing steel**			
Elastic modulus E_s (MPa)	195000	195000	195000
Yield point f_y*	1570	1570	1570
Ultimate strain	0.035	0.035	0.035
Yield strain	0.002	0.002	0.002
Poisson's ratio	0.3	0.3	0.3
Type of failure			
	Crushing in concrete	Crushing in concrete	Crushing in concrete

- measured by test

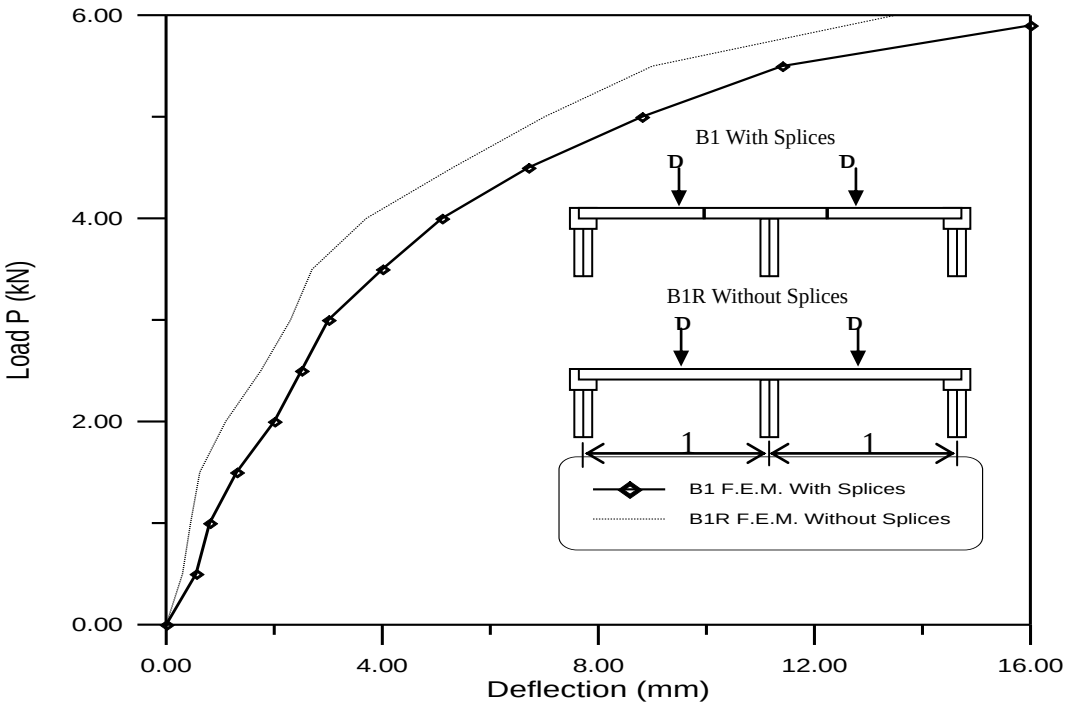

Fig.(15) Girder B1 –B1R: F.E.M. load – deflection variation at mid-span considering the splicing effect.

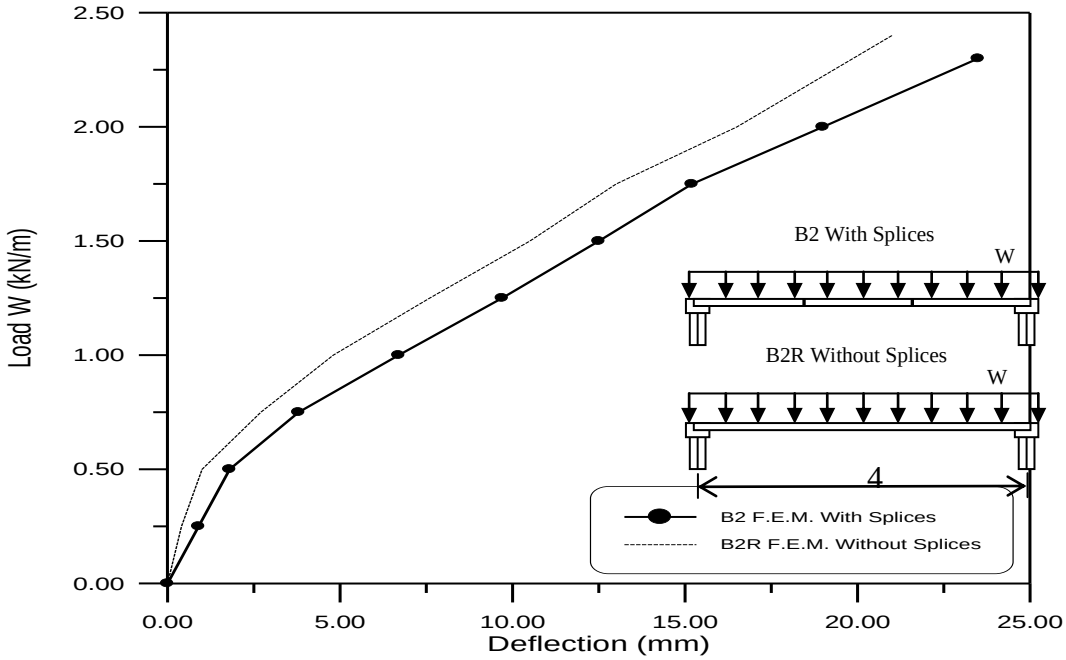

Fig.(16) Girder B2 –B2R: F.E.M. load – deflection variation at mid-span considering the splicing effect.

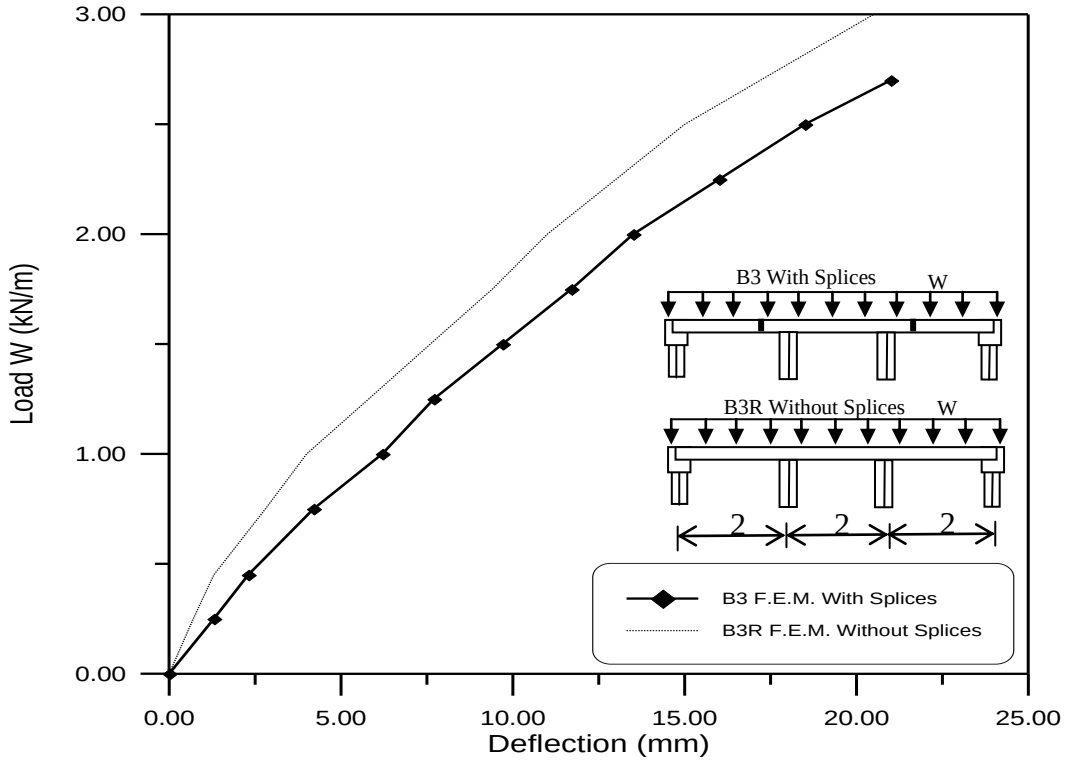

Fig.(17) Girder B3 –B3R: F.E.M. load – deflection variation at mid-span considering the splicing effect.

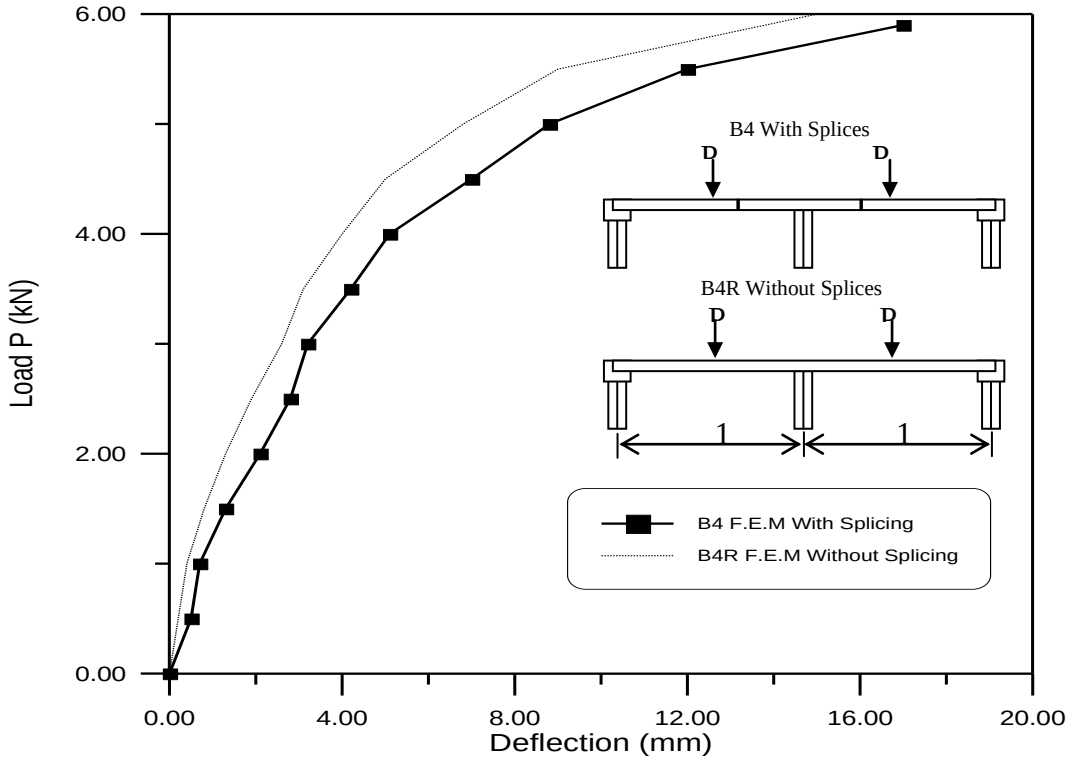

Fig.(18) Girder B4 –B4R: F.E.M. load – deflection variation at mid-span considering the splicing effect.

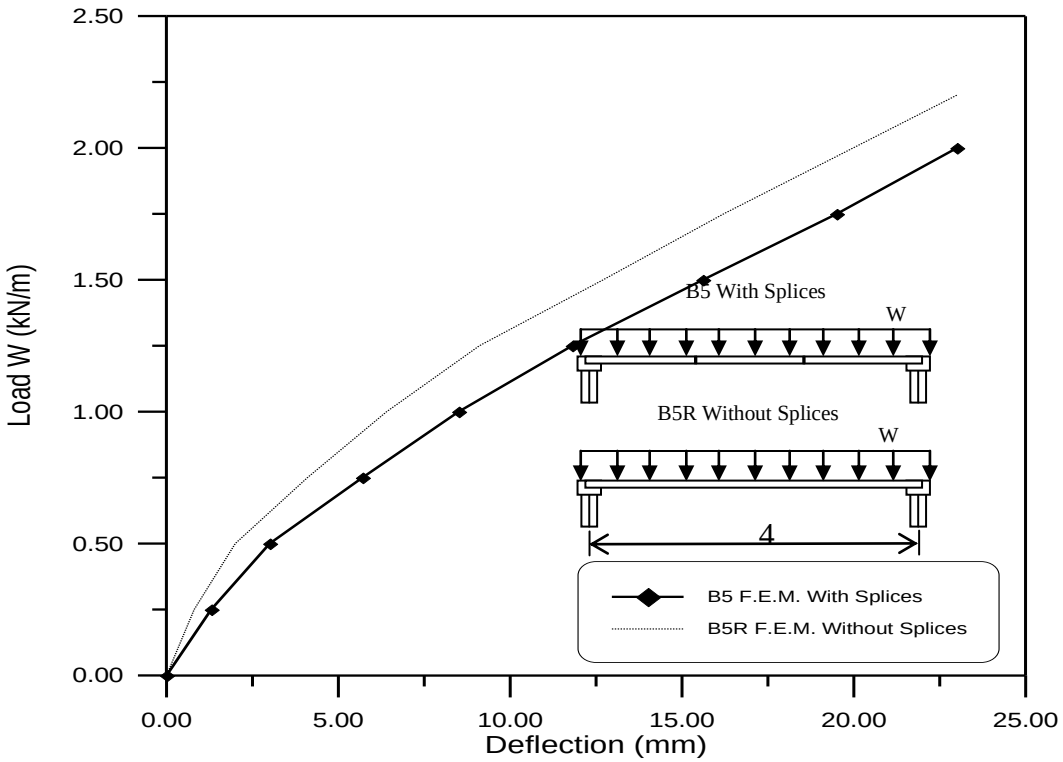

Fig.(19) Girder B5 –B5R: F.E.M. load – deflection variation at mid-span considering the splicing effect.

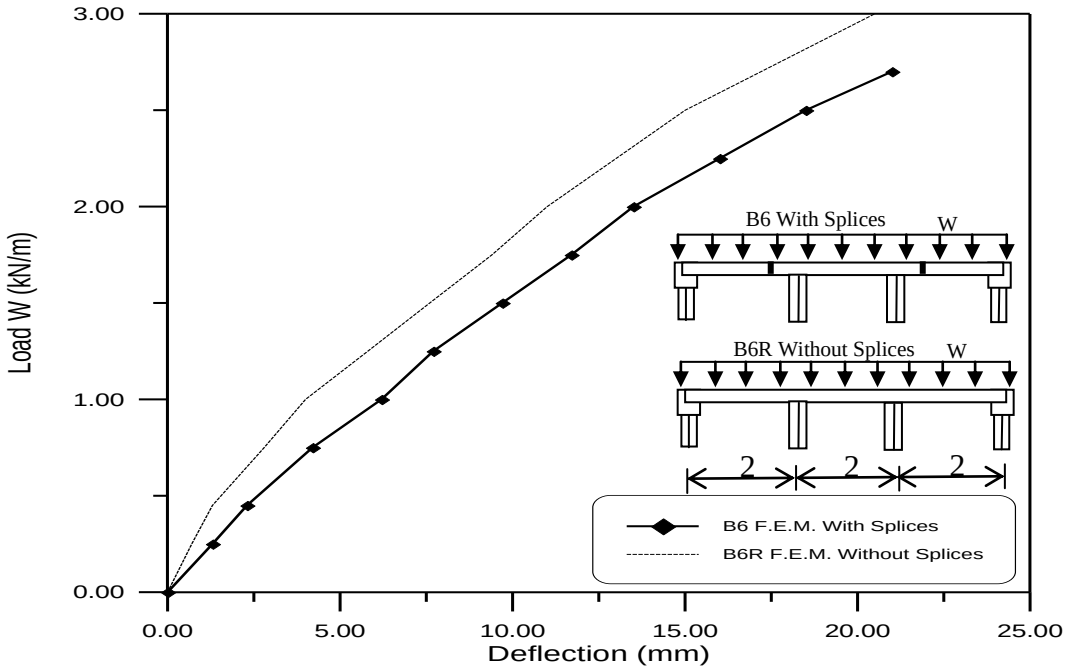

Fig.(20) Girder B6 –B6R: F.E.M. load – deflection variation at mid-span considering the splicing effect.

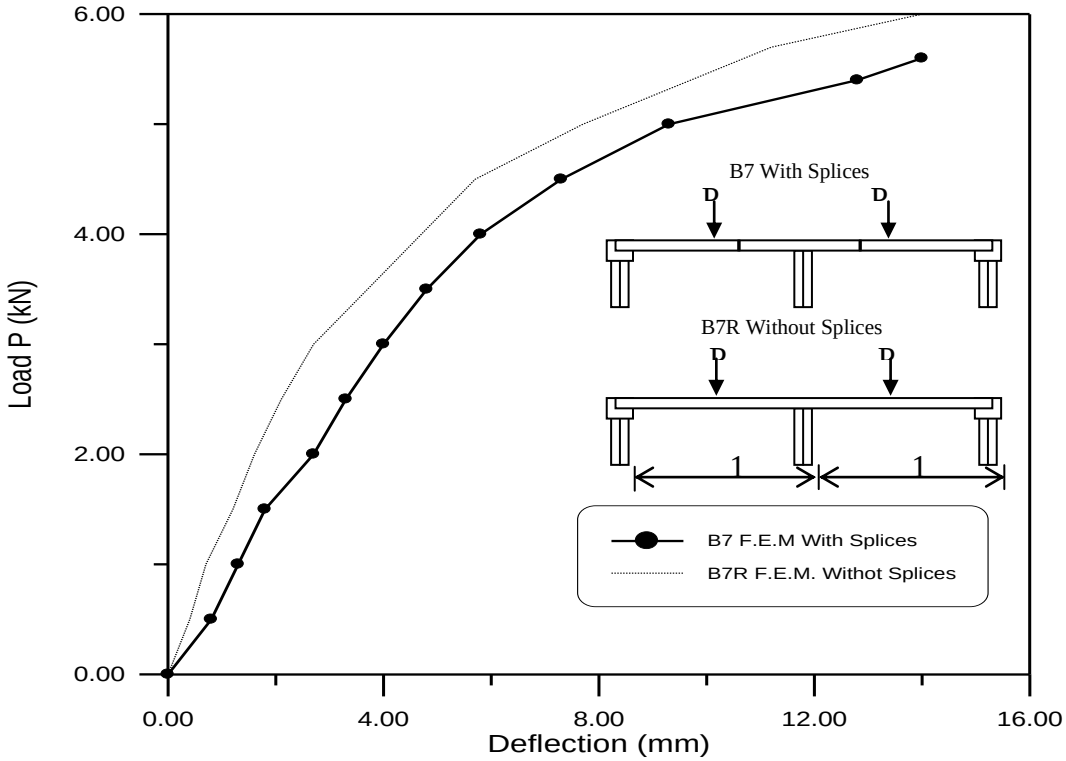

Fig.(21) Girder B7 –B7R: F.E.M. load – deflection variation at mid-span considering the splicing effect.

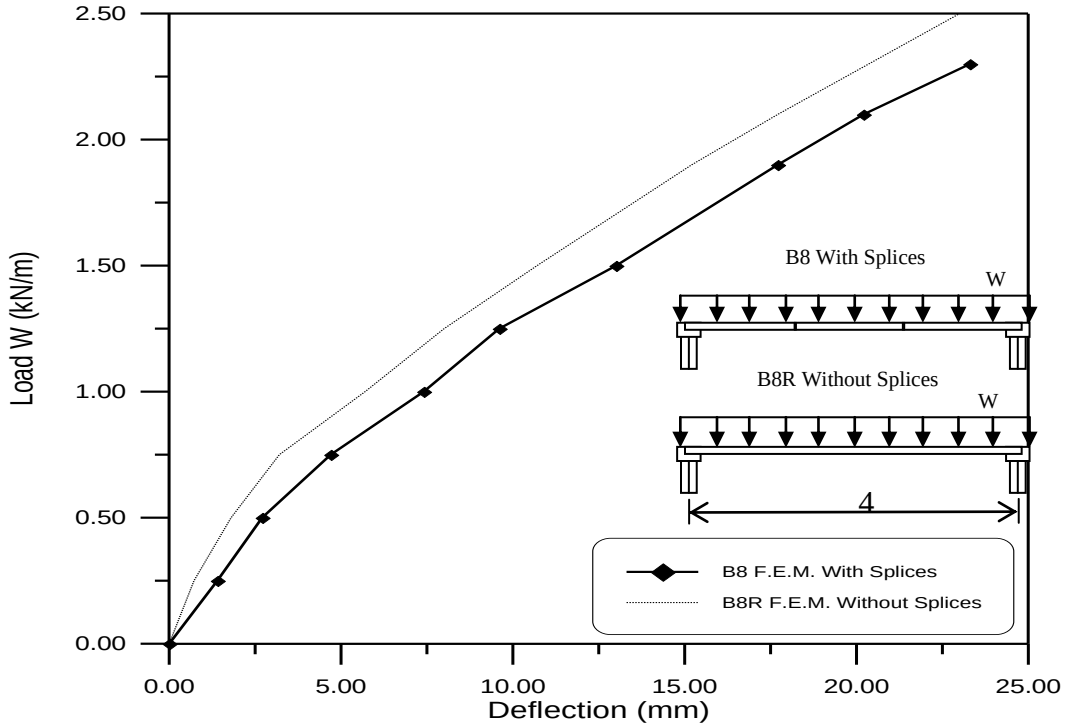

Fig.(22) Girder B8 –B8R: F.E.M. load – deflection variation at mid-span considering the splicing effect.

Discussion of Results

Table (5.6) summarizes the experimental and the finite element results for the spliced and non-spliced test girders. The table shows the deflection at 50% of the ultimate load for each girder which approximately corresponds to the serviceability limit state. Also given in the table is the ultimate load capacity for each girder.

All the differences for the above two cases results are normalized with respect to the analytical (Finite Element) results for the corresponding non-spliced case.

Table (5.6) Summary of Experimental and Analytical Results for the Test Girders

Girder No.	Mid-span Deflection at 50% of the Ultimate Load (Normalized)		Ultimate Load (Normalized)	
	Non-Spliced (F.E.M.)	Spliced* (F.E.M.)	Non-Spliced* Experimental	Spliced* Experimental
B1	1.000	1.211	0.912	0.773
B2	1.000	1.226	0.937	0.851
B3	1.000	1.292	1.090	0.832
B4	1.000	1.191	0.921	0.847
B5	1.000	1.177	0.930	0.831
B6	1.000	1.320	0.920	0.822
B7	1.000	1.223	1.150	0.767
B8	1.000	1.200	1.087	0.850

*Normalized with respect to the Finite Element Result for non-spliced corresponding case.

CONCLUSIONS

- The nonlinear finite element method presented in this study was shown to be capable of reproducing the experimental response of the spliced pre-stressed concrete girders. The isoparametric brick elements with embedded steel bars proved to be suitable for predicting the state of ultimate load and deflections with good accuracy. Generally, the differences with experimental values (in deflection or ultimate load) were in the range (8-12%) for the case of spliced and non-spliced girders.

- The experimental results showed that at about 50% of the ultimate load which corresponds to the serviceability limit state the deflection of the spliced girders is greater than that of the non-spliced girders in the range of (10%-15%) and the ultimate load for the non-spliced girders is greater than that of the spliced girders in the range of (12%-17%).

- The concept of lumping equivalent nodal forces used in the present study is capable to simulate the loads exerted by the pre-stressing tendon upon the girders. The contribution of the pre-stressing tendon stiffness to the element stiffness is found to have some effect on the analysis.

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