EFFECT OF COMPOSITE ACTION OF CONCRETE SLAB ON UNSYMMETRICAL STEEL PLATE GIRDER UNDER COMBINED BENDING AND TORSION MOMENTS

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Abstract: *In general, the reinforced concrete slab in composite unsymmetrical steel plate girder contributes in increased the ultimate strength of composite section under combined effect of bending and torsion moments. The contribution value of slab in composite section is unknown, so this study is adopted. Six specimens were either non-composite or composite reinforced concrete slab and with symmetrical/unsymmetrical steel plate girders were adopted in this study. The specimens were divided into three non-composite steel plate girders and the others were composite with RC slab. The specimens were tested under effect of combined bending and torsion moments.*

The general behavior and response of the tested specimens were recorded and discussed in this paper. For each tested plate girder, the ultimate strength, load at cracking, failure's mode, and load/deflection relationship at mid-span and under points load were gaged. The experimental results show that the concrete slab contributes in increasing the ultimate load of composite section by a ratio (53.85)% for symmetrical section and (155.63 – 242.51)% for unsymmetrical section when the composite girder under loaded out of supported plane, and the contribution value of concrete slab in composite plate girder increased in unsymmetrical section than symmetrical section this is due to the ideal use of materials.

Keywords: unsymmetrical plate girder, composite section, combined bending and torsion moments.

1.INTRODUCTION

Plate girders can be characterized as a beams built up from plate components to satisfy a more efficient arrangement of material than is provided with rolled beams or to manufacture a large size girder that cannot be manufactured as a hot or rolled sections. These built up elements (both flanges and webs) may be

compact, non-compact or slender but these girders are usually very deep so that their webs will be either non-compact or slender.

Plate girders are considered as an economical section this is due to their properties. These properties are represented by long span and allow to sparing in expense proportioning for specific necessities. The cross area of plate girders can take a few forms such as box girder which providing improved torsional stiffness for curve long span, and (I) section which represents an effective section use in of material for maximizing stiffness. These plate girders may be of riveted or welded construction. They are additionally might be double symmetrical, single symmetrical or unsymmetrical plate girders. Sometimes in plate girders, the strength of steel flange is higher than in web or webs at this case it is called hybrid plate girders [1].

Concrete slab, in almost cases, is used to be in a composite action with steel girder to increase the ultimate load capacity of section. In composite section, concrete slab and steel girder are connected to gather by shear connectors. In general, concrete slab and top flange of steel girder are used to resist the compression stresses due to applied load while the bottom flange is used to resist the tension stresses. The used of composite steel plate girder with unsymmetrical flanges will improve its ultimate load capacity of section under combined effect of bending and torsion moments [2] [3].

The main objective of this investigation is to predict the contribution value of concrete slab in the ultimate load of composite section and the effect of concrete slab composite action with unsymmetrical steel plate girder on the ultimate load under combined effect of bending and torsion moments.

2.EXPERIMENTAL WORK

The experimental work contains tested six specimens which divided into two groups. First group represented by three specimens of noncomposite steel plate girders; one specimen had symmetrical cross section and the others had unsymmetrical cross section i.e. unsymmetrical flanges. The second group also represented by three composite steel plate girders with same steel girders that in first group. High strength concrete (HSC) is used in casting concrete slab of composite section. All specimens loaded out of supported plane to be under combined effect of bending and torsion moments. The experimental test was carried out in the site work at College of Engineering\ Al-Qadisiyah University.

2.1. SPECIMENS DESCRIPTION

Six built up (I-shape) steel plate girders specimens were designed and manufactured and tested as part of the experimental program. All specimens have (2000mm) length and (350mm) depth. The specimens classification according to composite action, three girders were noncomposite steel girders and three girders were composited with reinforced concrete deck slab has a dimensions (500mm) width and (80mm) thickness. Two of these girders have symmetrical section and four girders have unsymmetrical section (unsymmetrical flanges).

In composite specimens, a partial bond interaction between steel girder and reinforced concrete slab are used in this study. Single hooked shear connectors are used for bond interaction. Hooked shear connectors welded over center of girder's compression flange which spaced at (100mm). A hooked shear connectors are adopted in this study where a reinforcing steel bar (8mm diameter) is utilized in manufactured of hooked shear connectors; its length (45mm) and hook (25mm) can be written as (∅8mm-L45mm-H25mm).

Table(1) and Figure(1) explain geometrical details and specimen designation of steel plate girders that adopted in this investigation.

Two of these specimens (composite and noncomposite specimens) had a symmetrical plate girder i.e. symmetrical flange width (symbol by S) with width of both top and bottom flanges (b_{ft} = b_{fb} =100mm) and web thickness (3mm) (symbol by W3). These specimens are denoted by (NC.S.W3.BT and C.S.W3.BT.P), respectively.

The other specimens had a two cases study of unsymmetrical flanges width represented by (US1 and US2) differ by flange's width where US1 has top flange width (b_{ft} = 80mm) and bottom flange width (b_{fb} =

120mm) while US2 has (b_{ft} = 60mm) and (b_{fb} = 140mm). These specimens are denoted by (NC.US1.W3.BT, NC.US2.W3.BT, C.US1.W3.BT.P, and C.US2.W3.BT.P), respectively.

Table(1) Girders Description, Designation and Geometry

All specimens have t_f = 6mm and h_w = 350mm

| Description of Specimen	Specimen Designation	Geometry, (mm)		
		b_{ft}	b_{fb}	t_w
Symmetrical non-composite steel plate girder	NC.S.W3.BT	100	100	3
Unsymmetrical non-composite steel plate girder	NC.US1.W3.BT	80	120	3
	NC.US2.W3.BT	60	140	3
Symmetrical composite concrete steel plate girder	C.S.W3.BT.P	100	100	3
Unsymmetrical composite concrete steel plate girder	C.US1.W3.BT.P	80	120	3
	C.US2.W3.BT.P	60	140	3
	C.US1.W2.BT.P	80	120	2
	C.US2.W2.BT.P	60	140	2
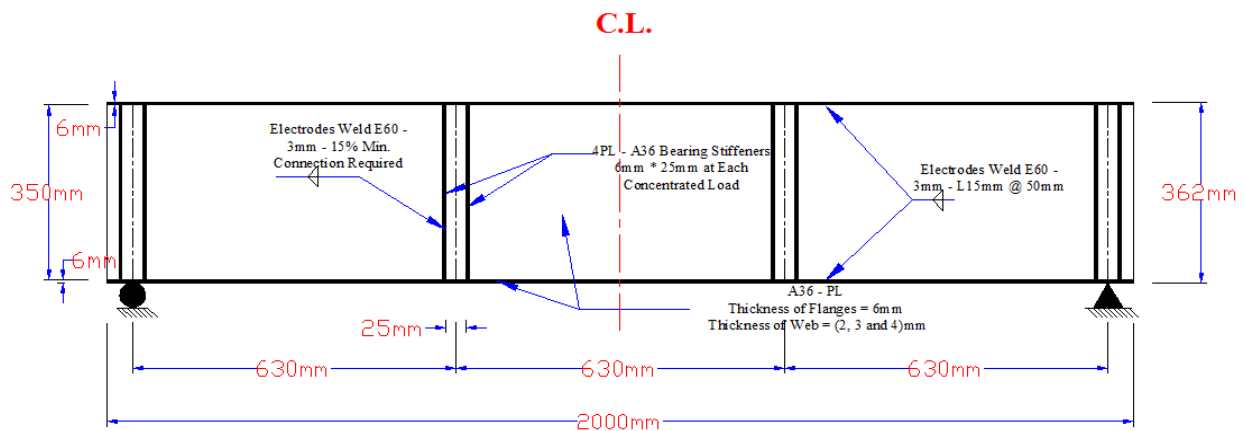
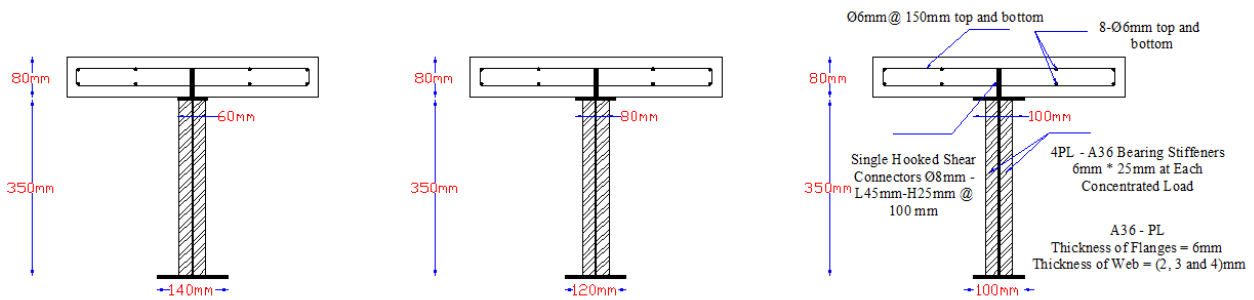(a) Noncomposite steel plate girder
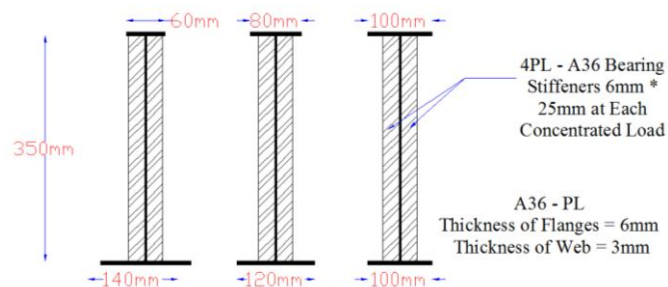
(b) Cross section of symmetrical and unsymmetrical noncomposite plate girder

Figure(1) Geometrical details of specimens
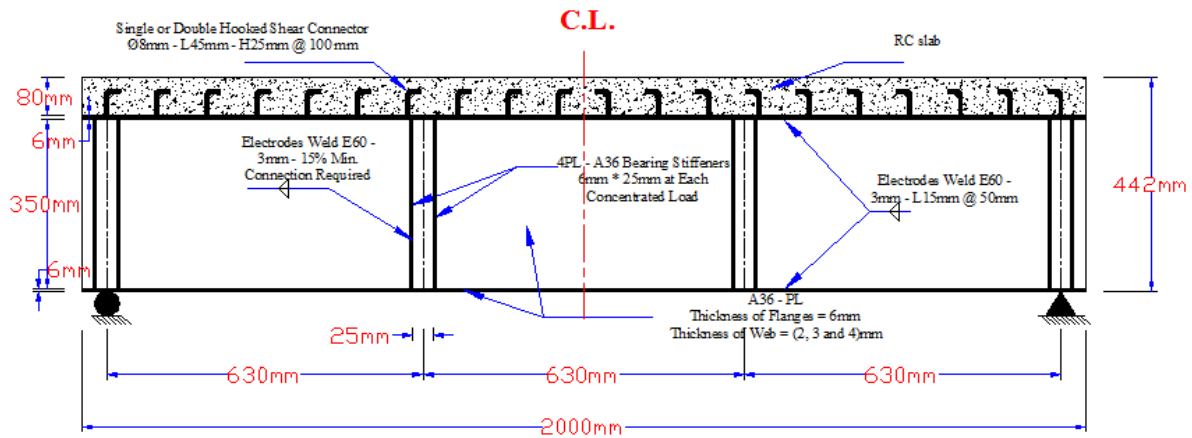
(c) Composite concrete steel plate girder

(d) Cross section of symmetrical and unsymmetrical composite concrete steel plate girder with partial bond interaction

Figure(1) Geometrical details of specimens (continued)

2.2. MATERIALS

High Strength Concrete (HSC) is used in this investigation and its production required prepares special materials. HSC contains mineral and chemical admixtures in addition to the main materials that used in production NSC (cement, sand, gravel and water). These materials were tested in laboratories of Engineering College of Al-Qadisiyah University. The concrete materials properties that used in this study will discussed in the following.

2.2.1. Cement

Ordinary Portland cement (Iraqi manufacturing) named Al-Jesser was utilized in this study for casting all the concrete specimens. This complies with ISS No.5-1984[6]. These testing completed in the Laboratory of Engineering College/Al-Qadisiyah University.

2.2.2. Fine Aggregate

Natural sand from Karbala was utilized in this investigation. The tests results demonstrated that it's grading and sulfate content complies with Iraqi specification No. 45/1984 \ zone (2)[6]. These tests were done in the Laboratory of Engineering College/Al-Qadisiyah University.

2.2.3. Coarse Aggregate

Natural gravel has a max. particle size 10 mm (crushed surfaces gravel) from Al-Nibaey was utilized in present study. The course aggregate was cleaned and washed several times then let for dry in air. It tested and found that it duplicated to the specified limits by the IS No.45-1984[7]. These tests were pluperfect in Engineering College-Al Qadisiyah University Lab.

2.2.4. Mineral Admixture

The mineral admixtures is use to improve the mechanical properties of concrete for example workability, strength and durability which are utilized as a replacement ratio to cement in concrete mixture. These admixtures are very fine ground materials' solid and chemically it's be effectively with cement's hydrating to create a modified paste microstructure.

Silica Fume (SF) is a kind of mineral admixtures which was utilized in this study. It's very fine produced noncrystalline silicate in furnaces of electric arc as a byproduct of the manufacture of elemental silicon as (ACI116R-2000)[8] characterized. It is typically classified as associated cementitious materials. Cementitious materials referred to materials that are utilized in concrete's mixes in addendum to cement's Portland. SF is spherical in shape and is about one hundred times less than the average cement's particle with an average diameter[9].

From trail mixes, (Sika Fume S92D) was used in this investigation as additive with a ratio (8%) by weight of cement. The chemical composition of silica fume utilized in this study and requirements of physical.

2.2.5. Chemical admixtures

In order to improvement built up times and reduce the required water/cement ratio of mixes of concrete, this type of admixtures involved all series of the chemicals' soluble are added to the mixes. Two types of chemical admixture [10] are used in this study represented by:

High performance concrete superplasticizer named (ULTRABOND SBR500–SBR BONDING AGENT – High Performance Water Resistant Bonding Agent and Admixture for Concrete and Cement Mixes).

1. HPC superplasticiser depended upon improved polycarboxylic ether called (GLENIUM54).

2. High water reduction, high workability without segregation or bleeding, coupled with high early strengths and improves other mechanical properties of concrete have a main positive effect on the applications.

The normal mouthful for GLENIUM54 is between (0.5-2.5) liters / 100kg cement or cementitious materials and the normal dosage for SBR is between (0.8-2.3) liters/100 kg cement or cementitious materials. In this study, from trail mixes it used (1.6liters/100kg cementitious materials for SBR and (0.9 liters/100 kg of cementitious materials for GLENIUM54.

2.2.6. Mixing and Curing Water

Water of concrete mixing must be clean from all harmful substances such as organic materials, salt….. etc., which that cause deleterious of concrete and steel reinforcement. In this investigation, tap water has been used for curing and mixing for all concrete specimens.

2.2.7. Steel Reinforcement

Deformed bar of size (Ø6mm) was used to reinforced the concrete deck slab in two directions. Three specimens of steel bar reinforcement were tested[11] under tensile force by using Universal Machine in the laboratory of Engineering College\Al-Qadisiyah University. The mechanical steel reinforcement specifications are agreed with ASTM A615-86. The results of tests that obtained for the yield stresses, and the ultimate stresses at fracture are arranged in Table(2).

Table(2) Specifications of used reinforcement

Nominal Diameter (mm)	Measured Diameter (mm)		Weight (Kg/m)		Yield Stress f_{sy} (MPa)		Ultimate Strength f_{su} (MPa)	
6	5.8	5.8	0.22	0.22	449.6	432	683.6	680.5
	5.8		0.22		423.9		672.3	
	5.8		0.22		422.5		685.7	
8	7.9		0.37		506.2		627.8	

2.2.8. Steel Plate

While build up (I-section) steel plate girder symmetrical and unsymmetrical section with various plates' thickness (6mm for flanges and (3mm for web) was adopted in this study, tensile tests were done by using Universal Machine in the laboratory of Engineering College\Al-Qadisiyah University. The results of tests that obtained for the yield stresses, and the ultimate stresses at fracture are arranged in Table(3).

Table(3) Mechanical properties of used steel plate

| Nominal Plate Thickness (mm)	Measured Plate Thickness (mm)	Weight (Kg/m^2)	Yield Stress f_{sy} (MPa)	Ultimate Strength f_{su} (MPa)
3	3	19.7	143.3	285.6
6	5.8	31.5	122.7	244.4

2.3. LOADING PROCEDURE

All specimens are tested under two points load applied out of girder supported plane (i.e. with eccentricity from center of girder) where bending and torsion moments will be developed in this loading condition, see Figure(2). Practically, in this loading test for both composite and non-composite section, a steel plate arm are made from the same properties of steel plate girder and welded at the point load to prevent local failure in concrete deck slab and to transfer the forces to the steel girder, see Plate(1).

At each increment load, deflection and marked buckling, the cracks and the load value at each crack are written. The test terminated when it noticed a loading drop, and the girder showed large deflection i.e. failure occurred. When the girder reached the failure point, the load removed, and then recorded of load failure and the cracks are marked on specimens.
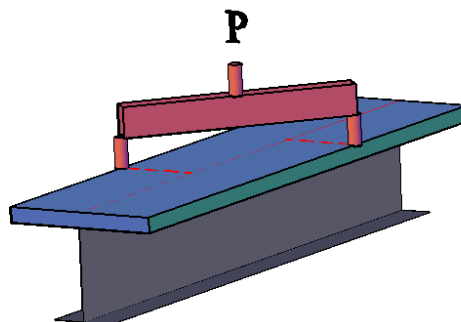
Figure(2) Adopted Loaded out of supported plane test
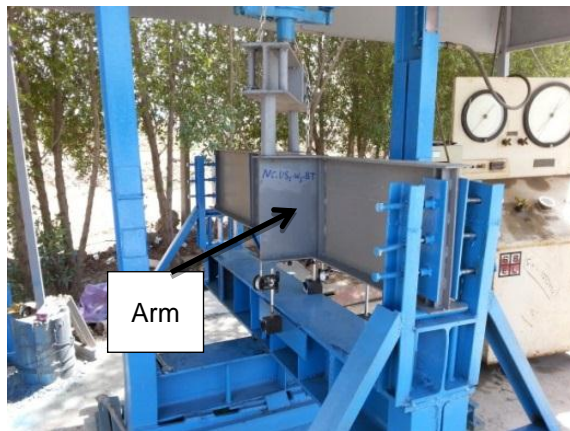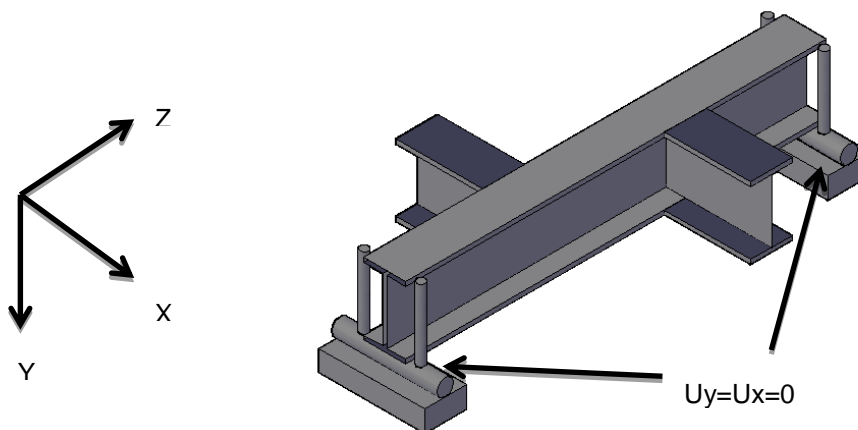
(a) Non-composite girder   (b) Composite girder

Plate(1) Adopted steel arm to generate torsional moment

2.4. SUPPORT CONDITIONS

While the specimens be under combined effect bending and torsion moments, the girder support conditions for this loading test is placed as a simple supports in planes (XY and YZ), i.e. simply supported beam to resist bending deformation (Uy=0) at both ends and lateral simply supported also (Ux=0) at lateral both ends to resist the torsional moment that developed due to loading condition in supports, see Figure(3).


Figure(3) Adopted support conditions

3. EXPERIMENTAL RESULTS

Six composite and noncomposite specimens have a symmetrical and unsymmetrical steel plate girders (I-section) with (2000mm) span were loaded out of supported plane until failure to be under effect of combined bending and torsion moments. The main aimed of this study to show the effect of composite action of concrete deck slab on unsymmetrical steel plate girder under combined moments and to show the contribution value of concrete deck slab on the ultimate strength. These girders were supported as a torsional simply supported beam i.e., the ends were simply supported with respect to torsional and bending restrains. Load deflection relationship, failure pattern, and deflected shape are recorded and discussed in the following.

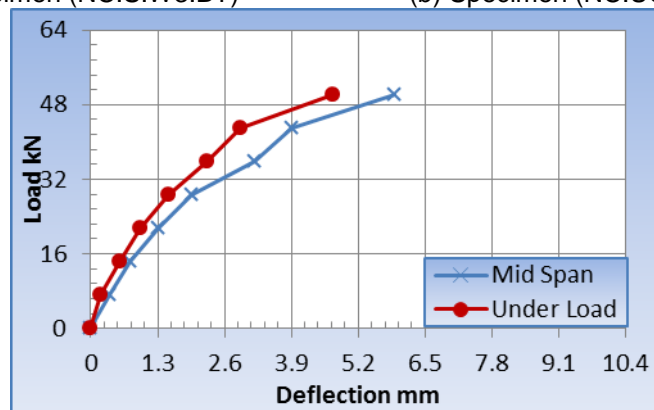### 3.1. LOAD DEFLECTION RELATIONSHIP AND FAILURE PATTERN

3.1.1. Noncomposite Steel Plate Girder

Deflections at mid span and under load (third span) were gaged at each loading incremental for each specimen. Figures(4a, b and c) are showing the load-deflection relationship of each specimen (NC.S.W3.BT), (NC.US1.W3.BT) and (NC.US2.W3.BT), respectively.
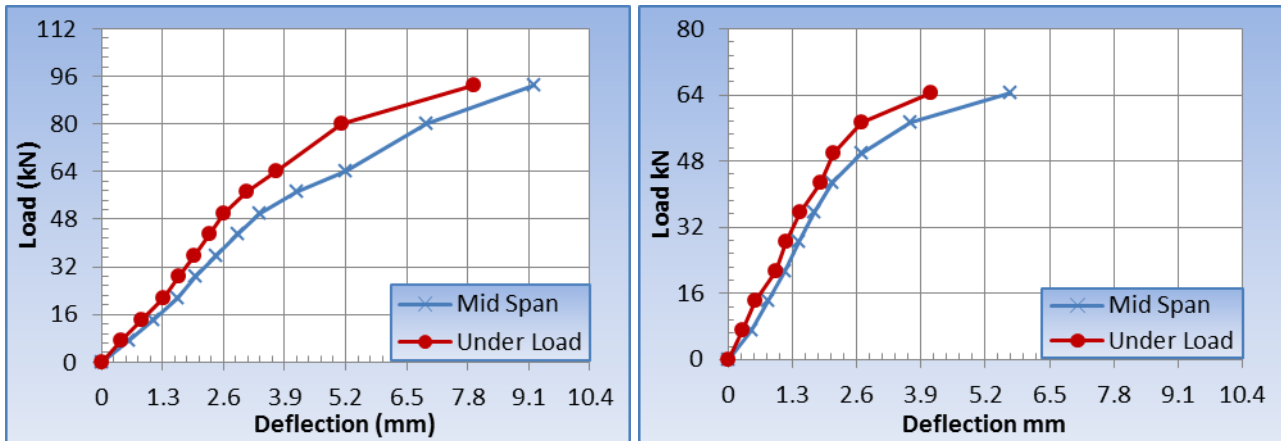
(a) Specimen (NC.S.W3.BT)   (b) Specimen (NC.US1.W3.BT)

(c) Specimen (NC.US2.W3.BT)

Figure(4) Load-deflection relationship of non-composite specimens

From load-deflection curve above, it can be noted that the relationship is approximately linear up to the first yield load and then it becomes nonlinear i.e. inelastic deformation continued and slope of load-deflection relationship of specimen began to decrease until failure. The ultimate load of unsymmetrical steel plate girders (NC.US1.W3.BT and NC.US2.W3.BT) decreasing by a ratio (30.77% and 46.15%) respectively than ultimate load of symmetrical steel plate girder (NC.S.W3.BT) with decreasing compression flange width (b_{ft}) and increasing tension flange width (b_{fb}) this is due to drooping centroid position of section due to decrease compression flange width. Table(4) shows 1st buckling load, load at ultimate stage and deflection at midspan of noncomposite specimens.

The failure of the adopted steel plate girders (NC.S.W3.BT), (NC.US1.W3.BT) and (NC.US2.W3.BT) were shown in Plates(2a, b and c), respectively. It can be noticed that deformed shape, diagonal web buckling and yielding in the top flange of specimen at loading arm which was occur in all specimens at ultimate load. The failure mechanism of all specimens have the same behavior where the plate girder showed initially elastic behavior and diagonal web buckling noticed and happened in all web panels approximately at the same time. As increased load, the top flange at the loading arm was yielding led to

collapse failure. It observed that in all specimens, top and bottom flanges of girder rotates and don't stay in their plane after failure collapse due to applied torsion moment.

Table(4) Load at ultimate stages and midspan deflection of noncomposite girders

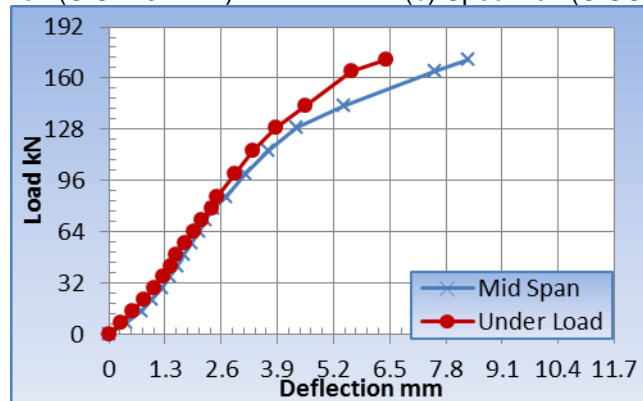| Specimen	(d/t)	1st Buckling Load (kN)	Ultimate Load (kN)	Midspan Deflection (mm)	
				Buckling Load	Ultimate Load
NC.S.W3.BT	116.67	50	92.95	3.36	9.21
NC.US1.W3.BT	116.67	57	64.35	3.7	5.7
NC.US2.W3.BT	116.67	47	50.1	5.91	5.91

3.1.2. Composite Steel Plate Girder

Load deflection relationship, failure pattern, and deflected shape, are recorded and discussed in the following. Figures(5a, b and c) explain the load deflection relationship of the adopted specimens (C.S.W3.BT.P), (C.US1.W3.BT.P) and (C.US2.W3.BT.P) and Table(5) below show the ultimate load of each specimen and other results. The results showed th.at ultimate strength of composite unsymmetrical steel plate girders (C.US1.W3.BT.P and C.US2.W3.BT.P) increased by increased bottom flange width by a ratio (14.9% and 20%) respectively than symmetrical section (C.S.W3.BT.P) so as to for deflection which increased by a ratio (7.14% and 26.4%) frequently.
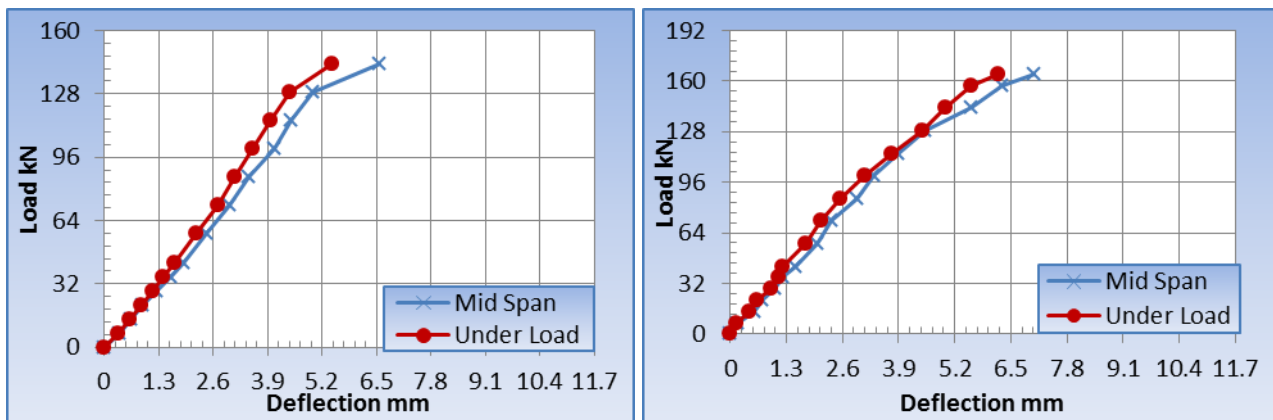
(a) Specimen (C.S.W3.BT.P) (b) Specimen (C.US1.W3.BT.P)

(c) Specimen (C.US2.W3.BT.P)

Figure(5) Load-deflection relationship of composite specimens

Table(5) The load at ultimate stage and midspan deflection of Group(2.1) specimens

Specimen	(d/t)	1st Cracking Load (kN)	Ultimate Load (kN)	Midspan Deflection (mm)	
				Cracking Load	Ultimate Load
C.S.W3.BT.P	116.67	71.5	143	3.01	6.58
C.US1.W3.BT.P	116.67	71.5	164.5	2.35	7.05
C.US2.W3.BT.P	116.67	78.65	171.6	2.42	8.32

In general, all specimens have the same behavior up to collapse. From load/deflection curve, it is observed that the response of composite plate girders to load is linear at initial stages. The nonlinear behavior of load/deflection is seen after concrete cracking, steel yielding represented by buckling. It is also watched that reduction in stiffness and strength of composite girders lead to an increase in the load. While loading is increased, it is led to the total collapse of the girder. In all specimens, it observed that no separation took place neither for partial bond interaction nor the complete bond interaction between top flange of plate girder and the deck slab of concrete that means full composite action.

Plates(3a, b and c) showed failure of composite steel plate girder and crack pattern of concrete deck slab of specimens (C.S.W3.BT.P), (C.US1.W3.BT.P) and (C.US2.W3.BT.P), respectively.

The failure mechanism is represented by appears diagonal cracks in the top face of concrete deck slab firstly when loading reach to cracking load where these cracks appears between the point load due to tension stressed that generated from torsional moment. As loading increase the diagonal cracks increase and appear longitudinal crack along shear connectors. Finally, composite girder may be failure either by deck slab concrete or web bucking then collapse which depends on web's stiffness.

Yielding in compression flange

Out of plane deformation
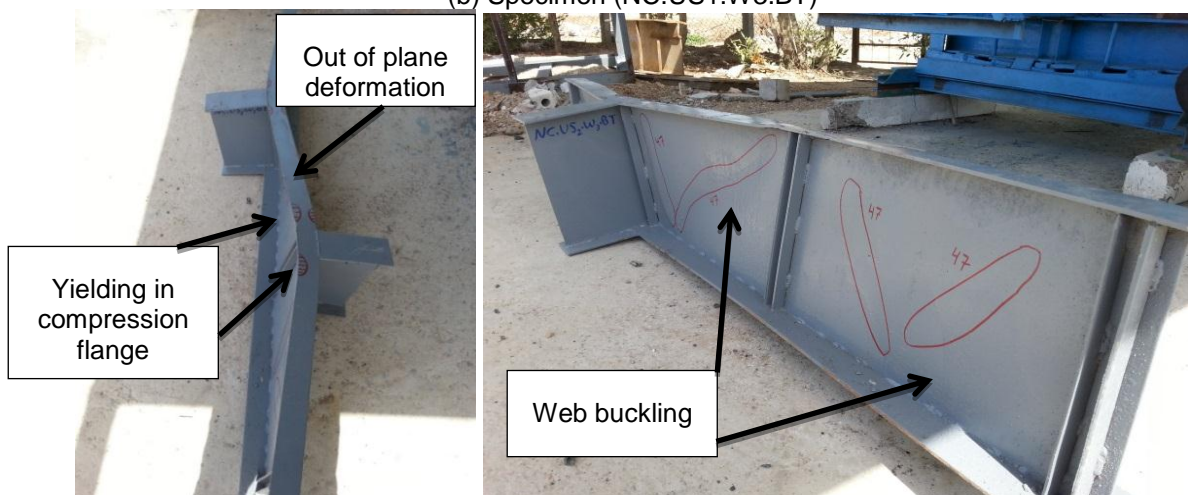
Web buckling
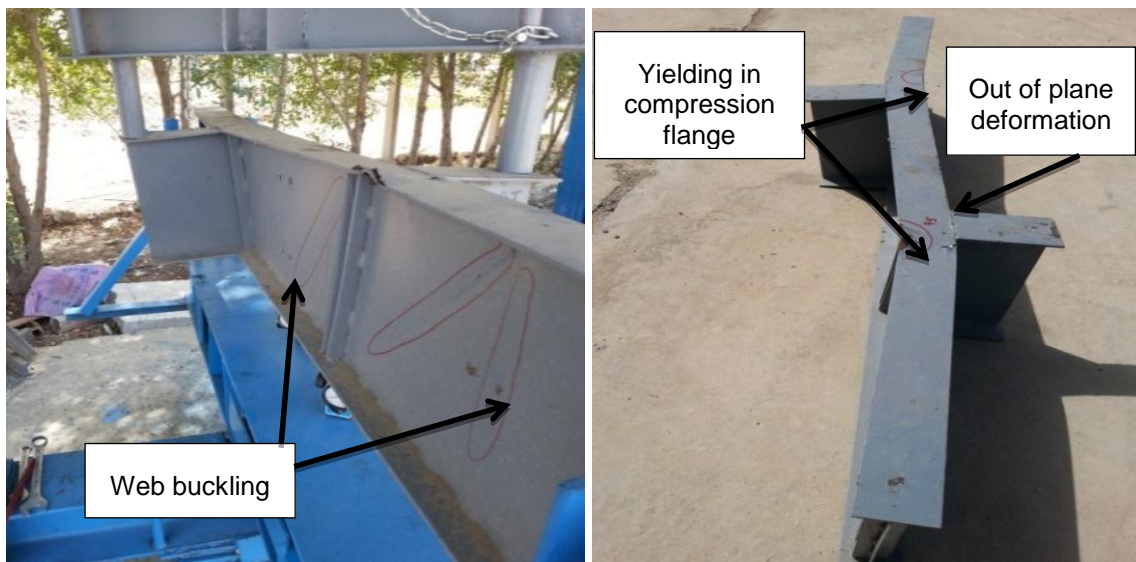
(a) Specimen (NC.S.W3.BT)

Plate(2) Failure of non-composite specimens
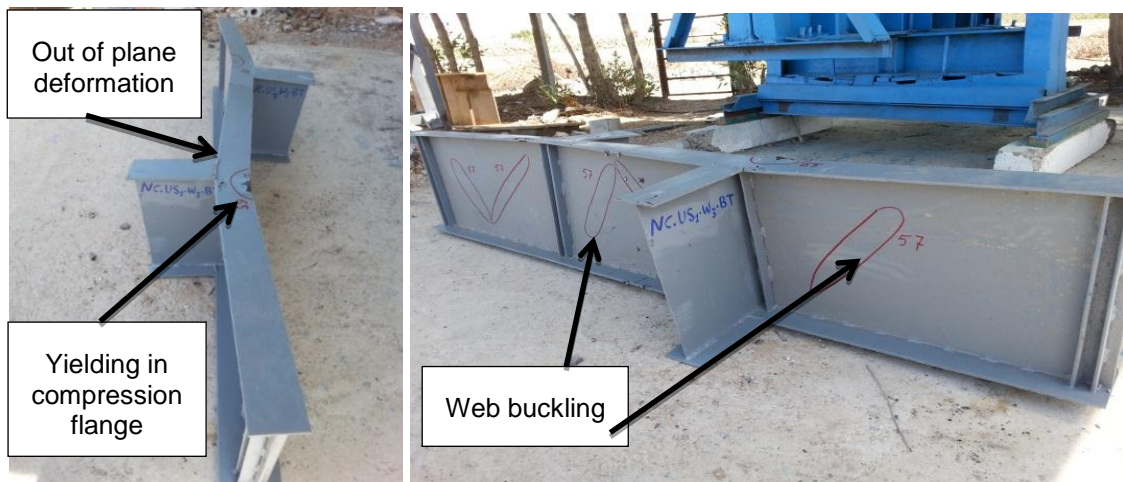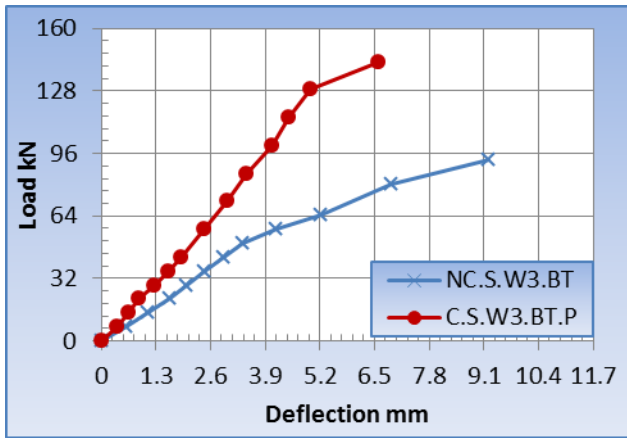
(b) Specimen (NC.US1.W3.BT)

(c) Specimen (NC.US2.W3.BT)

Plate(2) Failure of non-composite specimens (continued)

3.2. EFFECT OF CONCRETE SLAB COMPOSITE ACTION

It is important to know the concrete deck slab's effect in unsymmetrical composite section on ultimate load under combined bending and torsion moments. In experimental work, both composite and non-composite symmetrical and unsymmetrical steel plate girder were tested under combined effect of bending and torsion, Figure(6) show the load deflection relationship between composite and non-composite plate girders.

From experimental results, Table(6) show the effect of concrete deck slab on composite plate girder behavior and it is observed that the concrete deck slab contributes in increasing ultimate load by a ratio (53.85)% for symmetrical section and (155.63 – 242.51)% for unsymmetrical section. It is also seen that the contribution value of concrete deck slab increased in unsymmetrical section than symmetrical section.

(a) Specimen (S.W3.BT.P)
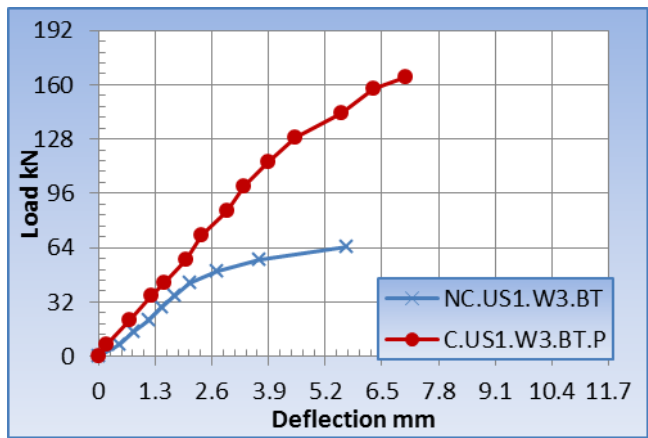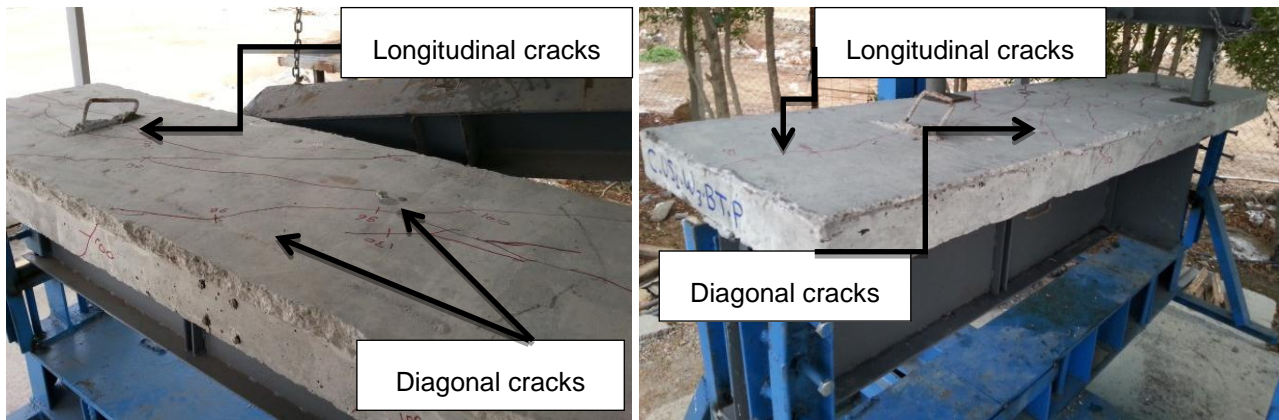
(b) Specimen (US1.W3.BT.P)
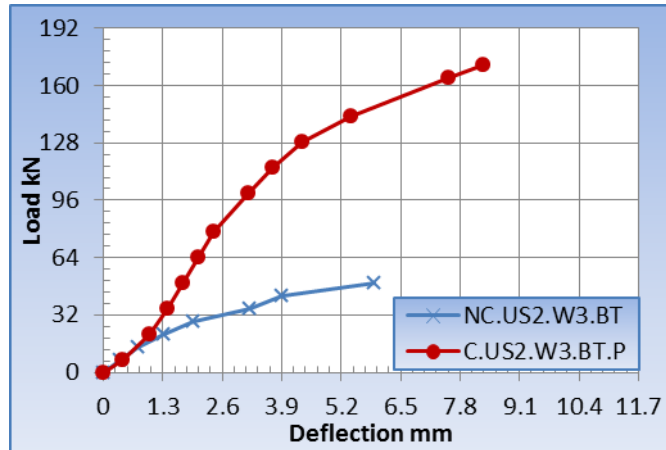
(c) Specimen (US2.W3.BT.P)
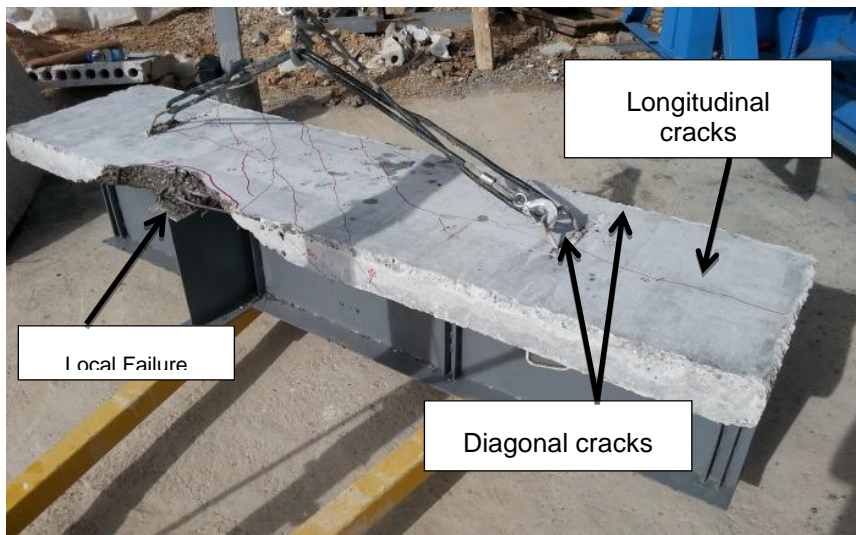
Figure(6) Effect of composite action on girder's behavior

Table(6) Effect of concrete deck slab in composite girder

Specimen	Ultimate load (kN)		Difference (%) = (C - NC)/NC
	Non-composite (NC)	Composite (C)	
S.W3.BT.P	92.95	143	53.85
US1.W3.BT.P	64.35	164.5	155.63
US2.W3.BT.P	50.1	171.6	242.51

(a) Specimen (C.S.W3.BT.P) (b) Specimen (C.US1.W3.BT.P)

(c) Specimen (C.US2.W3.BT.P)

Plate(3) Failure of composite steel plate girder and crack pattern of concrete deck slab

4. CONCLUSIONS

1. The concrete slab contributes in increasing the ultimate load of composite section by a ratio (53.85)% for symmetrical section and (155.63 – 242.51)% for unsymmetrical section when the composite girder under loaded out of supported plane.

2. The contribution value of concrete slab in composite plate girder increased in unsymmetrical section than symmetrical section this is due to the ideal use of materials, i.e. founded of concrete slab in compression zone required the benefit from that case to reduce the compression flange and increase the tension flange.

3. In addition to the improvement of strength capacity of steel plate girder by concrete slab in composite section, the concrete slab in composite section provides a restrained for the compression flange and prevents flange from warping due to torsion while the tension flange warped freely due to warping torsion effect.

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