Influence of Lateral Bracings in the Static Behaviour of Composite Box-Girder Bridges

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Abstract - *Composite construction is used extensively in modern buildings and highway bridges all over the world. Recently, composite box girder bridges with corrugated steel webs and trusses (CBGB-CSWT) were developed replacing the concrete box girders with large dead load. Studies proved that lateral bracings significantly increase both the flexural and torsional stiffness of such bridges when taken into account in design. Unfortunately, there are no comments on the beneficial effect of the influence of the lateral bracing on enhancing the structural performance of the composite girder. This research is focused on understanding how the bracing system affects the performance of composite box girders with corrugated steel webs and trusses for different lateral bracing patterns for static loads.*

Key Words: Composite, Box – Girder, Corrugated steel webs, Flexural, Torsional Stiffness, Lateral Bracing.

1. INTRODUCTION

Composite box girders have gained special attention in the field of structural engineering due to the advantages like reduced self – weight of the structure, increased load carrying capacity over that of a non-composite beam etc. One of the most promising ways to reduce the self-weight of bridges is to adopt steel–concrete composite structures. A box girder is formed when two web plates are joined by a common flange at both the top and the bottom. The closed cell which is formed has a much greater torsional stiffness and strength than an open section and it is this feature which is the usual reason for choosing a box girder configuration.

1.1 Composite Box Girder with Corrugated Steel Webs and Trusses

Nowadays, there are mainly three types of steel–concrete composite bridge structures: composite bridges with steel beams and top concrete slab, composite bridges with steel webs (or steel trusses) and top and bottom concrete slabs, and composite bridges with top concrete slab, steel trusses and bottom concrete-filled steel tube as shown in Fig.1(a). Among all the above mentioned types of composite bridges, the number of composite bridges with top concrete slab and bottom trusses is the smallest. This is because this kind of structure contains a lot of truss joints, and the fatigue and the stress concentration at such joints may lead to the failure at these locations before the global failure of the whole structure happens. That means the flexural capability of the bridge may not be fully utilized. To solve this problem, engineers proposed the composite bridge with Corrugated Steel Webs (CSWs) and Concrete-Filled Steel Tube as in Fig.1(b), where the trusses are replaced by corrugated steel webs so that the number of joints can be greatly reduced.

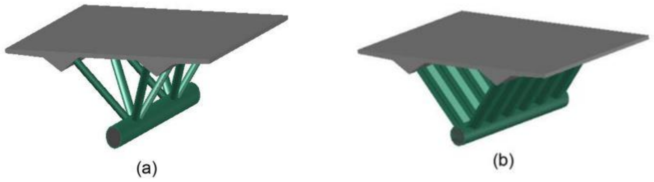

Fig -1: Typical cross-section of (a) composite bridges with top concrete slab, trusses and bottom CFST; (b) composite bridges with CSWs and CFST [1]

However, there are still some limitations in the composite bridge with CSWs and CFST. First, as the cross-section is triangular, the torsional stiffness and the resistance to overturning is relatively small. Second, the space for some construction procedures such as the welding between the corrugated steel webs and the steel tubes is limited. To further improve this kind of structure, the composite box girder with CSWs and trusses is proposed. A typical cross-section of this kind of structure is shown in Fig. 2. The most important feature is that the single concrete-filled steel tube in Fig. 1(b) is replaced by two bottom steel tubes filled with concrete and connected by trusses, which may enhance the capability to resist torsion and overturning. The space for construction and maintenance within a bridge cross- section is also enlarged.

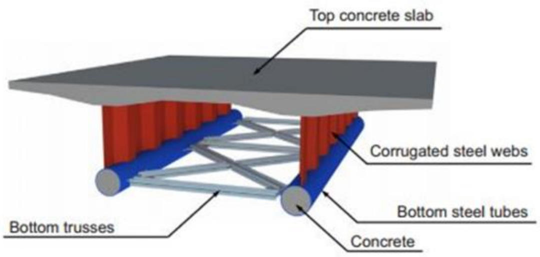

Fig -2: Typical cross-section of composite box girders with CSWs and trusses [1]

1.2 Need for Lateral Bracings

Composite beams and girders with corrugated steel webs have been achieving promising application in structure and bridge engineering around the world. Utilization of this composite member is driven by numerous advantages produced by its unique built-up arrangement. First of all, the replacement of concrete webs with steel webs considerably reduce the self-weight and speed up the construction process[10]. Secondly, the corrugation nature of the corrugated web plate considerably improves the shear resistance and out-of-plane stiffness, hence, eliminating the need for transverse stiffeners, which are essential for conventional steel beam with flat webs[11]. Indeed, the elimination of transverse stiffeners represent notable reduction of material consumption and implicitly. Torsion is recognized as one prominent effect in the girders which resist large eccentric load. Moreover, the torsional stiffness of these composite box girders can be considerably smaller than that of traditional girders. Thus, it is of great importance to thoroughly investigate the behaviors of this composite structure under pure torsion. Torsional effects can be effectively resisted by the

girder system, both during construction and while in-service, by providing cross-frames between the girders must be designed as primary load resisting members and adequately distributed along the girder span.

Lateral Bracings are members connecting the two ends at the top and bottom of the webs in box girders. Lateral bracing components are generally provided to stabilize the girder system during construction by enhancing the torsional resistance of the system. For resisting wind, racking and torsional forces, lateral bracings are provided. Many researchers concluded that the lateral bracings enable the bridge to improve its torsional stiffness and that some arranging patterns of lateral bracings have great effects on displacements despite using a small number of them. ElMezaini et al.[9] investigated the effect of bottom wind bracings on the structural performance of a bridge subjected to the Egyptian truck loading. The bridge model was a straight composite steel-concrete bridge. They concluded that wind bracings significantly increase both the flexural and torsional stiffness of such bridges when taken into account in design.

Lateral bracings provided for girders considering the torsional stability of the structure could be of many types: Single diagonal, K-type, X-type bracings or channel bracings as shown in Fig 3.

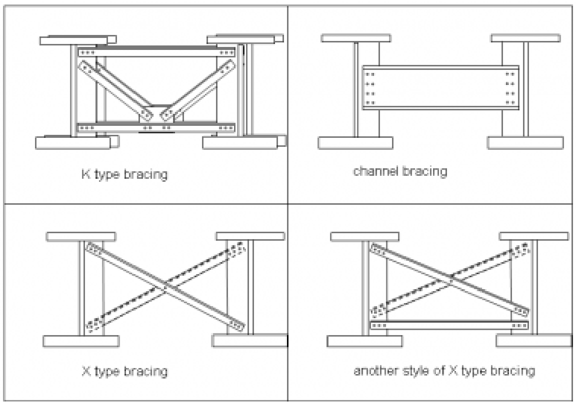

Fig -3: Types of Torsional Bracings [5]

1.3 Literature Review

A detailed literature survey was conducted for understanding the extends of developments and findings in the area of composite box girder bridges with corrugated steel webs and trusses and on the influence of lateral bracings on box girders till date.

Chen et al. [1] conducted an experimental study to investigate the longitudinal behaviour of CBGB-CSWT. Test beam was a scaled model of Maluanshan Park Viaduct, China, with linear dimension scale factor (S_l) of 1/5. The structure shows good ductility and integrity under flexural load The assumption that “plane sections remain plane” is not valid for the entire cross section. It was observed that the longitudinal normal strain of corrugated steel webs is small at the elastic and elasto-plastic stages. This indicates that the flexural loading is mainly sustained by the top concrete slab and the bottom trusses.

Chen et al. [2] did a preliminary investigation on the shear lag effect of the scaled model of CBGB-CSWT. In the first specimen (SP1), the bottom steel was filled with concrete and in the second specimen (SP2), the bottom steel tubes were left hollow. The results showed that the filling of concrete inside the bottom steel tubes does not greatly influence the shear lag coefficient (only a difference of 2%). The width-to-span ratio greatly affect the shear lag effect of a CBGB-CSWT. Smaller width-to-span ratio, smaller is the shear lag effect. The width-depth ratio does not show a great influence in shear lag effect.

Chen et al. [3] investigated the flexural behaviour of composite beams with CSWs and trusses. Two 1:5 scaled specimens of Maluanshan Park Viaduct in China were fabricated and tested, including Specimen SP1 with CFSTs and Specimen SP2 with hollow steel tubes. Both thetubes failed in a ductile manner. Any plane cross section of composite beams with CSWs and trusses remains plane after loading, and the CSWs can be ignored in the flexural performance analysis. The composite beams with CFSTs were found to have better flexural performance. The FE analysis on ABAQUS shows that the cubic concrete strength does not show a significant influence on the flexural stiffness, while a higher steel ratio results in a higher yield load and an increase in the flexural stiffness.

Z. Zhang et al. [4] studied the torsional behaviour of a box-girder with corrugated web and steel bottom flange. Two box-girders with corrugated steel webs and bottom steel plate with different web heights were fabricated and tested under pure torsion. The experimental results showed that the corrugated-web was still in elastic range even when the ultimate torque was reached. A finite element model was developed and it provided accurate simulation on the behaviour of box-girders with corrugated steel webs and bottom steel plates under pure torsion.

H. Maneetes and D.G. Linzell [5] studied the influence of Cross-frame and lateral bracing on curved steel bridge free vibration response for influential parameters affecting dynamic response of the system. Lateral bracing location relative to the girder cross-section has an appreciable effect on vertical and lateral bending stresses. Although higher natural frequencies were obtained for the X-type cross-frames, girder maximum vertical and lateral bending stresses and displacements were approximately 5% higher than those for K-type frames. The combination of these results indicated that, although certain parameters for X-type cross-frames were dominant when compared to those for K-type frames, the behaviour of the two systems could be considered practically identical. Lateral bracing orientation in plan had a negligible effect on vertical bending stress in this structure caused by self-weight.

2. MATERIAL AND MODEL

The details of the composite box girder are taken from the data with reference to the design of the left sub-bridge of the Maluanshan Park Viaduct in Shenzhen, Guangdong Province, China. The Maluanshan Park Viaduct includes a left and a right sub-bridges. A scaled model of the Maluanshan Park Viaduct with a linear dimension scale factor of 1/5 was designed and constructed for the study. The span length of the scaled model of the beam, which is corresponding to the distance between the centre lines of two adjacent expansion joints at the reference viaduct, is 9000 mm. The actual length of the model beam is 8984 mm, and the distance between the centre lines of two end supports is 8740 mm. The depth and width of the beam are 560 and 2080 mm, respectively. The thickness of the top concrete slab is 100 mm. The diameter of each bottom steel tube is 146 mm, and the thickness of the tube wall is 6 mm. The steel tubes were filled with concrete. The thickness of the corrugated steel webs is 4 mm, and the length and height of a corrugation are 320 and 44 mm, respectively. The corrugation angle is 31°. Longitudinal and transverse steel reinforcement bars with a diameter of 12mm were placed inside the top concrete slab and the end diaphragms forming reinforcement nets.

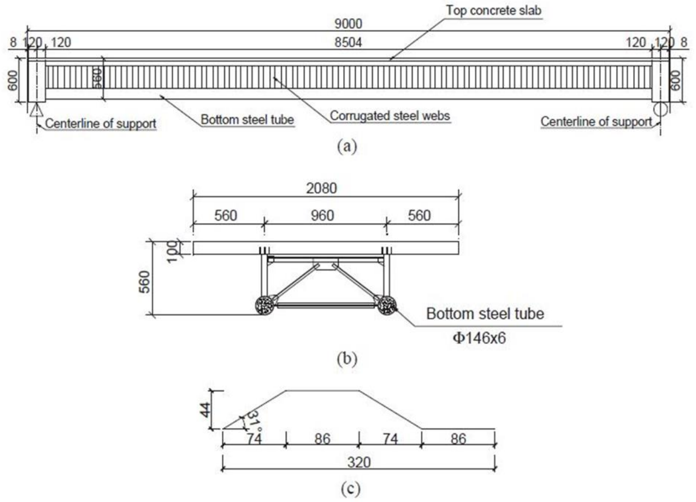

Table -1: Material Properties

Materials	Location	Young`s Modulus (MPa)	Compressive Strength (MPa)	Yield Strength (MPa)
Concrete	Top Slab	3.96×10^4	53.0	-
	Inside bottom steel tubes	3.68×10^4	49.5	-
Steel	Bottom steel tubes	2.03×10^5	-	316
	Corrugated steel webs	2.47×10^5	-	332

The numerical model was validated with reference to the study by Chen et al. [1] using ANSYS. The girder is simply supported at the two edges and is subjected to two point loading.

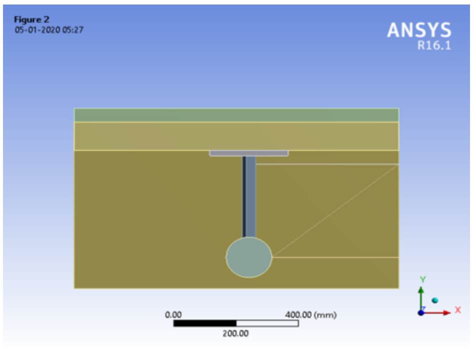

Fig -5: Quarter symmetric model of CBGB-CSWT with K-bracing

The deflected profile of the composite box girder is shown in Fig -6. The result obtained in the validation of software was used to plot a a graph as shown in Fig -7. The Load deflection curve from the studies conducted by Chen et al. [1] is shown in Fig -8 for a comparison.

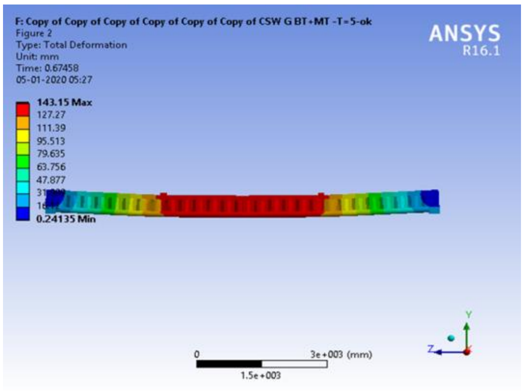

Fig -6: Longitudinal view of Deflected shape from analysis of CBGB-CSWT

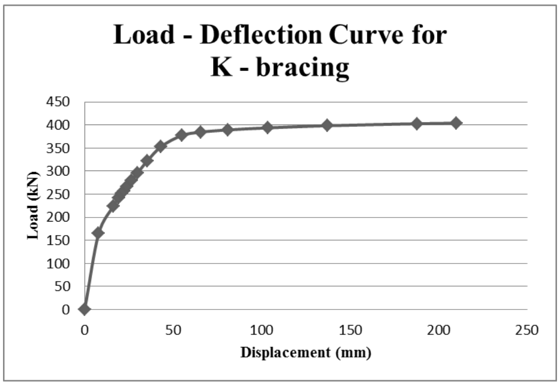

Fig -7: Load – Deflection curve of numerical model of CBGB-CSWT

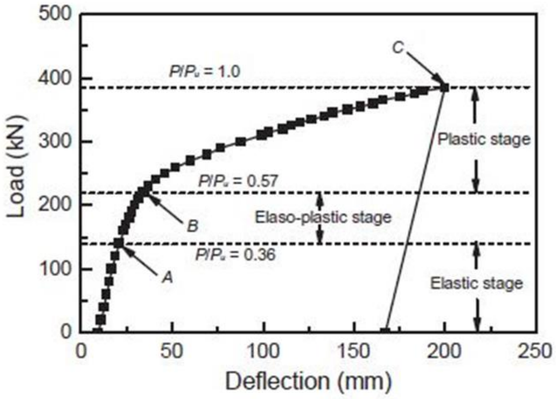

Fig -8: Load – Deflection curve of CBGB-CSWT obtained from the study of Chen et al. [1]

The result obtained from analysis is the deflection at the mid-span was 209.95mm (1/42.87 of the span length), and the ultimate load was obtained as 404.12kN. The experimental results obtained was that the beam has a maximum deflection of 199.7mm (1/46 of the span length), and the ultimate load was correspondingly calculated as 385kN. The result seems to vary approximately by 5%.

3. STATIC ANALYSIS OF CBGB-CSWT FOR DIFFERENT BRACING PATTERNS

Three types of lateral bracing patterns are chosen for the analysis: (1) Modified K – type Lateral Bracing with a Vertical Strut in the middle, (2) X – type Lateral Bracing and (3) Modified X – type Lateral Bracing with a Horizontal member connecting the two edges at the top. The box girder is to be modeled according to the structural details given by Chen et al.[1]. After modeling the structure, the static of all cases was be analysed for same loading condition and compared on the basis of their Load – deflection behaviour.

3.1 CBGB-CSWT with Modified K- Type Lateral Bracing with a Vertical Strut

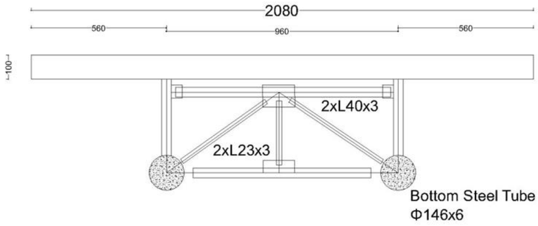

Fig -9: Sketch of CBGB-CSWT with modified K-type Bracing

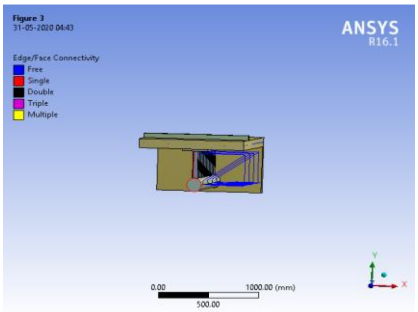

Fig -10: Quarter Symmetric Portion of CBGB-CSWT with modified K-type Bracing

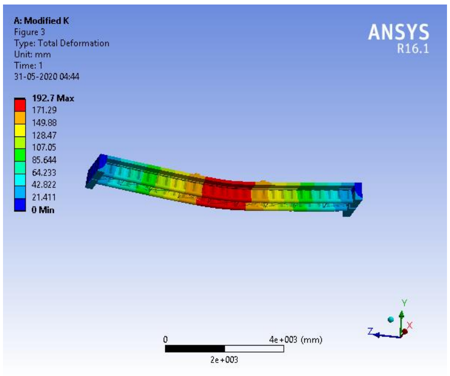

Fig -11: Longitudinal View of Deflected Profile of CBGB-CSWT with modified K-type Bracing

Table -2: Load – Deflection values of CBGB-CSWT with modified K –type Bracing

Load (kN)	Δ (mm)
0	0
313.148	35.864
400.64	54.456
429.04	74.343
437.56	94.443
443.28	124.11
448.28	168.33
450.28	192.7

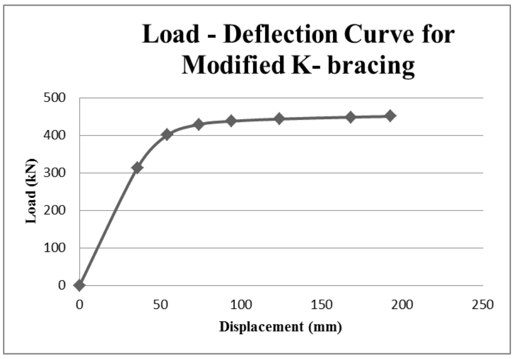

Fig -12: Load Deflection Curve of CBGB-CSWT with modified K – bracing

3.2 CBGB-CSWT with X- Type Lateral Bracing

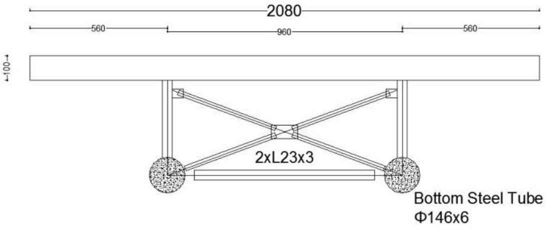

Fig -13: Sketch of CBGB-CSWT with X-type Bracing

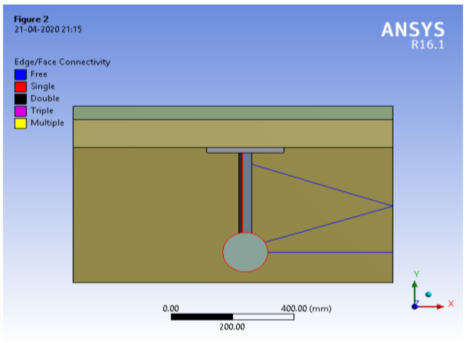

Fig -14: Quarter Symmetric Portion of CBGB-CSWT with X-type Bracing

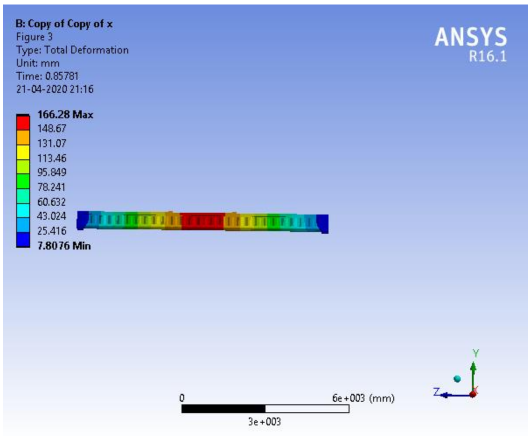

Fig -15: Longitudinal View of Deflected Profile of CBGB-CSWT with X-type Bracing

Table -3: Load – Deflection values of CBGB-CSWT with X –type Bracing

Load (kN)	Δ (mm)
0	0
318.192	36.082
431.76	75.063
448.44	135.21
455.6	194.28

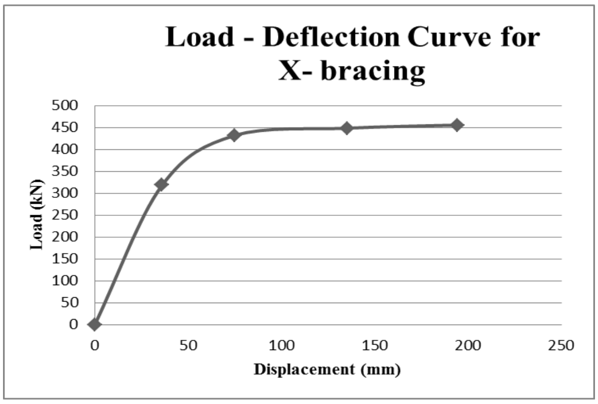

Fig -16: Load Deflection Curve of CBGB-CSWT with X - bracing

3.3 CBGB-CSWT with Modified X- Type Lateral Bracing with a Horizontal Member at the Top

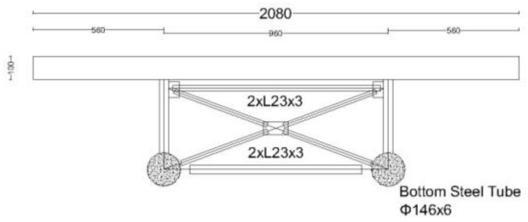

Fig -17: Sketch of CBGB-CSWT with modified X-type Bracing

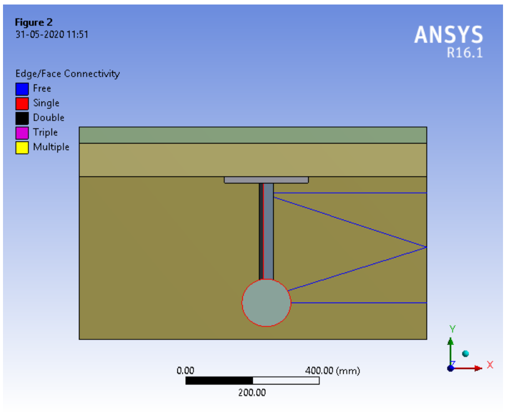

Fig -18: Quarter Symmetric Portion of CBGB-CSWT with modified X-type Bracing

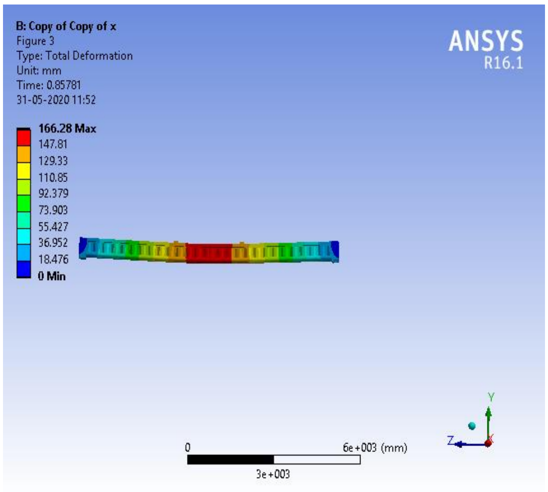

Fig -19: Longitudinal View of Deflected Profile of CBGB-CSWT with modified X-type Bracing

Table -4: Load – Deflection values of CBGB-CSWT with Modified X –type Bracing

Load (kN)	Δ (mm)
0	0
318.484	36.082
432.32	75.063
449.36	135.21
456.84	194.28

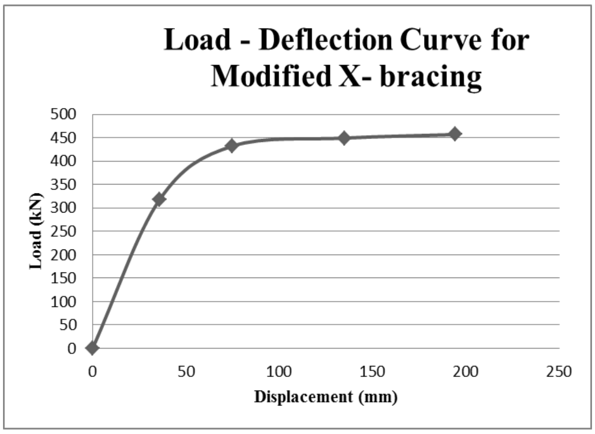

Fig -21: Load Deflection Curve of CBGB-CSWT with Modified X - bracing

3.4 Inference

Table -5: Ultimate Load and Deflection values of all ANSYS models

	Actual Value	ANSYS Model			
		K Bracing		Modified K Bracing	
		Value	% Error	Value	% Error
Ultimate Load (in kN)	385	404.12	4.96	450.28	16.95
Maximum Deflection (in mm)	199.7	209.95	5.13	192.7	-3.5
	Actual Value	ANSYS Model			
		X Bracing		Modified X Bracing	
		Value	% Error	Value	% Error
Ultimate Load (in kN)	385	455.6	18.34	456.84	18.66
Maximum Deflection (in mm)	199.7	194.28	-2.71	194.28	-2.71

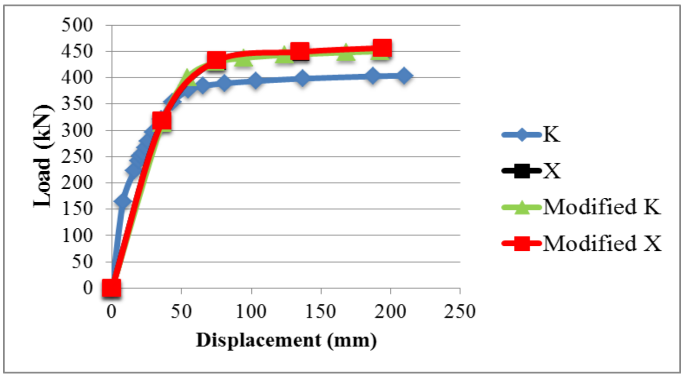

Fig -22: Plot of Load – Deflection curves of all ANSYS models

From the above table and graph, we can infer that the ultimate load of the composite box girder with X – bracing is 455.6kN and that with modified with X – bracing is 456.86kN. The maximum deflection of the girder is least for the one with modified K – bracing with a value of 192.7mm.

4. CONCLUSION

Composite box girder with corrugated with corrugated steel web and trusses is a new type of bridge structure. Composite box girders have gained special attention in the field of structural engineering due to the advantages like reduced self – weight of the structure, increased load carrying capacity over that of a non-composite beam etc.

A careful study was conducted on the influence of lateral bracings in the behaviour of the composite box girder with corrugated steel web and trusses under static and dynamic loading conditions. The girder was modeled, analysed and validated in ANSYS Workbench 16.1. Four different bracing types were used for the study: K – type, K – type modified with a vertical strut in the middle, X – type and X – type modified with a horizontal member at the top.

The composite girder with different bracing systems were modeled and analysed for static loads. From the results, we can infer that the lateral bracing pattern have significant influence in the behaviour of the composite box girder. From the results obtained, we can see that the X- Bracing and modified X-Bracing systems show greater values for ultimate load than that of K –Bracing and modified K – Bracing systems. The total deflection was found to be least for modified K – Bracing systems.

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