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Buckling Analysis of Corrugated Web Girders Analytical Study

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***Abstract*: The corrugated steel plate has been used in the field of structural applications for a long time because of its many advantageous properties. Steel and concrete composite bridges have been considered as an attractive solution for short and medium span bridges due to the benefits of combining both the two construction materials. In this paper long girders were modeled and analysed using the software ANSYS 16.1. The long girders were composed of steel and corrugations were introduced in the web. The corrugations are introduced in two different ways (i) Parallely and (ii) Perpendicularly. Buckling analysis was conducted on the girders with three different angles such as 30o, 45o and 60o then it is compared with the conventional girder with 90o corrugations.**

***Keywords*: Corrugated steel plate, parallel corrugation, perpendicular corrugation.**

1. Introduction

Replacement of the concrete webs in a concrete box girder bridge with corrugated steel webs considerably reduced the self-weight of the bridge by 10–30% and improves the seismic performance of the bridge. The corrugated steel plate has been used in the field of structural applications for a long time because of its many advantageous properties. Steel and concrete composite bridges have been considered as an attractive solution for short and medium span bridges due to the benefits of combining both the two construction materials. The continuous composite girders are the most common forms of bridge structures. The composite bridges with corrugated steel webs have many properties, such as lightness in weight, construction period is very low, aesthetically appealing, good seismic performance and optimum force distribution.

Advantages of replacing the conventional webs of box girders with corrugated steel webs are listed as follows: (1) the dead weight of corrugated steel webs are very low as compared to concrete webs, leads to reduction in seismic forces and smaller substructures, which will result in lower construction cost and the ability to increase the girders length; (2) the corrugated steel webs without additional stiffeners have higher shear buckling strength as compared to that of flat plate steel webs; (3) the corrugated steel webs can be fabricated and constructed more easily than concrete webs; (4) Shear forces can be distributed optimally into corrugated steel webs and bending forces to concrete slabs. As we know economical design of girder results in thin webs. But if the web is thin, problem of plate buckling may arise. It can be solved by using thicker webs or stiffeners. The best way to solve the problem of web buckling is the introduction of corrugations in the web. The purpose of using corrugated web is that it allows the use of thin plate without any additional stiffeners and also reduces the cost of fabrication and improves fatigue life. In this study long girders with different angles of stiffeners were considered and they are arranged in two different ways such as parallel and perpendicular. The angles considered are 30º, 45º and 60º then it is compared with the conventional girder with 90º corrugations. Buckling analysis was conducted on all the girders and it was conducted analytically using the software ANSYS 16.1.

2. Methodology

Replacement of the concrete webs in a concrete box girder bridge with corrugated steel webs considerably reduced the self-weight of the bridge by 10–30% and improves the seismic performance of the bridge. Cognac bridge was the first prestressed composite box girder bridge with corrugated steel webs built in France in 1986. In this paper, long girders were modelled by introducing corrugations in two different ways such as parallel and perpendicular. Three different angles of inclination were considered and they are 30º, 45º and 60º. Buckling analysis was conducted on all the girders using ANSYS 16.1.

3. Geometrical Details

The aim of the test is to determine the buckling resistance by different geometrical arrangements for the web corrugations. In this an 8 m long girder is considered. The web of all the girders were 500 x 6 mm, the flange width is 225 mm and the thickness of flange varies between 20 and 30 mm. Span is 1875 mm. in this trapezoidal corrugations are used with three different angles of stiffeners in the corrugation profile. The three different angles used are 30º, 45º and 60º and they are compared with the conventional long girder with 90º corrugations. The geometric profile of the trapezoidal corrugation is given below.

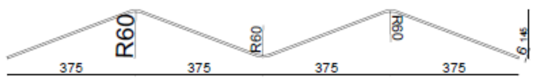


Fig. 1. Geometry of trapezoidal corrugations

4. Material properties

Table 1
Properties of Girder

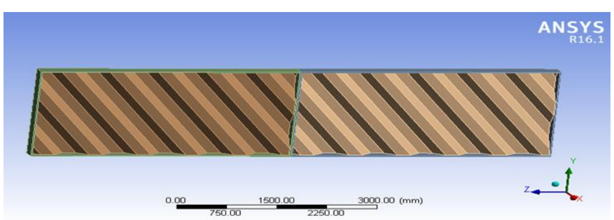
Flange	Web
Grade – Fe 345	Grade – Fe 345
Poisson's Ratio – 0.3	Poisson's Ratio – 0.3
Yield strength – 373 MPa	Yield strength – 379 MPa
Density – 7860 kg/m³	Density – 7860 kg/m³
Young's modulus – 20000 MPa	Young's modulus – 20000 MPa
Bi linear property	Bi linear property

A. Finite element analysis

The ANSYS 16.1 software was used to model all the specimens for buckling analysis. SOLID 186 from ANSYS library was used for 3-D finite element modeling of the corrugated web long girders. The stiffeners in the corrugations are arranged in two different ways such as parallel and perpendicular and are studied using ANSYS 16.1. In the two methods, three different angles are used, they are 30º, 45º and 60º and are compared with the conventional long girder with 90 inclined stiffeners in the corrugations. Fixed support was given for all the specimens. Uniformly distributed load was applied. FE models of corrugated web girders with different angles of stiffeners in the corrugations are given below.

B. Parallel inclination

The parallel corrugations are introduced in the trapezoid ally corrugated 8 m long girder. In this, the angles are aligned parallelly and all the three angles such as 30º, 45º and 60º are introduced in the corrugated web long girder. The geometry of the above mentioned angles are shown in figure 2.



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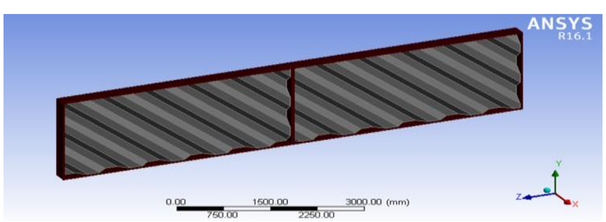

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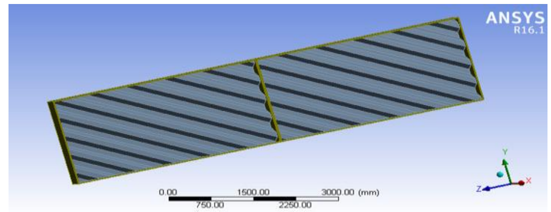

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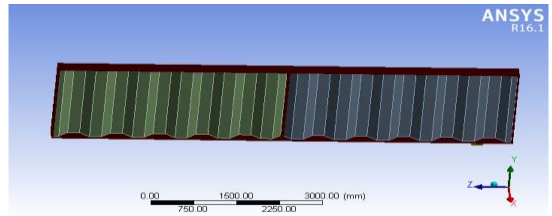
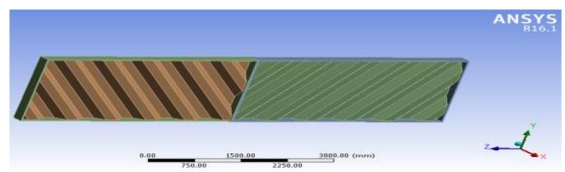


(iv)

Fig. 2. Geometry of angular corrugations in the web [(i) 30º, (ii) 45º, (iii) 60º and (iv) 90º

C. Perpendicular Inclination

The perpendicular corrugations are introduced in the trapezoidally corrugated 8 m long girder. In this, the angles are aligned perpendicularly and all the three angles such as 30º, 45º and 60º are introduced in the corrugated web long girder. The geometry of the above mentioned angles are shown in figure 3.



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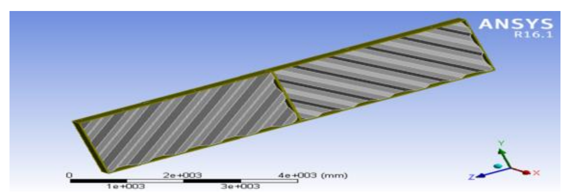

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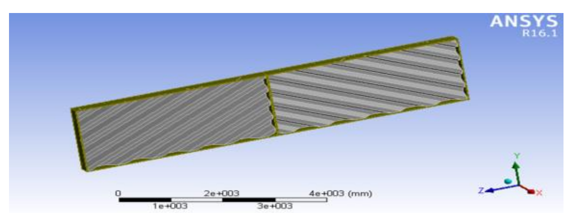

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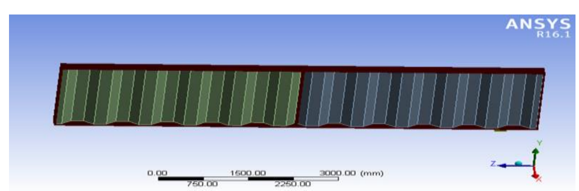


(iv)

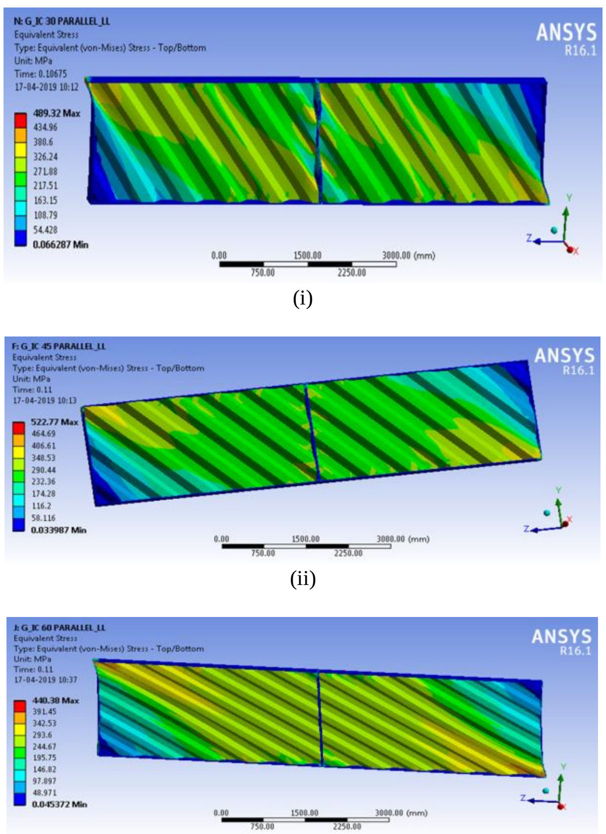
Fig. 3. Geometry of angular corrugations in the web [(i) 30º, (ii) 45º, (iii) 60º and (iv) 90º

5. Results

A. Parallel inclination

1) Equivalent stress

Equivalent (Von-Mises) stress distribution of three long girders with different angles of inclination of stiffeners in corrugation such as 30º, 45º and 60º are shown in figure 4. From the figures it is clear that, the long girder with 45º inclination angle has less buckling as compared to long girders with 30º and 60º inclination angle. So long girders with 45º inclination angle for stiffeners in corrugation can be selected for upcoming bridge girders.

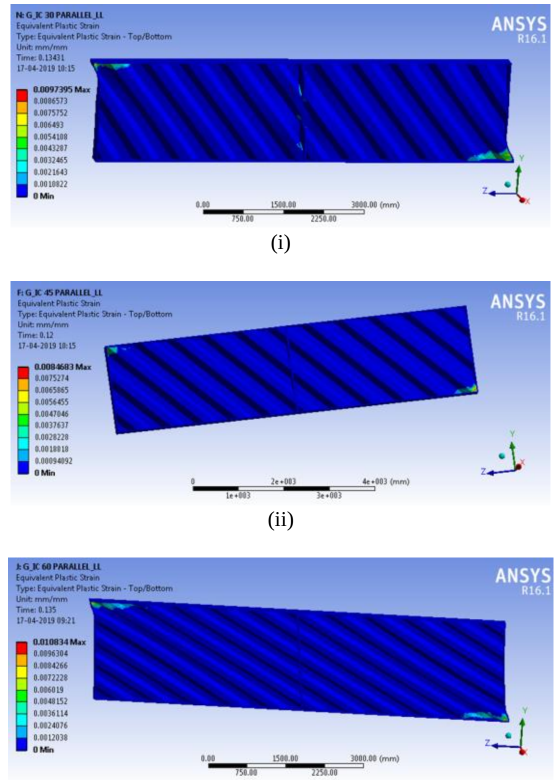


(i) (ii) (iii)

Fig. 4. Equivalent Stress of Three Different Angles of Corrugations in the Long Girder [(i) 30º, (ii) 45º, (iii) 60º]

2) Equivalent plastic strain

The equivalent plastic strain distribution of three long girders with different angles of orientation of stiffeners in corrugation such as 30º, 45º and 60º are shown in figure 5. Plastic strain is concentrated in the plastic hinge zone. In the figures it can be seen that, the long girder with 45º inclination angle for stiffeners in corrugation has less plastic strain as compared with the long girders with 30º and 60º inclination angle for stiffeners in corrugations.



(i) (ii) (iii)

Fig. 5. Equivalent Plastic Strain Distribution of Three Different Angles of Corrugations in the Long Girder [(i) 30º, (ii) 45º, (iii) 60º]

3) Load deformation behavior

Load deformation behavior of three long girders with different angles of stiffeners in the corrugations are compared with the conventional girder with 90º inclination is given in figure 6. From the figures, it can be seen that the long girder with 45º inclination angle has highest load carrying capacity as compared with others. It has less deformation, too. The obtained load and deformation of the three long girders are tabulated in table 2.

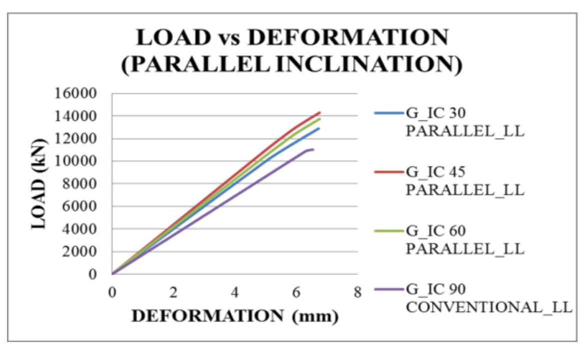


Fig. 6. Comparison of load deformation behavior of parallel inclination

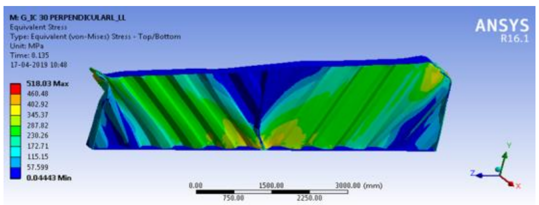
Table 2
Load Deformation Behavior

Angle	Load (kN)	Deformation (mm)
30º	12891	6.750
45º	14295	6.727
60º	13742	6.759

B. Perpendicular Inclination

1) Equivalent stress

Equivalent (Von-Mises) stress distribution of three long girders with different angles of inclination of stiffeners in corrugation such as 30º, 45º and 60º are shown in figure 7. From the figures it can be clear that the long girder with 30º inclination angle buckles more as compared with the long girders with 45º and 60º inclination of stiffeners in corrugation at the same time. The long girder with 60º inclination of stiffeners in corrugations on the web experiences less equivalent stress at the same time.



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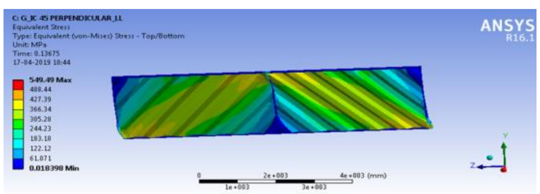

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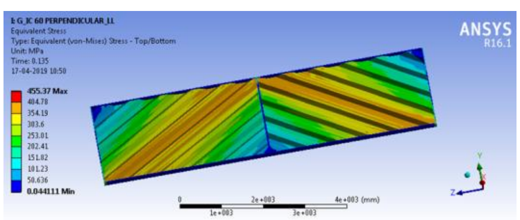
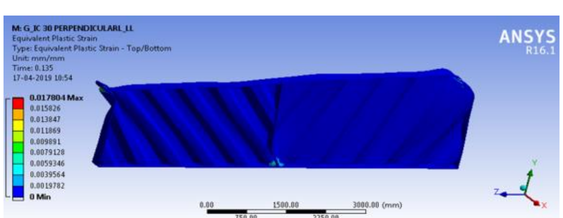


(iii)

Fig. 7. Equivalent Stress of Three Different Angles of Corrugations in the Long Girder [(i) 30º, (ii) 45º, (iii) 60º]

2) Equivalent Plastic Strain

From the figures shown below, it can be seen that the long girder with 60º inclination angle for stiffeners in corrugation has less plastic strain. Here the stiffeners of corrugated web are oriented perpendicularly. In this concept, the best inclination angle is 60º.



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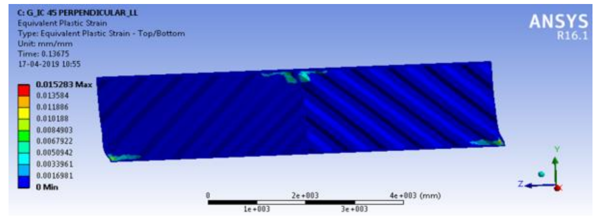

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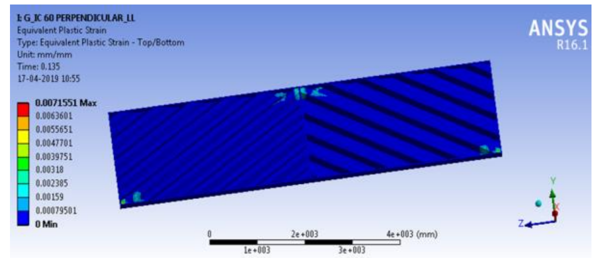

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Fig. 8. Equivalent Plastic Strain Distribution of Three Different Angles of Corrugations in the Long Girder [(i) 30º, (ii) 45º, (iii) 60º]

3) Load deformation behavior

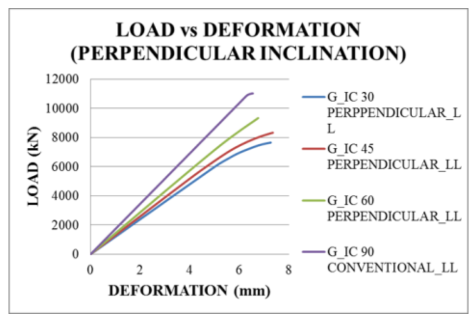


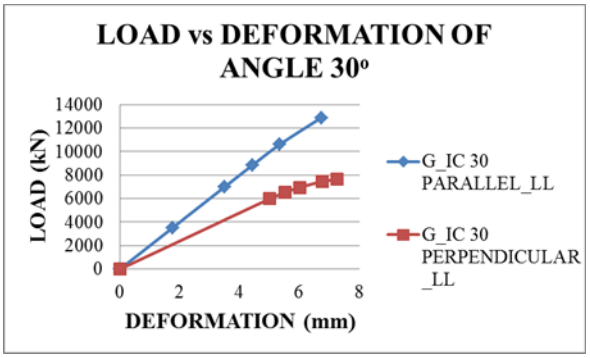
Fig. 9. Comparison of load deformation behavior of perpendicular inclination

The load deformation behavior of the long girders with three different angles of stiffeners in the corrugation are given in figure 9. From the figures it is clear that, the long girder with 60º inclination angle has more load carrying capacity than others.

Table 3
Load Deformation Behavior

Angle	Load (kN)	Deformation (mm)
30º	7651.3	7.264
45º	8329.1	7.349
60º	9331.0	6.755

From the graphs shown in figure 10, it can be seen that parallel inclination is excellent than perpendicular inclination. The load carrying capacity of girders with parallelly inclined stiffeners on the web of the girder are more when compared with the girders with perpendicularly inclined stiffeners on the corrugated web. From the study of orientation of angles in the stiffeners in the corrugations on the web of the long girder, it can be inferred that the long girder with 45º inclination on the stiffeners in the corrugated web is best suited for bridge structures.



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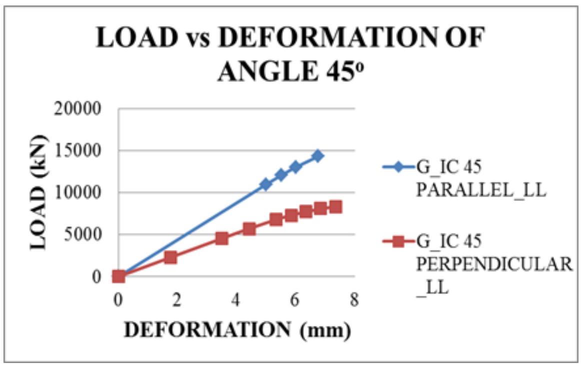

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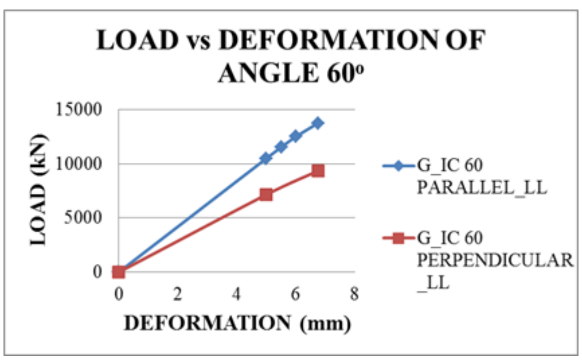

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Fig. 10. Load Deformation Comparison (30°, 45°, 60°).

6. Conclusions

Ultimate load behavior of girders with different angles of stiffeners in the corrugations on the web were examined in this study. The corrugated steel web itself provides the shear capacity of the girders where the shear strength is controlled by buckling and or steel yielding of the web. The flanges provide only the boundary supports for the web. From the orientation of angle study, parallely inclined corrugations and perpendicularly inclined corrugations were considered. The results proved that parallelly inclined stiffeners on the corrugations in the web is more reliable than perpendicular. The 45° parallely inclined stiffeners in the corrugations on the web has a load carrying capacity of 14295 kN, it was confirmed that tested girder has enough load carrying capacity.

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