Optimization of steel plate Girder Bridge with web openings and Stiffeners

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Abstract – *Steel Plate Girders are an inevitable part of industries due to its versatility in its utility. Here, an attempt to reduce its self-weight while still maintaining its functionality is made by introducing openings in the webs for functions like Crossing of pipes, Ducts across Beams or Girders. However, while introducing such web cut outs, the cross-section of the plate girder should be utilized to its optimum without compromising on the safety aspect. In general plate girders are much slenderer in comparison to the standard hot rolled section, this leads to a reduction in the use of steel. The positive effect of using plate girders could be optimized by reducing the further needed steel. This Paper Presents Optimization of steel plate girder bridge with web openings and stiffeners inclinations by using Finite element method. Web of plate girder is provided with Opening size of 0.8m and 1.0m and for each opening size stiffener inclination of 30°, 45°, 60°, 90° are provided and Analyzed with Finite element analysis Software by considering Class A, Class 70R and Class AA Vehicular Load As Per IRC-06-2017.Web openings reduces the shear strength of web and this strength is enhanced by providing stiffeners. As stiffener inclination increases, Shear stress and Bending Stresses Increases. Stress values does not differ widely in 30° and 45° Stiffener Inclination. Deflection is Increases with increase in stiffener inclination.*

Key Words: Steel plate Girder, Web openings, Optimization, Finite element analysis, Shear Stress, Bending Stress…

1. INTRODUCTION

The steel plate Girders have large surfaces of low-thickness steel web. To reduce the weight of the Plate girder, their web is taken into account thinner than their flanges. Due to thinner web, it buckles or yields before they acquire their ultimate flexural strength because of the shear forces. Due to the large depth of the plate Girder, they consume a large space of the structures, which contradicts architectural designs and structural aesthetics. For the optimize use of this space, researchers have proposed the solution of using the Steel plate girder with openings in their web. However, Because of openings, some structural problems such as lower strength, local buckling, and instability arrived. Due to wide use of the steel plate girder, some research has been done considering web without and with the web openings. However, limited research exists on the plate girder having openings with the Circular shape and stiffeners. Further research is to be done and developed in this paper for structural optimization to the design of plate Girder Bridges to minimize the cost of plate girder bridges.

1.1 Elements of welded plate girder

The various Components of Welded Stiffened and Unstiffened Plate girders, shown in Fig. 1.1 and Fig. 1.2, are as follows:

1. Web plate
2. Flange plate
3. Stiffeners
   a. Bearing stiffeners
   b. Intermediate transverse stiffeners
   c. Longitudinal stiffeners
4. Web splices
5. Flange splices

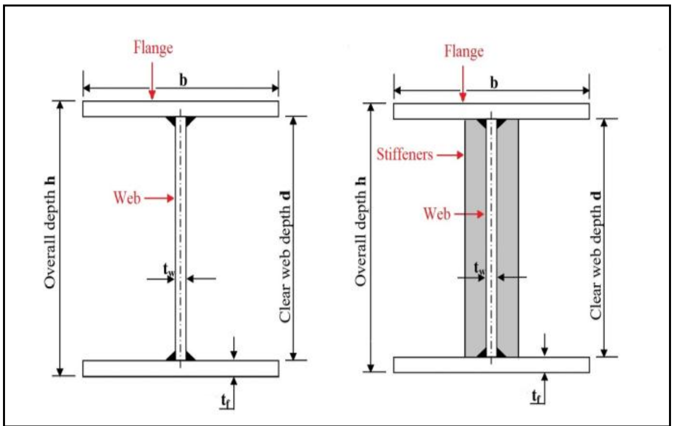

Fig -1: Stiffened and Unstiffened Plate Girder

1.2 Plate Girders with web openings

Web openings are often provided in the webs of plate girders to give access to service ducts, etc. Such web openings have specific influence on the behaviour of slender webs. Some Researches shows that slender web girders with openings do have post buckling resistance. However, some codes adopt a conservative approach and do not consider the reserve of resistance in girders with web openings. To provide a simple procedure, the shear resistance of the panel with web openings is taken as the buckling resistance. The drawback in such a procedure is that the shear resistance of the panel with web openings is much lower than the one without web openings. One option to overcome the disadvantage is to Provide stiffeners and if even shear resistance is less then reducing the stiffener spacing on either side of the web opening. This provision makes the buckling resistance of the panel with web opening is nearly equal to the full post-buckling resistance of the panels without web openings. [17]

2.PROBLEM STATEMENT

Total 24 Numbers of Simply supported steel plate girder having span 30 m are analysed with Web opening sizes of 800 mm and 1000 mm. Various stiffener Angles, i.e., 30°,45°,60°,90° etc. are provided with Web openings to study the shear Behaviour of All girders. Different Loadings as per IRC 6:2017, i.e., Class A, Class 70R, Class AA Loadings Are Considered on the Steel Plate Girder Analysis. Load to deflection criteria and stress behaviour is studied for 2000 mm web depth having web openings and different stiffener Inclination. Steel plate girders having span 30m, roadway width 6.6 m are analysed with web opening sizes and IRC-6:2017 loadings. A model is prepared by using Finite Element Analysis software by considering span to depth ratio of 15 with loading on it.

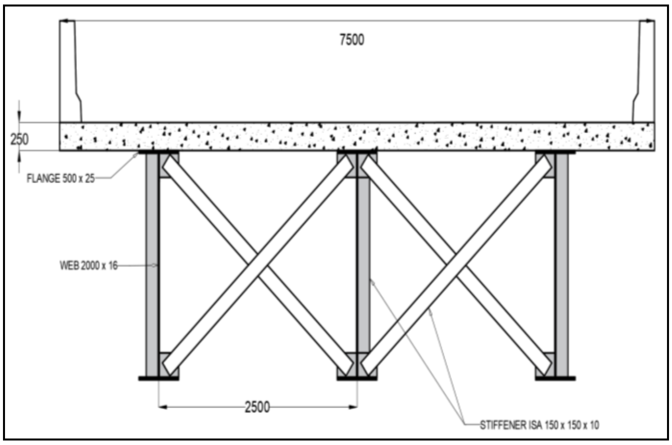

Fig -2: Cross Section of Plate Girder Bridge

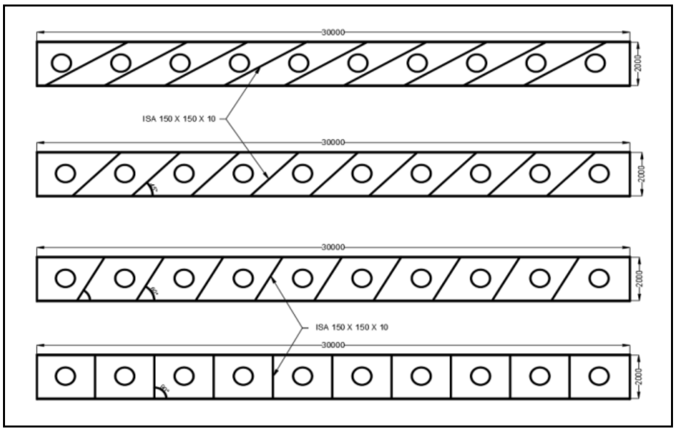

Fig -3: Elevation of Plate Girder

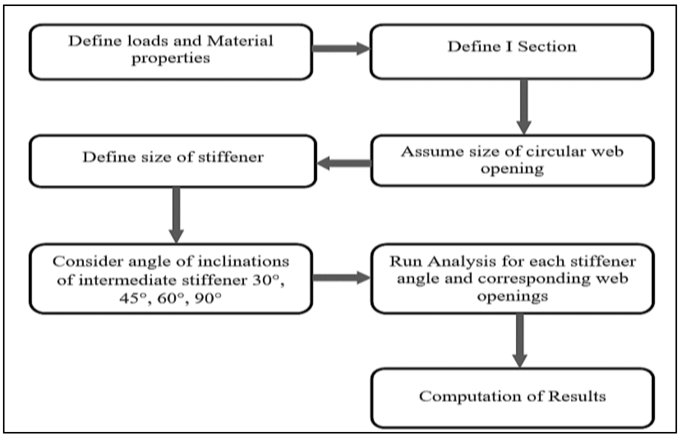

Fig -4: Flow Chart Procedure for Modelling and Analysis

- **Dimensional Details**

1. Span of Girder: 30 m
2. Cross Section: Steel Welded I Girder with Deck slab
3. Deck slab Thickness =250 mm
4. Flange Width=500 mm, Flange thickness=25 mm
5. Web Depth= 2000 mm, Web Thickness=16 mm
6. Size of Stiffener Angle = 150 x 150 x 10 mm
7. Web opening = 800 mm, 1000 mm.

- **Material Properties:**

○ Concrete

1) Grade of concrete = M45 = 45 N/mm^2
2) Young's modulus (E) = 3.34 × 10^7 kN/m^2
3) Poisson's ratio = 0.2
5) Coefficient of thermal expansion = 1.2 × 10 -5 °C

○ Steel

1) Grade of steel = E 250 = 250 N/mm^2
2) Young's modulus (E) = 2.05 × 108 kN/m^2
3) Poisson's ratio = 0.3
5) Coefficient of thermal expansion = 1.2 × 10 -5 °C
6) Yield stress = Fy = 250 N/mm^2
7)Tensile stress = Fu = 410 N/ mm^2

- **LOAD APPLICATIONS.**

A] Dead Load
1.Self Weight
2.Super Imposed Dead Load (Crash Barrier +Wearing Surface)
B] Live Load
1.Class A
2.Class 70R
3.Class AA

3.ANALYSIS OF PLATE GIRDER BRIDGE

1.Steel plate girder is First analysed by analytical modelling, for validating the results obtained from analytical modelling structure is analysed by using Finite Element Software MIDAS Civil 2021.

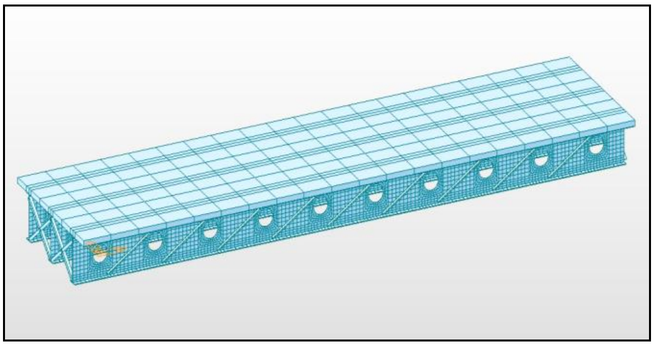

Fig -5: 3D model of Plate Girder Bridge

2.simply supported plate girders are analysed with 30m span and 6.6 m roadway width.

3.Plate girders subjected to a Dead load and live load of Class A, Class 70R, Class AA vehicular load As per IRC:6-2017 are applied on the Girder with provision of Intermediate Stiffeners and Openings in the web.

4.Results such as Bending stresses, shear stresses and deflection are Evaluated and compared.

Table -1: Plate Girder Configuration

Girder No.	Girder web Depth	Opening Size	Stiffener Angle	Loading Type as Per IRC 6-2017
1.	2000 mm	800 mm	30°,45°,60°, 90°	Class 70R, Class A, Class AA
2.	2000 mm	1000 mm	30°,45°,60°, 90°	Class 70R, Class A, Class AA

4.RESULTS AND DISCUSSION

Steel plate girders are compared with respect to web openings, stiffener inclinations and IRC Loadings.

4.1 BENDING STRESS RESULTS

1. For 800 mm Web opening Size

Table -2: Bending stresses Comparison (0.8 Opening)

Bending Stresses for	Stiffener Angle	Theoretical Results (N/mm²)	Software Results (N/mm²)	% Difference
Class A	30°	124.215	124.581	0.3 %
	45°	123.99	124.366	0.32 %
	60°	123.024	125.71	2.16 %
	90°	122.526	127.093	3.66 %
Class AA	30°	140.25	145.85	3.92 %
	45°	140.09	144.76	3.28 %
	60°	141.11	146.88	4.01 %
	90°	142.01	148.01	4.14 %
Class 70R	30°	152.98	153.521	2.30 %
	45°	151.712	155.665	2.58 %
	60°	153.874	158.88	3.21 %
	90°	155.01	159.89	3.10 %

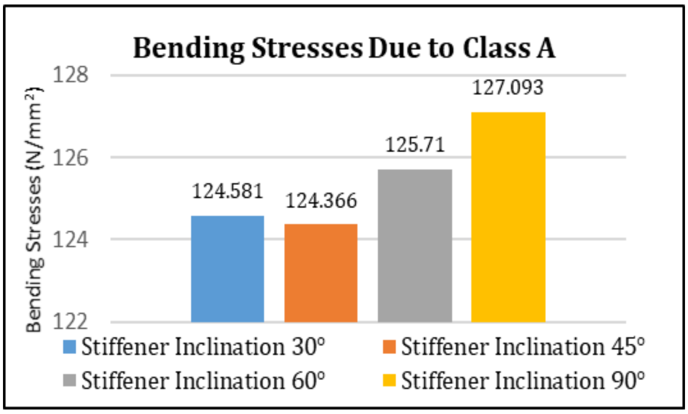

Chart -1: Bending stresses due to class A Loading (0.8 m)

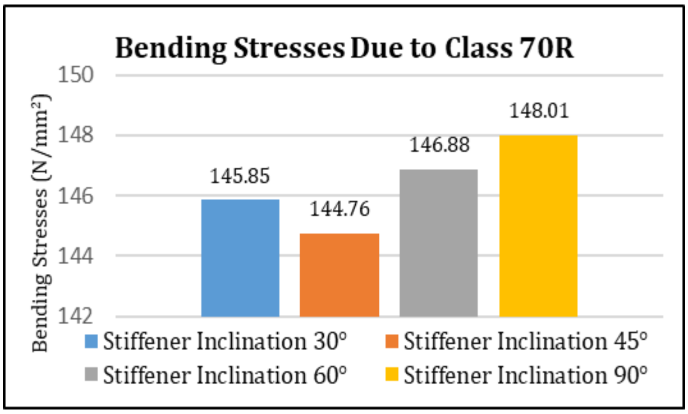

Chart -2: Bending stresses due to class70R Loading(0.8 m)

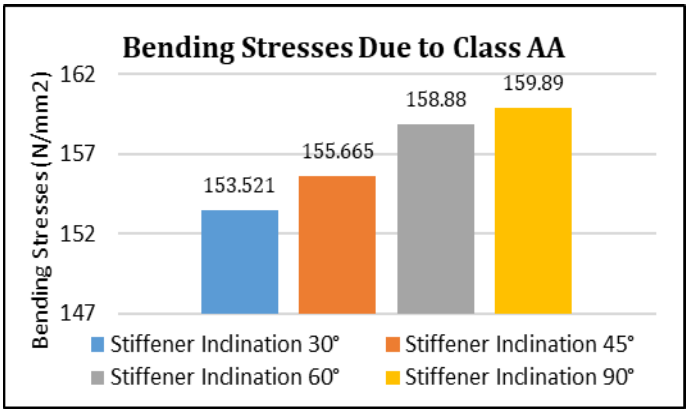

Chart -3: Bending stresses due to class AA Loading (0.8 m)

2. For 1000 mm Web opening Size

Table -3: Bending stresses Comparison (1m Opening)

Bending Stresses	Stiffener Angle	Theoretical Results (N/mm²)	Software Results (N/mm²)	% Difference
Class A	30°	123.912	132.006	6.33 %
	45°	122.881	131.502	6.44 %
	60°	122.124	133.638	9.00 %
	90°	121.751	134.021	9.60 %
Class AA	30°	139.875	147.016	4.98 %
	45°	139.514	146.76	5.06 %
	60°	140.214	147.87	5.31 %
	90°	141.091	148.39	5.04 %
Class 70R	30°	151.418	160.076	5.56 %
	45°	150.79	159.005	5.30 %
	60°	152.751	161.638	5.65 %
	90°	153.214	163.121	6.26 %

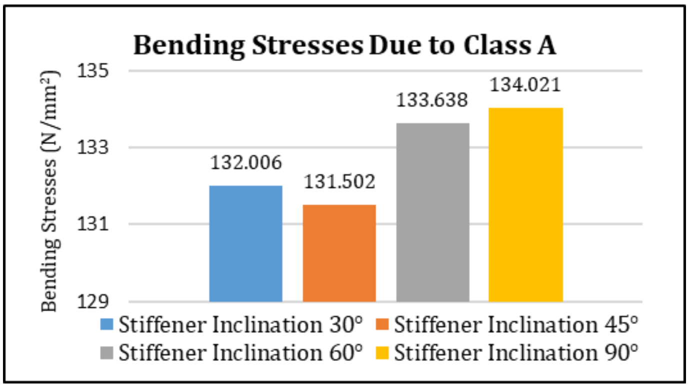

Chart -4: Bending stresses due to class A Loading (0.8m)

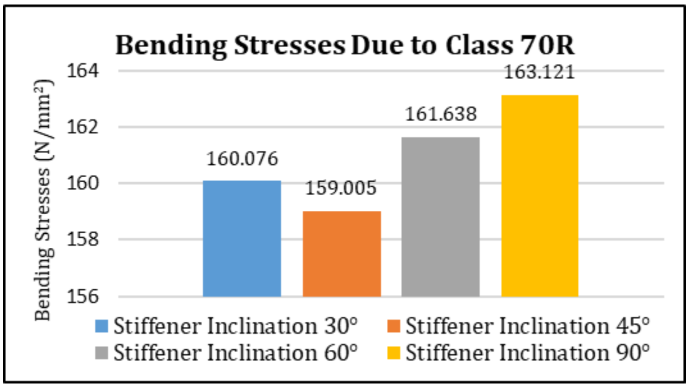

Chart -5: Bending stresses due to class 70R Loading (0.8m)

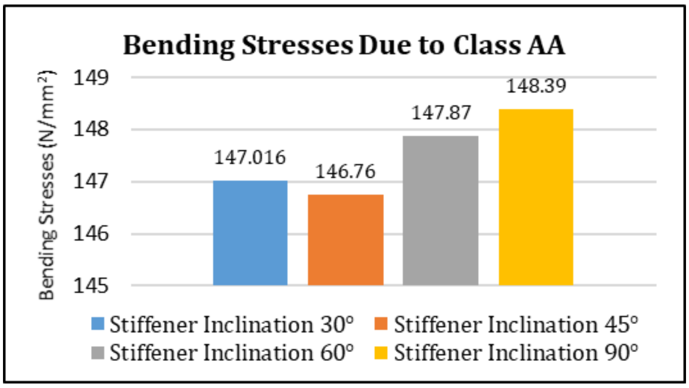

Chart -6: Bending stresses due to class AA Loading (0.8m)

4.2 SHEAR STRESS RESULTS

1. For 800 mm Web opening Size

Table -4: Shear stresses Comparison (0.8 m Opening)

Shear Stresses for	Stiffener Angle	Theoretical Results (N/mm²)	Software Results (N/mm²)	% Difference
Class A	30°	82.84	79.081	4.64 %
	45°	82.84	81.947	1.09 %
	60°	82.84	82.48	0.44 %
	90°	82.84	83.747	1.09 %
Class AA	30°	82.84	80.081	3.39 %
	45°	82.84	81.447	1.70 %
	60°	82.84	84.917	2.48 %
	90°	82.84	85.047	2.63 %
Class 70R	30°	82.84	84.981	2.55 %
	45°	82.84	84.117	1.53 %
	60°	82.84	85.917	3.65 %
	90°	82.84	86.047	3.80 %

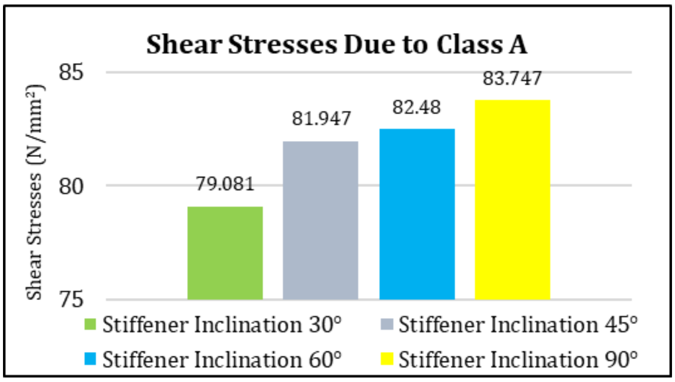

Chart -7: Shear stresses due to class A Loading (0.8m)

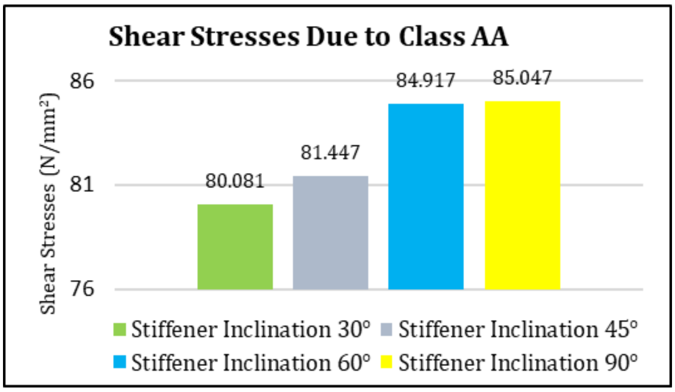

Chart -8: Shear stresses due to class AA Loading (0.8m)

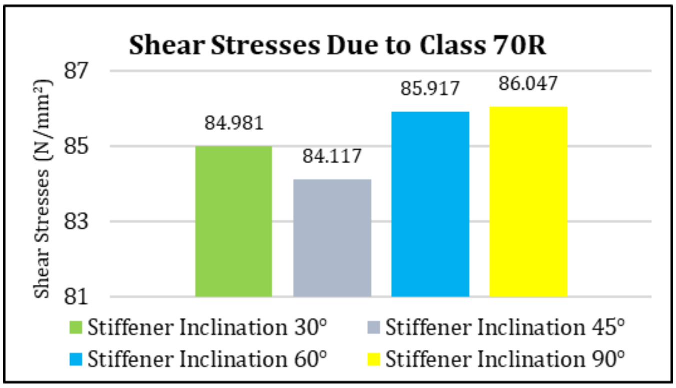

Chart -9: Shear stresses due to class 70R Loading (0.8m)

2. For 1000 mm Web opening Size

Table -5: Shear stresses Comparison (1 m Opening)

Shear Stresses for	Stiffener Angle	Theoretical Results (N/mm²)	Software Results (N/mm²)	% Difference
Class A	30°	81.69	87.548	6.92 %
	45°	81.69	84.213	3.05 %
	60°	81.69	88.009	7.45 %
	90°	81.69	88.273	7.75 %
Class AA	30°	81.69	85.467	4.52 %
	45°	81.69	86.001	5.14 %
	60°	81.69	88.298	7.77 %
	90°	81.69	89.233	8.83 %
Class 70R	30°	81.69	87.46	6.82 %
	45°	81.69	87.01	6.31 %
	60°	81.69	89.469	9.09 %
	90°	81.69	90.098	9.79 %

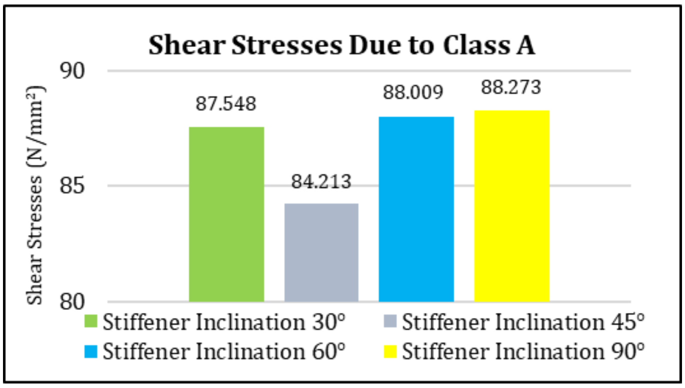

Chart -10: Shear stresses due to class A Loading (1m)

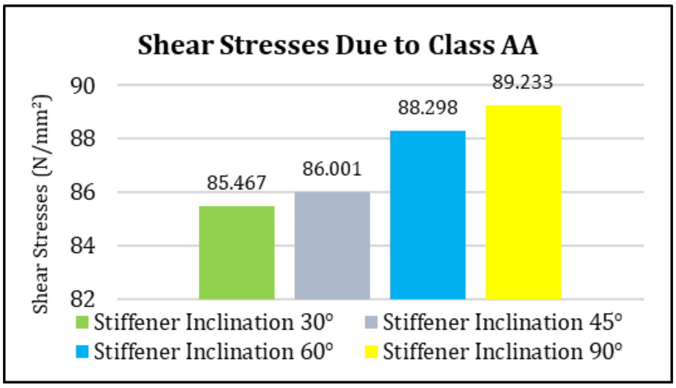

Chart -11: Shear stresses due to class AA Loading (1m)

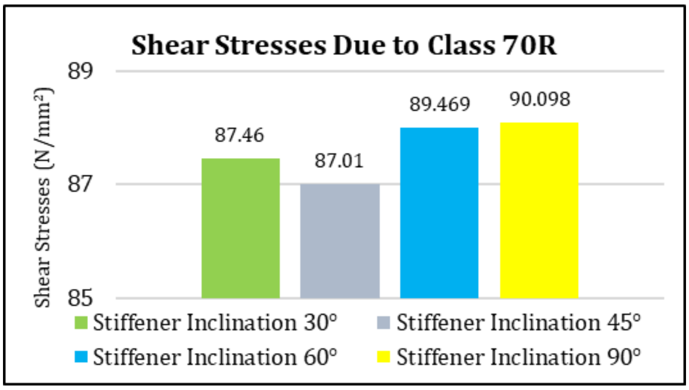

Chart -12: Shear stresses due to class 70R Loading (1m)

4.3 VERTICAL DEFLECION RESULTS

Table -4: Vertical Deflection Comparison

Web Opening Size	Stiffener angle	Deflection (mm)		
		Class A	Class AA	Class 70R
800 mm	30°	24.75	25.18	26.85
	45°	26.51	27.67	28.19
	60°	28.47	29.40	31.12
	90°	30.10	32.05	34.81
1000 mm	30°	30.89	31.98	32.78
	45°	32.13	32.02	33.41
	60°	33.51	34.69	35.621
	90s°	35.89	36.72	37.51

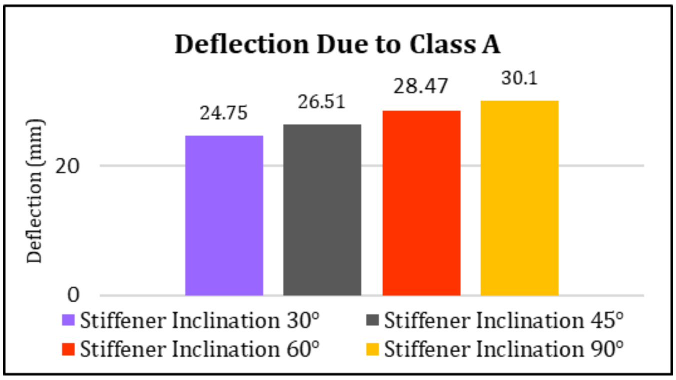

Chart -13: Deflection due to class A Loading (0.8 m)

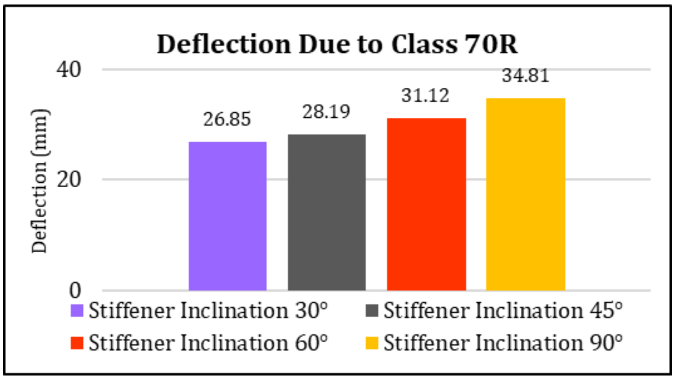

Chart -14: Deflection due to class 70R Loading (0.8 m)

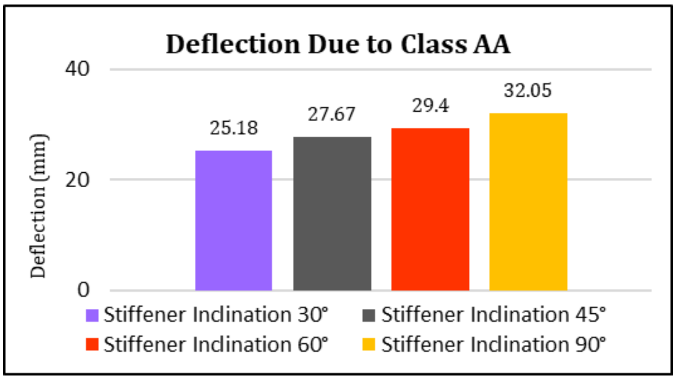

Chart -15: Deflection due to class AA Loading (0.8 m)

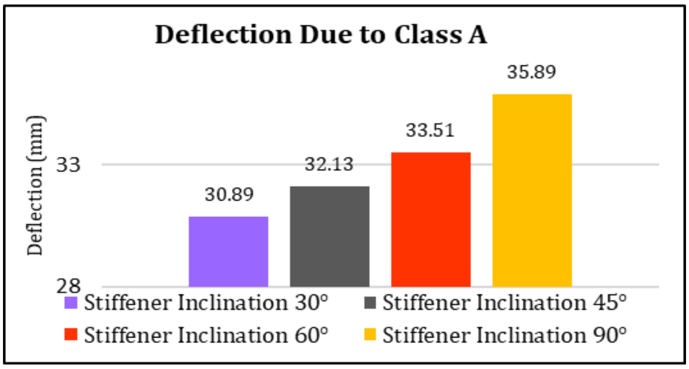

Chart -16: Deflection due to class A Loading (1 m)

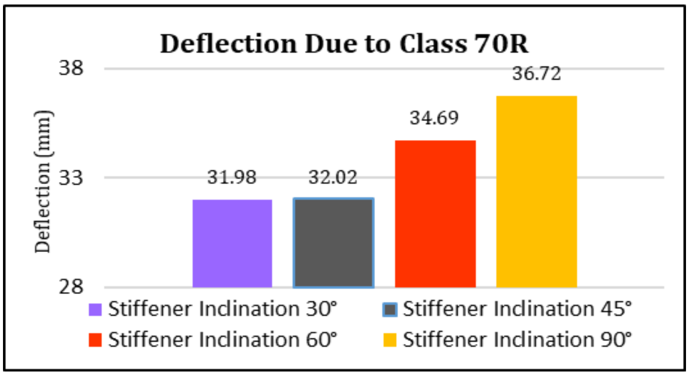

Chart -17: Deflection due to class 70R Loading (1 m)

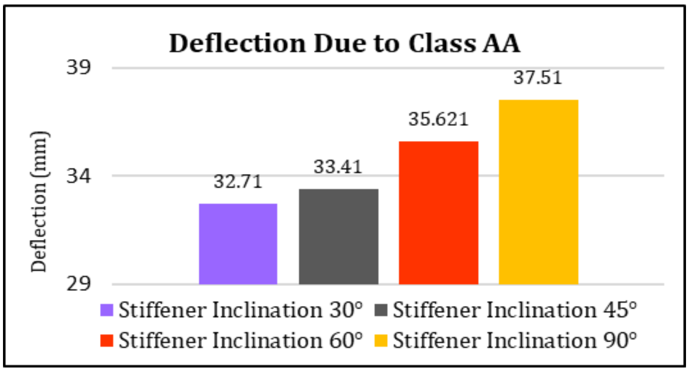

Chart -18: Deflection due to class AA Loading (1 m)

3. CONCLUSION

The steel plate Girder Bridge is analyzed with Dead Load and Live load of Class A,70R and class AA Vehicles with web opening of 800 mm and 1000 mm and Different Stiffener Inclinations. On the basis of above obtained Results, following Conclusions are made from the study:

1. Providing web opening reduces the shear capacity of web, this reduced shear strength is increased up to 7 to 9 % by provision of Stiffeners.
2. For 1000 mm web opening size, Shear stresses worked out are 4.5 to 5.0 % more than 800 mm web opening, hence web opening size of 800 mm is suitable.

3. Inclined stiffeners help the web to gain shear strength. In all stiffener's inclination, 45° stiffener inclination is helpful not only to enhance shear strength but also to resist diagonal compression developed due to Tension Field Action.

4. All the values of bending stresses and shear stresses for different Class Vehicles for each Girder are within the permissible stress limits.

5. Impact of 70R vehicular load is more because full length vehicle accommodation in given 30m Span of Girder and Wheel loading is also more than Class A and Class AA vehicle. Hence, deflection observed is also more in IRC class 70R vehicular loading.

6. According to observation of all results, plate girder with circular web opening 800 mm and stiffener angle 45° gives optimum results due to resistance of diagonal compression developed by Tension field action.

4. SCOPE FOR FURTHER STUDY

- In present Study Plate Girder Bridge having 2 lanes is analyzed, for further study more than 2 lane Bridge with multiple girders can be considered.
- In present study only Dead load and Live load is Considered for analysis, for further work seismic forces, Wind load, Temperature Effects and Combinations of All these can be studied.
- Here Optimization is done for Plate girder with circular web openings and inclined stiffeners having Simple supports, for further study horizontal and vertical stiffeners with fixed or cantilever support can be considered.
- Here Optimization of Plate Girder bridge is done by considering results parameters, for future study we can go for optimization with materials and their cost, ease of completion of Construction work, workmanship Etc.

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