International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

# A Parametric Study on the Effect of Multi-Corrugated Web Profile on the Performance of Steel Beam Section

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***Abstract****—The structural action of a beam is predominantly bending, with other effects such as shear, bearing and buckling. The web angle and the web profile are some parameters which influence the performance of corrugated web beam. Due to the more application of corrugated section in steel design, a comparative study between triangular, trapezoidal and sinusoidal web profile of corrugated web beam is adopted. A Comparative study using different corrugation angles ($0^{0}$,$30^{0}$,$45^{0}$,$60^{0}$) was also adopted. Eigen buckling analysis and static analysis was conducted to find out the buckling load, deflection, stress and moment reaction of the three web profiles. A parametric study by changing the web angle ($0^{0}$,$30^{0}$,$45^{0}$) was also conducted to find out the suitable web angle for the efficient performance of the girder by using ANSYS software. Modal analysis and transient analysis was done to find out the frequency, deflection and force reaction for the variation in web angle.. Hence finding the most efficient web profile for the corrugated web girder and the web angle for minimum deflection.*

***Keywords****— Corrugated web beam, triangular, trapezoidal, sinusoidal, web angle, Ansys.*

## I. Introduction

A beam is a structural element that is capable of withstanding load primarily by resisting against bending. The bending force induced into the material of the beam as a result of the external loads, own weight, span and external reactions to these loads is called a bending moment. Beams are characterized by their profile (shape of cross-section), their length, and their material. Most beams in reinforced concrete buildings have rectangular cross sections, but a more efficient cross section for a beam is an I or H section which is typically seen in steel construction.

The horizontal elements of the "I" are known as flanges, while the vertical element is termed the "web" where about 30–40% of the entire weight of a medium flange width or narrow flange type of beam is contributed by the web part. I-beams are usually made of structural steel and are used in construction and civil engineering. The web resists shear forces, while the flanges resist most of the bending moment experienced by the beam. Beam theory shows that the I-shaped section is a very efficient form for carrying both bending and shear loads in the plane of the web. On the other hand, the cross-section has a reduced capacity in the transverse direction, and is also inefficient in carrying torsion, for which hollow structural sections are often preferred. In construction application, the web usually bears most of the compressive stress and transmits shear in the beam while the flanges support the major external loads. Thus, by using greater part of the material for the flanges and thinner web, materials saving could be achieved without weakening the load-carrying capability of the beam. When load is applied, compressive stress in the web can exceed the critical point prior to the occurrence of yielding, thus the flat web loses its stability and deforms transversely. This can be improved by using corrugated web, an alternative to the plane web. The main benefits of this type of beams are that the corrugated webs increase the beam's stability against buckling, which may result in an economical design via the reduction of web stiffeners. Furthermore, the use of thinner webs results in lower material cost, with an estimated cost savings of 10-30% in comparison with conventional fabricated sections and more than 30% compared with standard hot rolled universal beams

*Corrugated Web Beams*

Corrugated web beams are built-up girders with a thin-walled, corrugated web and wide plate flanges. The flanges can be either concrete or steel The precast corrugated web girders are used for the bridge construction. In the case of plate girder bridges with flat webs, they have the maximum moment carrying capacity than any rolled sections. To carry the moments, the section has to be slender and the slender sections are susceptible to web buckling. So the web loses its buckling strength. Hence to avoid this buckling and to gain maximum strength the focus was on the provision of corrugations on the web. The purpose of using the corrugated web is that it allows the use of thin plates without the need of stiffeners reducing the cost of fabrication and improves fatigue life. It has been estimated that the girders with corrugated webs may be 9 to 13% lighter than the conventional stiffened girders with flat webs.

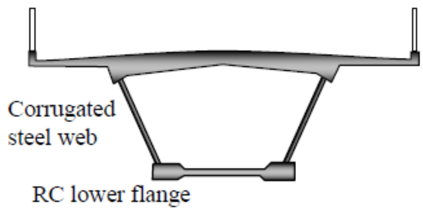


Fig. 1. Schematic representation of bridge girders with corrugated steel web.



Anna Baby and Kiran Jacob, "A parametric study on the effect of multi-corrugated web profile on the performance of steel beam section," *International Research Journal of Advanced Engineering and Science*, Volume 2, Issue 2, pp. 210-214, 2017.

## II. Dimensions of Beam

### A. Case I

The dimensions of corrugated web beam of three web profiles considered for the work were fixed with respect to the reference journal. Total length of the beam is 1.5m having three folds. Width of the beam is 1.2m and depth of the beam is 0.386m. Thickness of the flange and web is 0.01m and 0.02m respectively. Tensile yield strength of web and flange is 379 and 389N/mm$^2$ respectively. The side view and top view of a typical trapezoidal web profile is shown in figure 2 and figure 3.

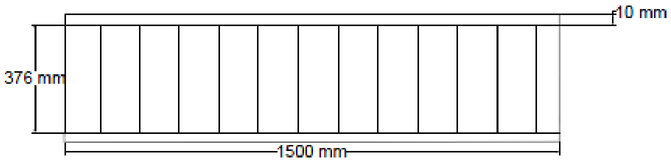

Fig. 2. Side view of trapezoidal web profile beam.

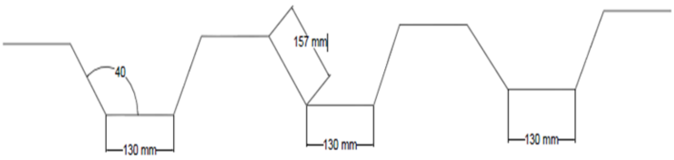

Fig. 3. Plan view of trapezoidal web profile beam.

### B. Case II

For the comparative study of the two profiles of sinusoidal and trapezoidal web profiles the dimensions of the corrugated web girder were fixed with respect to the reference journal. The total length of the girder is 11.12m. The top and bottom concrete flanges of girder are 11.7m and 4.17m respectively. Thickness of web and flange is 8mm and 200mm respectively. Depth of girder is 2.6m. Corrugation panel width is 420mm. Corrugation depth is 240mm.

## III. Concrete and Steel Properties

Concrete is defined as multi linear isotropic material. The properties assigned for M25 grade concrete are tabulated in the table I.

TABLE I. Properties of concrete.

| Sl No. | Concrete Properties | Value |
|---|---|---|
| 1 | Modulus of elasticity, $E_c$ | $2.5 \times 10^7$ kN/m$^2$ |
| 2 | Poisson's ratio, μ | 0.15 |
| 3 | Density | 2400 kg/m$^3$ |

The material properties adopted for steel in the present study are given in the table II.

TABLE II. Properties of steel.

| Sl No | Properties | Value |
|---|---|---|
| 1 | Modulus of elasticity, $E_s$ (N/mm$^2$) | $2.1 \times 10^5$ |
| 2 | Poisson's ratio, μ | 0.3 |
| 3 | Density, kg/m$^3$ | 7850 |

## IV. Load Calculation

*Dead Load*

The dead load acting on the girder or the member consists of the portions of the weight of the superstructure and any fixed loads supported by the member.

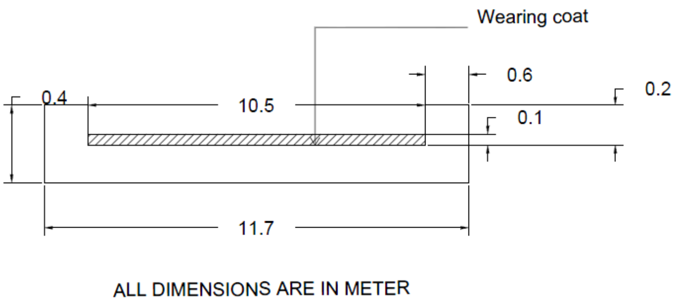

Fig. 4. Section view of girder.

Dead load on girder = Dead weight of deck slab+ Dead weight of wearing coat + Dead load of kerb

| | |
|---|---|
| Dead load of deck slab | = 29.25kN/m |
| Dead load of wearing coat | = 11.5kN/m |
| Dead load of kerb | = 3 kN/m |
| Total Dead load | = 29.25+11.5+3 |
| | = 43.75kN/m |

*Live Load*

The Live Load is assumed as per IRC:6- 2014 vehicle is passing over deck. As per IRC:6-2014 class A type loading is applied.

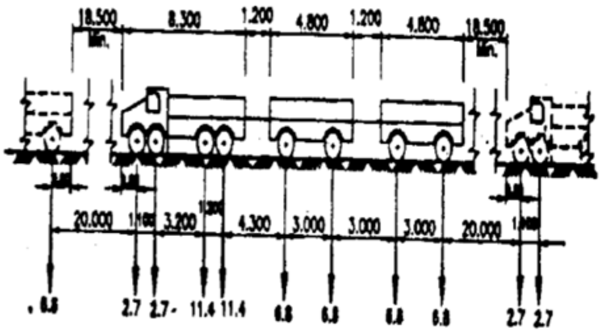

Fig. 5. Class A loading of vehicle.

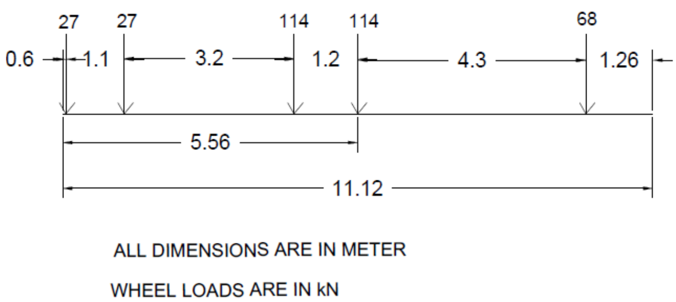

Fig. 6. Loading on girder.

Live load= 27+27+114+114+68 = 350 kN
Only half girder is considered for this study, since it is symmetric
Therefore, Total live load = 175 kN
Live load per metre = 15.74 kN/m

*Impact Load*

In the members of any bridge designed either for Class A or Class B loading (vide Clause 204.1 IRC:6-2014) impact

International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

fraction shall be determined from the following equations which are applicable for spans between 3 m and 45 m.
Impact factor fraction for reinforced concrete bridges

$$\frac{4.5}{6+L}, \text{ where L=length of span}$$

Impact factor fraction = 0.26
Impact load = Impact fraction x live load = 0.26x15.74
= 4.1 kN/m
Total Working load =Dead load +Live load +Impact load
= 43.8+15.74+4.1
= 63.64 kN/m

## V. Modelling and Analysis

Models of corrugated web beam of trapezoidal, sinusoidal and triangular web profiles were modelled and Eigen buckling analysis was carried out to find the buckling load. For this analysis a loading of 1 N is applied.

Models of corrugated web girder of trapezoidal and sinusoidal web profiles with different corrugation angles such as $0^0$, $30^0$, $45^0$ and $60^0$were modelled and Eigen buckling analysis and Non-linear static analysis was carried out. For the non- linear static analysis the load applied is calculated as per IRC: 6- 2014 class A Loading of vehicle.

For the parametric study by changing the web angle, modal analysis and transient analysis was carried out since the change in web angle mainly influence on the seismic performance .For this analysis Acceleration time history of the 1940 El Centro earthquake commonly referred to as the Imperial Valley earthquake, which had a Ritcher magnitude of 7 was considered. Fixed supports were provided for the models.

Acceleration time history of El Centro earthquake is shown in the figure 6.

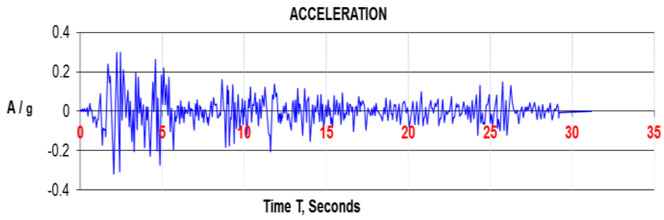

Fig. 6. Acceleration time history of El Centro earthquake.

Models of trapezoidal, triangular and sinusoidal web profile of corrugated beam are shown in figure 7, figure 8 and figure 9. Model of sinusoidal web profile corrugated web girder with corrugation angle $30^0$ and model of sinusoidal web profile corrugated web girder with web angle $30^0$ are shown in figure 10 and figure 11.

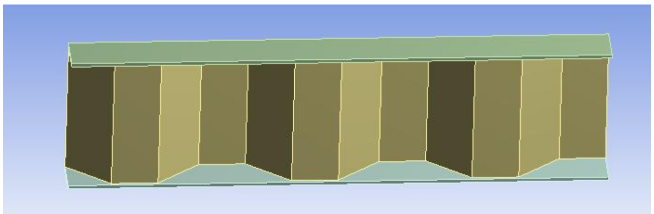
Fig. 7. Model of trapezoidal web profile corrugated beam.

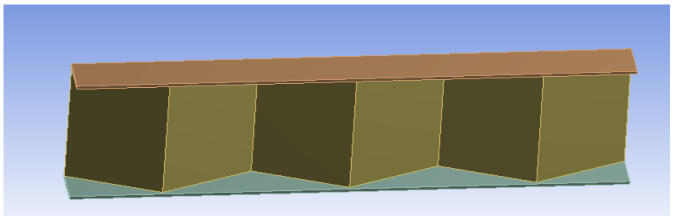
Fig. 8. Model of triangular web profile corrugated beam.

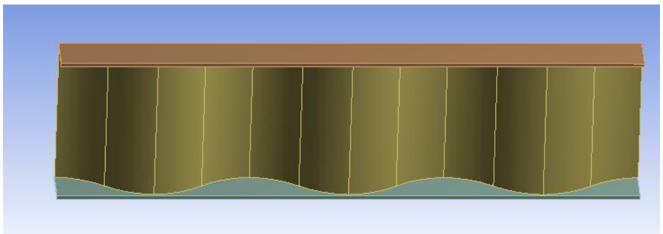
Fig. 9. Model of sinusoidal web profile corrugated beam.

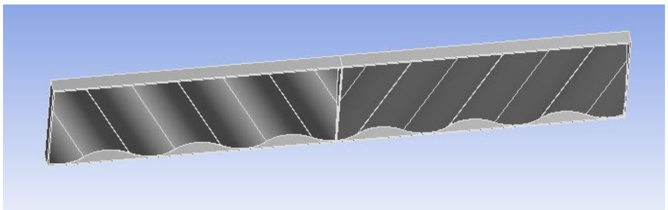
Fig. 10. Model of sinusoidal web profile corrugated web girder with corrugation angle $30^0$.

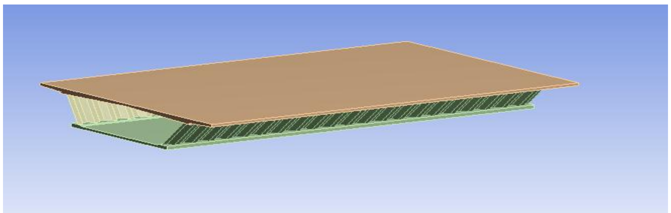
Fig. 11. Model of trapezoidal web profile corrugated web girder with web angle $30^0$.

## VI. Results and Discussions

Buckling is the major mode of failure for the corrugated web beam. Therefore Eigen buckling analysis was carried out to find out the buckling load of three web profiles. From the analysis it was seen that the least value of buckling load is for the triangular web profile beam. Thereby for further comparative study sinusoidal and trapezoidal web profile beams were considered.

### *A. Buckling load*

Buckling is characterized by a sudden sideways failure of a structural member subjected to high compressive stress, where the compressive stress at the point of failure is less than the ultimate compressive stress that the material is capable of with standing .Buckling load of three web profiles are shown in table III.

TABLE III. Buckling load of three web profiles.

| **Critical buckling load(N)** | | |
|---|---|---|
| Trapezoidal | Triangular | Sinusoidal |
| $6.16x10^5$ | $1.9x10^5$ | $1.6x10^6$ |



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From the result it is clear that the triangular web profile is having least value of critical buckling load. Therefore for finding out which profile is showing best performance further comparative study was done for the corrugated web girder of sinusoidal and trapezoidal web profiles under the working load condition. The comparative study with different corrugation angles $0^0$, $30^0$, $45^0$ and $60^0$was also conducted. Buckling load of sinusoidal and trapezoidal web profiles with different corrugation angles are shown in table IV.

TABLE IV. Buckling load of sinusoidal and trapezoidal web profiles with different corrugation angles.

| Model with different corrugation angle | First mode(N) | Load when One web buckle(N) | Critical buckling load (both the web buckles)(N) |
|---|---|---|---|
| Trap $0^0$ | $4.7x10^7$ | $4.78x10^7$ | $7.6x10^7$ |
| Trap $30^0$ | $4.79x10^7$ | $4.8x10^7$ | $6.92x10^7$ |
| Trap $45^0$ | $3.20x10^7$ | $3.3x10^7$ | $6.5x10^7$ |
| Trap $60^0$ | $3.2 x10^7$ | $1.6 x10^7$ | $5.15 x10^7$ |
| Sin $0^0$ | $7.2x10^7$ | $7.3x10^7$ | $1.05x10^8$ |
| Sin 30 | $4.7x10^7$ | $4.8x10^7$ | $9.5x10^7$ |
| Sin 45 | $3.13x10^7$ | $3.3x10^7$ | $7.5x10^7$ |
| Sin 60 | $1.6x10^7$ | $1.8x10^7$ | $6.5x10^7$ |

*B.* For the working load acting on the girder, non linear static analysis was carried out to find out the deflection, stress, strain and moment reactions of the corrugated web girder of sinusoidal and trapezoidal web profiles. Comparison of results of sinusoidal and trapezoidal web profiles with different corrugation angles are shown in table V.

TABLE V. Comparison of results of sinusoidal and trapezoidal web profiles with different corrugation angles.

| | Deflection (mm) | Stress ($N/mm^2$) | Strain (mm) | Moment reaction (Nmm) |
|---|---|---|---|---|
| Trap $0^0$ | 0.21 | 16.31 | $8.2x10^{-5}$ | $4.4x10^6$ |
| Trap $30^0$ | 0.3 | 21.86 | $1.1x10^{-4}$ | $4.5x10^6$ |
| Trap $45^0$ | 0.42 | 27.65 | $1.3x10^{-4}$ | $4.83x10^6$ |
| Trap $60^0$ | 0.9 | 43.19 | $2.1x10^{-4}$ | $5.87x10^6$ |
| Sin $0^0$ | 0.19 | 15.98 | $8.3x10^{-5}$ | $2.9x10^5$ |
| Sin $30^0$ | 0.25 | 20.17 | $1.1x10^{-4}$ | $7.6x10^5$ |
| Sin $45^0$ | 0.42 | 24.83 | $1.3x10^{-4}$ | $1.01x10^6$ |
| Sin $60^0$ | 0.94 | 38.62 | $2.4x10^{-4}$ | $4.25x10^6$ |

Results show that the deflection, stress, strain and moment reaction is less for the corrugated web girder with sinusoidal web profile with corrugation angle $0^0$. It can be seen that as the corrugation angle increases the deformation, stress, strain and moment reactions are increasing. There is no much influence of this angle variation on the corrugated web girder with different web profiles.

### *C. Parametric Study by Changing Web Angle*

*Results from Modal Analysis*

The six modes are incorporated in the analysis. These modes are not excited in the same manner. The extent to which dynamic loading excites a specific vibration modes depends on the frequency content of the load. It is necessary to include at least six modes in the analysis in order to obtain the most fundamental movements. It might be sufficient to consider only these modes in a preliminary analysis. The frequencies obtained after modal analysis of trapezoidal girders are shown in table VI.

TABLE VI. Frequencies obtained after modal analysis for trapezoidal girder with different web angles.

| | Trap 0(Hz) | Trap 30(Hz) | Trap 45(Hz) |
|---|---|---|---|
| Mode 1 | 0.89 | 0.74 | 0.72 |
| Mode 2 | 1.56 | 1.24 | 1.1 |
| Mode 3 | 2.00 | 1.96 | 1.56 |
| Mode 4 | 2.06 | 2.02 | 1.72 |
| Mode 5 | 2.16 | 2.08 | 1.9 |
| Mode 6 | 2.3 | 2.19 | 2.1 |

In trapezoidal, girder with $45^0$ has less mode frequencies compared to other two angles. For three angles, the frequency is increasing proportional to the mode number. The frequencies obtained after modal analysis of sinusoidal girders are shown in table VII.

TABLE VII. Frequencies obtained after modal analysis for sinusoidal girder with different web angles.

| | Sin 0(Hz) | Sin 30(Hz) | Sin 45(Hz) |
|---|---|---|---|
| Mode 1 | 0.92 | 0.81 | 0.87 |
| Mode 2 | 1.64 | 0.97 | 1.08 |
| Mode 3 | 1.99 | 1.18 | 1.52 |
| Mode 4 | 2.04 | 1.72 | 1.94 |
| Mode 5 | 2.11 | 2.08 | 2.00 |
| Mode 6 | 2.32 | 2.15 | 2.06 |

In sinusoidal, girder with $30^0$ has less mode frequencies compared to other two angles. For three angles, the frequency is increasing proportional to the mode number.

*Results from Transient Analysis*

From this analysis the maximum deflection and the force reaction values are determined. Deflection and force reaction value of sinusoidal and trapezoidal profiles for different web angles are shown in table VIII.

TABLE VIII. Deflection and force reaction value of sinusoidal and trapezoidal profiles for different web angles.

| | Deflection (mm) | Force reaction (N) |
|---|---|---|
| Trap $0^0$ | 16.62 | $2.14x10^6$ |
| Trap $30^0$ | 17.5 | $2.09x10^6$ |
| Trap $45^0$ | 11.84 | $1.72x10^6$ |
| Sin $0^0$ | 14.01 | $2.32x10^6$ |
| Sin $30^0$ | 13.04 | $1.86x10^6$ |
| Sin $45^0$ | 30.36 | $2.18x10^6$ |

## VII. CONCLUSIONS

Performance of the corrugated web beam of triangular sinusoidal and trapezoidal web profiles are investigated by conducting Eigen buckling analysis using ANSYS software. The influence of the corrugation angle of the girder was determined by conducting Eigen buckling analysis and non-linear static analysis for the working load on the girder in terms of deformation, stress, strain and moment reaction and the results are compared. A parametric study by changing the web angle was also done by conducting the modal analysis and non- linear transient dynamic analysis. The result of the present work shows that:

(1) Sinusoidal web profile is having the high value of critical buckling load than the trapezoidal and triangular web profiles.
(2) As the angle of corrugation of girder increases from $0^0$ to $45^0$, the critical buckling load value is decreasing whereas the displacements, stress, strain and, moment reaction values are increasing.
(3) Corrugation angle with zero degree showing the best performance.
(4) Under working load condition girder with sinusoidal web profile is having the least deflection, stress and moment reaction value.
(5) By changing the web angle, the trapezoidal girder with $45^0$ is having less frequency, deflection and force reaction value. Therefore trapezoidal girder is having better seismic performance when the web angle is $45^0$.
(6) Sinusoidal girder is having less frequency, deflection value and force reaction when the web angle is $30^0$. Therefore sinusoidal girder is having better seismic performance when the web angle is $30^0$.
(7) Among all the three the sinusoidal web girder is showing the best performance. Therefore the most efficient web profile is sinusoidal.

## ACKNOWLEDGEMENT

I wish to thank the Management, Principal, and Head of Civil Engineering Department of Ilahia College of engineering and technology, affiliated by Kerala Technological University for their support. This paper is based on the work carried out by me (Anna Baby), as part of my PG course, under the guidance of Kiran Jacob (Assistant Professor, Ilahia College of engineering and technology Muvattupuzha, Kerala, India). I express my gratitude towards her for her valuable guidance.

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