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Shear Capacity of Singly and Doubly Webbed Corrugated Web Girder

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ABSTRACT

A conventional plate girder involves the use of transverse intermediate stiffeners, especially in a slender web to avoid catastrophic failure associated with shear buckling of the web. In this study, a profiled web was used to replace the transversely stiffened web. The process involves introducing cold-formed ribs into a flat steel sheet to form alternative stiffeners. This study therefore seeks to establish comparative performance of conventionally stiffened plate girders and profiled web girders of a specially formed rib arrangement with single and also double webs. Nine numbers of specimens were tested to failure under a three-point-bending system. Failure of all the profiled web girders, with either a single or double webs, is characterized by a shorter yield plateau and a steeper descending branch, a failure mode that is commonly referred to as 'brittle'. The results of the tests on girders with profiled steel sheets, PSS(s) have shown that profiling is extremely effective in increasing the shear buckling load because it moves the sheet material out of the plane of the web, thereby increasing the rigidity 1.08 to 2.0 times higher than the equivalent conventional flat web plate girders. The experimental results also showed that post-buckling capacities are reduced by 30 % to 50 % of their ultimate shear capacities.

***Keywords**: girder, profiled web, shear capacity, local buckling, post buckling*

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Introduction

Generally, profiled web girders are manufactured with trapezoidal or sinusoidal corrugations. In this study, the use of profiled webs is a possible way of achieving adequate out-of-plane stiffness, whereby the profiled webs are replacing uniformly distributed stiffeners in the transverse direction. An enhancement to the existing profiled web girder was made through a cellular arrangement of a pair of identical trapezoidal corrugated profiled webs. In comparison with a conventional flat web, the profile enables usage of a thinner web. Another significant useful feature of profiled web girder with single or double webs is that it can reduce the material and fabrication cost since stiffeners are eliminated [1, 2].

According to Höglund [3], design procedure for trapezoidal corrugated webs was not considered in Eurocode 3, Part 1.1. For a single test series the results are slightly scattered. However, the average values of $\frac{V_{\text{exp}}}{V_R}$ for different test series are different, resulting in larger total scatter, the coefficient of variation being 0.19. Up to date, there is no recent study on doubly webbed corrugated web girders subjected to shear.

There are many factors that can influence ultimate shear capacity values. Among the factors are:

a. Geometric parameters on overall dimensions, such as web and flange thickness, corrugation depth and angle and also width of flat part of corrugation fold,
b. Residual stresses and initial imperfection due to welding and cold-forming of the flat sheet,
c. Temperature change, and
d. Types of loading, such as dynamic load.

This paper examines the ultimate load carrying capacity, unstable part of the post-buckling behaviour and buckling phenomena during the transition period from one buckling mode to another buckling mode as observed during experimental work.

Problem Statement

A conventional plate girder with slender web involves the use of transverse intermediate stiffeners to avoid catastrophic failure associated with shear buckling of the web. Sometimes stiffeners are used as bearing stiffeners to avoid crushing of the web due to concentrated loads or reactions. However, putting stiffeners are costly and are not feasible especially for buildings and bridges with moving loads. In this study, a profiled web was used to replace the flat web with transverse stiffeners. Hence, the load carrying capacities of profiled web girders were investigated.

Objectives of Study

The primary objective of this research work is to identify the shear load carrying capacities of profiled web girders with single profiled web and double profiled webs. The experimental works were intended to assess the followings:-

a. To study the nature of buckling and yielding of the webs, flanges, stiffeners and ribs.
b. To compare the load-carrying capacities of conventional flat plate girders with singly and doubly corrugated web girders.
c. To study the possibility of exploiting the post buckling strength of web sub-panels in a profiled web girder.

Methodology

Nine numbers of specimens were prepared to investigate the behaviour of plate girders with profiled webs under shear load. To achieve the objectives of this study, the configurations of every specimen are kept the same except on the followings:

i. Web depth (350 mm, 450 mm and 550 mm)
ii. Web arrangements (Conventional flat web, Single Profiled Web and Double Profiled Webs)

Figure 1 shows the dimensions of the profiled steel sheet (PSS), attached to the flanges of the girder by welding.

At present, the only specimen that can be designed in accordance with BS5950 Part 1: 2000 is the conventional flat plate girder. Hence the other specimens are derived accordingly. In this study, the stiffeners and end-posts were over design to ensure that the plate girder would not fail prematurely in an unforeseen mode. Continuous fillet weld was used instead of intermittent weld to avoid high residual stress concentration

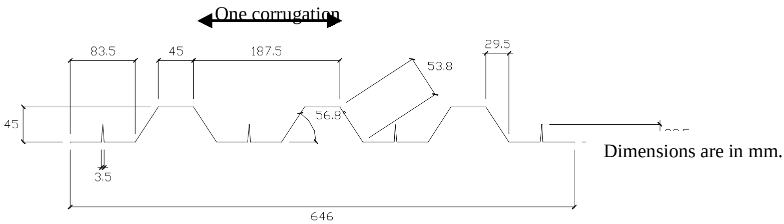
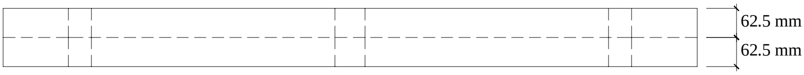
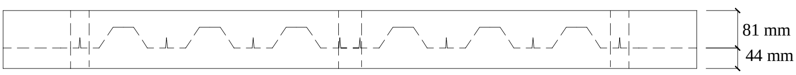


Figure 1: Profiled Steel Sheet

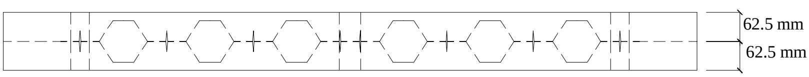
and rupture. The centre of the corrugation of the web was welded to the flange. Figure 2 shows the positions of the web-to-flange connections of the girders.



a) Welding Position of Web-to Flange for Flat Webbed Girder



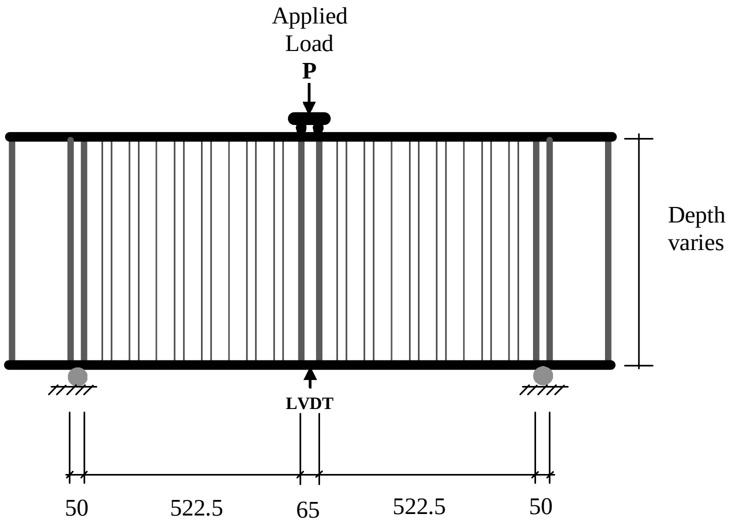
b) Welding Position of Web-to Flange for Singly Webbed Girder



c) Welding Position of Web-to Flange for Doubly Webbed Girder

Figure 2: Welding Positions

Each specimens was simply supported with a single point load (three point bending) applied at the centre of the specimens. LVDT (Linear Voltage Displacement Transducer) was used at the mid-span of the girder to measure the deflection. One bracing was placed on one side of the panel to restraint the flanges from experiencing lateral torsional buckling. Figure 3 shows the instrumentation of the experimental test setup. Small initial loading and unloading cycle were used to ensure the specimens were stable and sitting on the supports. After the entire instruments had been initialized, the load was then applied in small increments of 2.5 kN and then the load, transducer readings and strains were recorded in a data logger for each increment of load.



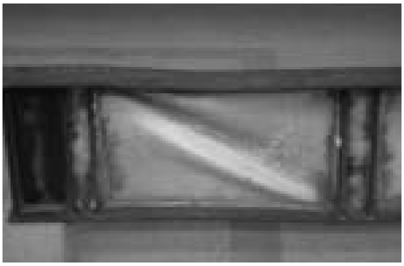
Dimensions are in mm.

Figure 3: Experimental Instrumentations

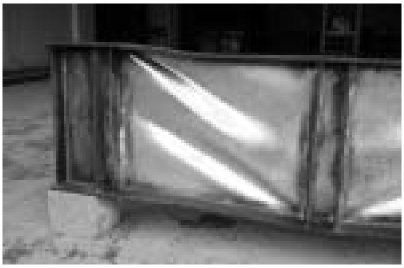
Results and Discussions

All of the test specimens were tested to failure. For every conventional flat webbed specimen, failure occurred in the typical shear failure mechanisms, as shown in Figure 4. The failure of the web panels is characterized by elastoplastic shear buckling, due to the development of large strain of yield zone and inclined tension field and the formation of plastic hinges. These characteristics are typical for flat web specimens as what has occurred in this experimental investigation. Figure 5 presents the shear load deflection response for the three tested conventional flat webbed specimens. The curves indicate a reasonably stable postpeak behaviour.

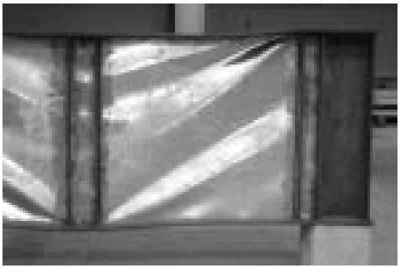
There are three types of buckling modes for the web of corrugated specimens. They are local, zonal and global buckling modes. However, according to Elgaaly *et al*. [1], buckling modes are categorized as either local or global. Figure 6 illustrate the three different buckling modes. However, the experimental results in this investigation have shown different behaviour.



a) Buckling Mode of Specimen F350-1



b) Buckling Mode of Specimen F450-1



c) Buckling Mode of Specimen F550-1

Figure 4: Buckling Mode of Conventional Flat Webbed Specimens

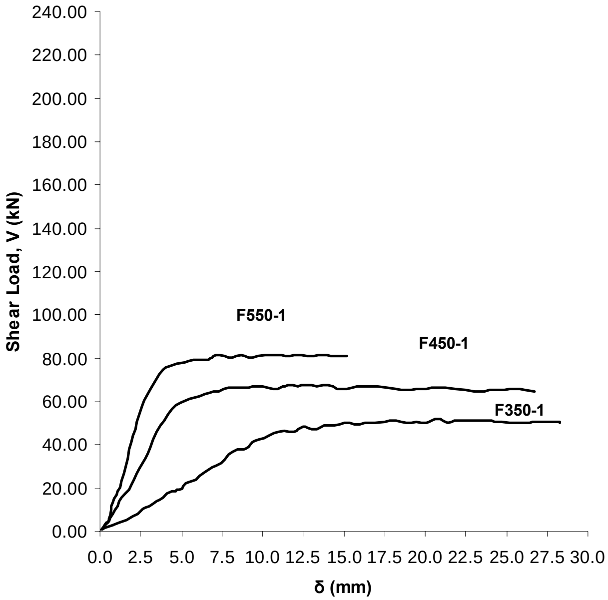


Figure 5: Shear Load-Deflection Curves of Conventional Flat Web Specimens

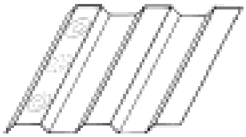


Figure 6a: Local Buckling Mode

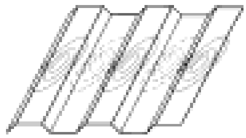


Figure 6b: Zonal Buckling Mode

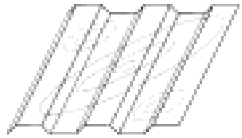
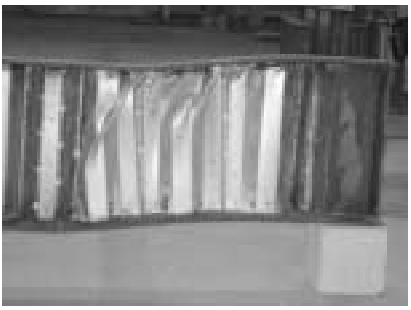
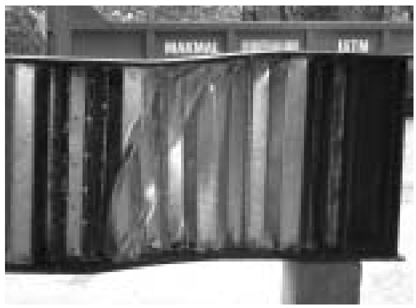


Figure 6c: Global Buckling Mode

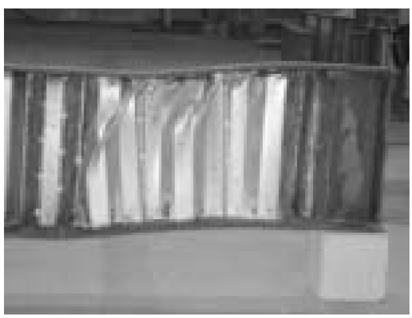
Figure 6: Buckling Modes of Corrugated Web



a) Zonal Buckling Mode of Specimens S350-1



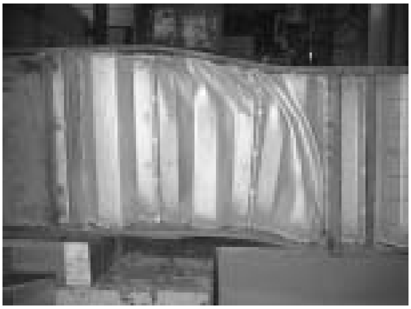
b) Zonal Buckling Mode of Specimens S450-1



c) Global Buckling Mode of Specimens S550-1

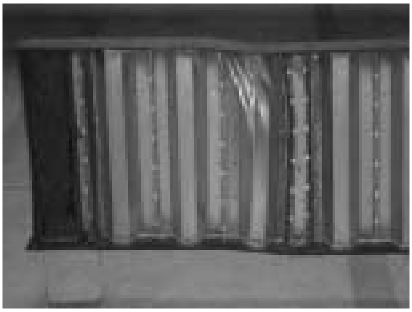
Figure 7: Buckling Mode of Single Web Corrugated Web Girder

The web buckling does not restricted in the plane part of the fold only but also crossing across to the other folds. Global buckling mode has occurred in specimens S550-1 and D450-2, where the buckling involved several folds and created yield lines crossing the folds. However, the buckling continued to develop in the post-buckling stage. From observation during loading, the web buckled initially in the local buckling mode which occurred either at top, middle or bottom flat part of the fold. The buckling propagated to other flat part of the folds which transformed to a zonal or extended to a global buckling mode in a diagonal direction of tension field action. This occurred when the load was already beyond the peak load (post-buckling stage). This implies that there is no post-buckling for conventional flat webbed girder. At post buckling stage, it was also observed that the profiled web specimens gradually buckled due to crippling of the web and subsequently buckled to bend till the flanges yielded vertically into the web. This implies that the web crippled first, then only followed by buckling of the flanges. In this post-buckling stage the specimens buckled completely before the final failure. Figures 7 and 8 show the buckling mode of single and double corrugated web girders after failure.



a) Zonal Buckling Mode of Specimens D350-1

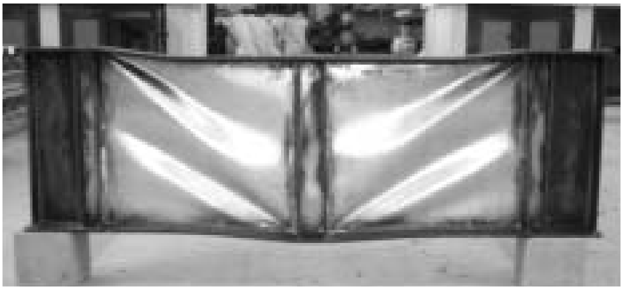
b) Global Buckling Mode of Specimens D450-2



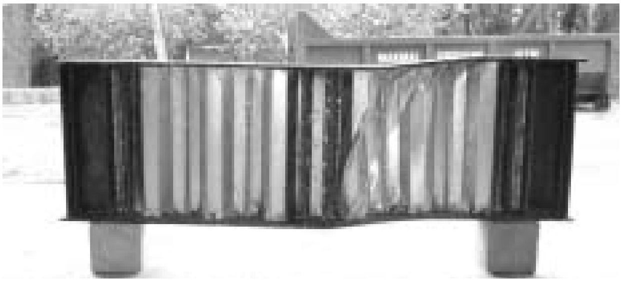
c) Zonal Buckling Mode of Specimens D550-1

Figure 8: Buckling Mode of Double Web Corrugated Web Girder

In this experimental investigation, all of the corrugated web specimens either with singly or doubly webs did not buckle symmetrically. One of the two panels buckled and pulled the flanges due to tension filed action. From observation, that phenomena happened because of the unstable part of corrugation folds, the fold started to buckle in one buckling mode and then change to another buckling mode for one of the panel, whereas the another panel remained stable. For all conventional flat web specimens, the web and flanges buckled in symmetrical arrangement. Figure 9 has shown the different buckling behaviour of flat and profiled web girders.



a) Symmetrical Web Buckling of Conventional Flat Web



b) Unsymmetrical Web Buckling of Single Web Corrugated Web

c) Unsymmetrical Web Buckling of Double Web Corrugated Web

Figure 9: Symmetrical and Unsymmetrical Web Buckling of Plate Girder

Figures 10 and 11 present the shear load deflection curves for three specimens for single web and another three for double corrugated web girder. After reaching ultimate load, each curve indicates a sudden and a steep descending branch. Table 1 shows the ultimate and post-buckling shear capacities expressed as reaction forces. The ultimate shear capacities are taken from the peak load values and the post-buckling capacities correspond to their plastic stage. That was shown an abrupt reduction of the shear capacity in average 55-70 % of ultimate shear capacity. These results are different where compared to results shown in Lou and Edlund [2] and Khalid *et al*. [4]. Lou and Edlund [2] obtained 20-30 % reduction of post-buckling capacity from ultimate capacity and Khalid *et al*. [4] did not get the reduction in post-buckling capacity. Another recent research by Elgally *et al*. [1, 5] and Evan *et al*. [6] also presented the reduction on ultimate capacity but did not mention amount of the reduction of the post-buckling capacity.

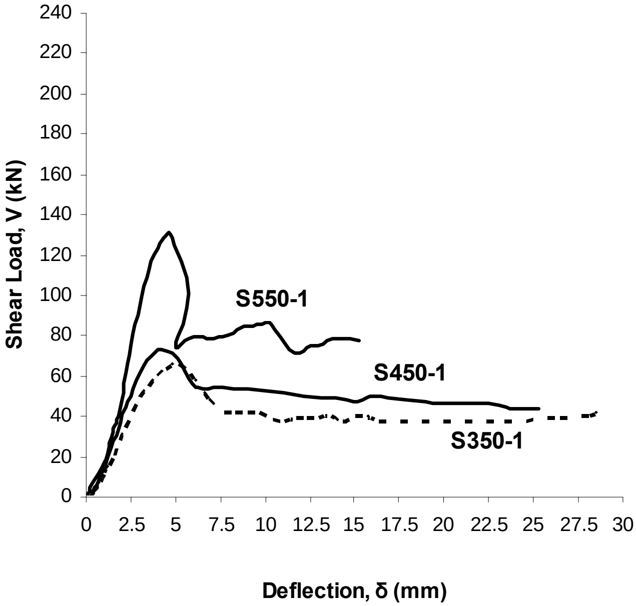


Figure 10: Load Deflection Curve for Singly Webbed Specimen

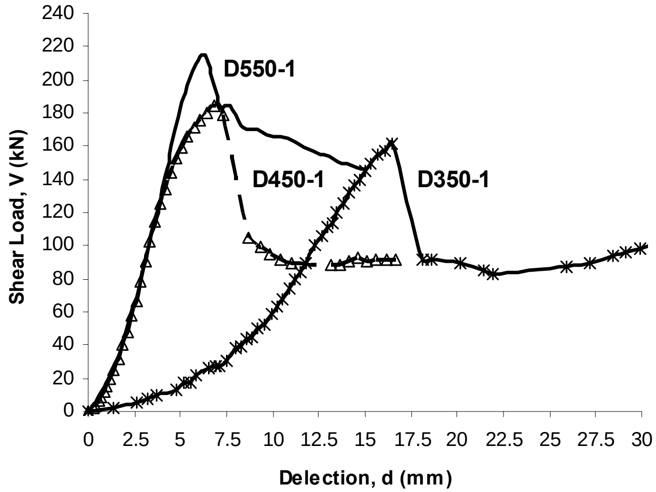


Figure 11: Load Deflection Curve for Doubly Webbed Specimen

Table 1: Summary of Experimental Result and Caparison with Conventional Flat Web

Specimen Name	Web depth (mm)	Flange Size, B × T (mm)	σ_{yw} (N/mm²)	σ_{yf} (N/mm²)	V_u	$\frac{V_{ult(Profiled)}}{V_{ult(Flat)}}$	$\frac{V_{post}}{V_{ult}}$
F350-1	350	125 × 9	405	300	50.00	-	-
F450-1	450	125 × 9	405	300	67.60	-	-
F550-1	550	125 × 9	405	300	81.50	-	-
S350-1	350	125 × 9	405	300	62.75	1.26	0.58
S450-1	450	125 × 9	405	300	73.05	1.08	0.65
S550-1	550	125 × 9	405	300	130.00	1.60	0.58
D350-1	350	125 × 9	405	300	161.20	3.22	0.57
D450-1	450	125 × 9	405	300	183.95	2.72	0.58
D550-1	550	125 × 9	405	300	215.15	2.64	0.68

Conclusions and Recommendation

Profiled web can gain higher ultimate shear capacity when compared to the equivalent conventional flat web girder. However its post-buckling capacity is reduced. This implies that profiled web girders can only use elastic design.

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