International Journal of GEOMATE, Oct. 2023, Vol. 25, Issue 110, pp.251-258
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.110.3978
Geotechnique, Construction Materials and Environment

NUMERICAL INVESTIGATION OF PLATE GIRDER HAVING CORE WEB WITH ZIGZAG CORRUGATED PANEL

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ABSTRACT: Corrugated steel flat plates have a number of benefits over conventional steel flat plates, including better buckling strength, a greater load capacity, a longer fatigue life, and cheaper construction costs. Corrugated plates have thus been used in a variety of civil engineering projects, including bridges, industrial structures, and steel coupling beams. To further enhance these properties, the web can be constructed as a core composed of two outside flat plates and a middle-corrugated panel. In this research, finite element software (ABAQUS 2017) was used to examine the effectiveness of steel plate girders containing various web types (flat plate, zigzagly corrugated plate, and core web with zigzagly corrugated panel). A large number of simply supported beam specimens were simulated and investigated under a three-point load in order to determine how the type of web affects the performance of girders under shear and flexural loadings. Three shear span-to-depth ratios (a/d) of 1.0, 1.83, and 2.5 were examined. Corrugation depth's impact on girder performance was also explored. The results of the study demonstrated that replacing flat plate web with corrugated plate having a zigzag shape improved the performance of the girders in regards to ultimate load and ductility. Additionally, when a core web was utilized, the performance of the girders was further improved. When compared to a steel girder with a flat web, the ultimate loads for girders with a core web and girders that only consisted of a corrugated plate web increased by 47% and 21%, respectively.

Keywords: Zigzag corrugation, Core web, Plate girder, Finite elements, Span to depth ratio

1. INTRODUCTION

In the modern era, steel has risen to the top of the list of the most often used building materials worldwide. The use of steel effectively reduces the consumption of cement as the main binder in concrete. This involves lowering CO2 emissions that cause air pollution and putting green building and sustainable construction principles into practice [1].

Steel plate girders (SPG) are mostly used in various structural applications (composite bridges, buildings, etc.) [2]. The concern arises when deep sections are used in constructions with large spans and high loads, which result in web buckling problems [3, 4]. The stiffeners can be used to reinforce the thin webs of deep steel plates. However, this method requires a high fabrication cost and may reduce the fatigue life [4].

Cold-formed steel (CFS) is a versatile building material with positive aspects including high strength-to-weight ratio, termite and mold resistance, and recyclable material. In contrast to its earlier use as non-structural parts, it’s now utilized as structural components [5,6].

The use of steel girders with corrugated web instead of flat web is a competent method to acquire lighter and more efficient structures [7-10]. In Europe and Japan, a steel member with a corrugated web was used in building structures and bridge constructions between 1960 and 1980 [9,11]. Recently, there has been an increase in the utilization of steel members with a corrugated web in various structural applications (airplane hangars, bridges, hydraulic structures) [12]. One of the reasons for the growing use of corrugated plate web is its high shear buckling strength compared to conventional flat web. Other reasons to use corrugated webs in the steel girders are their high stability, long fatigue life, and reduction in construction cost. Automated techniques, such as robots, have been employed in the production of steel members with corrugated web to accelerate production and reduce labor costs [9].

Different forms of web corrugations (square, rectangular, trapezoidal, triangle, and sinusoidal) to enhance shear bucking resistance have been examined [14-23]. The trapezoidal form of corrugated web is the most common among others, and it may fail due to the problem of local buckling compared to the sinusoidal form, which reduces this problem [15]. The zigzag form of corrugated web showed greater strength compared to the trapezoidal form.

The shear stress of steel girders with flat and corrugated webs was numerically studied by Riahi. The results of the evaluation revealed that employing a thinner corrugated web is more cost-effective than using a thick flat web. [18]. Using the analytical technique, it was determined how pure bending span and the shear span-to-effective depth ratio affected the failure process of steel beams with corrugated web (SBCWs) [19]. The results demonstrated that the shear span increase had a stronger effect on CWSB stiffness and load capacity than the pure bending span increase. Sayed-Ahmed [20] has investigated the behavior of an I girder with corrugated web according to lateral-torsional buckling resistance by adopting a numerical analysis (FEA). The outcome showed that an I-girder with corrugated webs has stronger resistance to lateral-torsional buckling than one with flat webs.

Ammash and Al-Bader [21] research study aimed to increase both the strength and stiffness of corrugated-web girders through the addition of two plates (skins) to form a core web. The results of the study revealed that girders with a core web have a enhanced load capacity compared to those without.

Abdullah and Muhaisin [22] examined the performance of steel beams with core webs having trapezoidal corrugated plates, two core depths (30mm and 60 mm) and different shear span-to-depth ratios were examined. The findings showed that using a trapezoidal corrugated core web enhanced the ultimate strength and ductility of the structure more than a traditional flat web. In addition, the highest ultimate load capacity was obtained with a 30 mm core thickness and at a/d. = 1.0. Other studies showed the same enhancement when using sandwich-core steel girders with rectangular corrugated web [23].

In this work, finite element software (ABAQUS 2017) was utilized to examine the effectiveness of steel plate girders with various web types (flat plate, zigzagly corrugated plate, and core web with zigzagly corrugated panel). The performance of girders under shear and flexural loadings is influenced by the type of web, which has been studied and simulated for a number of simply supported beam specimens under a three-point load.

2. RESEARCH SIGNIFICANCE

At the present time, it is vital to design and construct an efficient and economical structure. For steel girders, plate girder characteristics such as stiffness and stability can be enhanced by using a corrugated plate web rather than a conventional flat web, resulting in a cost-effective and high-performance structure. To add extra strength and stiffness to steel girders made with corrugated web only, the core web can be used instead. The core web is composed of two flat plates (skins) and one corrugated central panel. It is essential to understand the behavior of steel beams with core webs constructed using zigzag corrugated plates to evaluate their performance in different structures. Ultimate load capacity and failure mode are some of the different factors affecting girder performance. Researchers believe that the buckling strength of the web and subsequently the girder strength are influenced by core depth and the shear span to depth ratio. This work examined the behavior of steel girders with the zigzag corrugated core web using finite element Analysis (FEA). Using advanced computational tools like FEA is an alternative method. The main advantage of FEA is that it is frequently faster and costs less than experimental studies while producing a considerably more comprehensive set of results.

3. NUMERICAL PROGRAM

Finite element software (ABAQUS 2017) was used in this study; it is considered a good tool for predicting load, displacement response, and failure modes. The shell element (S4F) was chosen to model the web and the flanges. The element is capable of deflection, large strain, and plasticity under stress. Both materials and geometric nonlinearities were considered. The initial imperfection effect on the nonlinear behavior of specimens was also taken into account. An initial imperfection with a value of (h_w /200) based on the recommendations of Riahi [18] was assumed in this investigation.

A total of 15 simply supported steel girders were simulated and analyzed to achieve the objective of the study. The girders were divided into 3 groups based on the web type (See Fig.1) as follows:

1. Group I (FW): consisting of three girders with flat plate webs with different a/d. ratios (1.0, 1.83, and 2.5). The specimens of this group used as reference specimens.
2. Group II (CW): consisting of 6 steel girders having a web made of zigzag corrugated plate at different a/d. ratios (1.0, 1.83, and 2.5). Three of the specimens have 30 mm corrugation depth, the other 3 specimens have 60 mm corrugation depth.
3. Group III: consisting of 6 steel girders having a web made of core with middle zigzag corrugated plate and two outer flat panels at different a/d. ratios (1.0, 1.83, and 2.5). Three of the specimens have 30 mm core depth, the other 3 specimens have 60 mm core depth.

The investigated girders have span lengths of 600 mm,1100 mm, and 1500 mm for a/d. of 1.0, 1.83, and 2.5, respectively. All of the specimens have a 300 mm web height, 200 mm flange width, and 6 mm flange thickness. The material properties of the elements used in this analysis are listed in Table 1. Table 2 includes the description of the investigated specimens. All specimens were analyzed under a three-point load.

Table 1. Materials Properties of the specimens

Plate thickness	Component	Strength (MPa)	
		Yield	Ultimate
6 mm	Flange and stiffener	358	467
3 mm	Web	402	455
1 mm	Outer and middle plates of the	305	410

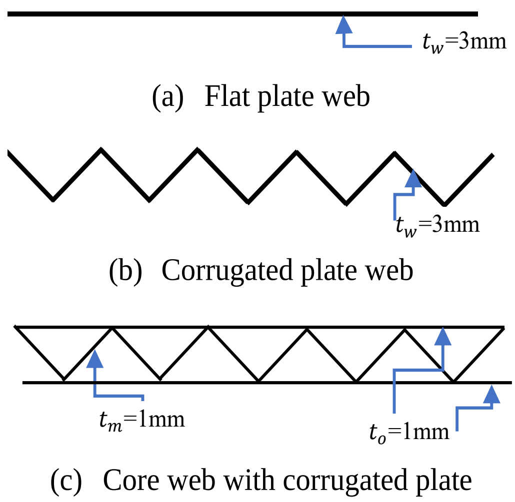


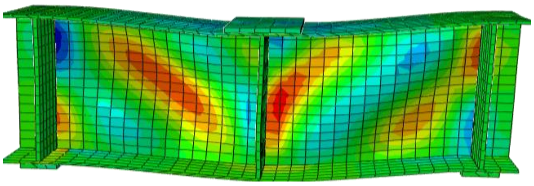
Fig.1 Web types investigated in this study

Table 2. Description of the investigated specimens

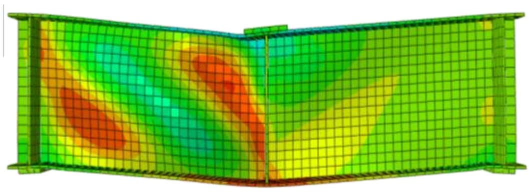
No.	Group No.	Beam Symbol	Web thickness (mm)		Description
			Middle plate	Outer plates	
1	I	FW1.0	3		Specimen having flat web with a/d.=1.0
2		FW1.8			Specimen having flat web with a/d.=1.83
3		FW2.5			Specimen having flat web with a/d.=2.5
4	II-1	CW30-1.0	3		Specimen with corrugated plate web with corrugated depth =30 mm at a/d.=1.0
5		CW30-1.8			Specimen with corrugated plate web with corrugated depth =30 mm at a/d.=1.83
6		CW30-2.5			Specimen with corrugated plate web with corrugated depth =30 mm at a/d.=2.5
7	II-2	CW60-1.0	3		Specimen with corrugated plate web with corrugated depth =60 mm at a/d.=1.0
8		CW60-1.8			Specimen with corrugated plate web with corrugated depth =60 mm at a/d.=1.83
9		CW60-2.5			Specimen with corrugated plate web with corrugated depth =60 mm at a/d.=2.5
10	III-1	CCW30-1	1	1	Specimen with core web having corrugated plate with core depth =30 mm at a/d.=1.0
11		CCW30-1.83	1	1	Specimen with core web having corrugated plate with core depth =30 mm at a/d.=1.83
12		CCW30-2.5	1	1	Specimen with core web having corrugated plate with core depth =30 mm at a/d.=2.5
13	III-2	CCW60-1	1	1	Specimen with core web having corrugated plate with core depth =60 mm at a/d.=1.0
14		CCW60-1.83	1	1	Specimen with core web having corrugated plate with core depth =60 mm at a/d.=1.83
15		CCW60-2.5	1	1	Specimen with core web having corrugated plate with core depth =60 mm at a/d.=2.5

4. RESULTS AND DISCUSSION

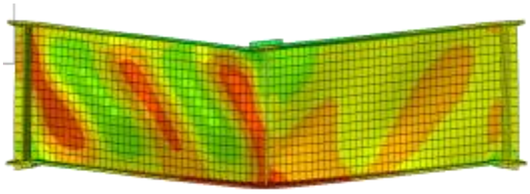
Figures. 2–6 represent the stresses and modes of failure for the selected specimens. Fig. 2a shows the stress distribution for a beam having a flat web at a/d. =1.0 while Fig. 2b and Fig. 2c are for specimens with a/d. =1.0 and 1.83, respectively. It can be noticed from these figures that the distribution of stresses is changed as the behavior of the specimens was altered from shear controlled for specimen with a/d. = 1.0 to flexure-controlled for that with a/d. = 2.5.



(a) FW1.0



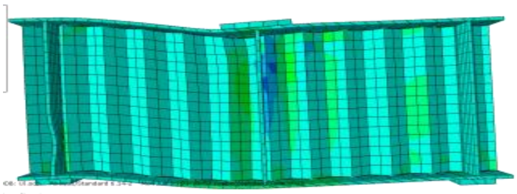
(b) FW1.83



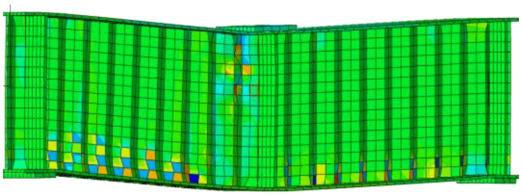
(c) FW2.5

Fig. 2 Stresses distribution and failure mode for group I Specimens

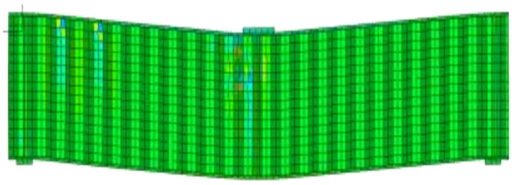
The same was noticed for specimens of group 2 and group 3. The distribution stresses of girder specimens having corrugated web with corrugated depth(dc) of 30 mm for different a/d. is shown in Figs. 3a to 3c. Figs. 4a to 4c represents the distribution for those with dc=60 mm. From these figures, it can be observed that the behavior of the specimens was different from those with the flat web. The results also showed that the performance of the specimens was slightly affected by the depth of corrugation. The same was observed for specimens with core web, as shown in Figs. 5 and 6.



(a) CW30-1.0

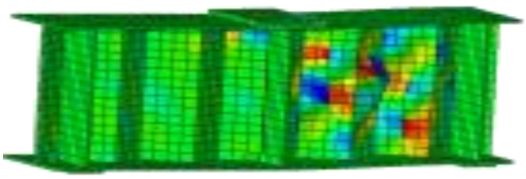


(b) CW30-1.83

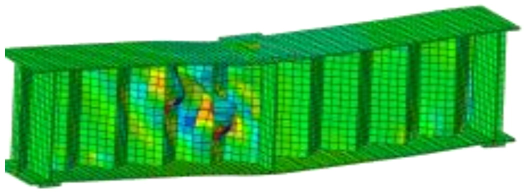


(c) CW30-2.5

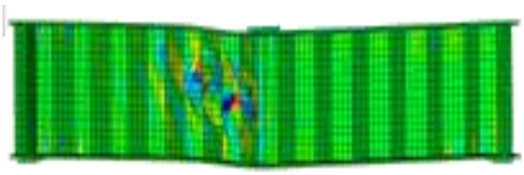
Fig. 3 Stresses distribution and failure mode for group I Specimens



(a) CW60-1.0

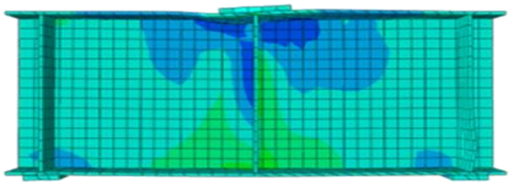


(b) CW60-1.83

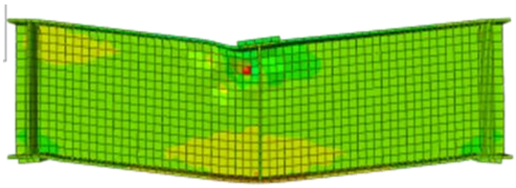


(c) CW60-2.5

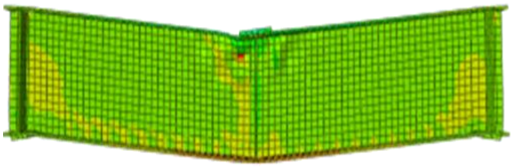
Fig. 4 Stresses distribution and failure mode for group II-2 Specimens



(a) CCW30-1.0

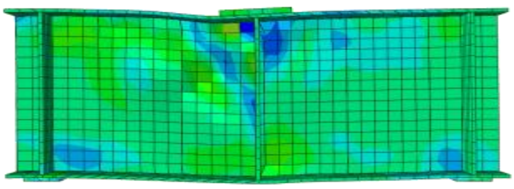


(b) CCW30-1.83

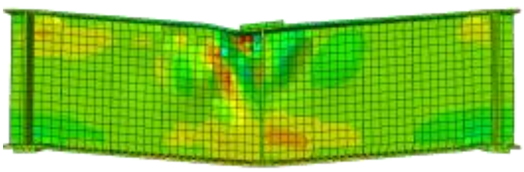


(c) CCW30-2.5

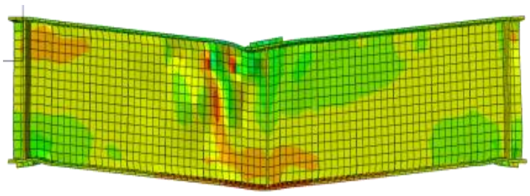
Fig. 5 Stresses distribution, failure mode for group III-1 Specimens



(a) CCW60-1.0



(b) CCW60-1.83



(c) CCW60-2.5

Fig. 6 Stresses distribution, failure mode for group III-2 Specimens

The load- deflection curves for all web types (FW, CW, and CCW) at different (a/d) ratios of 1.0, 1.83, and 2.5 are presented in Figs 7, 8, and 9, respectively.

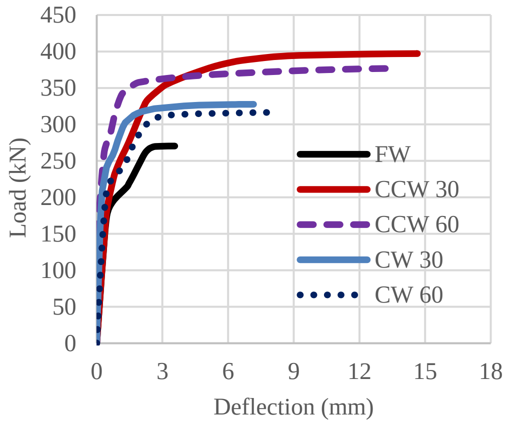


Fig. 7 Influence of web type and core depth on the behavior of girders at a/d. =1.0

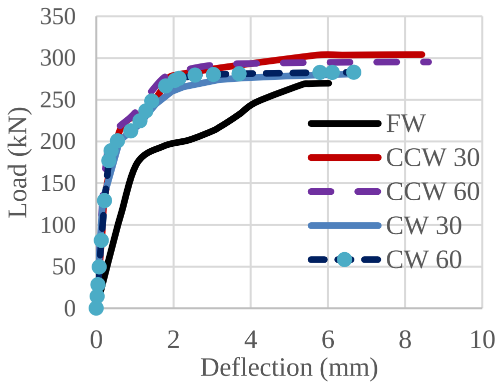


Fig.8 Influence of web type and core depth on the behavior of girders at a/d. =1.83

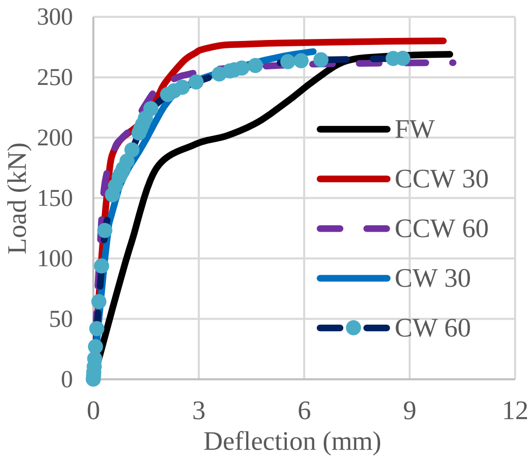


Fig.9 The influence of web type and core depth on the behavior of girders at a/d. =2.5

The ultimate load capacities at the same selected values of a/d. for each web type are reported in Table 3 and Fig. 10. The percentage change in the ultimate load of girders with different web types as a result of varying the shear span is shown in Fig. 11.

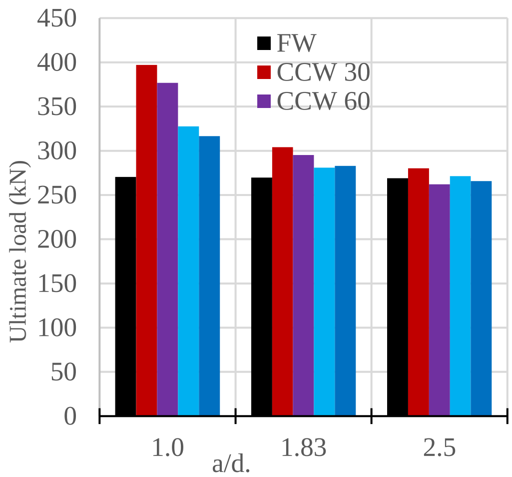


Fig.10 Effect of a/d. and web type on the ultimate load capacity of plate girders

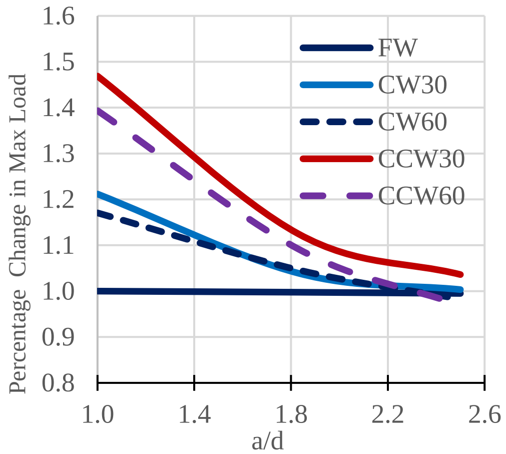


Fig 11. Changing in ultimate load capacity for different web type versus a/d.

Table 3 Ultimate load for conventional web and Core web girders at various a/d.

a/d.	Ultimate load (kN)				
	FW	CW 30	CW 60	CCW 30	CCW 60
1.0	270.4	327.6	316.5	397.1	376.7
1.833	269.7	280.9	282.9	304.1	295.2
2.5	269.0	271.3	265.7	280.1	262.1

From the results reported in the above figures, the following were observed:

- The ultimate load capacities for specimens with corrugated web and core webs having corrugated plates decreased with an increase in the shear span to depth ratio (a/d.). The lowest ultimate load capacities occurred at a/d. of 2.5; this decrease might be attributed to the fact that the behavior of girders with a/d. = 2.5 is flexure-controlled and the web has less contribution to its strength compared to girders with a/d. = 1.0, where they are shear controlled.
- Using a web with a core depth of 30 mm (CW30) causes a notable rise in both ultimate load capacity and ductility; the ultimate load was increased by 35% compared to a girder with a flat web.
- The efficiency of steel girders with core webs was slightly affected by corrugation depth (dc). With regard to ultimate strength and ultimate displacement capacity, girders with a dc of 60 mm did not perform as well as those with a core depth of 30 mm. This may be attributed to the local buckling failure. This failure is more concerning in girders with corrugated web having a core depth of 60 mm since the unsupported panel length is twice that of those with a core depth of 30 mm.
- At a/d. =1.0, specimens with corrugated web, and core web having corrugated plates support higher loads and have greater dactylitis than those with a/d. of 1.833 and 2.5. The ultimate loads of the specimens with a/d. of 1.83 and 2.5 were reduced by around 23% and 15%, respectively, compared to the corresponding values at a/d. = 1.0.
- Using corrugated plate with a zigzag configuration as an alternative to flat plate web enhanced the response of the girders in terms of both the ultimate load and ductility. The maximum enhancements occurred at an a/d. of 1.0. Moreover, when a core web consisting of two outer flat plates and one middle zigzagly corrugated panel was used, the performances of the girders improved further.
- Using corrugated plate with a zigzag configuration as an alternative to flat plate web enhanced the response of the girders in terms of both the ultimate load and ductility. The maximum enhancements occurred at an a/d. of 1.0. Moreover, when a core web consisting of two outer flat plates and one middle zigzagly corrugated panel was used, the performances of the girders improved further. The ultimate load was increased by 21% by using corrugated plate web and by 47% when core web was used compared to a steel girder with a flat web.

5. CONCLUSION

This study presents a numerical examination of the behavior of steel girders constructed with different types of webs (flat web, corrugated web, and core web having zigzag corrugated plate). The study included modeling and analyzing several beams with simple spans having various web types, corrugated depths, and span-to-depth ratios. The investigation was conducted using finite element software (Abaquas 2021). The findings of the study showed that the investigated specimens' ultimate load capacity and ductility were improved by replacing the flat plate web with a zigzag corrugated plate web. Additionally, the use of a core web enhanced the performance of the girders even more. As compared to a steel girder with a flat web, the ultimate loads of the girders with a core web and those with a merely corrugated plate web increased by 47% and 21%, respectively. The results also showed that the performance of the constructed girder specimens for both categories (steel girders with purely corrugated plate and steel girders with a core web having corrugated plate) is significantly influenced by the span-to-depth ratio (a/d). However, the performance of steel girders with a typical flat web is slightly impacted by this aspect. In comparison to beams with a/d. 1.83 and 2.5, conventional beams and beams with core webs have the highest ultimate load capacity at a/d. = 1.0. Finally, of the core depths considered in this study, core depth appears to have a slight effect on steel girder performance

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