Numerical and experimental investigation of the shear behavior of hardened cold-rolled beams

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ABSTRACT
As large-span beams, plate girders can be excellent substitutes for rolled profiles that cannot be used in construction everywhere and at all times. Further, these members can withstand heavy loads that cannot be sustained by existing rolled profiles. Typical web plates are susceptible to buckling under loading. Cold rolling is an economical solution to prevent web plate buckling. Making deformations in the web plate enhances its geometric stiffness and strength around the weak axis. In this light, a detailed investigation of the capacity of plate girders with web deformations is in order. Accordingly, the Riks analysis was used to optimize the dimensions of these deformations and investigate their effects on elastic buckling in the plate and plate girder.

KEYWORDS
Hardened cold rolled steel plate, shear behavior, press, corrugated steel web.

1. Introduction

Several studies have addressed plate girders integrating standard or corrugated webs. These studies used numerical and experimental methods to investigate the behavior of beams under bending and shear, effects of the web plate geometry on the beam performance, behavior of composite beams with a corrugated web, the combined effects of corrugated web plates with stiffeners, and performance of corrugated-web beams under cyclic loading among other topics [1].

Shear stress is rarely problematic for rolled profiles and beams with a normal span. In other words, the shear strength of typical beams surpasses their strength against bending moments [2]. However, in plate girders and rolled beams with small spans to withstand heavy loads, shear stress can be critical. Shear strength is an important design parameter that must be taken into account in cases where structures are designed with thin steel plates. In 2007, Real et al. [3] studied the shear responses of a stainless steel plate girder. The experimental study focused on plate girders of different dimensions and geometries under near-service loading, and the results were verified with Finite-Element (FE) software tools.

Daley et al. [4], in 2017, studied the shear strength of an unstiffened steel I-beam. According to the results, the flange in I-beams ensures uniform stress distribution across the web. The flange has a negligible contribution to bearing the shear stress, but helps reduce the maximum stress applied to the web.

Transverse web stiffeners are plates placed at *a* intervals along the beam and normal to the web, between the flanges. In beams where the section is not sufficiently strong for the allowable shear stress, diagonal buckling can be prevented using transverse stiffeners [5].

Typical, flat web plates are susceptible to buckling under loading. Web buckling can be prevented by increasing the plate thickness or using longitudinal and transverse stiffeners. Creating corrugation in the web through making local deformations is an economical solution to preventing buckling. Relying on cold rolling, the production of these plate girders is straightforward and low-cost. Creating folds in the thin girder web plate enhances the geometric stiffness and strength of the plate around its weak axis. Light weight, high strength, out-of-plane stiffness, and facility of use are some advantages of these plate girders. Accordingly, these girders help reduce the structural weight, enhance the strength while bringing down material consumption, and facilitate construction, helping cut down project costs. Another remarkable point here is reducing stiffeners in the web plate, which most importantly lowers the expenses. The original idea was proposed and implemented by Goldbeck [6] in 1997. In as much as little analytical and experimental information is available on the behavior of plate girders with web deformations and few studies have addressed the issue, its investigation seems to be necessary.

2. Finite-Element Model

For a parametric study of models under uniform loading, a pushover analysis was carried out using ABAQUS. The Riks solver employed in the present study is highly effective for analyzing the behavior of structures with local or global instabilities, particularly, buckling problems and post-buckling analysis considering geometric imperfections. The materials used in this study include steel, which is characterized in the following.

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Boundary Conditions and Meshing

The 5R8S element was used for meshing all models. The element represents a reduced-integration shell element with eight 5 DOF nodes. The plate girder was modeled with hinged boundary condition on one side and roller boundary condition on the other and, therefore, movement was restricted in *x*, *y*, *z* directions on the hinged side and in *x* and *y* directions on the roller side. The lateral movements of beams normal to the plane, the *x* direction, were also restricted (Fig. 1).

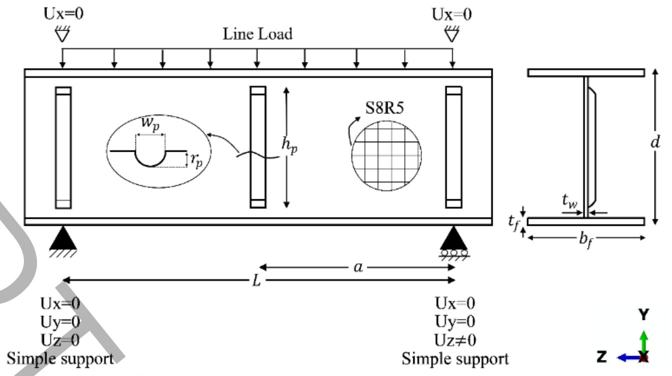

Figure 1. Boundary conditions and geometrical specifications of the cold-rolled plate girder.

3. reparing an Experimental Specimen and Investigating the Results

At this point in the study, an experimental specimen was prepared to make sure the ABAQUS numerical results are accurate, suggesting an improvement in the plate's load-bearing capacity. The experimental and numerical results are compared in the following. The specimen was made with two *3-m* sheets of steel for the flange, a thin *3-m*-long sheet for the web, and thick *3-cm* plates for stiffeners. The girders were cut, welded, and assembled at the Saraman Structural Steel production plant in Razi Industrial Park, Iran. The trapezoidal deformations were created in the girder's web using a press brake. The specimen was transported to the testing laboratory after fabrication. Hinged supports with specific dimensions were used to install the plate girder with trapezoidal web deformations in the test frame. Further, a double-web IPE27 beam was placed under the supports of the main girder. The specimen was laterally-braced by angle beams installed diagonally and in parallel by welding one end to the top or bottom flange and attaching the other end to the test frame using four screws (Fig. 2).

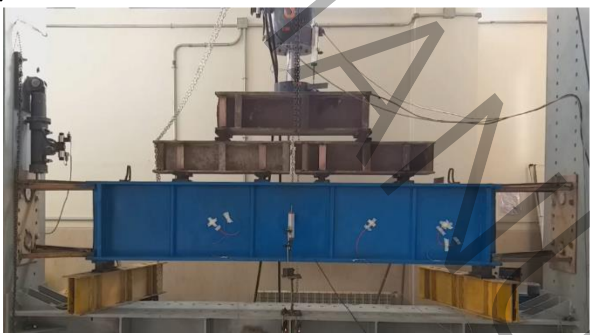

Figure 2. Test frame and the placement of the specimen before testing.

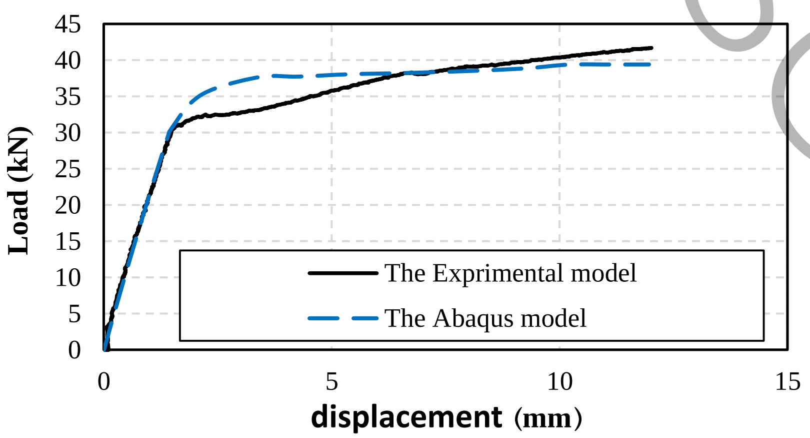

Figure 3. Comparing numerical and experimental results for the plate girder with trapezoidal web deformations.

Verification of the Experimental Specimen

Based on the mechanical properties of the steel, the plate girder with trapezoidal deformations was placed under nonlinear loading and analyzed by the Riks method. A linearly distributed (four-point) load was applied over a beam with hinged support on one end and roller support on the other. Further, lateral movements were restricted normally to the plane. The 5R8S element was used for regular meshing. The analytical and experimental results are compared in Fig. 3 and 4.

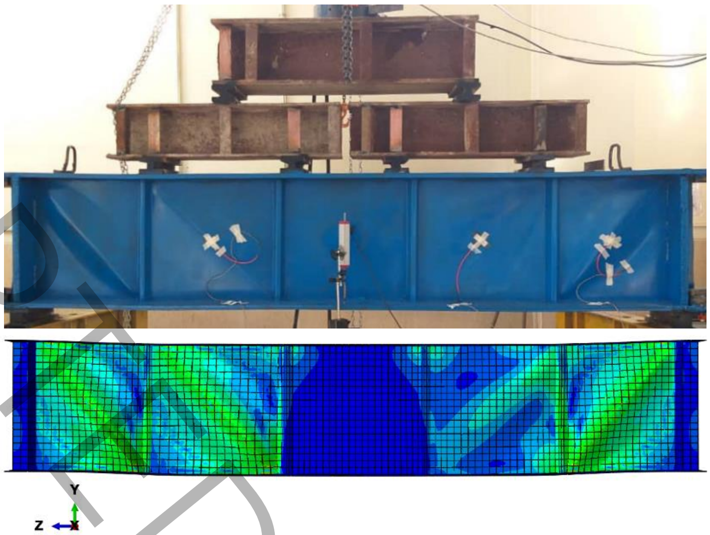

Figure 4. Plate girder with trapezoidal web deformations after the experiment.

4. Summary and Conclusion

A parametric study was carried out using ABAQUS on the behavior of cold-rolled plate girders under large deformations and the influence of different factors. The optimal fold dimensions (width, depth, and length) were optimized for different web thicknesses (*4*, *6*, and *8 mm*) for *1* and *2 m* beams to produce the maximum load-bearing capacity. The optimal width and depth of the fold were obtained at *20* and *40 mm*, and the length is often a few centimeters short of the web depth to provide clearance for performing welding and forming jobs. The elastic buckling was also analyzed in plate girders to investigate the effects of folds on the plate girder's load-bearing capacity. The results were suggestive of the folds' excellent performance, as the buckling strength of the three-fold plate girder was increased by a factor of *5.78* compared to the simple girder. After optimizing fold dimensions, its impact on long plate girders was examined. In this regard, *84* plate girder models with folds, as well as *84* simple plate girder models, were analyzed. In all cases, the load-bearing capacity of the plate girders with folds surpassed that of the simple girder, showing the effectiveness of the folds. Overall, the maximum strength of plate girders with folds were increased by *4–182%* in models with *4 mm* web thickness, by *29–193%* in models with *6 mm* web thickness, and by *15–121%* in models with *8 mm* web thickness compared to simple plate girders. A specimen was also fabricated to verify the accuracy of the numerical ABAQUS results, suggesting improvements in the plate's load-bearing capacity. Due to the considerable cost of making cylindrical deformations in the web plate, trapezoidal folds were alternatively used. The trapezoidal deformation considerably enhanced the load-bearing capacity of the plate girder, raising the linear region by *183%* and the ultimate strength by *87%*. In conclusion, trapezoidal folds, or in general any corrugation, can improve the load-bearing capacity of the plate girder.

5. References

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