A Cost Effective Method to Retrofit Steel Girders

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1. Introduction
In steel structures, I-sections are commonly used for beams and columns. These cross-sections often lack lateral rigidity and torsional stiffness. In this research, an effective method to improve their lateral rigidity and overall flexural resistance by welding two inclined rectangular plates to the compression flange and the compression portion of the web of hot-rolled or welded I-section is explored. The resulting section, referred to as a Delta girder can greatly increase the load-carrying capacity of the beam with appreciable cost and time savings.

2. Research Objectives and Practical Applications
The primary objectives of this research are to investigate the elastic and inelastic behavior of the proposed Delta girders and to develop guidelines and equations for the design of these girders. The research involves analytical and finite element formulations and verifications against available theoretical and experimental results. Anticipated applications for Delta girders include the design of new beams and the retrofit of existing beams.

3. Major Advantages of Delta Girders
   a) Improve flexural capacity.
   b) Increase shear resistance.
   c) Avoid local buckling by reducing the width-to-thickness ratio of both the compression flange and the web.
   d) Reduce incidences for lateral-torsional buckling (LTB) during transportation and erection.
   e) Provide a simple and cost effective means to strengthen existing beams.
   f) Reduce the need for longitudinal and intermediate stiffeners.
   g) Enhance torsional resistance for carrying eccentric loads.
   h) Improve the appearance of the girder and provide an obstruction free path for the wheel of a crane trolley.

4. Finite Element Modeling
The high fidelity finite element model used in the simulation study takes into account both geometric and material nonlinearities including the effects of initial imperfections and residual stresses.

5. Analysis for Flexure

6. Analysis for Shear

7. Design Recommendations
Flexural capacity:
The following equations are proposed:

\[ M_{ul} = \frac{1}{\Phi_{LT} + \left(\Phi_{LT} - \frac{3Z_FF_Y}{4M_{LT}}\right)^{1/2}} Z_F F_Y \]

in which \( \Phi_{LT} > 2 \)

\[ \begin{array}{c|c|c|c}
\text{cross-section} & \text{Limits} & b_d & b_t \\
\hline
\text{Delta Girders} & d/b_c \leq 2 & b_d/5 \text{ to } b_t/4 & b_d/5 \text{ to } b_t/2 \\
& d/b_c > 2 & b_d/5 \text{ to } b_t/3 & b_d/5 \text{ to } 3b_t/4 \\
\end{array} \]

Guidelines for delta stiffener configurations:

\[ V_u = \gamma \left( A_{ul} + 0.5A_d \right) \left( 1 + \frac{0.5A_d}{A_{ul} + 0.5A_d} \right) \]

8. Summary
Using theoretical analysis and high fidelity finite element modeling, the load carrying capacity of Delta girders were determined. Design guidelines and equations that engineers can use to design these Delta girders were derived. Based on a comparative study between Delta girders and I-sections, it has been shown that Delta girders can provide up to 394% and 89% increase in the flexural and shear resistance capacities, respectively. Moreover, comparisons that include the weight and fabrication cost show that cost savings greater than 35% can be achieved.