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328.1

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Unsymmetrical Plate Girders

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by

Alexis Ostapenko

Fritz Engineering Laboratory Report No. 328.1

LEHIGH UNIVERSITY
Bethlehem, Pennsylvania

Department of Civil Engineering
Fritz Engineering Laboratory

328

June 17, 1966

Mr. Knud H. Jensen
Bridge Engineer
Pennsylvania Department of Highways
Harrisburg, Pennsylvania

Re: Unsymmetrical Plate Girders

Dear Mr. Jensen:

Attached are a few remarks on the background of the proposed research on unsymmetrical girders. I hope they will show the real value of this research.

For your convenience, a summary of the reasons is repeated on this page.

1. Unsymmetrical girders are not covered by present specifications and design criteria for them are therefore needed (Engineers now design unsymmetrical girders as if they were symmetrical. This may often lead on the one hand to overconservative and on the other to relatively unsafe designs.)

2. It is expected that transverse stiffener spacing can be considerably liberalized.

3. The ratio of the girder depth to web thickness for which no stiffeners are required can be substantially increased, particularly in the area of the positive moment.

4. Acceptance of the ultimate strength and fatigue strength design criteria will result in a uniform factor of safety along the girder.

By reducing or even eliminating stiffeners items 2 and 3 will lead to a considerable reduction of fabrication costs for unsymmetrical plate girders.

I am looking forward to seeing you in New York on the 22nd.

Sincerely yours,

Alexis Ostapenko

Alexis Ostapenko
Research Professor of Civil Engineering

AO:fas
cc: E. L. Erickson
C. D. Jensen
C. Zwissler
L. S. Beedle

SUPPLEMENT TO PROPOSAL FOR RESEARCH ON UNSYMMETRICAL PLATE GIRDERS

A. Ostapenko

A Case for Research on Unsymmetrical Plate Girders

A brief summary of the reasons for research on unsymmetrical girders is as follows:

1. Unsymmetrical girders are not covered by present specifications and design criteria for them are therefore needed. (Engineers now design unsymmetrical girders as if they were symmetrical. This may often lead on the one hand to overconservative and on the other to relatively unsafe designs.)

2. It is expected that transverse stiffener spacing can be considerably liberalized.

3. The ratio of the girder depth to web thickness for which no stiffeners are required can be substantially increased, particularly in the area of the positive moment.

4. Acceptance of the ultimate strength and fatigue strength design criteria will result in a uniform factor of safety along the girder.

By reducing or even eliminating stiffeners items 2 and 3 will lead to a considerable reduction of fabrication costs for unsymmetrical plate girders.

A more detailed discussion of the background for the above reasons is given on the subsequent pages.

Design Practice for Highway Bridges

Design of plate girders for highway bridges is controlled by the current AASHO Specification (1961). Major requirements are the following:

The depth of girders without longitudinal stiffeners is limited to (Art. 1.6.75)

$d < 170t$	for carbon steel
$d < 145t$	for silicon steel
$d < 140t$	for steel without yield point of 50 ksi

where d is the depth of the plate girder and t is the web plate thickness.

Spacing of transverse intermediate stiffeners is given by Art 1.6.80:

12 feet or clear depth or

$$\frac{12,000}{s} t, \tag{1}$$

where s is the average shearing stress in the web. The last expression (Eq. 1) places a requirement that the web plate is not to buckle in pure shear. The factor of safety against buckling for this requirement varies from 1.15 to 1.70 depending on the aspect ratio of the panel. Stresses due to bending are not included in the spacing limitations.

Girders with

$$d < 60t \tag{2}$$

need no stiffeners (Art. 1.6.80). This is again an elastic shear buckling requirement with a factor of safety of about 1.75.

The above two buckling limitations (Eqs. 1 and 2) were derived for symmetrical girders assuming pure shear. In a simply supported girder this will seldom raise problems, but in the area at an intermediate reaction in a continuous or cantilever girder where a high moment and high shear are acting in the same area, it can be shown that buckling of the web will take place at a lower shear value than indicated as safe by the specification. The reason for no recorded failures having taken place is that the web has considerable post-buckling strength.

Except for a general recommendation that structural members be symmetrical, no mention is made in the Specification whether plate girder requirements are for symmetrical or unsymmetrical cross-sections, or both. However, most highway bridges, being composite, are unsymmetrical (orthotropic deck bridges are also unsymmetrical).

Unsymmetrical Girders - Buckling

If it is assumed that the Specification is fully adequate for symmetrical girders, the following problems arise when these rules are applied to unsymmetrical sections.

1. In the area of positive moment where all or at least a major portion of the web is in tension, the stiffener spacing required is overly conservative since the buckling shear stress will be considerably higher. In fact, the limitation on the unstiffened depth can be substantially raised from $d < 60t$. Thus, a saving in the number of stiffeners or their complete elimination would be possible if the actual stress conditions were used.

2. On the other hand, in the areas of negative moment, where most of the web is in compression due to bending, the stiffeners are inadequate to prevent buckling even at working loads.

It can be demonstrated that the factor of safety against web buckling in the areas of positive moment will rise from 1.7 to about 5.0 and in areas of negative moment drop from, say, 1.2 to 0.7.

At this point it can be concluded that in the web buckling criteria there is much room for updating, especially for unsymmetrical girders. Such work can be performed without much difficulty since theoretical and experimental information on buckling is already available. (Some current specifications such as German are formulated along these lines)

Ultimate Strength

Our present state of knowledge indicates that buckling criteria are misleading in evaluating the strength of plate girders. Research at Lehigh University and other institutions has shown that plate girders develop a maximum strength which considerably (often several times) greater than the web buckling strength. The latest AISC Specification for buildings takes this strength into consideration. The work, however, has been done only on symmetrical girders. The behavior and strength of unsymmetrical girders has not been investigated. Similarly to the buckling strength, the ultimate strength of unsymmetrical girders is expected to be substantially different from that of symmetrical girders. Application of the methods for symmetrical girders to unsymmetrical girders will lead to conservative results in the area of positive moment and unconservative (unsafe) in the areas of negative moments.

Thus, in order to fully utilize the plate girder strength with a uniform factor of safety, it is necessary to know how to evaluate it. Only then the maximum economy can be achieved.

Fatigue

Highway bridges are loaded repetitively and therefore are subject to fatigue. Logical design for fatigue requires information on the behavior of the components of the structure (stress variation) and on the fatigue strength of these components (S-N curves).

Fortunately, research for the ultimate strength gives also data on the behavior of the girder in the post-buckling range which can be utilized in the fatigue analysis.

Symmetrical Plate Girders

Research on symmetrical girders is at the stage that the development of guidelines for the fatigue strength design is underway (B. T. Yen's project).

Unsymmetrical Plate Girders

Plate girder components which are endangered by fatigue are: junction of the web to the stiffener, junction of the web to the flange, splices in the flanges. These are the same for symmetrical and unsymmetrical plate girders. Therefore, if research is conducted on the behavior and ultimate strength of unsymmetrical girders, design criteria for the fatigue strength of these girders can be defined using information available for symmetrical girders.

The same research will thus give data for both strength limitations: the ultimate strength and fatigue.

Proposal for Research on Unsymmetrical Plate Girders

The preceding discussion was intended to point out the need for research on the behavior and ultimate strength of unsymmetrical plate girders used for highway bridges. The proposal submitted earlier to PDH and AISI outlines the details of the necessary work and the required budget. Here, I would like to explain why we feel it is advantageous to conduct this research at Lehigh and as soon as possible.

In the first place, the need for urgency is dictated by the desirability of having design criteria for unsymmetrical plate girders, and most girders in highway bridges are unsymmetrical, at least at a comparable level to those for symmetrical girders. Secondly, a research program on the behavior of unsymmetrical girders, if started now, will very smoothly dovetail into the development of design procedures for the fatigue strength of symmetrical girders. The result will be that design procedures for unsymmetrical plate girders could be developed concurrently or soon after, with a minimum loss of time. Additional advantage of doing the work soon is coupled with the opportunity of utilizing the experience of some research and technical personnel at Lehigh who participated in the earlier research on plate girders. Their familiarity with testing procedures and personal observations of the plate girder behavior will be of considerable assistance in the new research. Finally, facilities of Fritz Laboratory are well suited for conducting tests anticipated in the program.