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Final report on research projects on symmetrical welded plate girders, December 1972.

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FINAL REPORT ON RESEARCH PROJECTS
ON SYMMETRICAL WELDED PLATE GIRDERS

by

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INTRODUCTION

This report briefly summarizes the objectives, research programs, findings, implementation of results, and recommended future research in the area of welded plate girders. Specifically, the report is for "symmetrical welded plate girders" (PennDOT Research Project 58-4) for the reason that the results of separate efforts on "unsymmetrical plate girders" have been summarized in another report(1).

The research programs were carried out at the Fritz Engineering Laboratory and Department of Civil Engineering, Lehigh University. The programs included four projects under the direction of different research workers. The project titles are:

Welded Plate Girders
Fritz Engineering Laboratory Project 251

Fatigue Strength of Welded Plate Girders
Fritz Engineering Laboratory Project 303

Longitudinally Stiffened Plate Girders
Fritz Engineering Laboratory Project 304

Welded Plate Girders - Design Recommendations
Fritz Engineering Laboratory Project 327

The time periods, sponsors, and research workers of each of these projects are shown in Table 1.

Technical guidance to the projects were provided by the Subcommittee on Welded Plate Girders - Lehigh University, Structural Steel Committee of the Welding Research Council. The members of the Subcommittee during these years are listed in Table 2.

The support and encouragement of the sponsors and the Subcommittee members are gratefully acknowledged.

OBJECTIVES AND PROGRAM

The initial objectives of the research undertaking was to study the web buckling strength of girder web panels, the influence of flange restraint on the behavior of the web panels, and the static load-carrying capacity of heavy-flange thin-web plate girders. As work progressed and results accumulated, new objectives developed and corresponding research programs were then established. These are summarized in Table 3.

The project "Welded Plate Girders" investigated theoretically and experimentally the static strength of thin-web plate girders, and developed design guidelines. Investigations were also made on the behavior of transverse stiffeners on webs, of girder ends, and of partial length coverplates. Design recommendations resulted in new specifications for plate girders in buildings.

Preliminary application of project-recommended design rules for building-girders to bridge-girders led to the project "Fatigue Strength of Welded Plate Girders". Experimental studies were carried out together with analysis of the influence of repeated lateral deflection of web on the strength of plate girders.

The influence of longitudinal stiffeners on the static behavior and load-carrying capacity of plate girders constituted another extension of the initial project. Adoption of analytical methods of girder strength prediction to girders with longitudinal stiffeners coupled with experimental observations in providing background information for bridge girder design.

The last project, "Welded Plate Girders - Design Recommendations", incorporated results of earlier studies for the formulation of design recommendations for bridge plate girders. Proof-testing of girders, designed according to these rules, was a part of the program.

RESEARCH FINDINGS

Some of the more important results of the projects are the following:

1. Buckling of a web seldom occurs on steel plate girders. Web buckling strength is not the strength of a plate girder, neither is the girder load-carrying capacity a linear function of the web buckling load (251.11 to 14 and 251.29).

2. The bending strength of a plate girder is determined from the strength of an equivalent compression flange column which consists

of the compression flange proper and an effective part of the web. The resistance of the equivalent column against buckling (lateral, torsional, and vertical towards web) is therefore of paramount importance (251.19).

3. Girder panels under high shear have high post-buckling strength if adequate transverse stiffeners or boundary supports are provided. Tension fields develop, analogous to the tension diagonals of a Pratt truss, and contribute to the shear strength (251.20).

4. The strength of girder panels subjected to both bending moment and shearing is, in general, governed by either bending or shear alone. Interaction is significant only when bending and shearing stresses are both high, for example, above 75 percent of yield point and 60 percent of computed tension field stress, respectively (251.21, 251.29).

5. Methods for prediction of load-carrying capacity of plate girders were verified by the results of testing large-size girders. Girder strength can be expressed in terms of the yield point of the girder material and geometrical parameters (251.19 to 21).

6. Transverse stiffeners can be cut short from the tension flange to facilitate fabrication (251.6).

7. A minimum area as well as a minimum rigidity are required of transverse stiffeners to sustain the tension field action of web panels (251.20).

8. Ends of girders must be strong enough to anchor a tension field action. One way of providing for such anchorage is to add an end plate transverse to the girder web. The other is to place the stiffeners for the last panel so as to prevent a tension field action from developing (251.20, 251.29).

9. Stress transfer from a flange to a partial-length cover plate is found to be gradual. No sudden increase of stress occurs at the cutoff points (251.15).

10. Stress transfer in loading stiffeners is also found to be gradual, being almost linear from the loading end to the opposite end (251.15).

11. Longitudinal stiffeners reduce lateral deflection of girder web when compared to deflections of webs with only transverse stiffeners (304.8, 327.7).

12. In girders subjected to bending, a longitudinal stiffener at one-fifth of the web depth from the compression flange effectively maintains the linear distribution of beam-theory flexural streses across the girder depth (304.8).

13. The bending strength of the longitudinally stiffened girder can be determined in the same way as for transversely stiffened plate girders if beam theory stresses are used (304.9).

14. For girders subjected to high shear, longitudinal stiffeners force separate tension fields in the subpanels. The shear strength of a panel is the sum of the strength of the subpanels (304.8, 304.9).

15. Correlations were good between predicted and experimentally observed load-carrying capacity of girders with longitudinal stiffeners (304.9).

16. Longitudinal stiffeners must fulfill requirements of rigidity, cross-sectional area, and width-to-thickness ratio so as to be effective (304.9).

17. If repeated loads are applied to a girder, its web moves repeatedly between two lateral positions and in synchronization with the load (251.26A, 303.10).

18. The consequence of severe lateral movement of web is the possibility of fatigue cracks along the boundary of thin webs (251.26A, 303.10).

19. The web plate bending stress ranges by lateral deflections were found to correlate well with the number of load cycles at which cracks occurred (303.10).

20. A method was developed for estimating, from measured web deflections, plate bending stresses at web panel boundaries. These calculated stresses were in good agreement with stresses obtained from measured strains (327.2).

21. Longitudinally stiffeners reduce lateral deflection of web and the possibility of fatigue cracks at web panel boundaries (327.7).

22. For plate girders with web thickness conformed to the minimum requirements for highway bridges, the lateral deflections of web were relatively small and no fatigue cracks were observed in these web panels in the test girders of these projects (327.7).

These results have been presented in various reports. Table 4 lists the published and some unpublished reports of the projects.

IMPLEMENTATION

1. Based on the findings of the initial research project on welded plate girders (251), design recommendations were formulated for plate girders in buildings (251.23) and for the static strength design of bridge girders (251.25).

The recommended limits on web slenderness ratio, web panel proportion, stiffener size and rigidity, stiffener spacing, and flange proportioning were all incorporated by the American Institite of Steel Construction in its specifications since 1961[(2)].

2. From the results of studies on longitudinally stiffened girders (304), on fatigue of plate girders (303), as well as on unsymmetrical plate girders, design recommendations were derived for highway bridges by the

load-factor design procedure[3]. These recommendations have now been adopted by the American Association of State Highway Officials[4].

For the design of highway bridge girders using the allowable stress approach, recommended rules are included in Fritz Engineering Laboratory Report 327.6F, entitled "Design Recommendations for Bridge Plate Girders". The submission of these proposed rules through the Pennsylvania Department of Transportation to AASHO for adoption is expected.

RECOMMENDATIONS FOR FUTURE RESEARCH

One of the results of these research projects is the widespread interest in plate girder strength in this country and abroad[5]. Most of these recent studies are refinements to the analyses by the projects which are summarized here. Efforts may be made to incorporate the refinements into detailed design rules.

More urgently needed for design purposes, thus recommended here, include the following areas:

1. Strength of composite plate girders (not beams) with and without transverse stiffeners.
2. Strength and behavior of haunched (straight and curved) plate girders.

3. Load-carrying capacity of horizontally curved plate girders.

4. Application of available results from plate girder studies to the analysis of box girders.

Work is in progress which covers parts of items 1 and 4 above. Research pursuit in the direction of items 2 and 3 should be initiated.

TABLE 1

Project Title	Welded Plate Girders (251)	Fatigue Strength of Welded Plate Girders (303)	Longitudinally Stiffened Plate Girders (304)	Welded Plate Girders - Design Recommendations (327)
Project Period	February 1958-July 1963	August 1963-July 1966	August 1963-July 1966	August 1966-September 1969
Sponsors	Welding Research Council American Institute of Steel Construction U. S. Bureau of Public Roads Pennsylvania Department of Highways (58-4)			Welding Research Council American Iron & Steel Institute (134) U. S. Federal Highway Administration Pennsylvania Department of Transportation (58-4)
Other Contributors	Association of American Railroads Fort Pitt Bridge Co. Great Lakes Steel Corp. R. C. Mahon Co.			
Project Personnel	L. S. Beedle B. Thurlimann K. Basler B. T. Yen P. B. Cooper J. A. Mueller H. S. Lew M. U. Taysi J. S. Toh	L. S. Beedle B. T. Yen A. Ostapenko P. B. Cooper J. A. Mueller J. A. Corrado K. E. Dudley	L. S. Beedle T. V. Galambos A. Ostapenko P. B. Cooper B. T. Yen D. J. Fielding M. A. D'Apice	L. S. Beedle B. T. Yen A. Ostapenko J. A. Mueller J. A. Corrado J. S. Huang P. J. Patterson

TABLE 2

Members of Subcommittee on Welded Plate Girders - Lehigh University, Structural Steel Committee of The Welding Research Council

E. L. Erickson	W. B. McLean
M. Denterman	W. A. Milek
G. F. Fox	N. W. Morgan
J. H. Adams	T. A. Mowatt
A. Amirikian	W. H. Munse
L. S. Beedle	J. F. Oyler
Karl deVries	E. O. Paulet
L. H. Daniels	E. Pisetzner
F. H. Dill	E. J. Ruble
J. L. Durkee	F. Sankey
E. R. Estes	C. F. Schelley
J. A. Gilligan	J. E. South
LaMotte Grover	R. H. Stuchell
W. C. Hansell	Bruno Thurlimann
K. H. Heilman	Neil Van Eenam
T. R. Higgins	J. Vasta
W. H. Jameson	Ivan M. Viest
C. D. Jensen	George Winter
Knut Jensen	W. Spraragen
Bruce G. Johnston	C. A. Zwissler
H. Juhl	C. F. Larson
R. L. Ketter	
M. L. Hoehler	
K. H. Koopman	
George Lam	

TABLE 3

PROJECT OBJECTIVES AND RESEARCH PROGRAMS

Project	Objectives	Programs
Welded Plate Girders	1. Survey knowledge of plate girder behavior, stability and load-carrying capacity. 2. Theoretical studies on static strength of plate girders. 3. Observation of static behavior. 4. Development of design guidelines.	1. Literature Survey. 2. Development of methods for the prediction of plate girder strength in bending, shear, and combined bending and shear. 3. Testing of large-size welded plate girders under static loading. 4. Formulation of design recommendations.
Fatigue Strength of Welded Plate Girders	1. Observation of fatigue behavior of web panels of welded plate girders. 2. Analysis of influence of repeated lateral deflection of web on the strength of plate girders.	1. Testing of large-size welded plate girders under repeated loading. 2. Development of method for estimation of web boundary stresses and fatigue strength of web panels.
Longitudinally Stiffened Plate Girders	1. Theoretical studies on static strength of plate girders with longitudinally stiffeners. 2. Observation of static behavior.	1. Development of methods for the prediction of load-carrying capacity of girders under bending and shear. 2. Testing of large-size girders.
Welded Plate Girders - Design Recommendations	1. Development of Design Recommendations considering both static and fatigue strength of plate girders. 2. Experimental verification of recommended rules.	1. Formulation of design recommendations. 2. Proof-testing of large-size welded plate girders designed according to recommended rules.

TABLE 4

A. LIST OF PUBLISHED REPORTS

251.2 B. Thurlimann
STRENGTH OF PLATE GIRDERS
Proc. AISC National Engineering Conference, April 1958

251.6 K. Basler and B. Thurlimann
PLATE GIRDER RESEARCH
Proc. AISC National Engineering Conference, April 1959

251.7 K. Basler and B. Thurlimann
BUCKLING TESTS ON PLATE GIRDERS
Preliminary Report, 6th Congress of IABSE, 1960

251.11 to 251.14 K. Basler, B. T. Yen, J. A. Mueller and B. Thurlimann
WEB BUCKLING TESTS ON WELDED PLATE GIRDERS
WRC Bulletin No. 64, September 1960

251.15 J. A. Mueller
STRESSES IN COVER PLATES AND BEARING STIFFENERS
WRC Bulletin No. 63, August 1960

251.16 K. Basler
FURTHER TESTS ON WELDED PLATE GIRDERS
Proc. AISC National Engineering Conference, June 1960

251.18 K. Basler and B. Thurlimann
BUCKLING TESTS ON PLATE GIRDERS
Final Report, 6th Congress of IABSE, July 1960

251.19 K. Basler and B. Thurlimann
STRENGTH OF PLATE GIRDERS IN BENDING
Proc. ASCE, Vol. 87, ST6, August 1961

251.20 K. Basler
STRENGTH OF PLATE GIRDERS IN SHEAR
Proc. ASCE, Vol. 87, ST7, October 1961

251.21 K. Basler
STRENGTH OF PLATE GIRDERS UNDER COMBINED BENDING AND SHEAR
Proc. ASCE, Vol. 87, ST7, October 1961

251.23 K. Basler
NEW PROVISIONS FOR PLATE GIRDER DESIGN
Proc. AISC National Engineering Conference, May 1961

251.25 B. T. Yen and K. Basler
STATIC CARRYING CAPACITY OF STEEL PLATE GIRDERS
HRB Proc., Vol. 41, 1962

251.26A B. T. Yen and P. B. Cooper
FATIGUE TESTS OF WELDED PLATE GIRDERS
AWS Welding Journal, Vol. 42, No. 6, June 1963

251.29 P. B. Cooper, H. S. Lew and B. T. Yen
WELDED CONSTRUCTIONAL ALLOY STEEL PLATE GIRDERS
Proc. ASCE, Vol. 90, ST1, February 1964

303.5 J. W. Fisher and B. T. Yen
Discussion on FLEXURAL FATIGUE TESTS OF PRESTRESSED STEEL I-BEAMS by W. D. Reneker and C. E. Ekberg
Proc. ASCE, Vol. 90, ST4, August 1964

303.10 B. T. Yen and J. A. Mueller
FATIGUE TESTS OF LARGE-SIZE WELDED PLATE GIRDERS
WRC Bulletin No. 118, November 1966

304.8 M. A. D'Apice, D. J. Fielding and P. B. Cooper
STATIC TESTS ON LONGITUDINALLY STIFFENED PLATE GIRDERS
WRC Bulletin No. 117, October 1966

304.9 P. B. Cooper
STRENGTH OF LONGITUDINALLY STIFFENED PLATE GIRDERS
Proc. ASCE, Vol. 93, ST4, April 1967

304.10 P. B. Cooper
THE CONTRIBUTION OF LONGITUDINAL STIFFENERS TO THE STATIC STRENGTH OF PLATE GIRDERS
Highway Research Record 167, 1967

327.2 J. A. Mueller and B. T. Yen
GIRDER WEB BOUNDARY STRESSES AND FATIGUE
WRC Bulletin No. 127, January 1968

327.7 P. J. Patterson, J. S. Huang, J. A. Corrado and B. T. Yen
FATIGUE AND STATIC TESTS OF TWO WELDED PLATE GIRDERS
WRC Bulletin No. 155, October 1970

327.9 A. Ostapenko, B. T. Yen and L. S. Beedle
RESEARCH ON PLATE GIRDERS AT LEHIGH UNIVERSITY
Final Report, 8th Congress of IABSE, September 1968

TABLE 4

B. LIST OF SOME PROJECT REPORTS

(not included in List A)

251.8 K. Basler
STRENGTH OF PLATE GIRDERS
October 1959

251.22 K. Basler
DESIGN RECOMMENDATIONS FOR PLATE GIRDERS
March 1961

251.30 L. S. Beedle and B. T. Yen
A FINAL REPORT ON PROJECT 251 - WELDED PLATE GIRDERS
December 1963

303.1 B. T. Yen
ON THE FATIGUE STRENGTH OF WELDED PLATE GIRDERS
September 1963

303.4 K. E. Dudley, J. A. Mueller and B. T. Yen
LATERAL WEB DEFLECTIONS OF WELDED TEST GIRDERS
June 1966

303.13 B. T. Yen
A SUMMARY REPORT ON THE BEHAVIOR OF THIN-WEB PLATE GIRDERS UNDER REPEATED LOADING
August 1966

304.6 P. B. Cooper
BENDING AND SHEAR STRENGTH OF LONGITUDINALLY STIFFENED PLATE GIRDERS
September 1965

304.11 P. B. Cooper and A. Ostapenko
FINAL REPORT ON PROJECT 304, LONGITUDINALLY STIFFENED PLATE GIRDERS
July 1966

327.4 J. S. Huang and B. T. Yen
STIFFENER REQUIREMENTS FOR PLATE GIRDERS
June 1968

327.6F B. T. Yen
DESIGN RECOMMENDATIONS FOR BRIDGE PLATE GIRDERS
June 1972

REFERENCES

1. Ostapenko, A.
FINAL REPORT ON RESEARCH PROJECT "UNSYMMETRICAL PLATE GIRDERS"
Fritz Engineering Laboratory Report No. 328.16, May 1972

2. AISC
SPECIFICATION FOR THE DESIGN, FABRICATION AND ERECTION OF STRUCTURAL STEEL FOR BUILDINGS (with Commentary)
November 1961

3. Vincent, George S.
TENTATIVE CRITERIA FOR LOAD-FACTOR DESIGN OF STEEL HIGHWAY BRIDGES
American Iron and Steel Institute, February 1968

4. AASHO
INTERIM SPECIFICATION, 1971

5. IABSE
SUMMARY REPORT, COLLOQUIM ON THE ULTIMATE RESISTANCE OF PLATE GIRDERS WITH STIFFENED WEBS
April 1971