

Welded Continuous Frames and Their Components

Progress Report G

STRUCTURAL RESEARCH AT CAMBRIDGE UNIVERSITY

and

CURRENT OR RECENTLY-COMPLETED RESEARCH

AT OTHER ENGLISH INSTITUTIONS

The report of a visit to the Engineering Laboratory, Cambridge University, during the months of October, November, and December, 1949.

by

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SPONSORS

Welding Research Council
American Institute of Steel Construction
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Office of Naval Research
Bureau of Yards and Docks
Bureau of Ships
American Iron and Steel Institute
Column Research Council
Lehigh University Institute of Research

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Fritz Engineering Laboratory
Department of Civil Engineering and Mechanics
Lehigh University

PURPOSE OF TRIP

At the time of the U. S. Navy-sponsored plasticity symposium at Brown University (April, 1949) Professor J. F. Baker extended an invitation to the writer through Mr. A. Ramsay Moon⁽¹⁾ to spend three months with his research team at Cambridge University. The sponsors of the Lehigh University project, "Welded Continuous Frames and Their Components," subsequently approved financial support of the trip with the intent to promote closer liaison between the similar projects at the two institutions.

In the project at Lehigh carried on in the Fritz Engineering Laboratory of the Department of Civil Engineering and Mechanics, the behavior of rolled structural steel members in the initial yield and plastic zones is being studied. Many published reports describe the Cambridge University project, "Investigation into the Behavior of Welded Rigid Frame Structures", being carried on under the auspices of the British Welding Research Association. In most of their experimental program, first commenced in 1936, tests have been made on large numbers of small models.

Some of the specific objectives of the trip to Cambridge were:

1. to observe their methods and participate in actual research work,
2. to exchange unpublished data,
3. to mutually criticize Cambridge and Lehigh programs, and
4. to visit other laboratories in England in which similar work was underway.

In summary, as expressed at the October meeting of the Institution of Structural Engineers, London, it was hoped to establish such a contact at Cambridge University that each group could participate in the planning of one-another's projects, thus making more complete use of the limited research funds available.

INSTITUTIONS VISITED

A majority of the time was spent in Cambridge, although seven days out of the eleven weeks stay were used in visiting other places in England as noted below:

<u>Organization</u>	<u>Personnel</u>	<u>activities</u>
Strip and Sheet Metal Users Technical Association	Prof. M. Ros	Prof. Ros delivered a paper on static failure and fatigue

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 (1) Former Director, British Welding Research Association

<u>Organization</u>	<u>Personnel</u>	<u>activities</u>
Institution of Mechanical Engineers	Dr. H. J. Gough	Dr. Gough delivered the IME Presidential Address on fatigue under combined cyclic and static stresses
Institution of Structural Engineers	Prof. J. F. Baker	Paper, "The Design of Steel Frames"
King's College (University of London)	Dr. A. W. Hendry	Discuss column, connection, frame projects
University of Bristol	Prof. A. G. Pugsley Mr. J. V. duPlessis Dr. Flint Dr. Cullimore Mr. Chilvers	Examine structural research facilities, discuss projects
Naval Establishment, Bath	V. G. Shephard L. G. Stevens H. T. Johnson R. J. Daniel	Round table discussion of structural problems of mutual interest
National Physical Laboratory (Teddington)	D. G. Sopwith C. E. Philips H. L. Cox F. Lughtie	Inspect Engineering Division facilities and discuss research projects
Institution of Civil Engineers (meeting of The Institute of Welding)	Henri M. Schnadt	Paper on methods of studying and testing metals

The writer's activities and discussions at Cambridge University were primarily with members of the team studying plasticity in structures: Prof. J. F. Baker, Dr. J. W. Roderick, Mr. M. R. Horne, Mr. R. A. Foulkes.

ACTIVITIES AT CAMBRIDGE UNIVERSITY(2)

As a temporary member of the Cambridge team, the writer assisted in current projects wherever feasible, by this method becoming familiar with their techniques. Specific activities:

1. participate in tests of small-scale columns and beams,
2. assist in fabrication of test specimens and in preparations for tests,
3. prepare preliminary computations prior to tests and carry out some analysis of test results,
4. review some unpublished data and reports,

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(2) See Appendix 1 for itinerary outline.

5. prepare two memoranda on column tests,
6. study design methods (using plasticity),
7. review several engineering projects other than those of the plasticity group, and,
8. engage in frequent round-table discussions.

SUMMARY OF CURRENT WORK

The listing of structural research projects in this section claims to be complete only in the case of the plasticity group at Cambridge University.

Additional information on the following projects is available from the writer upon request.

I. Cambridge - Plasticity Group - Projects Underway

1. Design studios...A handbook is being prepared to guide engineers in using the plastic design method. A number of chapters have been completed and it is hoped to release the work shortly. Numerous examples have been worked out, comparison being made with the results of elastic design.
2. Column tests...
 - (a) Problems arising out of the design studies are examined, use being made of the recently-developed scale model technique. These tests are conducted in a frame designed to accommodate a 7-story structure (10-inch story heights) with three bays in each of four perpendicular directions from the central column. The twenty-inch span length is adjustable.
 - (b) The analytical solution of the more general problem --the column as part of a tier building frame --is under continued study.
3. Lateral buckling of beams...Small-scale I-section models are being loaded with pure bending moments to investigate this type of failure in the inelastic range.
4. Development of small-scale I-section model technique...This work is nearly complete, the specimens being used in studies 2 and 3 above. Flanges and webs, cut from sheet material, are joined by silver soldering. Ends are arc-welded to the loading mechanism.
5. Further Design Research...Dr. Neal and Professor Symonds are continuing work commenced at Brown University (U.S.A.).

II. Cambridge - Plasticity Group - Past Work (Unpublished).

Professor Baker has described past unpublished work in his paper, "A Review of Recent Investigations into the Behaviour of Steel Frames in the Plastic Range", January 1949, Institution of Civil Engineers. In outline the following subjects have been studied:

1. Lateral buckling of beams of rectangular section
2. Wind loads on structures
3. Influence of internal stresses

4. Theoretical study of column problem using rectangular section
5. Lateral instability of I-section beams with "fixed" ends
6. Simply-supported mild steel beams
7. The influence of strain-hardening
8. Miniature portal frames
9. Floor loads on structures
10. Effect of shear
11. Moments in rigid welded structures
12. Welded connections
13. Full-scale portal frame tests

III. Cambridge - Plasticity Group - Past Work (Published). This is summarized in two 1949 papers by Professor Baker: the Institution of Civil Engineers paper (above) and "The Design of Steel Frames", The Structural Engineer, October, 1949. Both articles contain extended bibliographies. Subjects covered: design methods, beams, portal frames, columns of rectangular and I section bent in single and double curvature about their minor axes, wind loads, moment distribution.

IV. Cambridge - Other Structural Research - Current or Recently Completed.

1. Impact on welded structures
2. Plates under edge compression and lateral uniform pressure
3. Lateral buckling of beams - light alloy
4. Columns - light alloy
5. Battened columns
6. Resistance welding
7. Pressure vessel research
8. Brittle fracture research

V. King's College - University of London. Dr. A. W. Hendry has recently transmitted two papers to the Institution of Structural Engineers for publication in their Journal. His tests have been performed on connections of various types, on rectangular portal frames under vertical load and on columns of short length under combined axial load and bending moment. Considerable attention has been devoted to the effect of shear forces.

VI. University of Bristol, Department of Civil Engineering. Professor Pugsley's group has been working on the following:

1. Study of elasto-plastic deformations
2. Influence of loading sequence (columns)
3. Columns under bi-axial moments
4. Local buckling of cold-rolled sections
5. Lateral buckling of beams
6. Torsion of aluminum alloy structural members

FUTURE WORK OF CAMBRIDGE PLASTICITY GROUP

For the time being considerable emphasis is being placed on the completion of the portal frame design handbook. Therefore, a portion of the experimental program is aimed at solving problems that may arise during this study.

No full scale frame tests are planned in the immediate future. It is probable that small scale portals will eventually be tested making use of the new built-up I-section technique previously mentioned.

The tier-building column problem will continue to receive attention, both analytically and experimentally on the column testing frame previously described.

GENERAL ATTITUDE TOWARDS PLASTIC DESIGN IN ENGLAND

Professor Baker is the leader in promoting the adoption in England of the load factor design method based on collapse of the structure. The preponderance of fundamental study in the field of plastic behavior is being done by the Cambridge group. Others look to it for leadership.

"The Design of Steel Frames", by Professor J. F. Baker, was received at the October 1949 Structural Engineers' meeting as an "epoch-making" event. Steel designers, the potential users of the method, are rapidly becoming aware of this work. Requests come to members of the Cambridge team to present papers at technical meetings, considerable discussion taking place at such times.

Important to note is the fact that the British designer is now allowed to use the method. BSS 449⁽³⁾ specifies a load factor of 2.0. Section 29c states, in part:

"...For the purpose of such design accurate methods of structural analysis shall be employed leading to a load factor of 2, based on the calculated or otherwise ascertained failure load of the structure or any of its parts, and due regard shall be paid to the accompanying deformations under working loads, so that deflections and other movements are not in excess of the limits implied in this British Standard."

Considerable interest was expressed in the construction of a building designed by "plastic" methods. Among other things this may have to await the downward revision of the load factor from 2.0 to result in substantial economies over the elastic method. Research on suitable load factors is needed, and a value of 1.75 was often mentioned at Cambridge.

SOME COMMENT RECEIVED ON THE LEHIGH PROGRAM AND ON COLUMN RESEARCH COUNCIL ACTIVITIES

The current investigation of corner connection types should prove to be valuable. The Cambridge group has no such study underway.

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 (3) British Standard Specification, "The Use of Structural Steel Building".

The influence of various connections in the continuous beam investigation was of interest, particularly to the designers at the Naval Establishment, Bath.

The Lehigh column test program was of additional interest to some because the sequence of loading is the reverse of that used at Cambridge, thus providing possible comparison. A proposal outlined by the writer to test columns with fixed end rotations (but a variable in the program) would be supported by Cambridge personnel. It was also suggested that the Lehigh program include columns of annealed material.

There was a universal expression of the need for Dr. Bleich's literature review, "The Buckling Strength of Metal Structures", and for the survey of current instability research, in which Professor Baker and others are assisting. These reports will receive considerable distribution in England.

COMMENT ON THE CAMBRIDGE PROGRAM

The Cambridge group with Professor Baker as its chief, has earned its present leading position. Further worthwhile results, both analytical and experimental, will definitely be forthcoming.

The new scale model technique by which small I-sections may be inexpensively built up seems very promising. A section 2" deep, with a flange width of 1" and in lengths varying from 9" to 48" have successfully been tested as beams. It is the writer's opinion that a scale effect, possibly peculiar to structural steel, requires study, and further efforts are to be made along this line.

RESULTS

The immediate goals of the trip were accomplished. It has been arranged with Professor Baker to exchange proposals for future tests. In particular, the program of column tests to follow the pilot series in which the writer participated at Cambridge will be forwarded to Lehigh for comment. By the same token, future plans for tests at Lehigh will receive scrutiny from the Cambridge group in time for inclusion of their ideas in the Lehigh investigations wherever possible. This, and the future intimate exchange of data constitute one of the most worthwhile results of the trip.

A series of model tests (using members other than rolled shapes) is not planned at Lehigh. There seem to be sufficient problems inherent in rolled members to make worthwhile the continuation of "full-scale" tests without the use of models since Professor Baker's group is making excellent coverage of the "small-scale" field. The two investigations support one another in this respect.

Advantage was taken of the opportunity of getting criticism from the Cambridge group on several American proposals, not a part of the current Lehigh welded rigid frame investigation.

Consideration is being given to the exchange between the two groups of material for coupon tests. A direct comparison of steels and of coupon test methods would be afforded since both Lehigh and Cambridge would make tests from the same material.

To investigate the possible scale effect of yielding in I-shaped members of structural steel, it is planned to test a column under loading conditions similar to those used at Cambridge in one of the previously-mentioned pilot column tests. The test planned at Lehigh involves but a slight modification of program and a rearrangement of schedule.

ACKNOWLEDGEMENTS

Particular comment should be made of the hospitality accorded the writer by those he visited in England. The Cambridge group was especially cooperative in making available any data desired and in their frank discussions of projects.

The support of sponsors of the current Lehigh investigation, of the Column Research Council and of the Lehigh University Institute of Research made the trip financially possible. The Office of Naval Research provided transportation through the Military Air Transport Service.

Finally, personal acknowledgements are made to Professor Baker, Mr. A. Ramsay Moon, and Dr. Bruce G. Johnston for continued help in arrangements for the trip.

ITINERARY OUTLINE

1949

- Sept. 27 Leave Washington, D.C. 7:30 p.m.
 28 Washington, D.C. to Azores
 29 Azores to London
 30 Arrive Cambridge
- Oct. 1 to 20 Cambridge: Discussions with personnel, lateral buckling tests, column test, study papers
 21 London: Papers by Ros, Gough, BWRA luncheon
 22 to 26 Cambridge: Study papers, column notes, beam test
 27 London: Professor Baker's paper at Institution of Structural Engineers
 28 to 30 London: King's College, Dr. Hondry (28th)
 31 Cambridge: Study papers
- Nov. 1 to 12 Cambridge: Beam test, computations for column tests, fabrication of model specimens
 13 to 14 Bristol: Visit to Engineering Laboratories and discussion with personnel.
 15 Bath: Naval Establishment (Admiralty)
 16 London: Office of Naval Research
 17 to 19 Cambridge: Discussions with Dr. Roderick.
 20 to 21 London: National Physical Laboratory
 22 to 30 Cambridge: Set-up and test first I-section model column, commence design studies, colloquium on graduate research in America
 30 London: Building exhibition, lecture by M. Schnadt
- Dec. 1 to 8 Cambridge: Design studies
 Preparation and test of second I-section column
 Memo on column tests
 8 London: Athenaeum (Professor Baker)
 Office of Naval Research
 9 to 13 Cambridge: Memo on design requirements of columns
 Discussion of plate tests
 Meeting with Professor Baker and Dr. Roderick
- Note: Each Thursday afternoon and evening discussed general objectives and methods with Dr. Roderick.
- 13 Leave Cambridge
 14 Burtonwood, England (awaiting transportation)
 16 Leave Burtonwood
 17 Azores to Washington, D.C.
 18 Washington, D.C. to Portsmouth
 27 Meeting with Mr. Crowley in Washington, D.C.
 Return to Bothlechem
 Dec. 28 Return to Fritz Engineering Laboratory.