205A.39

COLUMNS IN CONTINUOUS FRAMES

"PROJECT 205A"

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A FINAL REPORT

by

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INTRODUCTION

The research work on the project "Columns in Continuous Frames" (205A) will be formally terminated on June 30, 1964. At that time this project will have been in existence for 16 years. Its termination marks the fact that most of the original objectives have been reached, and that further work can best be accomplished in the framework of newer projects.

The official completion of the project does by no means signify that all problems in connection with beam-columns have been solved. There is yet much to be learned about these members, and the work continues, within different contexts and with somewhat altered objectives, in the research projects,

Multi-Story Frames (273)

Frame Stability (276)

Restrained Columns (278)

Plastic Design in High Strength Steel (297)

This brief report is written to review the history of Project 205A, and to bring into perspective the importance of the research results on recent developments leading to a better design of steel structures.

PROJECT OBJECTIVES

Very early in the development of Plastic Design it was realized that the practical implementation of this new design method depended on a full knowledge of the behavior of the individual members comprising the structural frame. The first item listed among the original objectives of the project "Welded Continuous Frames and Their Components" (approved by the Lehigh Project Subcommittee of the Welding Research Council, March 1950) states this need as follows:

> "To determine the behavior of steel beams, columns, and continuous welded connections, with emphasis on plastic behavior, and to develop theories to predict such behavior".

Thus the objectives of the 205A project were to find out as much as possible about the behavior of steel beam-columns, especially in the inelastic range, and to develop design procedures which reflect the true behavior of such members to a better degree

than the previous procedures. Importance was to be placed on the development of theories which would permit the efficient utilization of beam-columns in plastically designed steel frames.

The original objectives of the work have now been achieved. Present research in plastic design is concerned with the behavior of a whole assemblage of members (for example, research on the behavior of multi-story frames), rather than with individual structural components. The research in beam-columns has furnished an important cornerstone in the present work, and it has led to an improved understanding of inelastic behavior.

HISTORY OF PROJECT 205A

The history of any research project is much more than a list of dates, reports, participants, and conclusions. A research project is most of all a succession of trials, errors, and sometimes, successes. It furnishes the arena in which students mature and in which eventually understanding is gained. These intangible aspects of research should be remembered as the following tangible facts are reviewed.

One of the principal reasons for the rejection of plastic design by European engineers (IABSE Congress, 1936) was the realization that beam-columns do not possess an unlimited yield plateau,

and that the prediction of the inelastic behavior of beam-columns is anyway too hopelessly complicated to ever allow tractable design office calculations. Despite this pessimistic augury of their European collegues, the research groups at Cambridge and Lehigh had faith that the problem could be resolved. Plans were made right after World War II to commence work on plastic design at Lehigh, and the preliminary work on beam-columns got started in 1946 under the leadership of Prof. Bruce Johnston and the sponsorship of the American Institute of Steel Construction. (Project 204).

In 1948 the column project was combined with several other projects to form the present "Welded Continuous Frames and Their Components" project (205). The column work continued as a sub-project of the 205 work.

This research was guided since 1948 by the Lehigh Project Subcommittee of the Welding Research Council, with Dr. T. R. Higgins as chairman.

Financial sponsorship of the project was shared by the following agencies:

American Institute of Steel Construction

American Iron and Steel Institute

U. S. Navy, Office of Naval Research

U. S. Navy, Bureau of Yards and Docks

U. S. Navy, Bureau of Ships

Lehigh Institute of Research

Welding Research Council

In addition to the guidance received from the WRC and the sponsoring agencies, various committees and task groups of the Column Research Council acted in advisory capacity to project 205A.

The following persons were employed as research workers, supervisors, and directors of the 205A work:

B. G. Johnston
L. S. Beedle
J. A. Ready
C. H. Chen
J. Ruzek
R. L. Ketter
E. L. Kaminsky
P. C. Paris
R. C. Van Kuren
Y. Fukumoto
T. V. Galambos
P. F. Adams
M. G. Lay

In addition to the persons listed above, there were many who contributed in working on special graduate research projects, who assisted in the experimental work, and who gave much of their time in advice and encouragement.

ORGANIZATION OF THE RESEARCH

The research on beam-columns proceeded by a combination of literature search, theoretical work, experimental work, and

evaluation of the results. It can be roughly subdivided into the following interrelated phases:

(1) Study of material properties (yield stress level, residual stresses - in conjunction with another research project).

(2) Evaluation of available beam-column research performed elsewhere or prior to this work.

(3) Moment-Curvature studies.

(4) Development of ultimate strength interaction curves.

(5) Study of the effect of lateral-torsional buckling.

(6) Full scale beam-column tests.

(a) Development of a test set-up and testing procedure.

(b) Tests on unbraced wide-flange beam-columns (27 tests).

(c) Tests on braced wide-flange beam-columns (10 tests).

(7) Study of the inelastic deformation capacity (in conjunction with the project "Restrained Columns").

(8) Development of interaction equations for use in design.

(9) Evaluation of the reliability of widely used design rules.

RESULTS AND CONCLUSIONS

Following is a list of the principal results of the research carried out in the 205A project:

(1) Elastic theory is unable to give rational account of the behavior of beam-columns.

(2) The ultimate strength of beam-columns cannot be accurately predicted unless the influence of residual stresses is included in the analysis.

(3) Numerical methods were developed for determining the ultimate strength of steel beam-columns which are subjected to moments in a plane of symmetry and which fail by excessive inelastic deformation in the plane of the applied moments.

(4) Calculations were performed for various practical loading cases and the results were presented in the form of ultimate strength interaction curves which related the axial force, the slenderness ratio and the applied moments.

(5) Some of these interaction curves were reduced by curve fitting into simple empirical equations which are now incorporated into Part II of the 1963 AISC Specifications.

(6) The reliability of the ultimate strength predictions was shown to be excellent by comparison with tests performed at Lehigh in conjunction with the theoretical work, and with tests performed elsewhere.

(7) The interaction equations in Part I of the AISC Specifications were examined in the light of the ultimate strength theory, and found satisfactory.

(8) Methods were developed (in conjunction with project 278) to predict the complete load-deformation history of beam-columns failing by excessive bending in the plane of the applied moments. The theoretical relationships were in good accord with experimental measurements, and they served as the basis of further work on multi-story frames.

(9) Analytical procedures were developed for predicting the onset of lateral-torsional buckling in wide-flange beams and beam-columns in the inelastic range. Theoretical and experimental results showed good agreement. It was found that the size of the wide-flange member and the residual stresses have a marked effect on the lateral-torsional buckling strength.

(10) It was shown how the inelastic rotation capacity is influenced by loading condition, end moment ratio, axial force, slenderness ratio, and lateral-torsional and local buckling, and curves were presented for assessing rotation capacities of many practical situations.

IN SUMMARY

Largely as a result of the research performed in the 205A project it is possible to predict with very good accuracy, the behavior of beam-columns loaded such that bending results about one of the principal axes of the member. This research has given impetus to work in other universities and to the work at Lehigh on the projects concerned with restrained columns, high-strength steel, frame stability, and multi-story frames. The experimental and theoretical techniques which were developed can be used, and already are used in some cases, for studying beam-columns of other than wide-flange shapes (for example box shaped members), and of other materials than structural steel (high strength steels, aluminum, concrete).

FUTURE WORK

There is one area of study which has been included among the objectives of the 205A project but which has not been completed. This area of research is the work on the biaxial bending of beam-columns in the inelastic range. Some preliminary work was done, however, full scale research on this problem has not been performed.

One of the reasons for this omission is that the behavior of beam-columns under biaxial bending is vastly more complicated than the uniaxial situation. Should work continue in this area, it could only be performed as a full study within the framework of a separate project. At this time (1963) research projects on biaxial bending are in existence at various other institutions. Pending the outcome of this work, it was decided to wait until further work in this phase of beam-column behavior is resumed.

The problem of biaxial bending, and its related problems (for example, the post-buckling behavior of beam-columns after lateral-torsional or local buckling), remain to-day among the most important unsolved problems in structural research.

PRINCIPAL PUBLISHED REPORTS

WRC-ASCE
COMMENTARY ON PLASTIC DESIGN IN STEEL, Chapt. 7, COMPRESSION MEMBERS, ASCE Manual No. 41, 1961.

R. L. Ketter, L. S. Beedle, B. G. Johnston
COLUMN STRENGTH UNDER COMBINED BENDING AND THRUST, Welding Journal, 31 (12), p. 607, (1952).

R. L. Ketter, E. L. Kaminsky, L. S. Beedle
PLASTIC DEFORMATION OF WIDE-FLANGE BEAM-COLUMNS Trans. ASCE, Vol. 120, p. 1028 (1955).

R. L. Ketter
STABILITY OF BEAM-COLUMNS ABOVE THE ELASTIC LIMIT, ASCE Proc. Sep. 692, Vol. 81, 1954.

R. L. Ketter, T. V. Galambos
COLUMNS UNDER COMBINED BENDING AND THRUST, Trans. ASCE, Part I, p. 1, (1961).

Several further reports have recently been submitted for publication, and it is planned to submit several others in the near future.

Append entire list

Note: add related RLK tests at Buffalo