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The Lehigh Project:

WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS

(Objectives, Accomplishments, and Further Work)

I. OBJECTIVES OF THE LEHIGH PROJECT SUBCOMMITTEE

The program is designed to give basic information on the behavior of beams, columns, connections and rigid frame structures through the elastic range and into the plastic range, with the hope of developing a rational method of balanced design that will result in considerable savings in steel. It should also be possible to predict for engineering purposes the actual collapse strength of existing structures. The program has now completed its third year.

At its meeting in New York on March 24, 1950, the Lehigh Project Subcommittee of the Structural Steel Committee, Welding Research Council, approved the following statement of objectives.

1. 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.

2. To determine how to proportion various types of welded continuous frames to develop the most balanced resistance in the plastic range so that the greatest possible collapse load will be ~~reduced~~ reached.

3. To determine procedures of analysis that will enable one to calculate the collapse loads of welded continuous frames and to verify the analysis by suitable tests.

4. To determine procedures of analysis that will enable one to calculate the elastic and permanent deformations in welded continuous frames in the range intermediate between elastic limit and collapse load.

5. To explore limitations in the application of plastic range design over and above deformation limitations, namely, fatigue, local buckling, lateral buckling, etc.

6. To develop practical design procedures for the utilization of reserve plastic strength in the design of continuous welded frames.

II. ACCOMPLISHMENTS TO DATE

Over sixty tests on full-size rolled steel members have been conducted. As is the custom in research projects carried out at the Fritz Laboratory, analytical work has proceeded along with the testing, so that, wherever possible, theoretical curves are presented with experimental results. Comparison is frequently made with existing specifications. Numerous reports have been published in the Research

Supplement of the Welding Journal, and papers and discussions have been presented at the meetings of several other societies. Three PhD candidates have received their degrees having done their research on this program; one is in process at the present time. MS theses have also been completed.

Summarizing the results obtained to date, it is re-stated here that welded continuous construction provides an excellent opportunity to make use in design of the inherent advantages of ~~welded continuous construction~~ welding.

The Lehigh project was originally suggested by the Structural Steel Committee of Welding Research Council to exploit these advantages. By welding, it is possible with economy to transmit the full strength of one rolled section to another. Thus, by continuous construction it is possible to use lighter members to carry the same load. There are possibilities of further economy in materials (of strategic importance at the present time) through use of the so-called "plastic design" methods that have been advocated for some years by Professor Baker in England. One of the important aims of the Lehigh investigation is to explore limitations that may be involved in the utilization of the plastic range in design. The following itemized list summarizes some of the findings up to the present time:

1. Are structural steel members really "elastic" up to the value predicted by theory? In tests of continuous structures yielding occurs at loads as low as about 20% of the predicted initial yield load. Thus at present day working loads most structures have a permanent set of undetermined magnitudes. This local yielding is due to stress-concentration at beam-column connections and at load points.

   As the load is increased, stress concentrations and residual stresses cause an increase in deflection, thus reducing the yield strength. Deflections at the predicted yield load for continuous beams may be from 15% to 28% greater than predicted by elastic theory depending on the rigidity of adjacent members.

2. What are the consequences of the above-mentioned lack of elastic behavior? The only result observed has been to increase the deflection of the structure. There is no particular significance in the theoretical elastic limit for a structural member.

   In structures in which deflection is not a critical item from a statistical point of view, there is nothing in the results of tests conducted which would prevent the further consideration of so-called "plastic design" procedures. It is known that at least one structure has been designed according to this procedure, indicating a substantial savings of material. General application of plastic theory should await further study of local instability.

3. Are bending members of WF-shapes as strong as predicted by current theories? Residual stress lowers the strength in the early plastic portion of the load-deformation curve by as much as 10%. However, after further plastic straining (unless limited by local buckling) the strength approaches that predicted by the simple plastic theory and at a deformation about five times the elastic limit deflection.

4. How do structural members "fail"? Except for a few corner connections which were tested by pulling apart the two members joined, all failures have been due to plastic instability. After a certain amount of straining beyond the elastic limit, flange elements buckle locally. The property of rolled sections to withstand this type of failure is thus important and is currently being studied.

For the heavier cross-sections tested in which instability failures have not occurred, the experiments have been stopped when the deflection became so large that further loading would be of no practical value.

5. What is the influence of residual stress? The project has shown that the buckling strength of a structural member is reduced by residual stresses. Both theoretical and experimental evidence indicates that the strength of a steel column cannot be predicted from tests of small coupons. However both theoretical and experimental methods have been developed to predict (over a limited range) the buckling strength of structural members containing reisudal stress. Through cooperation with the Column Research Council it is believed that it will be possible to move ahead toward developing practical means of translating this information into procedures for analysis and design.

In bending members, the predominant influence of residual stress is to increase the deflection of the member and does not reduce its load-carrying capacity in the plastic range providing local buckling does not occur.

6. To what extent will excessive deflections limit the use of the plastic range in design? It has been shown that the deformation of continuous beams and frames designed by the so-called "plastic methods" will usually be less than that of a similar determinate structure designed by conventional methods.

Methods for predicting deflection in the plastic range have been developed and are presently being reported upon.

It will be important to develop rational deflection limitations.

7. <u>Do current column design procedures provide uniform factors of safety?</u> Research on columns has shown that the best economy in design does not result from using the straight line interaction formula. In some regions the formula may be too conservative, and in other regions it is not conservative enough.

In addition to relative magnitude of axial load, a most significant factor is the condition of moment and axial thrust under which the column is loaded in a frame. The addition of bending moment causes a real reduction in the ability of a column to carry axial load.

8. It is possible to design and fabricate with economy simple connections which will carry the full plastic moment. Most of these connections are as rigid or more rigid than an equivalent length of beam. Those of the square type will maintain the plastic hinge moment through relatively large rotations when supported laterally.

Lateral support at the points of maximum strain is essential in portal frame connections.

9. The usefulness of plasticity in structural design is limited by the same factors which cause a modification in present day elastic design.....factors such as brittle fracture, fatigue, etc., when these factors are pertinent. Structures which have "plasticity" and in which deformation under load is not limited by brittle fracture, fatigue, etc., should be designed on the basis of limiting the deflection rather than upon limiting the stress.

10. It should not be overlooked that our present design procedures are based on a long history of satisfactory performance. For example, it is probable that the factor of safety for steel members has included the reduction in carrying capacity due to residual stress. It should be the aim of research to provide the designing engineer with information so that he may improve his knowledge of the behavior of steel structures to the extent that he will know with greater certainty those items which the factor of safety <u>does</u> cover, and may recognize areas in which he may save money through simple design methods and through economical use of material.

III. WORK TO BE DONE DURING THE COMING YEAR

1. Column studies will continue including analysis of data and tests carried out according to the approved program.

2. A series of welded connection tests will be conducted. The subjects for study relate to the design of straight knees (no bracket support), to methods for decreasing the cost and improving the performance of curved and haunched knees, and to the strength of variable-depth haunches built-up by welding.

3. If funds permit, an additional portal frame test will be performed using haunched knees. Frames subjected to sidesway loading must also be tested.

4. Further reports will be issued analysing the results of research and treating design problems.

5. A study of the buckling of flange elements of H-shaped members when stresses exceed the elastic limit will be carried forward both experimentally and analytically. As mentioned earlier this is a limitation to the strength of nearly all structural components.

[illegible] Other related projects are being carried out but are not listed here since they do not receive their financial support through the Welding Research Council. None-the-less, the results should contribute toward the objectives of the Lehigh Project Subcommittee.

IV. <u>BUDGET</u>

The annual budget for the work outlined above is about $27,000.