TWO AND ONE-HALF YEARS OF RESEARCH IN BUILDING MATERIALS
AT LEHIGH UNIVERSITY

by W.A. Slader (First Director of the Lab)

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Two and one-half years is a short time in which to achieve much in research, and fifteen minutes is a still shorter time in which to tell of accomplishments and of the prospects for the future. The best that can be done is to mention the principal projects with a brief sketch of each, then to give a little more detail regarding one of them and end up with a little philosophizing regarding research work in a university. That is what I hope to do.

Welding of structural steel has recently been taking the place of riveting in certain important building projects, and on my arrival at Lehigh University, almost before I had gotten my chair well warmed up, Professor Jansen was at work outlining a research on the welding of steel beams to steel columns. Professor Uhler soon fell into line, and after nearly two years of hard work they wrote a paper for the American Welding Society, which has been reprinted as a Bulletin of Lehigh University. This was nearly the first research work of its kind, and it does credit to Lehigh University.
In the Fall of 1928 the McClinton-Marshall Company asked us to test steel columns for them to determine the relative merits of riveting and welding of the parts of the columns. In one set of columns the plates were welded, and in the other they were riveted. The strengths of the two kinds of columns were found to be equal as nearly as such a series of tests could ascertain. It was found, however, that local stresses were set up by the welding, which were so high that it is likely that under working loads there were stresses approaching the yield-point of the steel. While the strength was not reduced thereby, it seems important that more study be given to this subject.

In the Summer of 1930 the American Welding Society called upon Fritz Engineering Laboratory to make tests of welded tanks of about the size of a range boiler, to form the basis of a ruling on the admissibility of this type of welding under the provisions of the boiler code of the American Society of Mechanical Engineers. The tests were made and showed good results. The report is being considered by the Boiler Code Committee and has been set in type for publication by the Society under the authorship of Professor M. O. Fuller and the speaker.

An extensive series of tests carried out at Columbia University recently, showed strong indication that flame cutting of steel may in some cases, cause such embrittlement of the steel as to endanger the safety of the structure using it.
The report was discredited by some who challenged the investigation, and the subject has become controversial. However, recent happenings in a steel building under construction in a nearby city indicated that there was ample occasion for concern, and Lehigh University was called upon to make tests of some of the questionable material. The results have shown that there was embrittlement and appear to vindicate the report from Columbia University. The tensile strength of the steel, however, was not seriously reduced, and it does not appear that the safety of the structure is endangered by the degree of embrittlement encountered. The tests are still in progress.

In the spring of 1929 the engineering profession was startled by information that the wires in the suspension cables of two important suspension bridges, then under construction, were snapping under a load less than the weight of the structure. Specimens of the wire were brought to Lehigh University and tests were started simultaneously at Fritz Laboratory and in the Department of Metallurgical Engineering to ascertain the conditions. However, even before preliminary results could be secured, the McClintic-Marshall Company, engineers and contractors for the bridges, took positive action, dismantling completely the cables that had been erected and replacing the wires with a wire which had stood the tests of years in previous structures. As our
tests were secured, they justified the action of the
McClintic-Marshall Company, for wires which showed high
strength when tested rapidly to failure, broke after a
few days of carrying an extremely low load. We then
carried out an extensive series of tests on the wire
which was used for replacement. This wire made a good
showing, and a paper based upon our report, was written
by Leon S. Moisseiff, Consulting Engineer, called in by
the McClintic-Marshall Company, and published in the PRO-
CEEDINGS of the American Society for Testing Materials.
Mr. Moisseiff, who is an eminent authority on suspension
bridges, has long been trying to bring about a thorough
laboratory investigation of suspension bridge wire, and
it required this near-disaster to bring the manufacturers
and fabricators to the point of recognizing its importance.

Under the rapidly increasing weight and speed of
locomotives, there has been an alarming increase of rail
failures in the United States, in spite of corresponding
increases in weight of rails. Many agencies have inves-
tigated the subject and though some believe they know the
cause, they have not found the remedy. Nor is there agree-
ment as to the cause. Recently, Fritz Laboratory has under-
taken tests to determine the strain set up by the unequal
cooling of different parts of the rail after rolling. No-
thing can be said regarding probability of ultimate success
except that initial strains at the surface and in the interior of the head of the rail have been small, indicating an initial stress there which was very much less than initial stresses found in structural steel due to other causes. Other parts of the rail may have higher initial strains, but the "transverse fissure" responsible for the failure is found in the head where the initial stresses found have been small.

The foregoing items have dealt with investigations of steel. The following have to do with concrete.

The new Arlington Memorial Bridge across the Potomac River at Washington, D.C., connecting Lincoln Memorial with the General Robert E. Lee Mansion at the Arlington Cemetery, has a draw-span to permit the passage of boats up and down the river. The counterweights used to assist in raising the leaves of the draw-span were required to be of concrete weighing 262 and 273 lb. per cu.ft. The specifications were very rigid, and the Phoenix Bridge Company, contractors, were unable to secure acceptance of any of their proposals. Fritz Laboratory was called upon by the Phoenix Bridge Company to design and test concrete of the required weight for this purpose. After considerable experimental and analytical work, a concrete was made up using steel punchings and iron ore as aggregate, and it was possible to secure any weight within one percent of
that for which it was designed. This concrete abundantly
met the strength requirements and was accepted by the
Government Engineers. Mr. C. C. Keyser is preparing a
paper on these studies for presentation to the American
Concrete Institute.

Colonel Hugh L. Cooper, who has built some of the
greatest power plants in the United States, including the
Wilson Dam of the Muscle Shoals plant, observed that some
of his structures in which the concrete contained larger
percentages of clay than are generally considerable desir-
able, had proven more weather-resistant than those in which
the concrete had no clay. This gave rise to the idea of
ascertaining scientifically the effect on permeability and
resistance to freezing and thawing, of varying quantities
of clay in the concrete. Colonel Cooper is now partially
financing such a research in each of a number of institu-
tions of which Lehigh University is one. Mr. G. W. Park-
inson, Research Fellow, is in charge of this work here.
It is a very complicated and difficult investigation, and
the results so far do not give encouragement to the belief
that the addition of clay to concrete improves any of its
properties except in certain cases where there is too little
cement and fine sand to fill the interstice between the
larger pieces. The work is still under way.
Inspection of concrete-placing has always been a difficult matter because of the ease with which a dishonest contractor can change a mix in a moment, while the inspector's back is turned, and because of the difficulty in making proper allowance for varying degrees of wetness of the sand used. A method has recently been proposed for separating concrete into its constituent ingredients and thus determining whether it meets the specifications. Messrs. Nettles and Holme are carrying out an investigation of the feasibility of the method and of an apparatus which has been built for the purpose.

In a reinforced concrete beam the tensile stresses are resisted principally by the steel reinforcing bars and the compressive stresses by the concrete. The computation of the compressive stresses is based upon theoretical considerations involving the distribution of the deformations set up whenever a beam is bent. At the request of the Portland Cement Association, and with their assistance, Whitn Engineering Laboratory carried out a series of tests to determine whether the strength of a concrete beam is in harmony with the strength predicted on the basis of the stresses computed in accordance with the common theory of flexure. This investigation confirmed the results of previous tests in showing that the higher the strength of the
concrete, the more closely did the results of the tests harmonize with the theoretical analyses used in design. The results of this investigation have been embodied in a paper written by Mr. Lyse of the Portland Cement Association, and the speaker, and published in a recent JOURNAL of the American Concrete Institute. The paper is being reprinted as a Bulletin of Lehigh University.

Although to all external appearances the columns of a reinforced concrete building remain constant in length, it has long been known that a concrete member subjected to continued compressive stresses shortens or "flows" over a long period of time. Steel, however, does not under ordinary conditions shorten appreciably in this manner. If the columns of a building were made wholly of concrete the flow would merely reduce the height of the building slightly, without producing any important effect on the stresses developed. However, if a concrete column reinforced with longitudinal steel rods flows under load, the concrete shirks part of its job, and makes the steel carry more than its original share of the load. To use an exaggerated illustration, it is as though a column were made up by filling a pipe with water and letting the water freeze hard. A heavy weight could be placed upon the end of the column and the ice and the steel of the pipe would
carry the load jointly. If, however, the water melts, the steel pipe is left to carry the load alone. The concrete does not melt, but it shortens slightly and leaves an excess load upon the reinforcing bars. This fact has been known for fifteen years or more, but recognition of it has not found its way into building codes.

About a year ago Fritz Laboratory began an extensive series of tests to afford the basis for a revision of the design standards for reinforced concrete columns. This investigation is being supported by the American Concrete Institute and is being duplicated for the most part at the University of Illinois. Mr. I. Lyce of the Portland Cement Association, who is now stationed at Lehigh University, is in direct charge of the work. As one part of the investigation, 108 columns in each laboratory are being held under their design loads for one year. Up to the present time they have been under load about five months. The stress in the concrete, due to its shrinkage and yielding, has in that time decreased from about 1200 to about 200 lb. per sq.in., and that in the steel has increased from about 11,000 to 35,000 lb. per sq.in., and the end apparently has not yet been reached. In view of the fact that the stress in the reinforcement is rapidly approaching the yield point, the problem presented is of great importance.
In the absence of any other information, the results would be alarming, for columns used in reinforced concrete buildings are subject to conditions at least as severe as those of the test columns. The reassuring feature is that so far as I know, there is not on record a case of failure of a reinforced concrete building except those failures which have occurred during construction due to some abuse such as removing the formwork too soon, or allowing the concrete to freeze before it has thoroughly hardened. Yet measured strains in columns doing satisfactory service in a building have shown stress in the reinforcement of 45,000 lb. per sq.in. The reassuring feature affords no excuse for not getting at the facts, and I believe the concrete industry is to be commended for facing the situation in spite of the fact that until a satisfactory solution is reached, competitive interests may use such information to discredit this type of construction.

The question may reasonably be asked, "Why do columns not fail if the steel is stressed to the yield point?" Of course we do not know the answer, but it seems probable that it is more tradition than reason that leads one to think that they ought to fail. Engineers are steeped in the tradition that under no
circumstances may the stress under design load safely exceed say one-third or one-half the yield point stress. However, since the overloading of the steel has practically unloaded the concrete, the necessary factor of safety is present in the form of the concrete which is ready to take more load whenever the steel becomes too much deformed. Somewhat the same situation exists in Steel structures, though I have no evidence that it is so severe. The welding of reinforcing plates to the sides of a steel column has been shown by tests, to put certain parts of the column under high compression, but at the same time other parts were relieved from carrying their full share of the load. However, when the more highly stressed parts are loaded to the yield point, the unstressed parts come to the rescue and the welded columns carried as high loads as the riveted ones, in spite of the high stresses.

A part of the concrete column investigation is aimed at determining how great a load a column will carry indefinitely without failure. It seems likely that classical methods of design may be completely upset, but so far there has been no evidence that the loads which such columns are to be considered capable of carrying indefinitely, must be reduced. There are even some indications that the flow of the concrete may be advantageous in
certain respects, but that is ahead of the game. The end of the story cannot be known before the completion of the investigation.

Now I wish to conclude with a little philosophizing. Two important services can be rendered by our laboratory, first establishment of properties of materials and principles of design that are of importance to industry, and second, turning out research men. It is difficult to say which of the two functions is the more important, and which is a by-product of the other. The two go hand-in-hand. It is impossible to do any quantity of effective research work of this nature without developing research men, and to me it seems equally impossible to train research men without having real live research work going on around them. We are trying to give a graduate course in methods of research in engineering materials. I would not belittle the value of this course, especially since I am giving it, but there can be no doubt that so far as academic training for research is concerned, the most important factor is a solid foundation in mathematics, physics, chemistry, metallurgy, and English, such as I wish I had.

Too often in the planning of research, insufficient attention is paid to the provision in the organization of an adequate number of men who are capable, not only of making tests under direction, but of planning an investigation,
carrying it out, and writing the report. This failure is likely to result in an accumulation of valuable data in the files, awaiting an opportunity for preparation for publication. Too often the opportunity never arrives. So far we have been protected from the failure to write up our reports by the fact that much of our work has been done for someone who pays for it and who therefore applies sufficient pressure to secure a report more or less promptly. We should like to have the assurance of much more money for research so that we could look farther ahead in planning our work. However, if with the money, came the tendency toward delay in getting out reports, it is not so certain that the net result would be a gain.

We have been fortunate in securing capable research fellows with an affinity for hard work. It is our hope to establish a reputation for the character of our work that will attract men of high calibre and enable us to select those who give high promise of later achievement.