Discussion

Plastic Design of Eccentrically Loaded Fasteners

Paper presented by A. L. ABOLITZ (July 1966, Issue)

Discussion by **JOHN W. FISHER and GEOFFREY L. KULAK**

In his paper, "Plastic Design of Eccentrically Loaded Fasteners", the author bases his approach entirely upon the premise that in a fastener group "under heavy stress each fastener will exert its full resistance, irrespective of its location". Although he correctly states that the principal limitation on the method lies in whether or not the full plastic capacity of the individual fastener can be attained, he makes no examination of the basic load-deformation behavior of such a fastener. This discussion will attempt to show that mechanical fasteners do not have load-deformation characteristics which make them suitable for simple plastic analysis.

A great many tests have been performed on mechanical fasteners to determine their deformation response under a shear type loading.[1] Typical results are shown in Fig. 1. The deformation referred to here includes bending, shear, and bearing of the fasteners and bearing deformation of the plate. In the tests referred to by the author, similar results were obtained from rivets loaded in shear by a compressive force on the jig.[2] From Fig. 1, it can be seen that a fastener subjected to a shear type loading does not exhibit any well-defined yield point. Shown on each curve is the theoretical shear yield, τ_y, taken as $\sigma_y/\sqrt{3}$. It is readily apparent that no plateau exists at this theoretical shear yield value. It is because no distinct shear yield plateau is present that fasteners traditionally have been assigned allowable stress values based on their ultimate shear strength in joints.

The shape of the curves shown in Fig. 1 is such that as the critical fastener in a group reaches its maximum load, that is, is at incipient failure, other fasteners with lesser deformation will be resisting the load with less than their ultimate capacity. The amount of this reduction can be considerable and depends on joint geometry. Stated differently, this means that unlike simple plastic theory where only equilibrium need be considered, both equilibrium and compatibility must now be satisfied.

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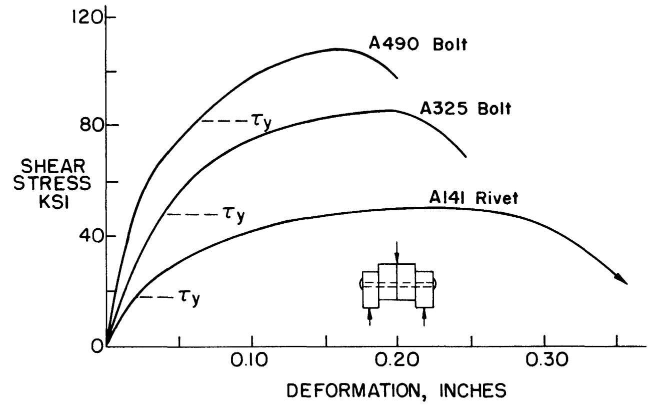

Fig. 1. Stress-deformation curves

The importance of the need to consider compatibility can be seen by examining Fig. 2. The case illustrated[3] is for direct shear alone—one limit of the author's presentation. The theoretical average shear strength of A325 bolts connecting A7 steel is shown as a function of joint length. The fasteners were proportioned according to the current (1966) allowable shear stress of 22 ksi. At a joint length of 27 in. (10 bolts in line at a pitch of 3 in.), for example, the average shear strength of the fasteners, considering both equilibrium and compatibility, is 60 ksi. If each fastener carried an equal load, the average shear strength would be 73 ksi. It is apparent that the assumption of equal fastener resistance is valid only for compact joints.

The same line of reasoning can be applied to joints in which eccentricities exist. To illustrate, in joints under large eccentricity the center of rotation can be assumed to coincide with the centroid of the fastener group. Each fastener, then, would undergo shearing displacement proportional to its distance from this centroid. Since a load-displacement relationship such as shown in Fig. 1 is still applicable for individual fasteners, the fasteners near the centroid would offer little resistance to the applied load. Those fasteners at the extremities would, of course, be offering their maximum resistance at the time that the ultimate strength of the connection is reached.

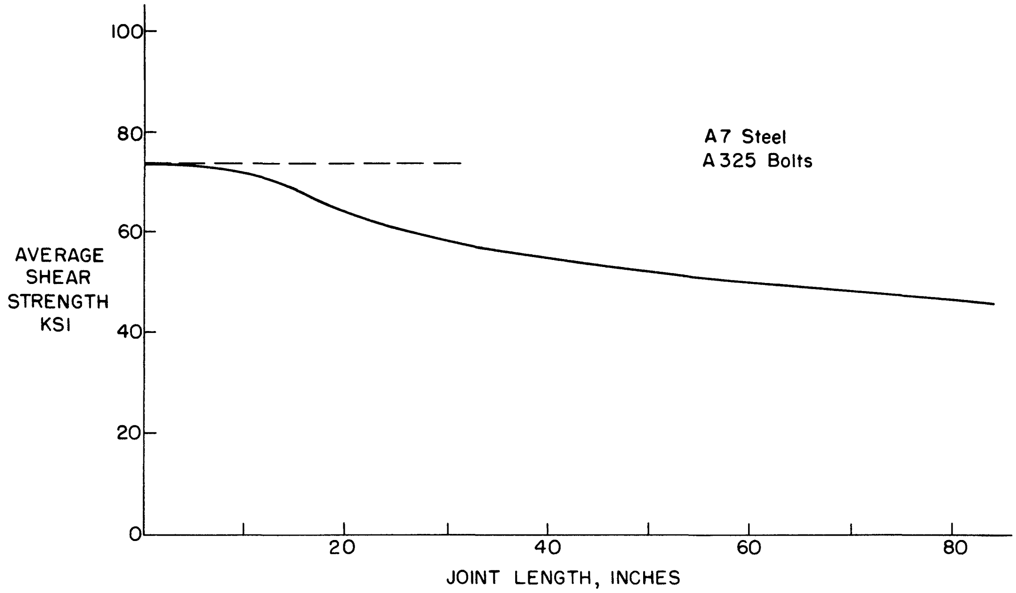

Fig. 2. Effect of length on ultimate strength of mechanically fastened joints

Shermer has suggested an approach similar to the author's and has conducted a few experiments.[4] However, his tests covered only compact patterns of fasteners. The effects of the true load-deformation behavior of fasteners are not likely to be evaluated in such tests. The early work of Francis was likewise limited.[5] It has also been shown that fillet welds exhibit little ductility under high stress so that the similar limitations are present.[6]

Although the development of a theoretical solution recognizing the true load-deformation response of the fasteners is not impossible, the problem is very complex. The writers feel that the empirical solution presented by Higgins[7] is the only satisfactory approach at the present time.

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Discussion by **A. L. ABOLITZ**

Professor Fisher and Mr. Kulak have written a stimulating discussion of this paper.

The use of a simplified mathematical model of an engineering phenomenon does not imply that the model accurately represents the phenomenon; rather, the model serves as a working approximation to facilitate analysis. The paper does not claim that, in actual fact, "under heavy stress each fastener will exert its full resistance"; it only states that the mathematical model used—the plastic theory—postulates this.

Both the elastic and the plastic theory are currently used in the analysis of flexural members, in steel and other metals as well as in reinforced concrete. For most of these materials, notably concrete, the stress-strain diagrams deviate more from the idealized plastic diagram than the curves given in the discussers' Fig. 1. Even so, for all these materials the plastic theory is a better working model for the prediction of ultimate capacity than the elastic theory.

A490 bolts and also some types of welds exhibit more limited ductility than most other fasteners, and it would probably be wise to apply the plastic method to A490 bolts and welds with some modifications. (In an analogous manner, in the current American Concrete Institute Code, Section 1503g, reduced coefficients are specified for the plastic design of very high strength concrete.)

The "long joint" effect shown in the discussers' Fig. 2 is an important consideration. Its order of magnitude appears, however, to be about the same in connections carrying moment as in those for concentric load only, so that any rules and limitations that may be imposed on long concentric connections will probably be suitable for eccentric ones too. Tests to investigate this matter would, of course, be helpful.

The equations derived in the paper hold for any discrete point resistances complying with the assumptions of the plastic theory, regardless of whether the points represent bolts or piles. It is, however, a matter of practical importance to investigate to what extent the actual behavior of groups of fasteners conforms with any of the available theories.

Two very useful series of tests are those reported by Mr. Higgins[7] and Professor Shermer.[4] In Reference 7, the "AISC Manual Method" when applied to the test results gives a standard deviation of P_{test}/P_{calc} of 10.6 percent of the mean, whereas the plastic method gives 5.1 percent. The correlation between the plastic method and the tests is even better in Reference 4, in which Professor Shermer states that "the agreement between theoretical and test results was amazingly close.... This method has the advantage of being consistent with the actual behavior of connections. . . . "

The amount of testing published so far is, however, quite limited, and additional research in the behavior of eccentrically loaded groups of fasteners is certainly warranted.