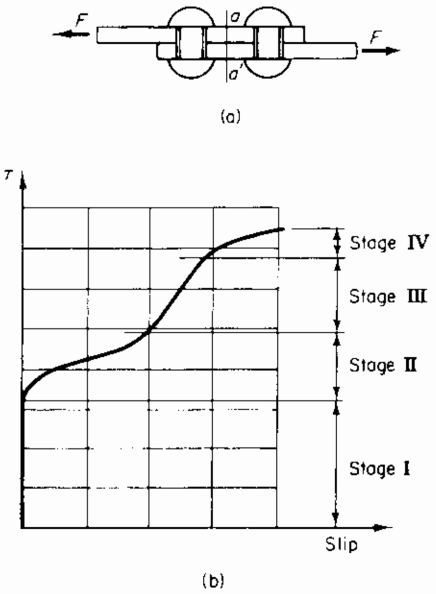
with respect to the ultimate shearing strength of a single rivet (see Ref. 6.4). This is comparable to the margin of safety against tensile fracture of main material. The shear yield load of a rivet is not clearly defined and may be affected by such things as frictional resistance, the degree of hole filling, and the complex state of stress which actually exists. If one were to assume a state of pure shear and an effective yield point for the driven rivet of 33,000 psi, yielding might be expected to start at a shear stress of $33{,}000/\sqrt{3} = 19{,}100$ psi, which implies a margin of safety of $19{,}100/15{,}000 = 1.27$, a rather low value. This oversimplifies actual conditions, however, and the accepted allowable stress has proved quite satisfactory. The AISC Specification also prescribes a working shear stress of 10,000 psi on the unthreaded body area of A 307 bolts and threaded parts of A 7 steel. The lower allowable for steels which have essentially the same properties as A 141 driven rivets is intended to compensate for the possibility of threads in the shear planes.



7 **Fig. 6.10.** Shear stress vs. slip, two-row joint.

Whether or not rivets or bolts in a joint loaded to the working value actually experience significant shearing stress depends upon the initial tension in the fasteners and the frictional resistance on the faying surfaces. It also depends upon whether or not the joint is assembled with the fasteners initially in contact with the sides of their holes, but this factor will be eliminated from present consideration by assuming concentricity of fastener and hole and clearance between the two. If a two-rivet joint is loaded in single shear, the relation between the nominal shear stress in the rivets and the relative movement of points a and a' on the two plates (Fig. 6.10a) will have the characteristic form shown in Fig. 6.10(b) (Ref. 6.4). While not representing precisely the performance of a single rivet, this is the simplest case of any practical interest. In Ref. 6.12, the four stages of this characteristic curve are described as follows: "In the first stage static friction prevents slip; in the second stage the load is greater than the static friction, and the joint slips until the rivets come into bearing; in the third stage, rivets and plates deform elastically so that the load-slip relation is linear; and, in the fourth stage, yielding of plates, rivets, or both, occurs until either plate fracture or complete shearing of the rivets results."

Fig 6.10b

Overlapping effects may make the distinctions between stages less clear-cut than depicted, and variation must be expected in the terminal points of the different stages. In tests of simple joints made with carbon-steel rivets (Ref. 6.4), the end of stage I was found to occur at nominal shear stresses varying from about 12,000 to 18,000 psi. Initial tensile stresses were not measured in these tests, but, if one assumes that they were of the order of 90 per cent of the yield point of the undriven material, which in this case was about 38,000 psi, the computed static friction coefficients range from $12{,}000/0.9 \times 38{,}000 = 0.35$ to $18{,}000/0.9 \times 38{,}000 = 0.53$. A working shear stress of 15,000 psi falls within the range of stresses at which some slip may be expected to occur. For A 141 rivets, which may have yield points and hence initial tensile forces less than those which probably existed in the reported tests, slip may or may not occur prior to the working load. If it has not, the rivet experiences no shear and the load is transmitted by friction.

As mentioned earlier, the AISC and AASHO Specifications recognize two classes of high-strength bolted connections, friction type and bearing type, with different provisions for each. Friction type of connections would normally be used in joints subjected to repeated stress variation and in other locations where slip at working loads would be undesirable. For A 325 bolts in bearing type of connections the AISC Specification prescribes an allowable shear stress on the body area of 22,000 psi when threads are excluded from the shear planes and 15,000 psi when threads may extend into the shear planes. For friction type of connections the allowable is 15,000 psi regardless of the extent of the threading. No oil, paint, or galvanizing is permitted on the contact surfaces within friction type of joints. In all cases the factor of safety with respect to ultimate failure in shear is at least as high as that found in riveted joints.

Because high-strength bolts are often used in locations where stress fluctuations are severe, resistance to slip and the degree to which loads are resisted by friction are of more interest than static strength. Although friction coefficients varying from about 0.20 to 0.60 have been observed in tests of joints having unpainted faying surfaces and a tight mill-scale covering, a value of 0.35 may be taken as typical for computing the limit of frictional resistance. Using this, the nominal shear stresses at incipient slip for A 325 bolts pretensioned to the proof load are computed in Table 6.3. For design at a stress of 15,000 psi there is a margin of from 1.3 to 1.5 depending upon the size of bolt. Except for occasional instances of abnormally low frictional resistance, slip will not occur at working loads; the load will be transmitted by friction and the bolt will be unstressed in shear. On the other hand, if a bearing type of connection is satisfactory and advantage is taken of the higher working stress to reduce the number of bolts, the margin is less than or, at best, approximately equal to unity. Slip will probably occur close to the working load, and the bolt will be stressed in shear. Oil, paint, galvanizing, or the like, on the faying surfaces will increase this possibility. OF SLIP

The stages characteristic of the performance of a simple riveted joint also

Table 6.3. A 325 Bolts in Shear

Size	Body Area (in.^{2})	Proof Load (lb)	0.35 × P.L. (lb.)	Nom. Stress $= \frac{0.35 \times P.L.}{B.A.}$ (psi)	$\frac{\text{Nom. Stress}}{15{,}000}$	$\frac{\text{Nom. Stress}}{22{,}000}$
$\frac{5}{8}$	0.307	19,200	6,700	21,800	1.45	0.99
$\frac{3}{4}$	0.442	28,400	9,900	22,400	1.49	1.02
$\frac{7}{8}$	0.601	36,050	12,600	21,000	1.40	0.96
1	0.785	47,250	16,500	21,000	1.40	0.96
$1\frac{1}{8}$	0.994	56,450	19,700	19,800	1.32	0.90
$1\frac{1}{4}$	1.227	71,700	25,100	20,500	1.37	0.93

apply to a high-strength bolted connection. The initiation of slip would be deferred because of the higher clamping force. When slip does start, however, it is apt to progress more abruptly than in a riveted joint. Also, the total slip will probably be somewhat greater for there is more hole clearance than in a riveted joint.

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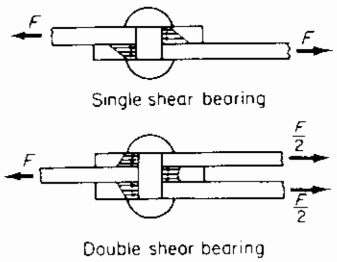
Bearing stresses are nominal stresses computed by dividing the load on the rivet or bolt by the product of its diameter and the thickness of the connected part. Since the actual contact stress distribution is somewhat as pictured in Fig. 5.9, bearing stresses are average rather than true stresses. If bearing is critical, the material in the fastener or plate, or both, will eventually crush as in Fig. 6.9(c). The material is confined and cannot fracture. Therefore, bearing failure can only be defined rather arbitrarily on the basis of judgment as to when deformation due to crushing becomes excessive. Lately, bearing has been viewed with respect to its effect on the tensile strength of the joint rather than as an isolated factor. As stated in the AISC Specification Commentary, tests on riveted joints have shown that the tensile strength is not impaired when the computed bearing stress at working load is as much as $2\frac{1}{4}$ times the allowable tensile stress on the net area. For this reason the AISC permits an allowable bearing pressure of $1.35\,\sigma_y$ (approximately 2.25 times $0.60\,\sigma_y$, the tensile allowable). Obviously, this average stress will result in some inelastic deformation at the working load, but it will not be objectionable. In friction type of high-strength bolted connections bearing stresses need not be investigated at all.



Single shear bearing

Double shear bearing

Fig. 6.11. Classes of bearing.

Some older specifications distinguish between single shear bearing and double shear bearing, conditions illustrated in Fig. 6.11. Higher allowable bearing stresses are permitted for the latter in the belief that the stress distribution in double shear bearing is more uniform and generally more favorable. Later tests have failed to bear this out, and the distinction is no longer made. While there must be a difference in stress distribution in the two cases, particularly at low loads, it is reduced by plastic redistribution to the point where it has no apparent effect on ultimate performance.

Several methods are used to prevent shear or tear-out at the end of a plate (Fig. 6.9d). The AISC Specification requires that, for riveted connections having no more than two rivets in the line of stress, the distance from the center of the fastener to the end of the plate shall be at least equal to the rivet cross section divided by the plate thickness for a rivet in single shear, and twice this distance for a rivet in double shear. Similar requirements are given for other fastener groups.

6.4. CONCENTRIC SHEAR ON RIVET AND BOLT GROUPS

(> 2 FASTENERS

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The sketches in Fig. 2.3 are typical of riveted and bolted connections in which the shear load on a group of fasteners is concentric or in which any eccentricity is small enough to neglect. In the conventional design of joints of this type all fasteners are assumed equally loaded; the allowable load per fastener is computed from working stresses of the kind discussed in the preceding article, and the required number of fasteners is found by dividing the force on the group by this load.

In the ideal two-rivet (or two-bolt) joint of Fig. 6.10(a), symmetry requires that the fasteners be equally stressed. When there are more than two fasteners, the analytical problem becomes difficult but, by making some simplifying assumptions, one may obtain a qualitative understanding of some of the conditions that must prevail. To illustrate, the simplest case, that of a three-rivet joint, will be studied (Fig. 6.12). The conclusions apply in a general way to all multifastener, concentrically loaded connections. The approach used by Hrennikoff will be followed (Ref. 6.13). The main assumptions are: (1) The plates and rivets are elastic, (2) there is no friction on the faying surface, (3) the rivets completely fill their holes, (4) force transfer between plates takes place at the center line of each rivet, and (5) the stress in each plate is uniform between rivets.

By symmetry, the forces transferred by the outer rivets must be equal. Calling these F_1 and letting the total force transmitted by the connection be F, the distribution of forces in the plates and rivets is as shown in the free-body diagrams of Fig. 6.12(b). The problem is statically indeterminate. Each plate segment will stretch from its initial length p to the values shown in Fig. 6.12(c). The inner rivet will deform an amount Δ_i, and the outer rivets by amounts Δ_o. From the figure,