Bolt force distribution in friction grip eccentric shear joints

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The Authors' form of measurement of bolt shears in friction grip connections is a technique that could find wide application in connection research. The bending strain plotted in Fig. 8 shows a smoothly non-linear response to applied shear. What are the reasons for this non-linearity? Was it mirrored by the deflexion of the single bolt lap joints? What happened if the specimen was off-loaded before slip? The curve shows no reduction in load during or after slip. This is contrary to my observations of behaviour during slip where a sharp fall-off in load occurred and also contrary to the generally accepted notion that dynamic friction is less than static friction. How was the load maintained during slip? Are the Authors confident that their measurements were accurate during this part of the test?

33. In § 21 the Authors state that two stages of failure were discernible, i.e. initial slip and general slipping with bolt bearing imminent. For example, with specimen E3 they quote a first slip test load of 130 kN and general slipping test load of 134 kN; corresponding theoretical loads are 98 kN and 139 kN. Figure 6 shows that the specimen became non-linear at an applied moment of 120 kNm, corresponding to a load of 87 kN. What definition of first slip did the Authors use? The first slip load that they quote implies a moment of 180 kNm for the same connection, which caused a connection rotation of 0.003 radians. This corresponds to a displacement of 0.6 mm on the bolt furthest from the centre of rotation, if plate displacements are ignored.

34. One clearly needs to consider a connection's behaviour in its structural context and related to a given design philosophy. In view of their greater cost, the current trend is to use high-strength friction grip bolts only in situations where rigidity is required, e.g. in a rigid frame.

35. While accepting that the connections shown are not typical beam/column moment connections, as an example of the influence of connection behaviour on rigid construction it is worth noting that a rotation of 0.003 radians at a beam/column connection would cause approximately a 30% reduction in hogging moment and a 120% increase in beam deflexion. In what context do the Authors envisage these sorts of connection being used and how do their failure criteria fit in with limit state design philosophy?

36. In § 12 the Authors state that there is ample evidence to suggest that

equalization of fastener forces eventually occurs in bearing type connections. This is true only for the limited set of circumstances where the connector deformation capacity is sufficient for the connectors subject to the greatest deformation to retain their load carrying capability while the strength of the others is mobilized. If the connection fails by bearing in the plate, the deformation capacity is substantial—approximately half the bolt diameter—and such equalization can effectively take place. However, if the connection fails by shearing of the bolts, the connector deformation capacity is very small: only 2–3 mm for high strength bolts. In such cases if the plate strains are substantial, or the connection is large so that the integration of even modest strains along the plates causes significant incompatibilities at the connectors, or there is misalignment of the clearance holes, the distribution of bolt forces will differ substantially from that given by either simple theory. With limited deformation capacity, equalization of bolt forces will not have taken place before failure and a simple plastic analysis will overestimate connection strength. In extreme situations, the extra reserve implicit in elastic analysis may be insufficient to ensure adequacy.

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Non-linearity arises from progressive breakdown of the friction zone. Interplate pressure varies from a maximum near the hole edge, to zero at approximately half to one bolt diameter away, depending on plate thickness. When shear load is first applied, the shear stress at the interface also varies as a result of differential surface stresses in much the same way as bolt shears are affected by differential plate extension in long bolted joints. Dislocation of the surfaces starts at the leading and trailing edges of the friction zone, where the above effects are maximal, and proceeds inwards to the edge of the hole. The shear stiffness of the joint declines correspondingly.

38. We have not investigated the effect of load removal before slip on the shear force-bending strain calibration but from casual observation it is clear that hysteresis occurs. The unloading curve is non-linear, following the pattern of the loading curve.

39. On the question of post-slip behaviour, the calibration curve is required to represent the form of controlled slip which, by virtue of load sharing, occurs in a multi-bolted joint. This is usually characterized by a smooth, repeated sequence of minor slip and recovery rather than a single large energy release. For this reason the calibration tests were based on controlled displacement and, in effect, follow the maximum shear envelope after initial slip has occurred.

40. The onset of non-linearity is therefore an unreliable criterion for defining initial slip and we would be particularly loath to recommend its use in conjunction with moment-rotation curves. In the tests, first slip was clearly indicated by the rate of increase of bolt bending, which was an order of magnitude greater during slip than before.

41. We share doubts with Dr Owens concerning the rotational stiffness of specimen E3, which differs appreciably from that of the other large eccentricity specimens. A more refined method of rotation measurement was used in tests E4–E6 and greater credence should perhaps be attached to these results. The implied plate distortions are much more feasible in the latter tests.

42. Rotational shear joints are quite viable for secondary moment applications. The higher cost of friction bolting is offset to some extent by the absence of welding. Typical applications include column brackets, U-frames, short vier-

endeel girders, web and flange cover plates—indeed any situation where slip is undesirable and co-planar connecting surfaces are available. Comparison with traditional beam to column moment connections can be misleading because the latter interrupt the prismatic continuity of members across a joint. This is not necessarily the case with shear joints. For example, in medium-rise construction it is sometimes advantageous to use twinned channel beams passing on each side of interior stanchions and cantilevered beyond perimeter stanchions. In this case the moment to be conveyed to the stanchions would be small compared with the beam capacity, especially under no-sway conditions.

43. We have proposed rules for designing against slip under service loading and against collapse under factored loading. Where the designer is unsure of the local loading on a joint, because of uncertainties concerning the distribution of forces in the frame as a whole, there will undoubtedly be a need for judgement. For instance, the draft replacement to BS 449¹⁰ recognizes that shear connections participating in plastic collapse mechanisms should have some reserve strength, in proposing that a non-slip basis should be used for their design. However, there are many applications where a once-only redistributive slip within service would be acceptable.

44. Dr Owen's warning concerning equalization of fastener forces in bearing connections is appreciated, particularly in relation to the strong steels now available for bolt and plate material. We presume that he is referring to connections of very low eccentricity which are also long in the direction of loading. For more compact groups of medium to large eccentricity the plate strains will assist rather than hinder redistribution by, in effect, introducing a circular shear lag. The contribution from fasteners within a significant distance from the instantaneous centre to overall strength is small; incomplete redistribution is readily compensated by a marginal increase in resistance of the outer fasteners.

Corrigenda

On page 806, § 14, line 3, *for* using single bolt tensile lap joints *read* using double bolt tensile lap joints.

On page 812, Fig. 10, a Theoretical slip load, *for* 496 kN *read* 446 kN.