Load indicating washers

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J O Surtees and M E Ibrahim discuss the influence of load-indicating washers on bolt relaxation in joints subject to high prying forces.

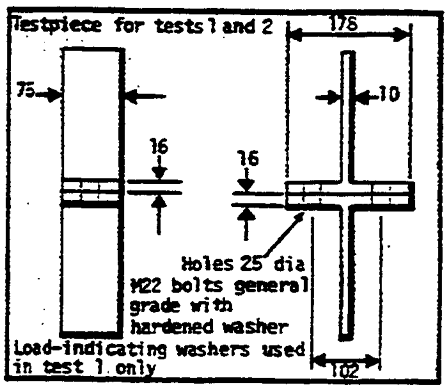
In normal use, load-indicating bolts and washers do not contribute significantly to bolt relaxation but occasional doubts have been expressed about their performance in applications where modest levels of external tension are to be transmitted. It is argued that such loading induces a further permanent compression into the indicating washer (or indicating head) which, on removal of load, contributes to bolt relaxation and lowering of shear resistance. There is no experimental or practical evidence for such a hypothesis, although in some cases of prying action (usually involving misalignment of the faying surfaces) increased bolt relaxation is known to occur whether indicators are used or not. However, the question is whether the relaxation in such cases is increased or decreased by the presence of an indicator device.

The tests described below are designed to compare the loss of pretension under extreme prying conditions with and without a load-indicating washer. They relate to a situation where the whole of the external tensile loading is attributable to imposed load, which is also an extreme condition. The joint details are based, in two cases, on work reported by Munter and Bouwman, which enables a further comparison to be made for joints without indicators. Grade 10-8 bolts were used in the above mentioned cases for this reason, also. It should, of course, be understood that BS 4604 part 2 prohibits the use of grade 10-8 bolts as friction grip bolts when primary tensile load is present, contrary to other major European codes.

Description of Tests

Tests 1 and 2 relate to joints with good initial fit between flange surfaces. Details of the test joints are shown in *Fig 1*. A thin flange was used to ensure maximal prying on the bolts. The bolts were calibrated under appropriate conditions (with or without washer) in a tension rig *(Fig 3)*, using a head strain method proven to an accuracy of ± 3 per cent at 99 per cent confidence level. They were then transferred to the test pieces and tightened to proof load using the established load (for two bolts) and unloaded similarly after a 10 min pause. The procedure was repeated after a further 10 min pause, up to a peak load of 80 per cent proof load, and so on in 20 per cent increments until a peak load of 160 per cent proof load was reached.

In tests 3 and 4, which simulated the effect of initial contact between the outer surfaces only, a thick flange was employed to ensure that the inner flange surfaces were not brought into contact by the application of bolt preload. The



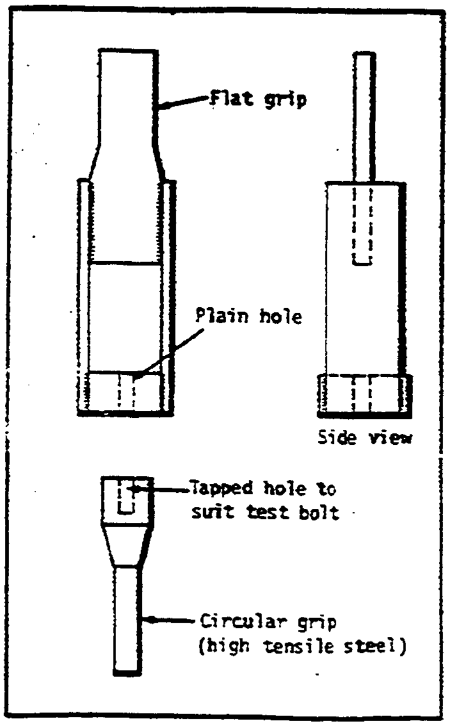
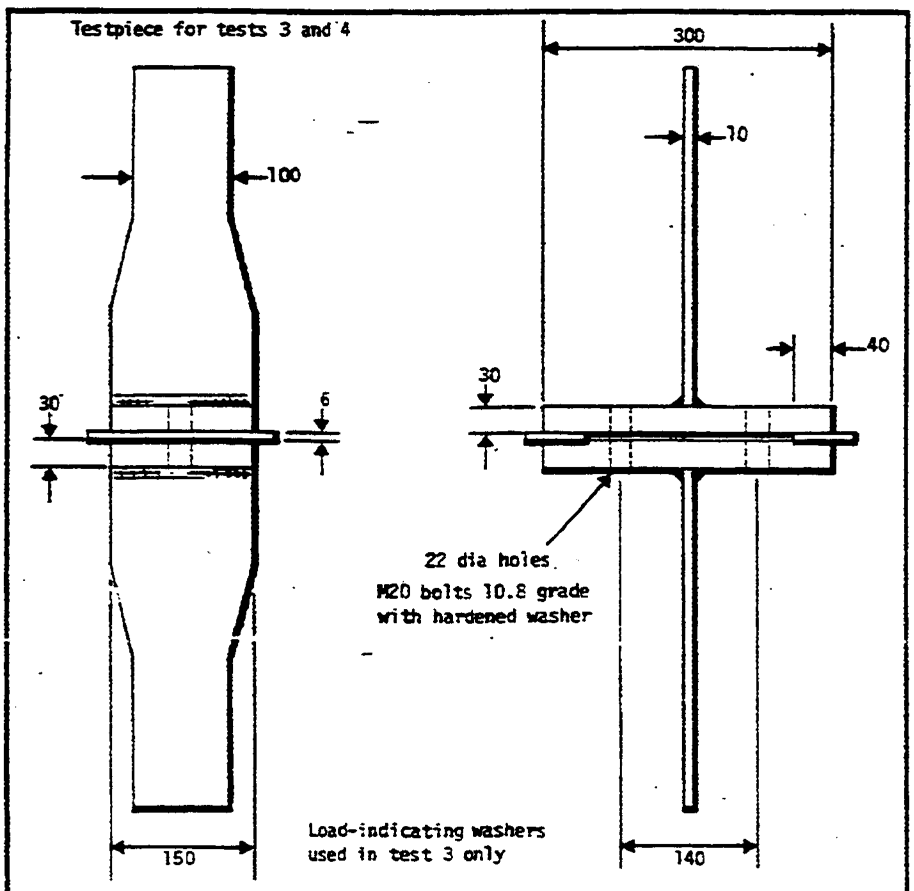


Fig 1 (left). Testpiece for tests 1 and 2. Fig 2 (below) Testpiece for test 3 and 4. Fig 3 (below, left) Calibration rig basic features.



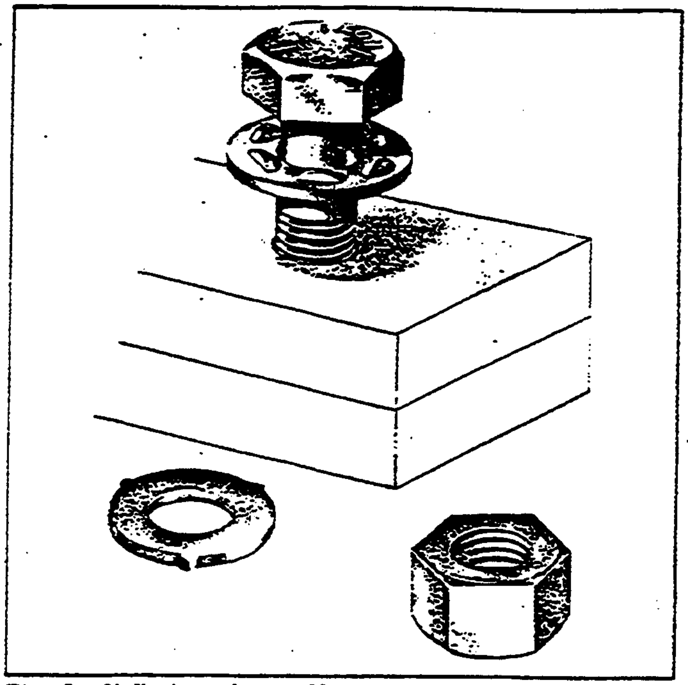


Fig 4. Load indicating washer assembly.

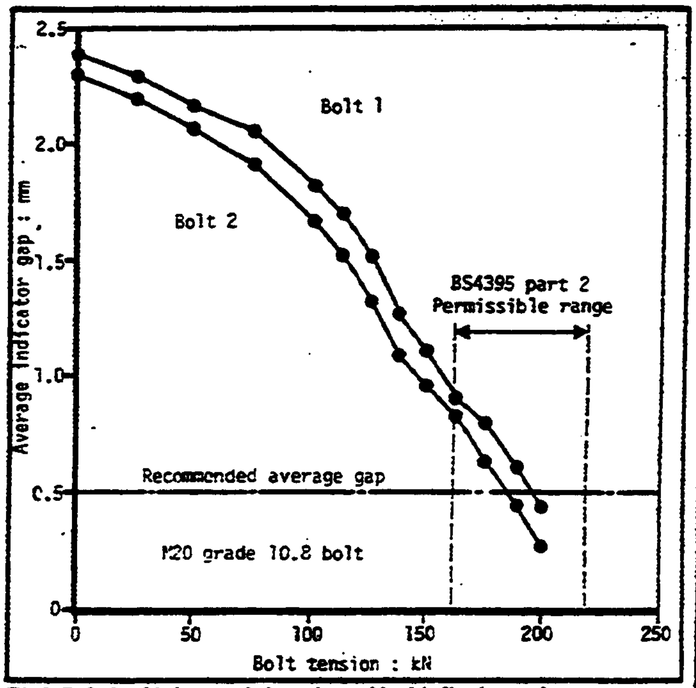


Fig 5. Relationship between bolt tension and load-indicating washer gap.

test pieces are shown in *Fig 2*. The calibration procedure was similar to that used in the previous tests. Loading was applied in steps of 25 kN up to an initial peak load of 20 per cent proof load (for two bolts) and released in similar steps after a period of 15 min. A further cycle was applied after 15 min, rising to 30 per cent proof load, and so on, for a total of seven cycles culminating in a peak load of 80 per cent proof load.

During calibration of the bolts for test 4, an opportunity was taken to examine the relationship between bolt tension and average load indicator gap. Four bolts were tested altogether, including the two subsequently used in test 4. The gap measurements were made by feeler gauge at three positions around the bolt head.

Test Results

Upper and lower extremes in the relationship between load indicator gap and bolt tension are shown in *Fig 5*. These relate to bolts 1 and 2, subsequently used in test 4. The average gap recommended by the manufacturer corresponded to measured bolt tensions ranging from 98 to 104 per cent of the minimum proof load, which was well within the range permitted by BS 4395 part 2 (viz ± 15 per cent of proof load).

The relationship between bolt tension and external load for tests 1 to 4 is shown in *Figs 6 to 9* respectively. Bolt tension is expressed as the percentage change from initial preload, whilst external load is expressed as a percentage of the proof load for a single bolt.

In tests 1 and 2, there was no significant difference in performance with or without load indicating washer. The change in bolt tension, following application and removal of a given level

Fig 6. Tests 1 and 2 – typical relationship between external tension and change in bolt tension.

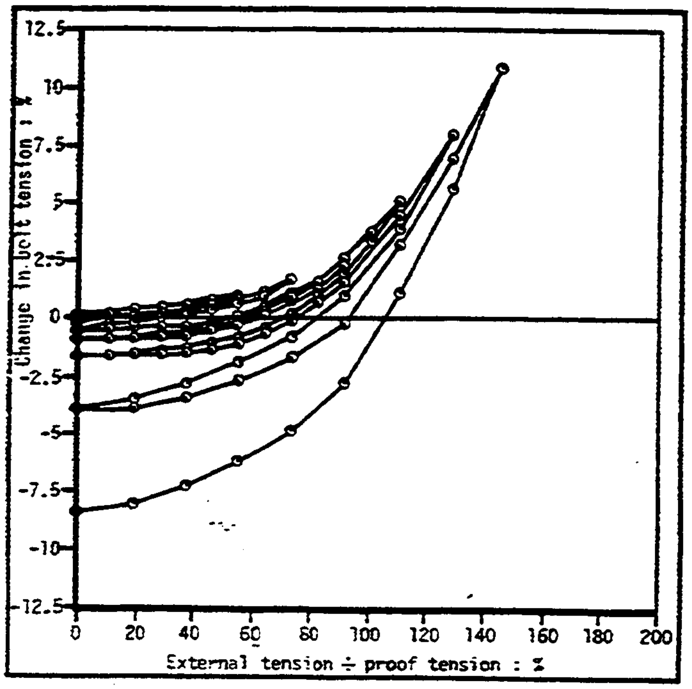
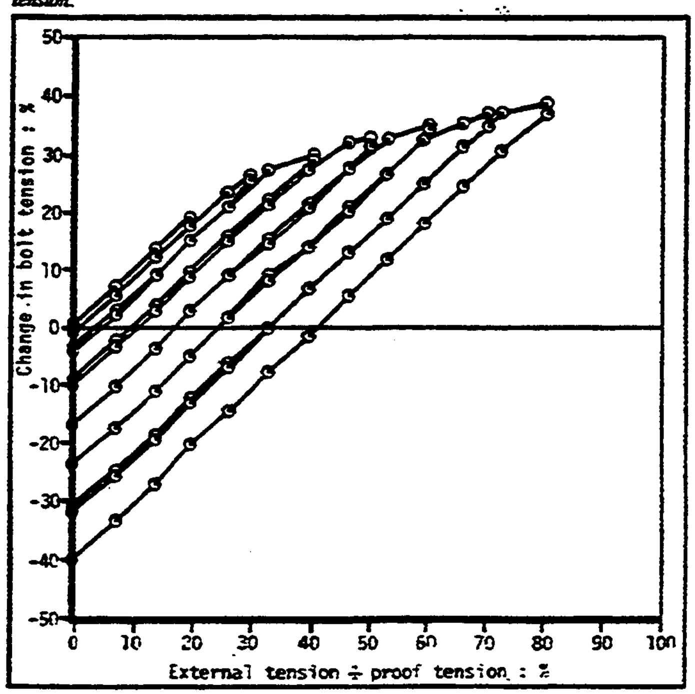


Fig 7. Test 3/bolt 1 – relationship between external tension and change in bolt tension.



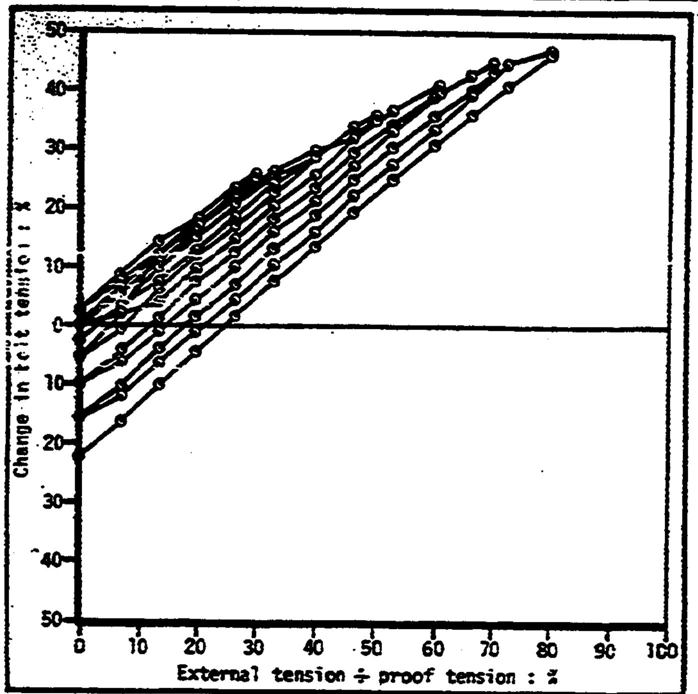


Fig 8. Test 3/bolt 2 – relationship between external tension and change in bolt tension.

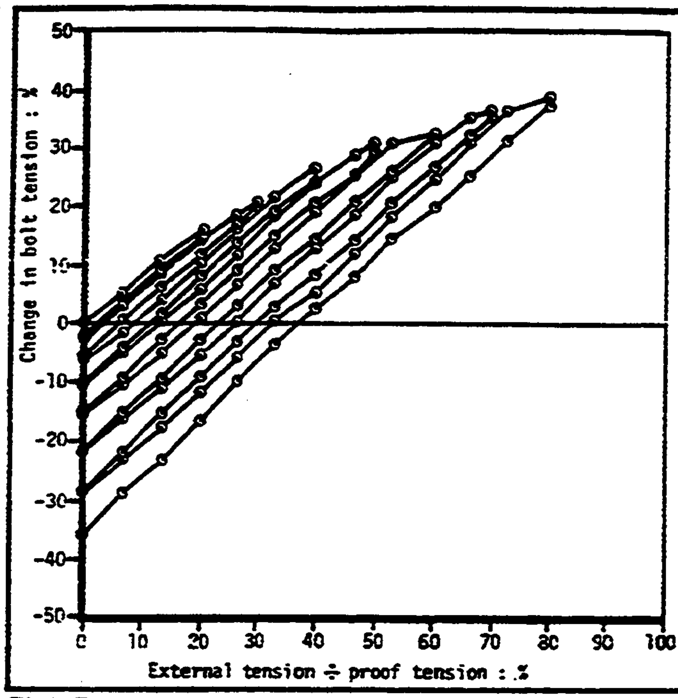


Fig 9. Test 4/bolt 1 – relationship between external tension and change in bolt tension (bolt 2 similar).

of external load, was marginally less when load indicators were used. At an external load per bolt of 60 per cent proof load (the maximum permitted by BS 4604 part 1 for general grade bolts) the change was less than 1 per cent of initial preload. At 160 per cent proof load the change was still below 10 per cent of preload.

In tests 3 and 4 the effects of prying action were quite evident. The change in bolt tension was approximately 80 per cent of the applied external load per bolt at low levels of external load and approx 100 per cent at medium-to-high levels of external load, thus confirming the result obtained by Munter and Bouwman. The difference between performance with and without load indicators was quite pronounced, also. The average loss of preload in two bolts after application and removal of an external load per bolt of 80 per cent load was 29 per cent when load indicators were used and 39 per cent when they were omitted. At typical design levels of external tension the loss of preload was not so acute, however. For example, at 30 per cent proof load the corresponding losses of preload were 3 and 4 per cent respectively.

In test 3, the tension in the two bolts differed increasingly as the test progressed, however, the individual loss of preload at any stage was always less than the corresponding loss in test 4. Although a careful tightening procedure was used in test 3, there was evidence that one side of the joint had closed fractionally more than the other. Careful attention was paid to tightening procedure in test 4 and in this case symmetrical closure was observed. Almost identical tensions were observed in the two bolts throughout the test. While the above phenomenon may be attributable in part to variation in bolt or plate properties, it is perhaps significant that in tests 1 and 2, where tightening procedure was of much less importance because of good fit between the plates, the relationship between external load and bolt tension was fairly consistent for all four bolts.

The beneficial influence of the indicator washer in test 3 might be attributed to several factors:

(i) The degree of prying is controlled by the location of the fulcrum (effectively, the centre of compression) in relation to the bolt axis. Initially, the fulcrum is located at the inner edge of the steel pack, but as the bolt extends, the centre of compression is displaced towards the flange tip. The additional resilience afforded by the indicator washer enables this effect to proceed more quickly.

(ii) The washer is harder than the flange material and reduces permanent indentation around the edge of the hole.

(iii) After the indicator gap has closed to less than 0·5 mm, a major portion of the energy subsequently stored in the washer is recoverable, whereas, substantial losses occur in the bolt in zones of plasticity at the junction between head and shank and at the base of loaded threads. A nett prestressing effect is thus provided by the washer. A similar effect will, of course, arise when two plain hardened steel washers are used instead of the customary single washer.

Conclusion

The results from two exploratory tests suggest that the presence of a load-indicating washer inhibits, rather than induces, loss of pretension in a bolt subject to high prying conditions. Although further flattening of the protrusions on the washer (as a result of gross overload) is seen as a source of internal deformation, it would appear that prying forces are lessened, thereby reducing permanent deformation in the bolt. In other words, deformation of the washer is substituted for deformation of the bolt and plate surface, with little change in the final deflected shape of the flanges. In another sense, the load indicator constitutes an additional hardened washer and by aiding dispersion of contact forces will, in any case, reduce permanent indentation of the plates.

Grade 10·9 bolts were used in the tests to intensify the effects under investigation. BS 4604 part 2 prohibits external tensile load on such bolts but it is clear from the tests that extremely high external load capacity exists, with only minor loss of preloading.

Acknowledgement

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