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Closure to "Active shear planes of bolted connections failing in block shear" by Drew D. A. Clements and Lip H. Teh

Drew Clements

Taylor Thomson Whitting, ddac998@uow.edu.au

Lip H. Teh

University of Wollongong, lteh@uow.edu.au

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Abstract

The writers thank the discussor for the interest in the original paper and for the discussion, which provides the opportunity to clarify and reiterate a few points made in the original paper. The writers agree with the discussor that the behavior of bolted connections is not as simple as they appear to be to the casual observer, which is one reason why many structural collapses have been associated with connection failures.

Furthermore, a substantial number of code equations for various ultimate limit states of bolted connections lead to considerable errors on either side of conservatism (Teh and Clements 2012; Teh and Gilbert 2012; Teh and Yazici 2013a).

Keywords

block, failing, connections, bolted, planes, shear, teh, active, h, closure, lip, clements, drew

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Closure to “Active Shear Planes of Bolted Connections Failing in Block Shear”
by Drew D. A. Clements and Lip H. Teh

Drew D. A. Clements¹ and Lip H. Teh² A.M.ASCE

The authors thank the discussor for his interest in the paper and for his discussions, which provide the opportunity to clarify and reiterate a few points made in the paper.

The authors agree with the discussor that the behaviour of bolted connections is not as simple as they appear to be to the casual observer, which is one reason why many structural collapses have been associated with connection failures. Furthermore, a substantial number of code equations for various ultimate limit states of bolted connections have been demonstrated to lead to considerable errors on either side of conservatism (Teh & Clements 2012, Teh & Gilbert 2012, Teh & Yazici 2013a).

The authors also agree that simplifying assumptions lead to savings in analysis time, and the finite element model should be accurate enough to provide useful results that can be interpreted to reach the correct conclusion. As stated in the paper, the aim of the finite element analysis is to confirm the location of the active shear planes indicated by the experimental evidence of Franchuk et al. (2003) and identified by Teh & Clements (2012). These active shear planes are regions of maximum shear stresses.

However, the authors disagree with the discussor’s statement that flexible solid elements should be used to model the bolts and initial bolt pretension. Firstly, whether the bolts are perfectly rigid or not does not affect the ultimate limit state of block shear failure of the bolted connections, nor the location of the active shear planes. As far as the test specimens are concerned, the high-strength steel bolts were virtually rigid, especially when compared to the connected thin sheets used in the laboratory tests, which was why each bolt was modelled as a 3D analytical rigid body revolved shell.

Secondly, bolt pretension should not be modelled in the analysis at all since there was no bolt pretension in the laboratory tests. The discussor is encouraged to read the referenced paper by Teh & Clements (2012), who presented the laboratory tests, in particular the section “Specimen Configurations and Test Arrangements”. It was stated that the bolts were installed by hand with minimal tightening, so there was no bolt pretension.

The “skid marks” mentioned by the discussor and apparently shown Figure 12(a) of the paper were not the result of clamped bolt heads, but due to scrubbing during the specimen fabrication. Marks almost transverse to the direction of loading can also be seen in the lower right region. The initially more flexible response shown in Figure 8 was not due to slippage of the bolted connection, but due to the slippage between the inner sheet and the shim plates used to make up the difference between the minimum jaw opening of 5.5 mm and the thin

¹Structural Engineer, Taylor Thomson Whitting, 48 Chandos Street, St Leonards, NSW 2065, AUSTRALIA.

²Senior Lecturer, School of Civil, Mining & Environmental Engineering, University Of Wollongong, Wollongong, NSW 2500, AUSTRALIA.

36 sheet thickness of 3 mm. These shim plates on both sides of the inner sheet are not shown in
37 Figure 4 since they were not relevant to the issue of concentric loading. As stated in the
38 section “Finite Element Analysis to Locate the Active Shear Planes”, there was also
39 flexibility or slippage in the testing system which manifested in the apparent response of the
40 tension coupon. In any case, slip behaviour is not relevant to determining the location of the
41 active shear planes since the load was transferred via the bolts bearing on the bolt holes.

42 The authors disagree with the discussor’s assertion that displacements should be imposed on
43 the inner sheet rather than the bolts. It is the relative displacement between the bolts and the
44 clamped end of the inner sheet that matters.

45 The curling behaviour (out-of-plane deformation) mentioned by the discussor was not present
46 in the laboratory tests of the specimens studied in the paper, all of which were double-shear
47 connections as depicted in Figure 4 of the paper. As pointed out by Teh & Gilbert (2012), the
48 inner sheet of a double-shear connection is not subject to out-of-plane failure modes since the
49 loading is concentric. It was for this reason that the mid-plane of the finite element model for
50 the inner sheet was restrained from out-of-plane displacements.

51 The first figure provided by the discussor is for a single-shear connection, which has very
52 different behaviour from the double-shear connections studied in the paper. The discussor is
53 encouraged to read the first paragraph of the section “Finite Element Analysis to Locate the
54 Active Shear Planes”, and look at Figure 4 of the paper. It was clearly stated that the finite
55 element models simulate the concentrically loaded inner sheets of double-shear bolted
56 connections.

57 The discussor is correct that the finite element analysis did not simulate fracture, because
58 such simulation is unnecessary for determining the ultimate limit load of a specimen failing
59 in block shear through the shear yielding and tensile rupture mechanism. As explained in the
60 paper, the ultimate load of such a specimen is reached due to necking of the tensile net
61 section, and before fracture. This phenomenon is indicated in Figure 8, and is particularly
62 evident in Figure 13. The load only dropped abruptly following fracture, which took place
63 after the limit load had passed.

64 | The shear failure planes shown in the second figure provided by the discussor **isare** not
65 correct, since it is not possible for maximum shear stresses to occur along those planes due to
66 the bolts bearing symmetrically on the bolt holes. In fact, Figures 10 and 11 show that there
67 are minimal if any shear stresses along the bolt centrelines, as logically expected. The use of
68 such planes has been shown to lead to excessive conservatism against laboratory test results
69 of the authors as well as independent test results on hot-rolled steel plate connections
70 obtained by various researchers around the world (Teh & Yazici 2013a).

71 The discussor’s statement that shear fractures occur from the edge to bolt hole (AB and CD
72 path shown in the second figure of the discussor) has confused the fracture at the edge due to
73 tensile stresses transverse to the direction of loading to be shear fracture. Shear fracture starts
74 from the bolt hole, not from the edge, as pointed out by Kim & Yura (1999) and Teh &

75 Yazici (2013b). It can also be seen in Figures 10 and 11 that the shear stresses are maximum
76 adjacent to the bolt hole, and decreases towards the edge as logically expected.

77 The potential misidentification of fracture at the edge due to tensile stresses transverse to the
78 direction of loading for shear fracture had been well anticipated by Teh & Yazici (2013b).
79 The discussor is encouraged to read that paper and look at Figs 4(b) and (5) of Teh & Yazici
80 (2013b), which show tensile fracture at the edge and shear fracture at the bolt hole,
81 respectively.

82 The discussor has misunderstood what in-plane shear stresses, denoted S12, are. These are in
83 fact the shear stresses mentioned by the discussor to be parallel to the AB and CD lines
84 (which, by the way, should be acting in pair with shear stresses perpendicular to themselves
85 for equilibrium in the plane of the sheet, hence the designation S12). The discussor has
86 confused the shear stresses parallel to the AB and CD lines to be S11.

87 In the second sentence of the second paragraph of the discussor's section "Failure Check",
88 the discussor confuses S11 to be the normal stresses along the BC line, which are actually
89 denoted S22 in ABAQUS. In the third sentence, however, the discussor confuses S11 to be
90 the shear stresses along AB and CD lines, which are denoted S12 in ABAQUS.

91 The S11 component mentioned by the discussor actually denotes the normal stresses in the
92 direction of the "1" axis, i.e. perpendicular to the direction of loading of the bolted
93 connection specimen. These stresses reach the maximum tensile values at the edge
94 downstream from the bolts, and can cause tensile fracture at the edge if the end distance e_1 is
95 small enough, as pointed out by Kim & Yura (1999). Such fracture should not be confused
96 with shear fracture, which would be initiated adjacent to the bolt hole.

97 The use of effective plastic strain (PEEQ) contours by the discussor and the use of von Mises
98 stress contours by other authors in the literature have obscured the mechanism of block shear
99 failures, as it was very difficult if not impossible to identify the regions of maximum shear
100 strains (or stresses) from the combined strain or stress contours. Furthermore, it is impossible
101 to tell from the effective strain contours, which are scalar quantities, whether a particular
102 region is subjected to tensile or compressive stresses. It was only when the in-plane shear
103 stress contours were plotted by the authors that the regions of maximum shear stresses could
104 be seen clearly for the specimens undergoing block shear failures.

105 The discussor's third figure does not appear to be connected to the topic (no pun intended), as
106 the gusset plates can be seen to buckle under compression. Block shear failures (or the
107 "ultimate fracture" mentioned by discussor) do not take place under such a condition.

108 For the purpose of determining the location of the active shear planes, which has been
109 indicated by experimental evidence and verified against laboratory test results, there is little
110 point in retracing the load-deflection paths. The discussor's statement that "Most of FE
111 studies present comparisons between two results with respect to characteristic behaviour"
112 does not provide a scientific reason for retracing the load-deflection paths in order to
113 determine the location of the active shear planes.

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