Transverse Slotted Holes Design Bearing Strength

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Introduction

No distinction is made in the *Steel Structures Standard NZS* 3404 (SNZ, 2007) between the design ply bearing capacity for a long slotted hole in which the slot is perpendicular to the direction of the bearing load and a standard circular hole. See figure 1. While the presence of a slotted hole does not reduce ply bearing capacity based on strength, there is increased hole elongation for a given bolt shear force compared to a standard hole. In this article, a design equation based on North American practice is presented for design ply bearing capacity limited by hole elongation. This equation will be applicable for situations such as seismic loading, where increased hole elongation associated with slotted holes loaded transverse to the direction of the bearing load is undesirable.

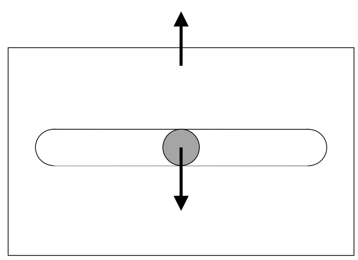

Figure 1: Long Slotted Bolt Hole, Slot Perpendicular to the Direction of the Bearing Load

NZS3404 Ply in Bearing

The capacity of the bolted element in a lap joint designed for bearing depends on the plate thickness, grade of steel and edge distance in the direction of force. The design must prevent bolt failure and the following types of connection failure as illustrated in figure 2:

- Fracture across the connected element
- Bearing failure at bolt interface
- Tearing failure

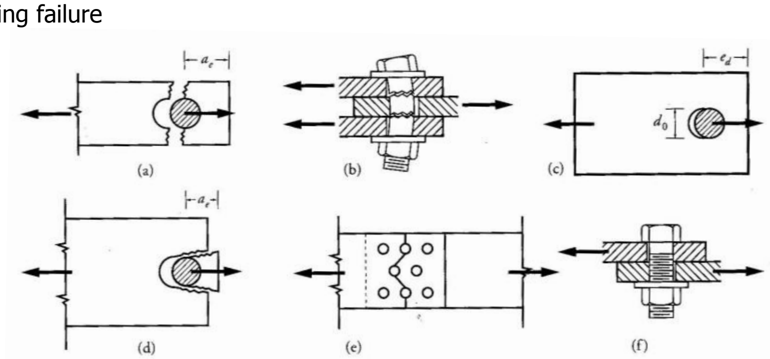

Figure 2: Bolted shear connections and the potential modes of failure of joint *a) plate fracture; b) bolt failure; c)crushing on ply to bolt shank interface; d) plate tearing failure; e) plate fracture where bolts are staggered; f) bolt hole clearance leads to slippage* (Gorenc et al, 2005)

A ply (plate) subject to an ultimate limit state design bearing force due to the bolt in shear is designed to clause 9.3.2.4.1 of NZS 3404 (SNZ, 2007) and must satisfy:

$$V_b^* \leq C_1 \phi V_b$$

Where

ϕ = strength reduction factor

V_b = nominal bearing capacity of ply

C_1 =1.0 for bolts in connections not designed for loads including earthquake loads
= reduction factor given in table 12.9.4.3 of NZS3404 for bolts designed for loads including earthquake loads

The nominal bearing capacity of the ply is dependent on the edge distance. Where the edge distance is relatively long i.e. greater than 3.5 times the bolt diameter, then the nominal bearing capacity is calculated using equation 9.3.2.4(1) of NZS 3404. This equation is:

$$V_b = 3.2 d_f t_p f_{up}$$

Where

d_f = diameter of bolt

t_p = thickness of ply

f_{up} =tensile strength of the ply

After major slip has occurred in a connection and the bolt bears against the side of the hole, a bearing pressure is developed on the plate adjacent to the hole and on the fasteners as shown in Figure 3(a). This pressure is initially concentrated at a point of contact but an increase in load causes yielding of the plate and embedment of the bolt. This results in a larger area of contact and a more uniform stress distribution as shown in figure 3(b). The actual bearing stress distribution is indeterminate and typically a uniform stress distribution such as shown in figure 3(c) is assumed.

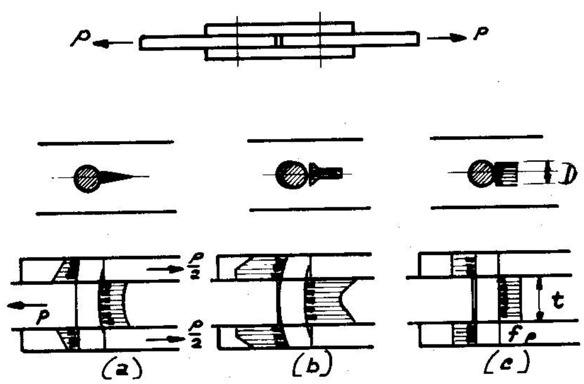

Figure 3: Ply Bearing Stress (Hogan et al, 1979)

The total elongation of a standard hole including bearing deformation that is subjected to a loading equal to the ply nominal bearing capacity of $3.2 d_b t_p f_{up}$ is in the order of the diameter of the bolt (RCSC, 2004). The C_1 coefficient was introduced into the equation to limit the amount of ovalling from earthquake loads. The reason being that joint movement or slop is detrimental to the performance of the structure in a minor earthquake (Nicholas, 1985). Structural behaviour becomes unpredictable when large slippage and ovalling of holes occurs in a major earthquake.

Long Slotted Hole Ply in Bearing – Loaded Perpendicular to Slot

Tests have shown that the presence of transverse slotted holes does not result in a reduction of the tensile strength of the plates or of the shear strength of the fasteners. Hence design capacity of the joint limited by ply in bearing is not reduced by slotted or oversized holes (Kulak et al, 1987). However there will be more local bearing deformation associated with the development of the nominal bearing capacity of a ply limited by strength. In North America the *Research Council on Structural Connections* has a similar general equation to NZS3404 for the nominal bearing capacity of a ply (RCSC, 2004). (*Research Council on Structural Connections* using a coefficient of 3 instead of 3.2) The *Research Council on Structural Connections* has a specific equation for a long slotted hole loaded perpendicular. To limit the amount of deformation to a 'reasonable' deformation the general nominal bearing capacity equation is reduced by a third. Therefore for situations where limiting deformations of the bolt hole is important such as for earthquake applications, the nominal bearing capacity of ply becomes:

$$V_b = 2.1 d_f t_p f_{up}$$

References

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