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On the bearing strength of bolts in clearance holes

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ABSTRACT

In the design of a bolted connection between carbon steel elements, the bearing strength of bolts in clearance holes is determined using codes of practice. The complexity of the formula for calculating the strength varies; the formulae in BS 5950 and the American AISC code are relatively simple but the one in EC3 is more complicated. A number of aspects concerned with the design procedure in EC3 could be improved; these are identified and discussed with reference both to the requirements of BS 5950 and theory. Initially, using simple theoretical arguments, small alterations are suggested for the minimum values specified in EC3 for some of the parameters involved in the calculation; these make the design procedure and the formula for calculating the bearing strength both logical and simple. A refined theoretical approach is then applied and it is found that, surprisingly, failure may occur due to shearing of the plates alone and bearing may not be involved in it at all. Strictly, these comments only apply to carbon steel elements. However, they could apply to elements in other ductile materials (e.g. stainless steels). The findings are applied to experimental results for both carbon steel and stainless steel specimens and it is shown that they provide good estimates of both the failure loads and failure modes of test specimens. Two possible design approaches are suggested.

1. Introduction

The load carrying capacity of a simple lap joint (see Fig. 1) is determined by considering the possible failure modes for the connection, calculating the failure load associated with each failure mode and identifying the lowest failure load. This is the capacity of the connection and the failure mechanism that provides this failure load is the actual failure mechanism. Several failure mechanisms must be considered for lap joints — failure of the bolts in shear, failure of the bolts/plate by bearing, failure of the plate by shearing (Fig. 1a,b) and tensile failure of the plate at the location of the bolts (Fig. 1c,d); a block tearing mode may also have to be considered in some cases. Shear failure of the plate can occur either at the location of the end bolts (Fig. 1a) or between two adjacent bolts located along the direction of the applied load (Fig. 1b); this failure mode will be referred to as "shear out". Shearing out and tensile failure are often avoided by specifying minimum values for the distance of bolts from the nearest plate edge (lengths e_1 and e_2 in Fig. 1), the pitch (p_1 in Fig. 1b) and the gauge (p_2 in Fig. 1d). So long as the design of the connection provides the minimum values specified for these parameters, it should be possible to design the connection by considering the first two failure modes only.

BS 5950 [1], the American AISC code [2] and EC3 [3] specify minimum values for e_1, e_2, p_1 and p_2. BS 5950 specifies the same minimum value for e_1 and e_2 but distinguishes between different ways of forming the plate edge. The value given for a rolled, machine flame cut, sawn or planed edge is indicated in Table 1. The code specifies the same minimum spacing between bolts in the two directions (p_1 and p_2), as indicated in Table 1. The corresponding minimum values specified in the AISC code and in EC3 are also indicated in Table 1. Note that some of the values are specified in terms of the diameter of the bolt hole (d_0) whereas others are specified in terms of the nominal bolt diameter (d). The values specified for the various parameters depend upon the material properties used in the design procedure so that small variations between the specified values are to be expected.

There are a number of aspects of the procedure specified in EC3 that do not seem to be logical. These will be discussed in the paper and alterations will be proposed following a simple initial theoretical study. The proposed alterations remove the unsatisfactory aspects of the current procedure and also simplify the calculations. A refined analysis will also be carried out and the predictions of these analyses will be tested by applying them to the test results that were used to verify the current EC3 procedure.

The comments made above relate to carbon steels. However, they could also apply to other ductile materials. Some structural stainless steels, for example, have a ductile stress–strain curve and the above comments could apply to them. The analysis developed below for carbon steels would then also be applicable to these materials. The proposed procedure is used to predict the behaviour of some stainless steel specimens and it is shown that it accurately predicts both the failure modes and failure loads for these specimens.

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