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DETERMINATION OF PRYING LOAD ON BOLTED CONNECTIONS

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ABSTRACT

This study concerns about the bolted connections of L and T sections which are subjected to tensile loads. Prying load holds quite important role in these connections since it increases the tensile load on the bolts and affects the decisions on the bolt type, material and its location at the flange. The effect of prying load on bolted connections through many finite element models generated for various combinations of the chosen design parameters such as bolt diameter, flange thickness, and edge distances. Finite element models are generated as linear models with contact definition. According to the results obtained, main factors affecting the prying ratio are discovered as the distance of bolt center to the clip web, flange thickness of the clip and preload on the bolt. Obtained results are collected to form simple functions for designers benefit without performing tests and analyses. Study is planned to be extended such that it includes the material nonlinearity effects.

INTRODUCTION

Design of airframes requires faster solutions as well as trusted ones. Aerospace industry performs considerable amount of tests for the solution of problems depending on many parameters. On the other hand, it is not feasible to test every possible configurations. For instance, prying load on tensile connections causes additional axial load on bolt and this additive might not be calculated analytically in an easy and accurate way. Moreover, these type of connections are used in the airframe frequently. Bruhn [14] and Niu [2] presented the main approaches about the subject in terms of aeronautics. As Bruhn's and Niu's works show, establishing the analytical methods and data plots depend on test data obtained for the various cases. In addition to aeronautical engineers, many civil engineers developed on analytical methods which fit the test data closely for different cases. Agerskov [8], Fisher and Struik [12], and Douty and McGuire [13] presented analytical approaches and verifications. Besides all, Kukreti [6], Krishnamurthy [5], Chasten [4], and Kamuro [3] conducted finite element analysis in stead of analytical methods and tried to obtain acceptable results.

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DEFINITION OF THE PROBLEM

Tensile connections (i.e. tension clips) are widely used in aircraft structures. In (Figure 1) sample tensile connection is given.

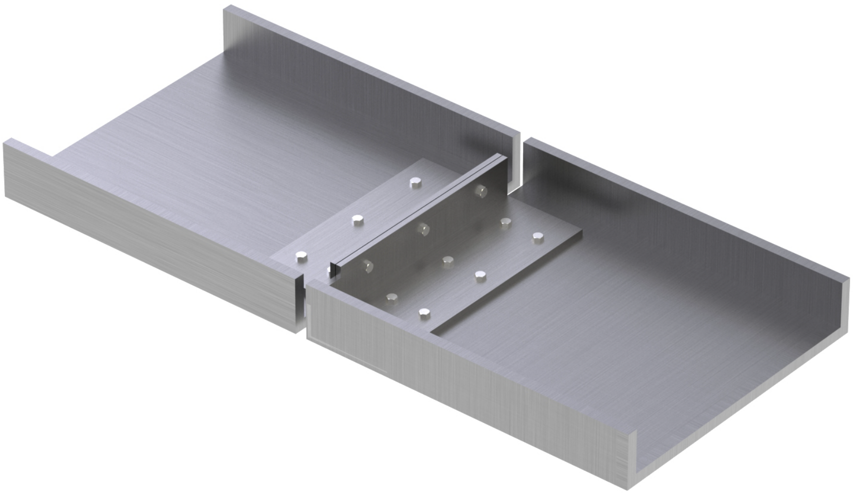

Figure 1: Sample Tensile Connection (Tension Clip)

Prying effect is arisen in tensile connections. As a result of tensile loading, eccentricity of bolt load with respect to the external load causes the toe of the flange to touch the ground structure. Distributed contact load at the toe of the flange is named as *Prying Load* and it increases the axial load (B) (Figure 2) on the bolt.

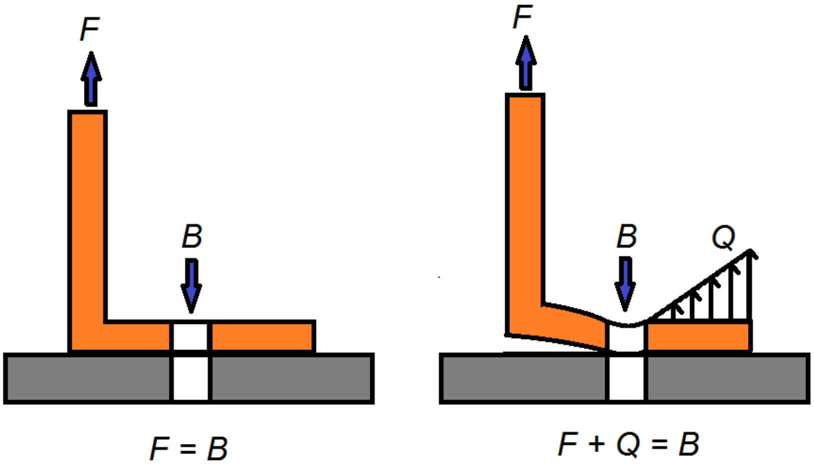

Figure 2: Prying Load on Angle Section

METHOD

Analytical Approach

In order to determine prying load on stringers or clips of L and T sections, first of analytical approaches are developed. For each section type, solutions depending on the geometry and external load are presented through the simple static and elastic knowledge. Free body diagram of T connection is given in Figure 3.

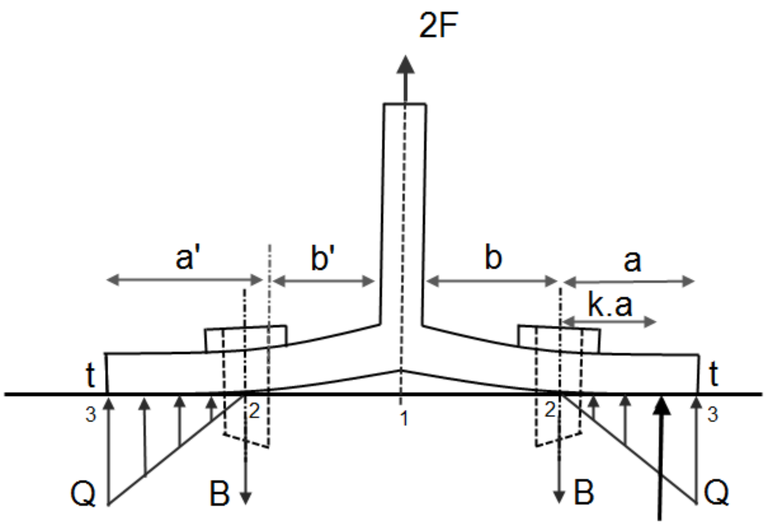

Figure 3: Free Body Diagram of T Sectioned Connection

According to these classical analytical approaches, the ratio of prying load (Q) and external load per bolt (F) for L and T sections are calculated as given in Equations 1 and 2.

$$\left(\frac{Q}{F}\right)_L = \frac{b}{ka} \tag{1}$$

$$\left(\frac{Q}{F}\right)_T = \frac{b}{2ka} \tag{2}$$

Analytical models presented by Douty [13] and Struik [12] are examined and simplified for practical purposes. In these studies Equations 3 and 4 are derived for T sectioned connections both.

$$Douty: \left(\frac{Q}{F}\right) = \frac{3b}{8a} - \frac{t^3}{20} \tag{3}$$

$$Struik: \left(\frac{Q}{F}\right) = \frac{3b'}{7a'} \tag{4}$$

Finite Element Modeling and Verification

Finite element models are formed by brick elements of C3D8 of Abaqus software. Material is decided as AL 2024 because of its widely usage. As a starting point, strain values are assumed small and elastic material model is used. Ground is modeled rigid as in the sample finite element model given in Figure 4. According to the general design knowledge, depth of the stringer is taken as four times the diameter of the bolt (4D) per each bolt.

In order to model the continuity of the stringer correctly, proper side surface constraints are defined. Although the primary model is linear, contact is defined between bolt, rigid ground and stringer. Contact definition is applied such that surfaces are able to interact only in the normal directions since the effect of the friction is found to be insignificant on the results obtained. External load is applied at the upper surface of the stringer.

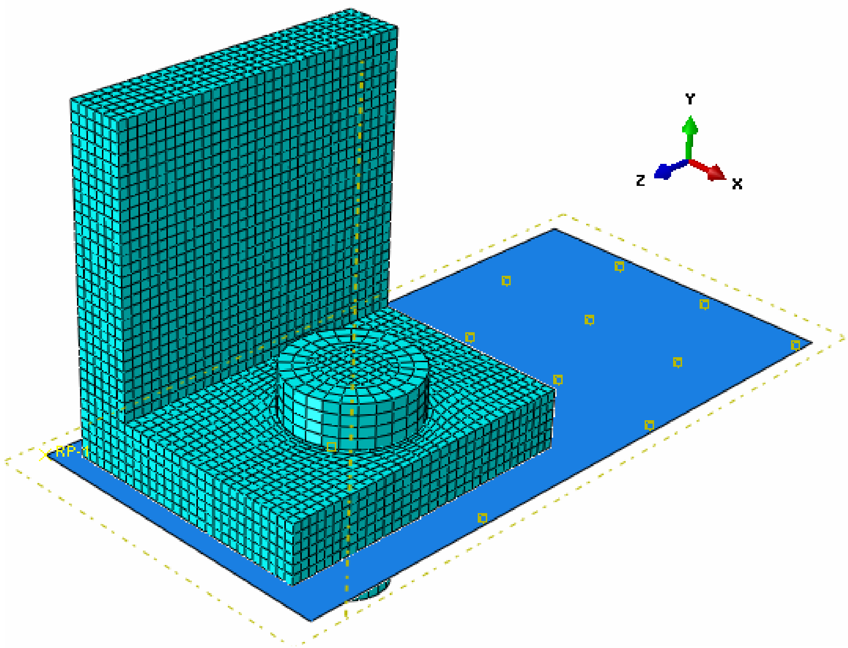

Figure 4: Finite Element Model

In order to verify the established finite element model, test results presented by Agerskov [8] is handled. For the suitable comparisons, models are created according to the properties supplied by Agerskov in terms of dimensions, materials and loading. In the Figure 5, analyses results are presented as ratios with respect to test results. Maximum error obtained is 9% among 19 test cases.

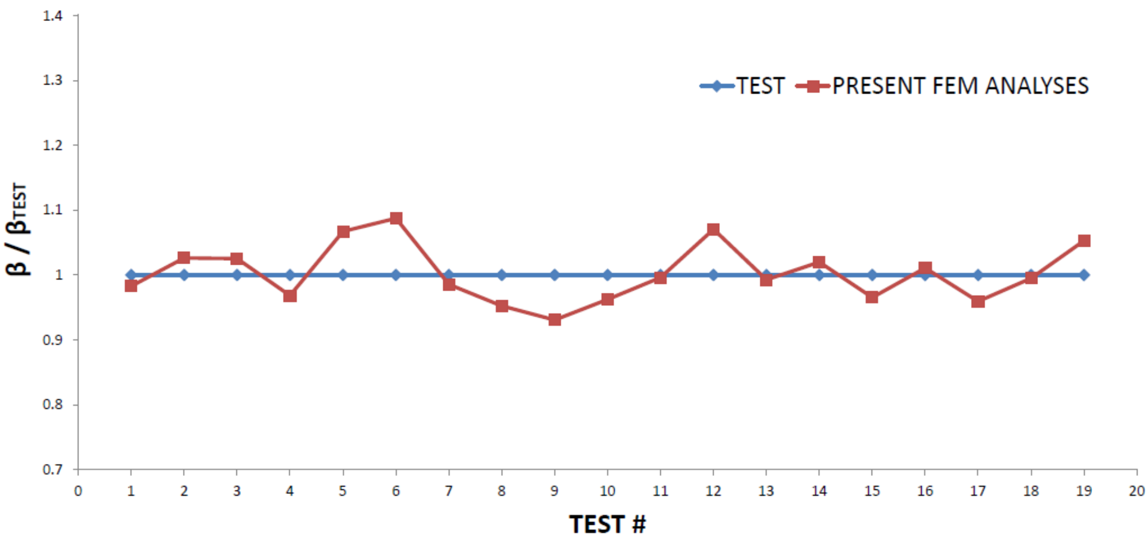

Figure 5: Comparison of Tests and Analyses Results

Parametric Study

After the verification of the model, results of many variations on the dimensions and on the magnitude of the preload on the bolt are collected and examined. Dimensions of a,b,t ve D shown in Figure 6 are chosen as the variables of parametric study.

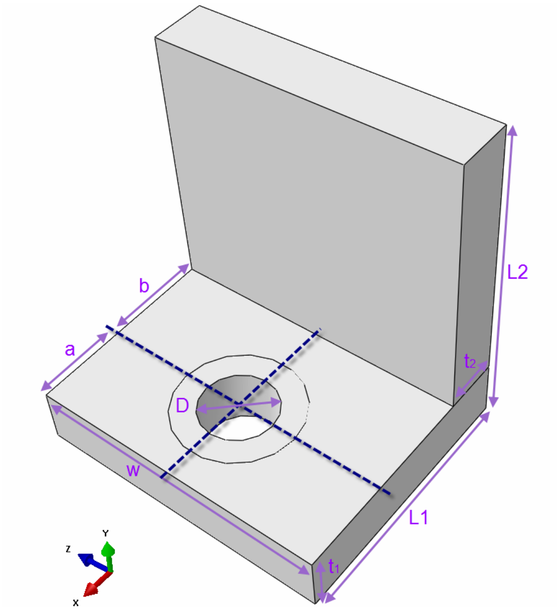

Figure 6: Dimensions Used in Parametric Study

Parametric modeling tool developed through Phyton language is used for the range of dimensions given in Table 1. These ranges are modeled and analyzed for both cases with and without preload. In this way, 1800 different models are formed and result data is collected and discussed by the same tool.

Table 1: Data Set Used for the Parametric Study

Set of Diameters		Set of b/D		Set of a/D		Set of t/D	
1	4.826	1	1.6	1	2.0	1	0.3
2	6.350	2	1.7	2	2.1	2	0.5
3	7.938	3	1.8	3	2.2	3	0.7
4	9.525	4	1.9	4	2.3		
5	11.113	5	2.0	5	2.4		
6	12.700						

Diameter values are in mm.

RESULTS

Distance of the bolt to the flange toe (a) is found to be least effective geometric variable on prying effect. Sample results obtained for varying (a/D) values are given in (Figure 7).

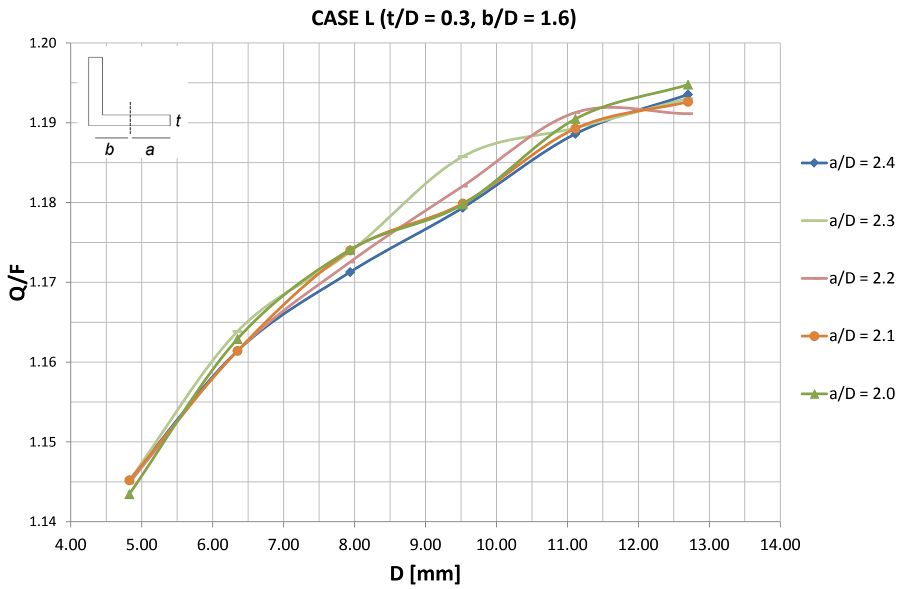

Figure 7: Effect of (a/D) Ratio on Prying Effect on L Sections

On the other hand, distance of the bolt with respect to the flange root (b) and flange thickness is discovered to be quite effective on the results as shown in (Figure 8).

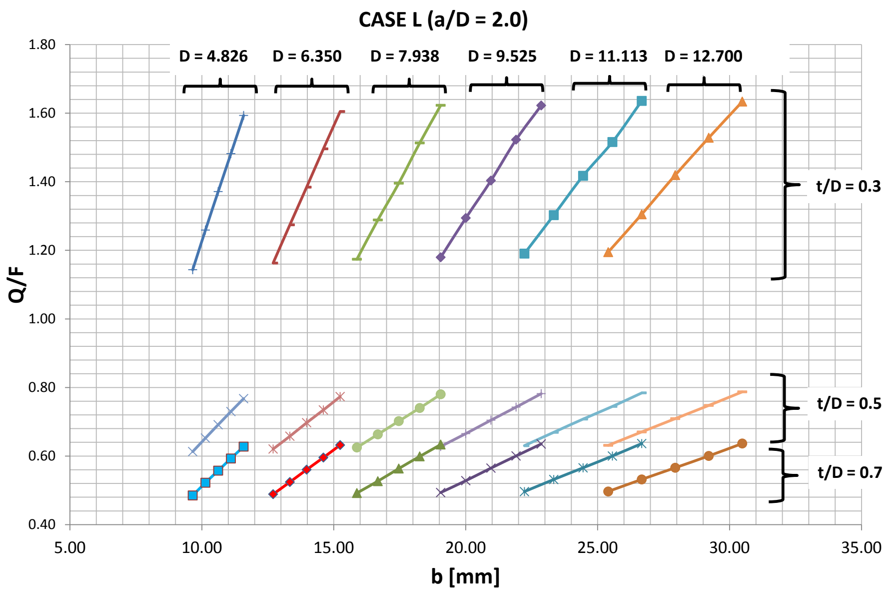

Figure 8: Effect of Dimension (b) on Prying Effect on L Sections

Analytical approaches presented by Struik and Douty are interpreted as not suitable for thin and light structures of airframes. Instead of them, new analytical equations obtained by the parametric study are suggested (see equations 5 and 6). Details of the results can be obtained from the complete work of the writer [1].

$$\left(\frac{Q}{F}\right)_L = \left\{ \begin{array}{cc} 2b/a, & t/D = 0.3 \\ b/a, & t/D = 0.5 \\ 3b/4a, & t/D \geq 0.7 \end{array} \right\} \tag{5}$$

$$\left(\frac{Q}{F}\right)_T = \left\{ \begin{array}{cc} 3b/2a, & t/D = 0.3 \\ 4b/5a, & t/D = 0.5 \\ 3b/5a, & t/D \geq 0.7 \end{array} \right\} \tag{6}$$

In addition, it is observed that the preload applied on the bolt is quite effective on the results and it increases the prying effect. Equations 7 and 8 are the results obtained while the preload is applied such that the bolt reaches 63.5% of yield stress.

$$\left(\frac{Q}{F}\right)_{LP} = \left\{ \begin{array}{cc} 13b/6a, & t/D = 0.3 \\ 11b/10a, & t/D = 0.5 \\ 4b/5a, & t/D \geq 0.7 \end{array} \right\} \tag{7}$$

$$\left(\frac{Q}{F}\right)_{TP} = \left\{ \begin{array}{cc} 12b/7a, & t/D = 0.3 \\ 10b/9a, & t/D = 0.5 \\ 3b/5a, & t/D \geq 0.7 \end{array} \right\} \tag{8}$$

CONCLUSION AND FUTURE WORK

Today, testing is quite important for the verifications and reliabilities of designs. On the other hand, when improving computational modeling methods and computer technology are considered, cost of testing might be reduced significantly. It is possible to try many cases quickly without losing reliability. In this study, relatively simple connection is modeled with the dimensions providing the appropriate conditions for airframe design. Through the parametric study, 1800 different models are prepared and results are discussed.

In the light of information obtained from comparisons and complete result data, studies of Struik and Douty are concluded not to be applicable for aircraft structures. Besides, it is concluded that analytical equations are required to be defined including the thickness effect and prepared for each different conditions separately in stead of forming one general rule. In this way, more reliable results might be obtained.

Study, as it is, satisfies the general design requirements with the linear modeling approach. However, it might be improved by including the material nonlinearity effect in order to present actual limitations on deformations and load carrying capacities of the connections especially in the case of post yield conditions are concerned.

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