digitool

Software Tools for Mechanical Designers

Bolted Connection Designer

Quick Start Guide

Contents

1.0 Introduction

The Bolted Connection Designer (BCD) by Digitool is a web based software tool for performing bolted connection calculations. The benefit to web based software over a conventional local installation is that it can accessed and used anywhere in the world on any device which has an internet connection, which makes it ideal for using in both an office environment and on site. It has also been developed with a responsive user interface which means it will be usable on mobile and tablet device without loss of quality and clarity.

The software utilises the elastic method of calculation which is a conservative approach, in contrast to the alternative instantaneous centre of rotation method [2]. For a moment connection the bolt group forces are calculated using elastic theory, which assumes a linear distribution of load throughout the group. Those fasteners which are the furthest away from the flexural neutral axis see the most load and there is a linear decrease in load as you approach the neutral axis of the bolt group. The XX moment forces and YY moment forces are then superimposed, which is permitted under elastic theory. Any direct tensile load is then added to the combined flexural loading to give a total bolt reaction force. The software can be used to analyse both pre-loaded and none pre-loaded connections. The pre load force is given as a percentage of the yield strength of the fastener. Preloaded connections behave like springs in parallel, where the connecting members are in compression and the bolt is in tension. The actual load which the bolt sees is a function of the bolt and member stiffness [1]. If there is additional torsion or shear on the connection then the actual compressive force around the bolt in used to find the resistance to slip. The concept of pre-loaded bolted connections is described in more detail in the user manual.

The aim of this quick start guide is to introduce the user to the software functionality and its limitations so as to enable calculations to be performed correctly.

2.0 The User Interface

The quickest way to start a calculation is to select the “Try as Guest User” from the Digitool homepage, (https://www.digitool.org). You will be presented with a screen containing a list of user generated connections. You can view the details of a connection by clicking on the connection name, which is contained in the column furthest to the left. For the purpose of this guide we will start a new connection. The actions side bar on the left hand side of the screen contains all the available actions. From the “Guest User’s Connections” screen select “New Connection” from the action side bar. On selecting this option you will be transferred to the “New Connection” input page. We will now look at this page in detail as the information entered here will define your bolted connection.

2.1 Input Connection Properties

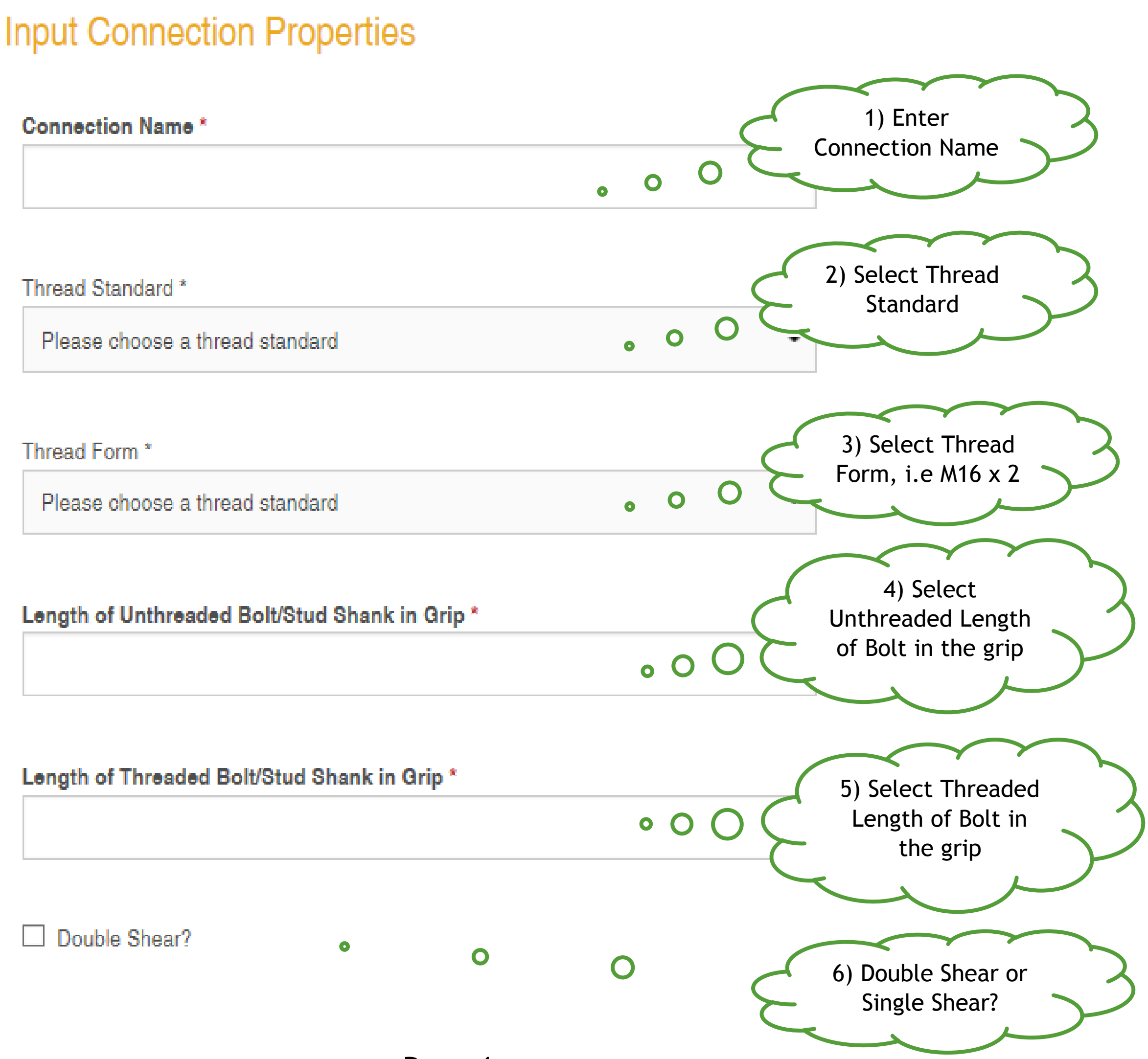


Fig 1.0 – Input Connection Properties

Below is a detailed description of each of the required inputs shown in Fig 1.0.

1) Connection Name

This one is rather self-explanatory, however it is worth noting that this field should take a descriptive name for the connection. You may want to analyse the same connection geometry for several different load cases. An example of this would be naming the initial connection "Load Case 1: Bending". This connection can then be copied preserving all the parameters and then renamed to "Case 2: Direct Load". The only changes required would be to the forces and moments and all other parameters would remain unchanged. Of course these are only recommendations and the name can be edited after initialisation.

2) Thread Standard

Currently there are two thread standards available to select. These are the British Standard BS3692 and the American Standard B18.2.1. The database contains all the data for thread forms defined by these two standards.

3) Thread From

The British standard covers both fine and course thread forms whilst the American standard only covers unified course thread forms (UNC). This can be edited after initialisation.

4) Unthreaded Length of Bolt in the Grip

The unthreaded length is the unthreaded shank length of the bolt which is inside the grip of the connection. The grip length is the total length of all members in the connection which are compressed by the pre-loaded bolt. Refer to Fig 2.0 below for more detail.

For a setscrew where the full bolt length is threaded, you would enter 0 into this field. The total grip length is the combined threaded and unthreaded length of the bolt in the grip. The reason for separating the bolt into two lengths is because the threaded and unthreaded portions have slightly different stiffness values and thus affect the calculation.

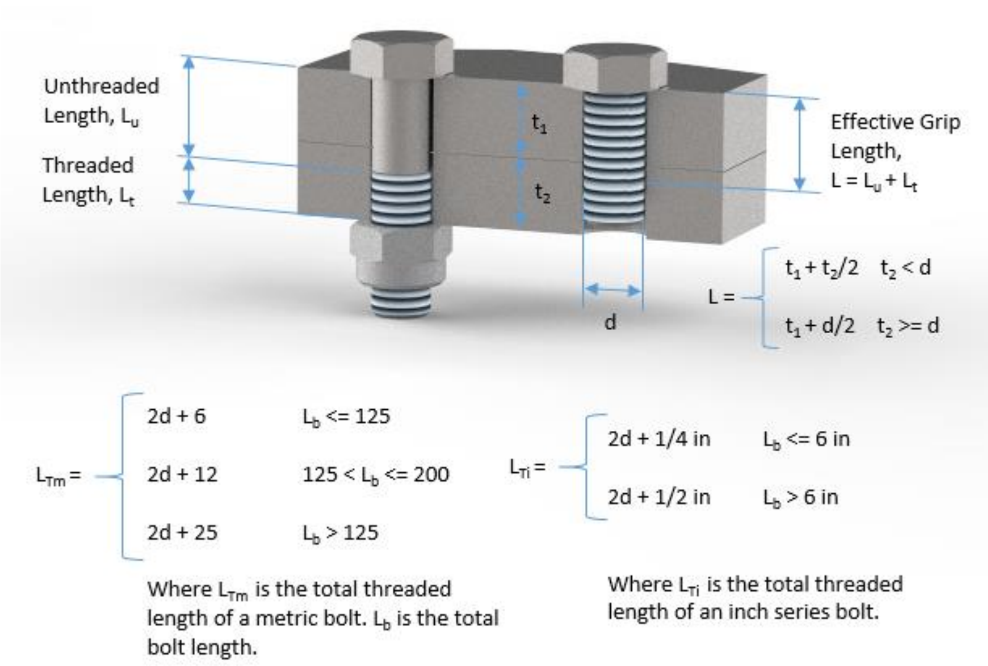


Fig 2.0 – Section through Bolted Connection

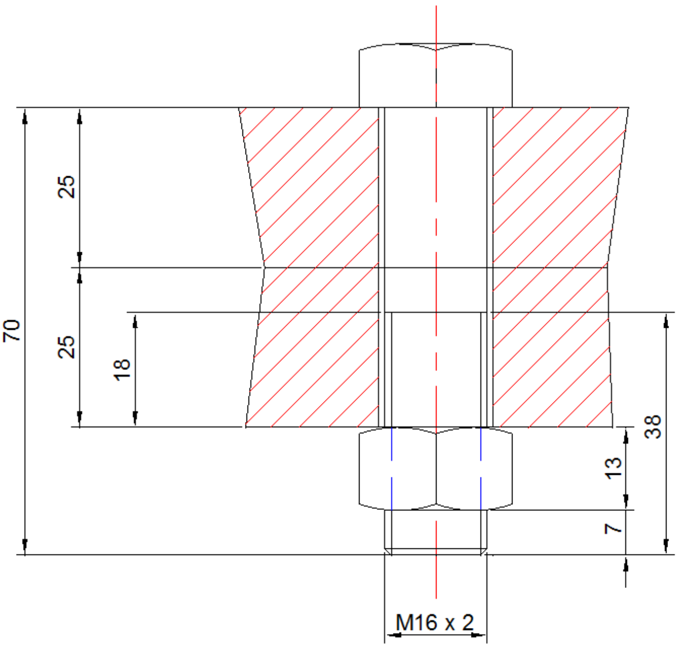
5) Threaded Length of Bolt in the Grip

This is the threaded portion of the bolt in the grip. For a bolt and nut connection, this can easily be calculated using the formulas given in Fig 2.0. See the example below.

Example

Question: A bolted connection clamps two 25mm plates together with M16 x 2 bolts and nuts. What is the threaded and unthreaded length of the bolt in the grip?

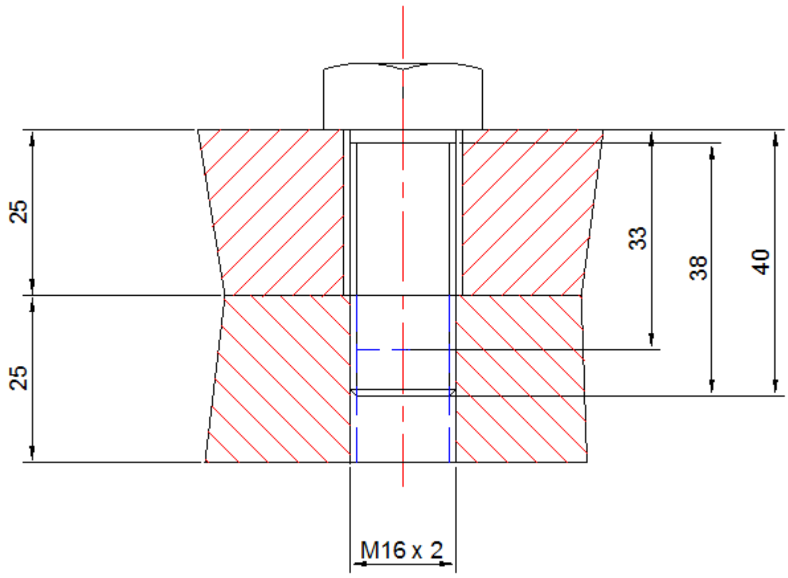
Answer: The grip length is 25mm + 25mm = 50mm. If we account for the nut height of 16mm and ensure that the thread is at least 3 pitches beyond the nut then the minimum bolt length is 50mm + 13mm + (3*2)mm = 69mm. The next available bolt length is 70mm. According to Fig 2.0 the threaded length would be 2*d + 6, or 2*16+6 = 38mm. Therefore the threaded length in the grip is total threaded length minus the threaded length beyond the grip or 38mm – (13mm + 7mm) = 18mm. The unthreaded length in the grip is therefore the total length minus the threaded length or 70mm – 38mm = 32mm.



Example

Question: An M16 x 2 x 40 Long bolt is used to secure two 25mm plates together. The first plate has a clearance hole drilled through whereas the second plate has an M16 tapped hole through. What is the threaded and unthreaded length of the bolt in the grip?

Answer: With reference to Fig 2.0 the effective grip length is t_1+d/2 or 25mm + 16mm/2 = 33mm as plate thickness t_2 is greater than the nominal bolt diameter. According to Fig 2.0 the threaded length is 2*d + 6, or 2*16+6 = 38mm. The threaded length in the grip is therefore the total threaded length minus the threaded length outside of the grip or 38mm-7mm = 31mm. The unthreaded length in the grip is the total grip length minus the threaded length in the grip or 33mm – 31mm = 2mm.



HINT!!

If you would like to perform a quick conservative calculation without having to first work out the threaded and unthreaded lengths, enter the full grip length as the threaded length and the unthreaded length as 0.

6) Double Shear

A bolt is said to be in “double shear” if two separate cross sectional areas of the bolt shank experience a shear force. See Fig 3.0.

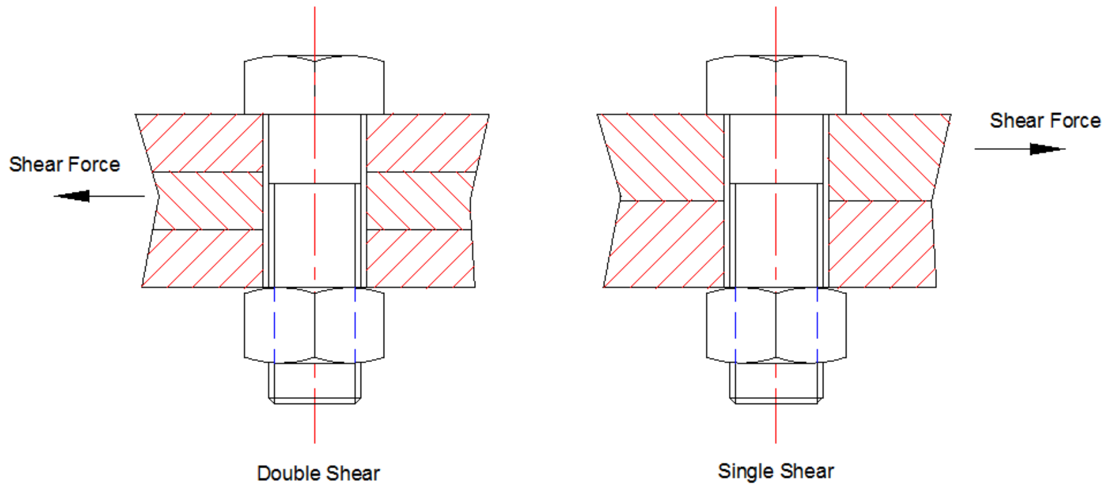


Fig 3.0 – Double Shear Diagram

2.2 Input Forces and Moments

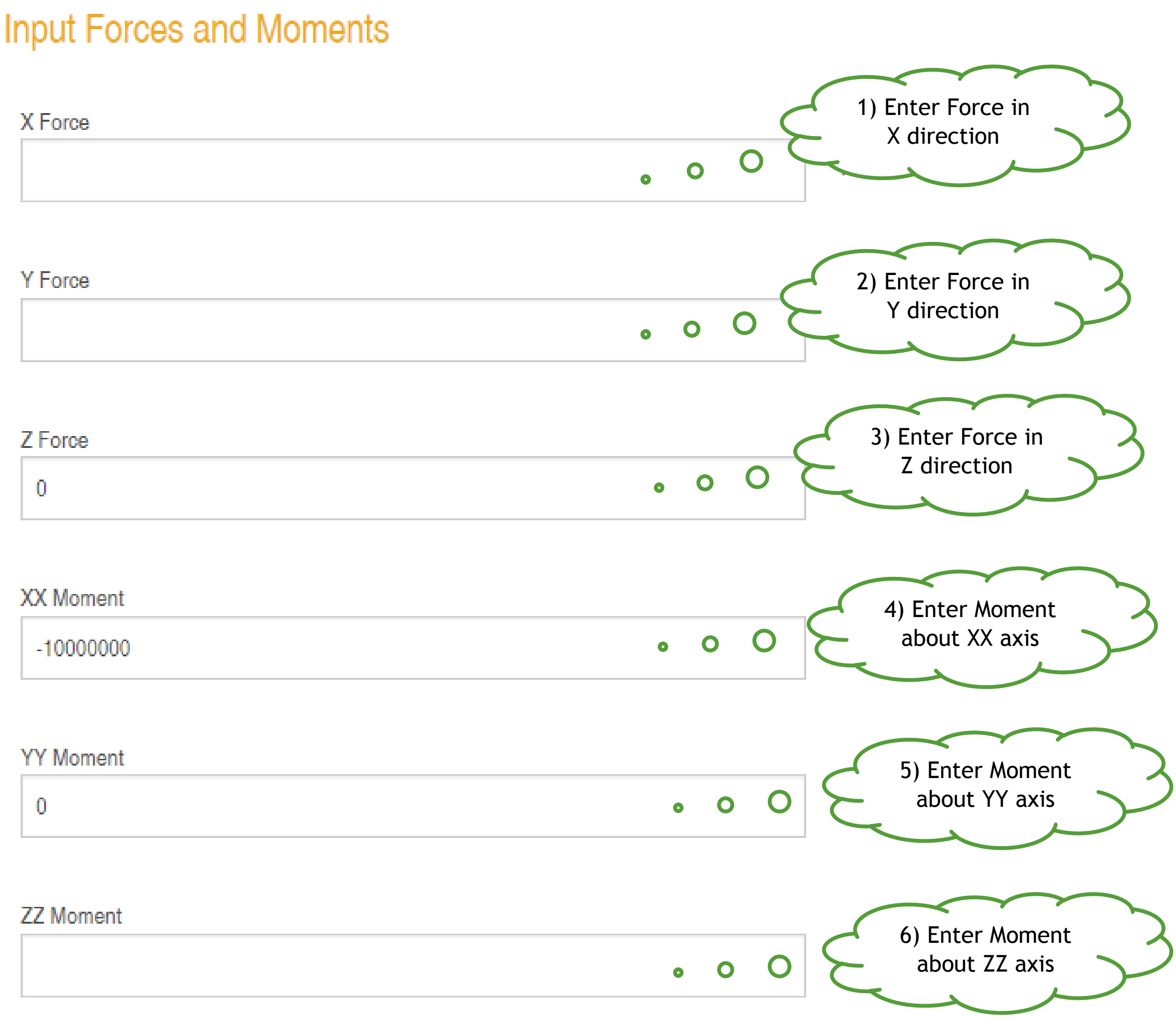


Fig 4.0 - Input Forces and Moments

1) Force in X direction

The positive X direction is depicted by the triad arrow in Fig 5.0. For example, if a force acts on a bolted connection from left to right when viewed from above (bolt heads at the top) then the force value entered into the software will be positive. Conversely, if the direction of force is from right to left when viewed from above then the force value entered into the software would be negative. Forces acting in this direction would generate a shear force in the bolt shank.

2) Force in Y direction

The positive Y direction is depicted by the triad arrow in Fig 5.0. For example, if a force acts upwards on a bolted connection when viewed from above (bolt heads at the top) then the force value entered into the software will be positive. Conversely, if the force acts downwards when viewed from above then the force value entered into the software would be negative. Forces acting in this direction would generate a shear force in the bolt shank.

3) Force in Z direction

The positive Z direction is depicted by the triad arrow in Fig 5.0. If the force acts out of the page, i.e. towards you, then the force value entered into the software will be positive. Conversely, if force acts into the page then the force value entered into the software would be negative. Forces acting in this direction would generate a direct tensile force in the bolt shank.

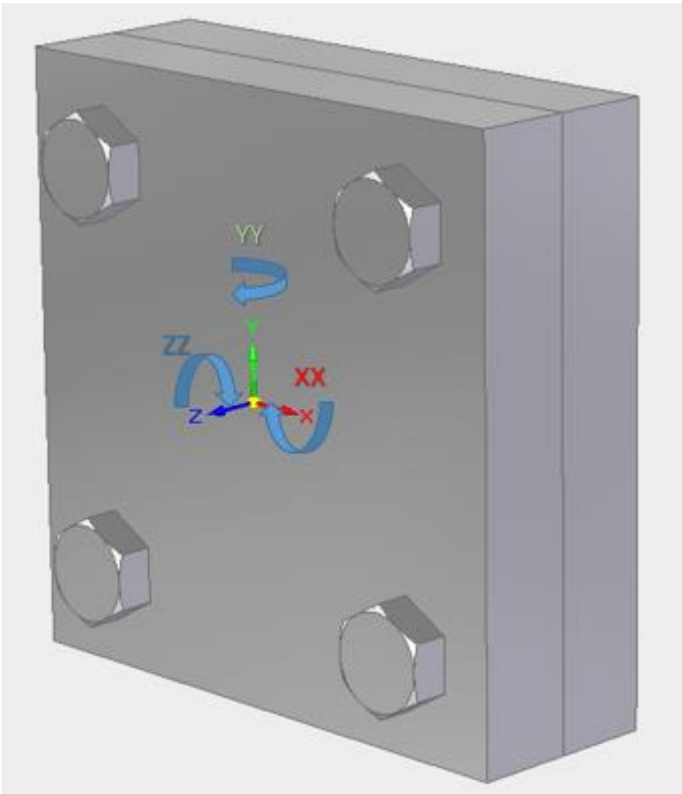


Fig 5.0 – Bolted Connection Sign Convention

4) Moment about XX

This moment acts about the X axis as shown in Fig 5.0. The moment is positive when it acts clockwise looking in the opposite direction to the X axis arrow towards the centre of the triad. For the bolted connection shown in Fig 5.0 the bolts below the XX neutral axis would experience an applied tensile force and the bolts above the neutral axis would experience an applied compressive force.

5) Moment about YY

This moment acts about the Y axis as shown in Fig 5.0. The moment is positive when it acts clockwise looking in the opposite direction to the Y axis arrow towards the centre of the triad. For the bolted connection shown in Fig 5.0 the bolts to the right hand side of the YY neutral axis would experience an applied tensile force and the bolts to the left hand side of the neutral axis would experience an applied compressive force.

6) Moment about ZZ

This moment acts about the Z axis as shown in Fig 5.0. The moment is positive when it acts clockwise looking in the opposite direction to the Z axis arrow towards the centre of the triad. This would give rise to a shearing force in each bolt which acts perpendicular to a line running from the bolt group centre point to the bolt in question.

2.3 Material Properties

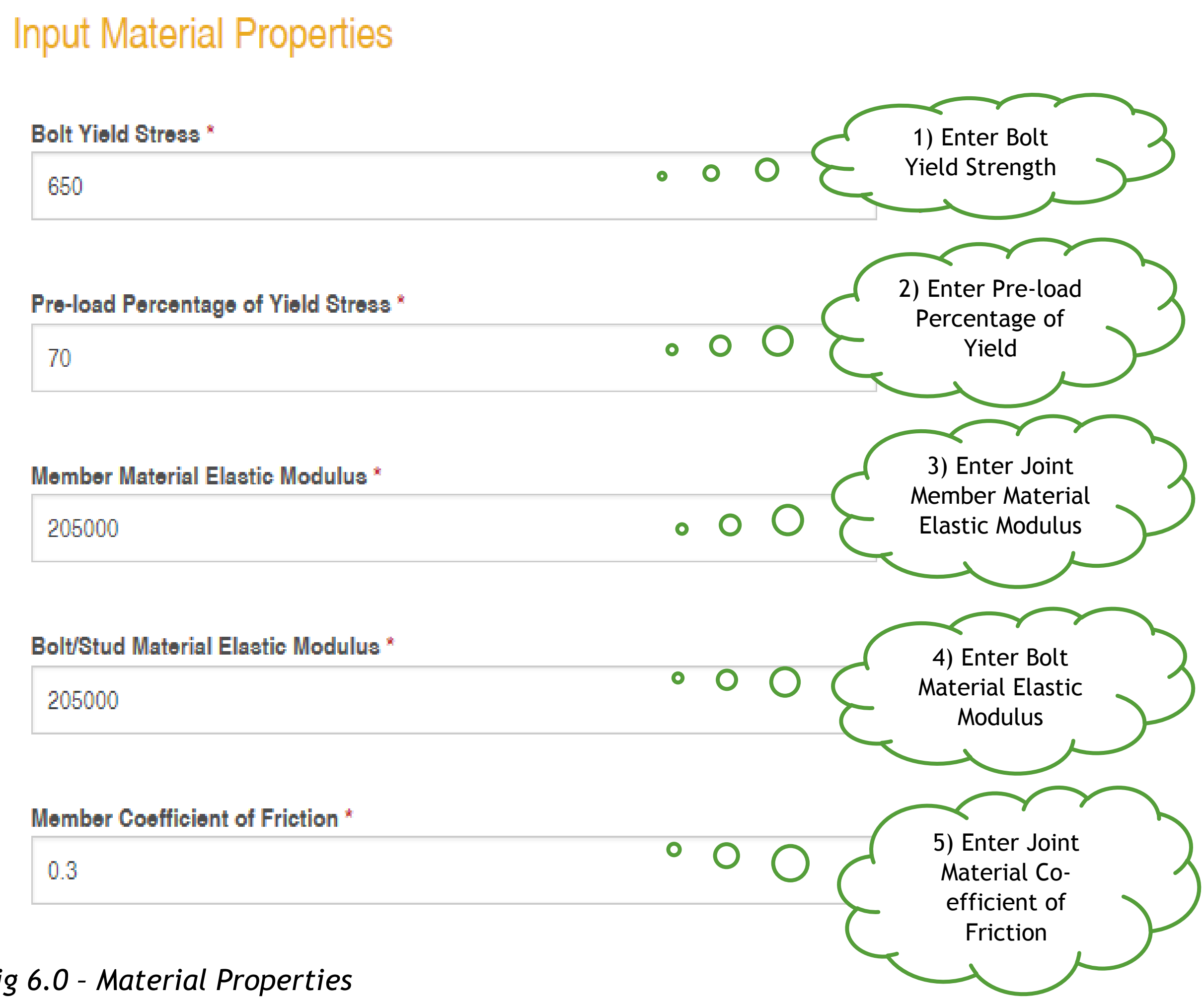


Fig 6.0 - Material Properties

1) Bolt Yield Strength

This is either the bolt material yield strength or the 0.2% Proof Stress. It is used when calculating the bolt pre-tension and for calculating the factor of safety on yield. These values can be found in the bolt standards and is usually given as a range or a minimum. Metric bolts are usually specified to BS EN ISO 898-1 and imperial bolts to ASTM A193/A320.

2) Pre-Load Percentage of Yield

This value is a percentage of the bolt yield strength. The pre-tension in the bolt is usually specified as a percentage of yield stress, and the standard is 75% of yield. This is sometimes increased for fatigue sensitive applications up to 85%.

For example, a standard M16 bolt to BS EN ISO 898-1 grade 8.8 will have a 0.2% proof stress of 640 MPa. The 75% proof stress would be .75*640 = 480 MPa and would give a theoretical pre-tension force of around 480*(pi*16^2)/4 = 96510 N. However, in reality this figure could change by as much as 40%. This is because applied torque is lost due to frictional torsion in the bolt shank and the coefficient of friction is an estimate amongst other factors. Bolts which control tension by the measuring the elongation at pre-load stress are more accurate and are usually within 5% of the calculated value.

If not using direct tension indicator bolts it is recommended that a factor of safety of at least 1.5 be used in the calculations.

3) Joint Member Material Elastic Modulus

This is the joint member material stiffness. For mild steels this is usually around 200-210 GPa (200000 – 210000 MPa).

4) Bolt Material Elastic Modulus

This is the bolt material stiffness and for low alloy steel bolts is usually in the range of 200-210 GPa (200000 – 210000 MPa).

5) Member Coefficient of Friction

This is the coulomb friction coefficient for the interface of the two bolted joint plates. These plates are clamped together when the bolt pre-load is applied and hence a frictional resistance against slippage is generated. See the table below for some typical values.

Contact Surfaces	slip coefficient
Steel On Steel- No treatment	0,15- 0,25
Steel On Cast Iron- No treatment	0,18 - 0,3
Steel On Steel- Machined (Degreased)	0,12- 0,18
Steel On Cast Iron- Machined (Degreased)	0,15 - 0,25
Grit -Sandblasted surfaces	0,48 - 0,55

Table 1.0 – Typical Coefficients of Friction for Bolted Joints

2.4 Adding Bolts to the Connection

Once the connection properties are established then the next step is to add bolts to the connection. Bolts can be incrementally added as single bolts, a line of bolts or a circle of bolts. They are added from the “Actions” side bar on the “Connection Details”. The side bar is shown in the figure below :-

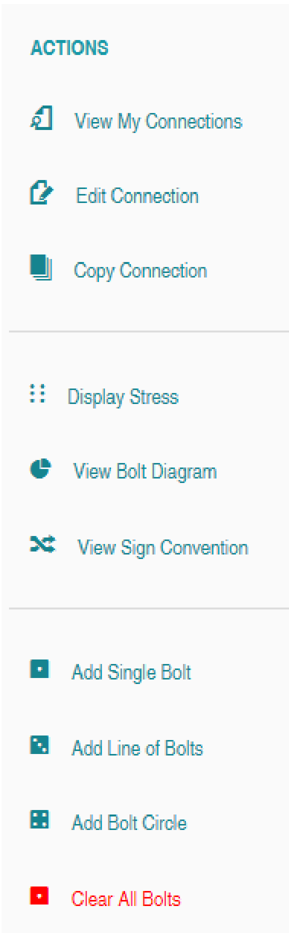


Fig 7.0 – Actions Side Bar

When the first bolt is added the calculation is performed. The bolt stresses are calculated along with the FOS against yielding. To visualise the stress plot click on the “Display Stress” link from the “Actions” side bar, see figure 7.0. Below is a typical bolted connection analysis result:-

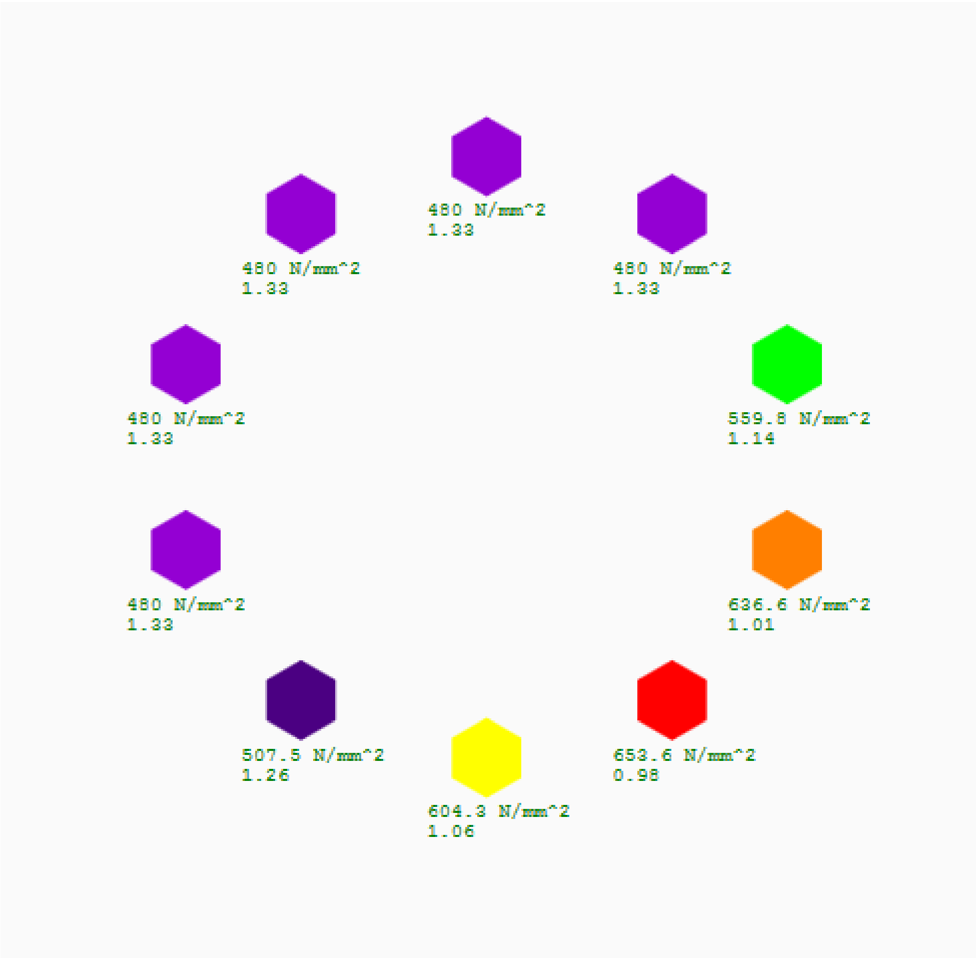


Fig 8.0 – Bolt Circle Analysis

The coloured bolt heads signify the level of stress in the bolt. The stress value is shown below the bolt head and the factor of safety on yield is shown below the stress value.

3.0 Assumptions and Limitations

It is important to understand the assumptions used and limitations of the software before performing calculations with it as the output could be completely meaningless at best and dangerous at worst.

The first major assumptions is that the member geometry is designed effectively as to prevent or significantly reduce any prying forces on the bolt. No calculations are performed on the connecting members and it is assumed that the designer has chosen adequate plate thicknesses to resist bending, bearing and direct pull out stresses.

The loads on the bolt are calculated independently and then superimposed. This is considered to be conservative and more realistic approach is to use the instantaneous centre of rotation method. More detail can be found in reference [2].

A perfect linear distribution of load is assumed when a connection is in bending, i.e the bolts furthest away from the flexural neutral axis see the most load. Bolts are in tension at one side of the neutral axis and in compression at the other side.

The stiffness of the members are calculated using the pressure cone frustra method with a pressure angle of 30 degrees. The interface diameter of bolt to member is assumed to be 1.5 x diameter of the bolt.

The frictional shear resistance is calculated using the residual member loads after any direct tension or bending tension is applied. Because this is calculated on each bolt part of the connection could slip whilst part of the connection is static. In reality this would not happen and the connection would remain static if the torsional and translation resistances to slip were greater than the applied load. This is a limitation of the software but is considered to produce conservative results.

4.0 Conclusion

This simple guide is intended to enable the user to quickly perform bolted connection calculations and help size the bolts and connection geometry. For highly loaded connections and fatigue sensitive connections it is recommended that a more detailed finite element analysis is performed by a competent stress engineer to validate the connection. Future releases of this software will include fatigue analysis and more options including the addition of torque requirement outputs and direct tension bolt technology input parameters.

For help using this software please post your questions in the forum (https://www.digitool.org/forum) and an administrator will respond promptly.

5.0 References

[1] Shigley's Mechanical Engineering Design (McGraw-Hill Series in Mechanical Engineering) 8th Edition

[2] www.bgstructuralengineering.com (Online Structural Engineering Resource)

6.0 Revision History

Revision	Change History	Date
1.0	Initial Release	11/01/2017