A review and casestudy: Bolt pretension

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Abstract— In the presented paper, an attempt has been undertaken to provide an account of some achievements in the area called bolt pretension. Discussion has been done on some of idea of bolt preload or pretension. The explanation was provided using graphical .The analytical method provided to calculate the factor of safety. The software base solution defines through case study to identify the factor of safety.This type of methodology is very usefull to identify the behavior of bolt before prototype development for mechanical structure.

Index Terms— Preload, Factor of safety, Non linear behavior, tensile force, Equivalent stress

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1 INTRODUCTION

THE initial tension in a bolt after it has been installed is termed "preload" or "pretension". Bolts must be installed to a minimum level of preload, usually expressed (in United States) as kips, or thousands of pounds. An ASTM A 325 bolt 7/8" diameter, for example, is to be preloaded to 39 kips, or more. There is no upper limit to this specified preload, only a lower limit. [1]

If a bolt has been preloaded to over 70% of the minimum specified ultimate tension for it's grade, as external load is applied to a connection, the bolt show only a change in tension which is a fraction of the external load. (Figure 1) The fraction seen is determined by the relative stiffness's of the bolt vs. steel plate connection. Conversely, (as in Figure 2), if a bolt has been preloaded only to a low value, the same external load fluctuation will produce a tension change in the bolt which is relatively higher compared to the initial preload

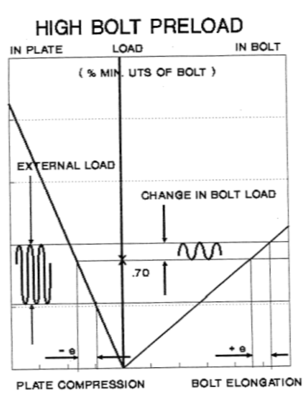

Figure 1: Effect of high bolt preload

Figure 3 shows the typical tension/elongation curve for an ASTM A 235 bolt loaded in pure tension. The specified minimum preload is 70% of the minimum specified ultimate strength (UTS) of the bolt, which is the highest point on its tension/elongation curve. Most high strength bolts have a minimum UTS somewhat higher than their specified minimum.

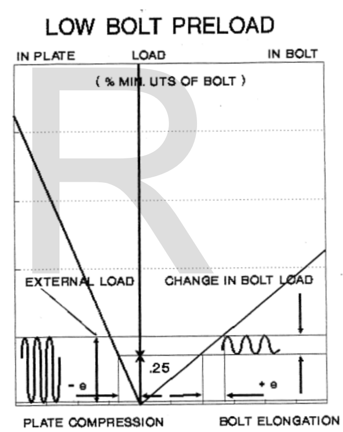

Figure 2: Effect of low bolt preload

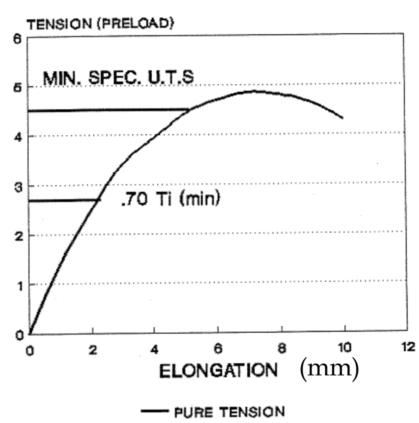

Figure 3: Curve for .70 percentage preload

J. M. Stallings and D.Y.Hwang [2] has contributed about the modeling of pretension in bolted connections based on finite element analysis approach. The pretensions are modeled by

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using temperature changes in the bolts. The methods presented provide a direct means of calculating the magnitudes of the temperature changes necessary to produce the desired pretensions without the use of trial and error or iterative methods. In the methods presented below, the appropriate temperature changes are calculated from the results of one initial analysis of the connection. The methods apply to connections of arbitrary shape with one or more bolts. The magnitude of pretension can vary from bolt to bolt. The methods presented are also applicable to other systems such as post-tensioned concrete structures where an initial level of tension force is specified. The bolt is installed in the connection at a specified pretension. During installation, the connected material shortens as the pretension is applied. Equivalent stress conditions will be created in the bolt and the connected material if the bolt is installed without pretension, and the temperature of the bolt is then decreased.

Toney K. Jack[3] study on fastening bolt connection which are weakest link in integral engineering equipment, bolted joint connections require proper attention and detailed analysis at the design stage for a fail safe operation in service. The analysis is often lengthy with several variables under consideration. He has given a step-by-step guide; together with all required equations for evaluating a typical bolted joint connection is given. A computer programmed solution in Microsoft Excel TM for such analysis is shown through a worked example. The author recommends a preload value of 70% - 80% of the static tensile strength. This for a safer condition is best taken as the yield strength of the bolt material. because of the straight line relationship between increasing tensile load and bolt stretch up to the yield point of the bolt, a bolt torque tightened within its yield strength will be capable of developing the full rated tensile strength when subjected to additional load in excess of the preload. (P_L) Thus,

$$P_L = y\sigma_{yp}A_s \tag{1}$$

Tension Load or tensile stress induced in bolt body (with tightening torque):

$$\sigma_{bt} = \frac{P_L}{A_b} \tag{2}$$

Torsional Shear Stress:

$$\tau = \frac{16T}{\pi D^3} \tag{3}$$

Principal Stress or Working Stress in bolt

$$\sigma_1 = \frac{\sigma_{bt}}{2} + \sqrt{\left(\frac{\sigma_{bt}}{2}\right)^2 + \tau^2} \tag{4}$$

Tension load in bolt:

$$F_p = (Y_p F_{ext}) + P_L \tag{5}$$

Maximum tensile stress in bolt in service

$$\sigma_{ts} = \frac{F_p}{A_b} \tag{6}$$

Compressive load induced in member

$$F_{cl} = \left(Y_m F_{ext}\right) - P_L \tag{7}$$

Minimum Preload to prevent loss in compression

$$P_{L\min} = Y_m F_{ext} \tag{8}$$

Equivalent Stress in Shank section

$$\sigma_{eqv.} = \sigma_{ts} + K_s\left(\frac{\sigma_{yp}}{\sigma_e}\right)\sigma_b \tag{9}$$

$$\sigma_{eqv.} = \sigma_{ts} + K_t\left(\frac{\sigma_{yp}}{\sigma_e}\right)\sigma_b \tag{10}$$

Stress concentration factors, Ks, Kt, are available as per material parameter. Area reduction or transitions such as bolt head fillet or chamfer, the start of the first thread and fillets in the plane of the nut are points of stress concentration.

Factor of safety for bending/fatigue: Fatigue assessment is based on the Soderberg criterion and the calculation of a safety factor or reliability index based on fatigue is:

$$n_f = \frac{\sigma_{yp}}{\sigma_{eqv.}} \tag{11}$$

changing the preload value through altering the preload-to-yield factor, significantly influences the degree of reliability of the joint. The question of an adequate preload is thus best answered by conducting a what-if type analysis with the program

Design check for Fatigue loading condition: Bolt working load or equivalent stress ≤ load at yield point.

N. Ganji [4] gives a thought about the joint connector in which it is necessary that the joint is fastended with a perticular tension.If the fastener pretension is too tight, it may cause damage to the structure or the fastened itself might break.On the other hand, if the applied pretension is too less, it might result in excessive vibration of the structure or unnecessary leaks.So, it is necessary that the fastener is tightened with appropriate tension. The author has define the procedure for the pretension

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method using ABAQUS software .The pretension surface has been define in finite element model for applying tension force.The surface is chosen approximately at the center of the fastener shank.Once,the assembly load is prescribed,it is then applied to the pretension surface of the element to simulate the tension of the assembly. A pretension node which control the pretension section should be defined.The pretension node is mainly used to apply load preload across the pretension section and maintain the tightening adjustment so that the load across the fastener may increses or decrease upon loading of the structure.This node hase only one degree of freedom. A point load is applied to the pretension node representing the torque applied to the fastener.This load acts in the diretion of normal on the part of the fastenet underlying the pretension section.The total force transmitted across pretension is the combination of reaction force at pretension node and any concentrated load at the node

H. CELIK explain [5] the study about, advanced computer aided engineering (CAE) methodologies, has been applied as method of solution. The stress distributions has been identify on the preloaded bolt connections using advanced CAE applications. The simulation and the stress distributions of the bolt-nut couples were determined through finite element analysis (FEA) with non-linear contact definitions using a commercially available FEA code. Simulation results showed that even though partial stress accumulations were seen on the bolts, these would not cause any plastic deformation or failure. For the final evaluation, safety factors of the fasteners were calculated according to the material yield point

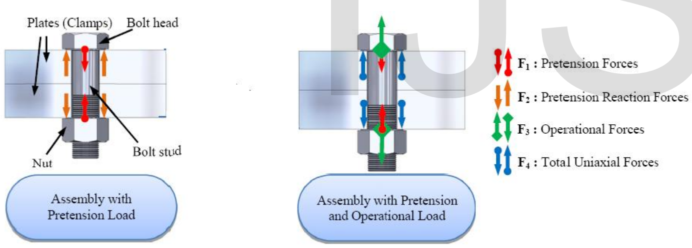

Figure 4: Forces direction [5]

Author has also discussed about the pretension triangle in uniaxial loading casewith in the elastic deformation limit, the triangle defines the relationship between forces, deformation existing on the plates/clamps and bolt, it is also known as Rotscher pretension triangle diagrams.

G.Dinger and C. Friedrich[6] talked about a numerical design method with finite element analysis for detecting and understanding of the self-loosening process at bolted joints and the influences of the preload generation for the residual shank torque in the numerical simulation. Fatigue and rotational self-loosening are the two most widespread reasons of failures during operation. Whereas the mechanism for failure in fatigue or preload relaxation of a bolted joint can be analysed with the help of analytic guidelines and design tools, no established and verified design method exists in case of preload loss caused by rotational self-loosening of the screw. A three-dimensional finite element (FE) model is established for detection and understanding of self-loosening at bolted joints and the influences of the preload generation for the residual shank torque

Y. SHOJI [7] said the pretension load of each bolt is applied using the special “bolt-pretension” capability of the program and the bolt length is "fixed" after tightening so that the changes of the bolt-tension can be captured. The material properties used in the analyses are such as: Young’s Modulus (E), Poisson’s Ratio(v)

The Constraints (Boundary conditions) (a) and (b) were considered to model different nut conditions: (a) Nut is allowed to rotate about its axis that is collocated to the bolt axis. Bolt top is allowed to move only in the radial (x-) direction. This is the case of "normal" situation. (b) Nut is allowed to rotate about its axis that is collocated to the bolt axis. Bolt top is allowed to move only in one radial (x-) direction, and the bottom is constrained not to move in the radial directions (x- and y-directions). This is the case of the first nut of "double nut" situation, or “constrained” situation. (c) After the pretension, nut is moved to the radial direction and in perpendicular to the bolt motion (z-direction) in order to "lock" the bolt by plunging nut thread into bolt thread.

To check the variation effect of the pretension loads, the author has considered different loadcases.The result of lateral displacement has been obtained. This means that the bolts are not loosened easily, if a certain preload is applied, or the bolts are tightened adequately

T.N.Chakherlou experimental results[8] shows that the bolted joint specimens, for which the fastener hole contains edge cracks, have a greater fracture strength than those which lack a bolt which would be the situation had in practice there been a bolt but very lightly tightened. it was found that the greater the bolt tightening torque, the greater the resultant fracture strength.

2. Numerical Experiment

The paper present to idea about the bolt pretension of deep tillage equipment.this study is further discussion of the the author discuss earlier [5].but , he has not given any idea about how force calculated and soil condition. In this study that has been explain.The factor of safety has been identify for the bolt – nut connector used in tillage tool. The material used in the study as shown below

Table 1: Material property

Name of part	Name of Material	Young’s modulus (MPa)	Yield/Tensile limit (MPa)	Density (Kg/m^3)	Allowable limit (MPa)
Bolt	ISO 4014	2.1E+05	640	7800	320
Other part	IS 2062 Fe410 WA	2 E+05	240	7850	120

The Poisson ratio has been taken 0.3. In the simulation study, the chisel tine bolt group is defined with four metric 8.8 property class bolt nut fasteners (in two are M20, two are M16). ANSYS Workbench commercial Finite Element code was utilized for the FEA with geometrical and face to face contact non-

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linearity assumptions. Bolt teeth were ignored for geometrical simplification operations and nuts are defined to bolt with bonded contact assumptions. Friction coefficient between all parts is assigned as 0.12

The further study has been covered on deep tillage tools used in agriculture, which experience high level soil reaction forces during tillage operations. These forces may cause plastic deformation or failure which is undesirable for tillage machines/tools. In particular, fasteners such as bolt connections, which are utilized in the fastening of structural elements to the tillage tool's framework, may become a key point for possible machine failure during tillage operations. Therefore, prediction of the stress distribution or likely failure point of the bolt connections during tillage operations is a very significant issue.

The soil is compaction occurs when a force compresses the soil and pushes air and water out of it so that it becomes denser. Compaction is more severe when the soil is wet and less able to withstand compression. Compaction is a concern because it affects plant growth. There are not enough pores or spaces in compacted soil to allow unrestricted root movement, infiltration, drainage or air circulation. In this study, the focus is on the determination of the stress distributions on the preloaded bolt connections of a chisel tine.
The property of soil used for experiment
- Bulk density(Kg/m^3)=1300
- Yield limit/pressure limit(KPa)=12.5
- Moisture content=13%

The teardown force 6500(N) has been calculated form the bulk density using volume of tool use for tearing.

In this simulation following part need to model with use of CAE tool such as pro-e (Creo element).The bolt- nut fastener are made from standard data sheet of metric hexagon bolts.Other part such as chisel leg and tine are available standard in market in much variety, which dimension given by customer

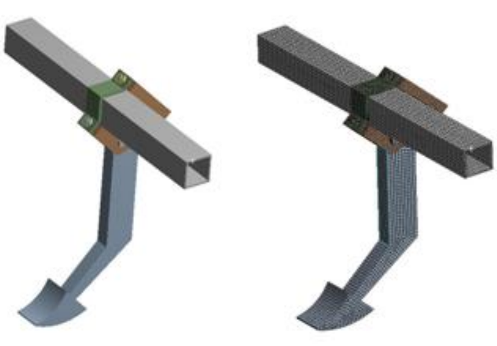
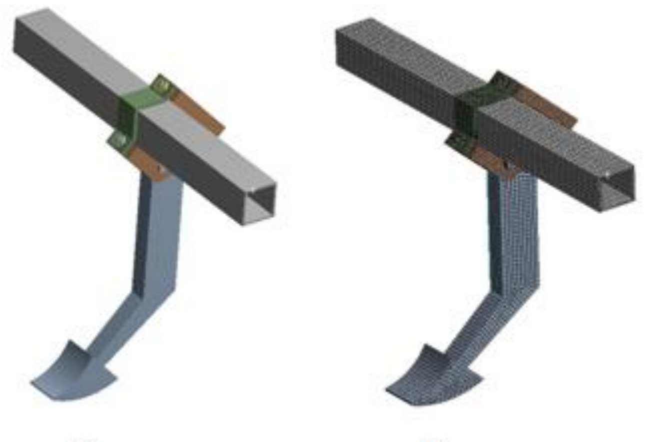

(a) (b)

Figure 5:(a) geometry,(b) Finite Element Model


(a) (b)

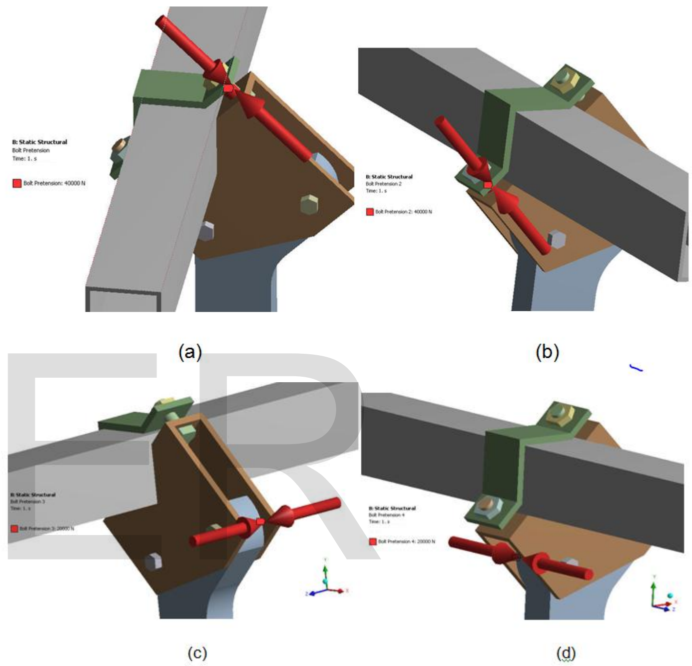


Figure 7:(a) and (b) 40000 N preload apply to M20 bolt.(c) and (d) 20000 N preload apply to M16 bolt

The actual capacity of preload of bolt material is higher, but the Value has been decide on the basis of geometry complexity and shape which show the non linear deformation.

3. RESULT

Actual Capacity of Preload 145000N for M20 Bolt and Actual Capacity of Preload 95000N for M16 Bolt.
(1) Case 1
The pre load has been set 40,000 N for M20 Bolts and 37,000 N for M16 Bolts. External Ploughing force 6500 N has been calculated from the soil bulk density and contact area of the chisel tool.

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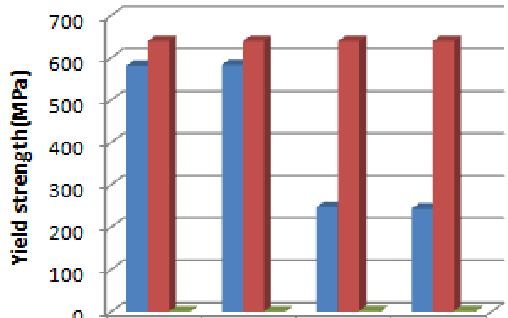


	(a)	(b)	(c)	(d)
Max.Equi.Stress(Mpa)	582.59	584.24	248.03	244.22
Yield Strength	640	640	640	640
FOS	1.10	1.10	2.58	2.62

Figure 8: Factor of safety chart for Load case -1

The chart illustrate, that the factor of safety obtain from the result is minimum than the allowable limit for bolt (c) and (d),if safety factor consider two.

(2) Case 2

Again the Preload has been set 20000 N for M20 Bolts and 18500 N for M16 Bolts. External ploughing force 6500 N has been applied.

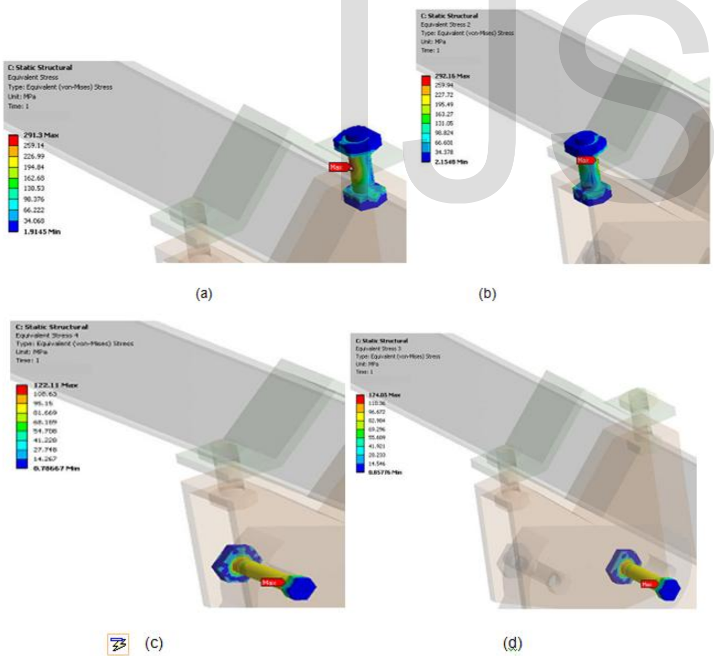
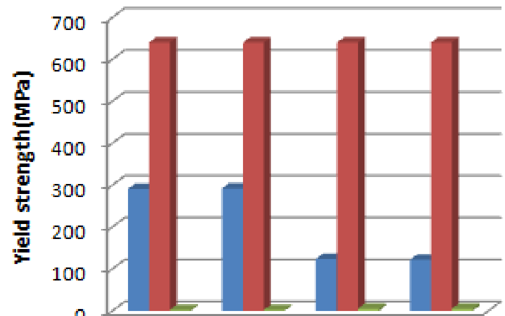


Figure 9: Stress plot (a) and (b) for M20, (c) and (d) for M16

Plot illustrare, the bolt connection which are in safer with considered preload value for this case.In addition, the safety factor has been comes more than two value for all four bolt connection as shown in Figure 10.



	(a)	(b)	(c)	(d)
Max.Equi.Stress(Mpa)	291.26	292.16	124.05	122.11
Yield Strength	640	640	640	640
FOS	2.19	2.19	5.15	5.24

Figure 10: Factor of safety chart for load case-2

4. DISCUSSION OF RESULTS

The Numerical results show that the bolted joint specimens, for 1st case the factor of safety (Figure 8) comes are higher than the allowable limit if considering factor of safety 2.

If consider 2nd case which give factor of safety more than 2 (Figure 10) which have a greater fracture strength than those which lack a bolt which would be the situation had in practice there been a bolt but very lightly tightened. Indeed, it was found that the greater the bolt tightening torque, the greater the resultant fracture strength, as can be seen from 1st case. The FE results also support this finding as the stress intensity factor for the bolted specimens was found to be consistently lower than for the bolt-less hole specimen and with a similar relative difference. The experimental results also show that the fracture strength reduced significantly with increased stress concentration length and that the relative improvement resulting from bolt clamping was realized across a wide range of stress concentration lengths. This finding is also supported by the FE results as the stress intensity factor was found to be greater for larger stress concentration for all the specimen variants considered

5. CONCLUSION

The FE analysis has shown that for a given applied tensile stress, the equivalent stress on the bolt joint is lower compared with a bolt-less hole containing similar edge cracks. This is due to the normal stress and friction force (stress) between contacting surface of bolt head (or nut) and plate which acts as a resistant force against external applied tensile load and reduces the stress (caused by external load) around the hole and crack tip.

The methodology has been very usefull to reduce the cost of component to know it actual bavaviour before the prototype. In addition,there are some other method also has been available, but it need some instrument and physical condition.This type of numerical base technique only need physical property and pa-

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rametric geometry with load condition which make fast evaluation time.

Nomenclature

A_s	Tensile Stress Area, mm2
A_b	Cross-Sectional area of body, mm2
D	Nominal Bolt Diameter, mm
D_s	Body Diameter, mm
E	Elastic Modulus, N/mm2
F_{ext}	External Load, N
K_b	Stiffness of Bolt, N/mm
K_m	Stiffness of Clamped member, N/mm
K_t	Stress Concentration factor for Thread
K_s	Clamping or Grip Length, mm
M	Bending Moment, Nm
P_L	Nominal Preload, N
T	Tightening Torque, Nm
Y	Preload-Yield factor
Y_b	Stiffness Parameter of Bolt
Y_m	Stiffness Parameter of Clamped Member
α	Coefficient of thermal expansion
L	Original length mm

Greek Letter

σ_{yp}	Yield Strength, N/mm2
σ_e	Fatigue Strength, N/mm2
$\sigma_{eq.}$	Equivalent Stress, N/mm2
σ_b	Bending Stress, N/mm2
σ_t	Tension Induced in Bolt, N/mm2
τ_t	Torsional Shear Stress, N/mm2
σ_1	Maximum Principal Stress, N/mm2
σ_c	Compressive Load Induced, N/mm2

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