# Finite element based Pretension analysis of threaded Fasteners with Experimental Investigation

Pradip D. Jamadar
*PG Student, Mechanical Engineering Department,*
*RCPIT, Shirpur, MS, India*

Hemant K. Wagh
*Assistant Professor, Mechanical Engineering Department,*
*RCPIT, Shirpur, MS, India*

Dr. Girish R. Desale
*Principal Scientist,*
*CSIR-NCL, Pune, MS, India*

Dr. Kartikeya Tripathi
*Professor,*
*SGSITS, Indore, MP, India*

**Abstract- Pretension load plays very important role in industrial assemblies in order to avoid accident by loosening of assemblies. The aim is to determine maximum limit of pretension load without thread failure using universal testing machine. The vibration test rig is developed for measuring the loosening performance of nut bolt assemblies. The samples of ISO Metric bolts of different size such as M8, M10, M12, M16 and M20 bolt having 1.25, 1.5, 1.75, 2 and 2.5 mm pitches respectively are used for testing. The maximum stresses developed and deformations occur due to pretension load applied on nut bolt assembly are obtained by finite element method using ANSYS Workbench version 14. The validations of results are carried out by using experimental method.**

**Keywords – Bolted joint, Stress analysis, Loosening performance, Pretension**

## I. INTRODUCTION

The design of a "nuts and bolts" might seem to be one of the least interesting aspects, but in fact is one most fascinating. Moreover, the design and manufacture of fastener is very big business and is a significant part of economy. Literally thousands of different types of fasteners are offered by vendors and thousands to millions of fasteners are used in a single complex assembly such as an automobile or aircraft. The Boeing 747 uses about 2.5 million fasteners, some of which cost several hundred rupees each. Preloading threaded fasteners means to set a torque value in order to tighten the joint. This torque determines the internal stresses in the joint. Some of the stress will disappear after some time due to settlement, defined early. This process is of great importance and either overtorquing or undertorquing can dramatically damage the parts. Generally the maximum preload is limited by the mechanical characteristics of the bolt. This preload has to ensure a correct joint without damaging the parts and avoiding plastic deformation of the threads.

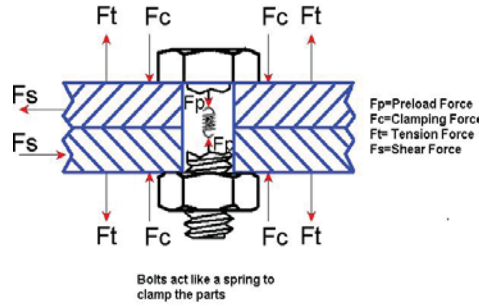


Figure 1. Force diagram for a bolted joint.Problem defination

## II. Problem Defination

This paper examines experimental methods for the effect of on ISO Metric bolts under tension loading conditions to check the thread failure limit using UTM machine. In tensile testing machine gives the proof load, ultimate tensile strength and braking load. Final tensile load obtaining from experimental methods used these value and using numerical methods uses finite element analysis to predict the behavior of such bolts in similar conditions in order to validate the experimental results and establish a reliable FE models to study fully the bolts behavior and failure mechanism. To determine the stress, preloading condition and loosening effect of fasteners by using experimental and numerical methods and comparison of all results.

## III. Experimental Methodology

In this paper, two types of experimental work have conducted in order to complete objectives.
1. Tensile testing for thread failure load calculation
2. Thread loosening performance of test rig.

### A. *Tensile testing for thread failure load calculation*

Thread failure testing used for determination of proof load limits applied on nut bolt assembly. Proof load is the maximum safe load that can be applied to a fastener without inducing permanent deformation, as with yield. For that tensile test of nut bolt assembly is taken in order to determine the maximum proof load and breaking load. Tensile test is better than compressive testing for shearing the threaded fasteners. The tensile test is done on Universal testing machine having capacity of 40 tones. The free body diagram for load application as shown in fig 3. The maximum load carried by first threads while the loads are reduced one by one on remaining [5]. The engaged threads are failing first and the maximum load for thread failure is obtained in load vs deflection curve. The bolts of M8, M10, M12, M16, and M20 and pitches are 1.25, 1.5, 1.75, 2 and 2.5 respectively are used for the tensile test.

#### *1) Tensile test results*

The load vs deflection curves of nut bolt assembly of M8 x 1.25, M10 x1.5, M12 x 1.75 , M16 x 2, and M20 x 2.5 as shown in graphs given below. The tensile stress area is used as shown table 1.1 as input to the UT machine. The behavior of curve initially a straight line, that shows maximum load sustained by threads before failure known as proof load. As load increases beyond the limits of ultimate tensile, the threads gets fail at breaking load. The purpose of this test is to decide the limits of proof load for applying the pretension load on nut bolt assembly without thread failure. Pretension load on assembly must be less than proof load for thread. If the pretension load exceeds the value of proof load, the thread failure occurs due to shearing between engaged threads of nut and bolt. The values of tensile loads, proof loads and breaking loads are obtained from tensile tests of different sizes of nut bolt assemblies as shown in table 1.1 the comparison of load deflections curves of various dimensions of nut bolt tensile test as shown in figure 3.

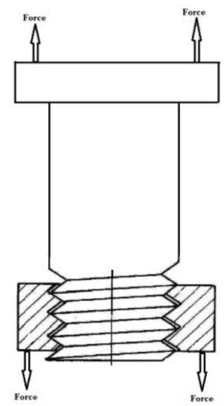


Figure 2. Tensile tests on Nut and bolt

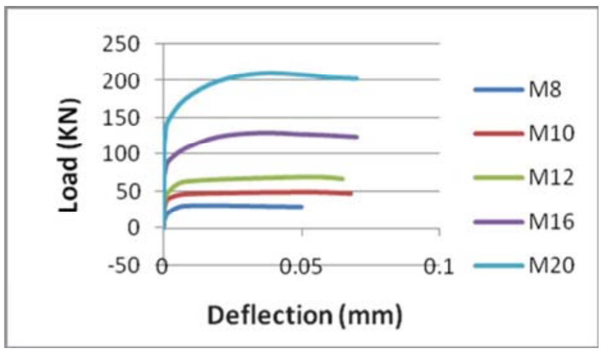


Figure 3. Comparisons of Load vs Deflection curves

*B. Thread loosening performance of test rig.*

The most widely used apparatus for experimental study of loosening performance of nut bolt assembly under dynamic shear load. The transverse vibration test apparatus developed by Junker. Similar model of manually operated test rig is fabricated as shown in Fig 4. It consists of two plates having thickness 10mm each with center holes for assembly of different diameters of nut bolts. The lower plate is fixed to the fixed base foundation while the upper movable plate is sliding over lower plate. In between these two plates rollers are inserted for reducing friction between them. The movable plate is connected to connecting rod which is also connected to eccentric shaft which produces the oscillations. The eccentric shaft is rotate on bearing supports. The big pulley is mounted on the eccentric shaft while small pulley is mounted on motor shaft. Both pulleys are connected by belt. The motor rotates at 1440 rpm reduced to 600 rpm to eccentric shaft in order to 600 oscillations per minute to the movable plate.

The torque wrench is used to apply preload calculated for different dimensions of bolts. The bolt is inserting in two plate of test rig and nut is tight. The preload is applied on bolt head, and then the machine is start. Check the loosening performance of nut with bolt at various stages during the rotation of machine. Lamps the top movable plate to the rigid fixed base through a threaded insert. Roller bearings are placed between the top plate and the fixed base to prevent galling. The top plate is subjected to a cyclic shear load through an arm connected to an eccentric. The influence of the type of slip on loosening is illustrated in Fig 5. Which shows a typical Preload versus No. of cycles plot of loosening obtained using the transverse vibration test apparatus. The loosening rate shows a drastic increase as soon as head slip changes from localized to complete slip.

Table -1 Tensile test results

| Size | Pitch | Area of Root of Thread | Tensile Stress Area of Thread | Proof Load | Breaking Load |
|---|---|---|---|---|---|
| | mm | $mm^2$ | $mm^2$ | KN | KN |
| M8 | 1.25 | 32.84 | 36.6 | 21.5 | 29.4 |
| M10 | 1.5 | 52.29 | 58 | 34 | 46.6 |
| M12 | 1.75 | 76.24 | 84.3 | 49.2 | 67.6 |
| M16 | 2 | 144.12 | 157 | 91.3 | 125 |
| M20 | 2.5 | 225.18 | 245 | 147.3 | 203.2 |

Figure 4. Thread loosening performance of test rig

## IV. NUMERICAL METHODOLOGY

The numerical modeling consists of three basic steps preprocessor, processor and post processor. Preprocessor includes 3D modeling of nut bolt assembly with two plates for supporting the assembly. Defining the materials for the assembly and meshing of the complete assembly. Preprocessor includes defining of boundary conditions and loadings and finally, post processor gives insight to the solution and such as stress distribution and deformation. Fig 6. shows the 3D assembly model of nut and bolt with two plates. Five nut and bolts are modeled with standard specifications of M8, M10, M12, M16 and M20. Two plates of 10 mm thickness are overlapped between nut and bolt for supporting and gripping during experimentation. The 3D model is created in PTC Creo by using simple extrude and sweep command for threads with specific pitch. The model is exported in .IGES format for further analysis in Ansys Workbench 14.

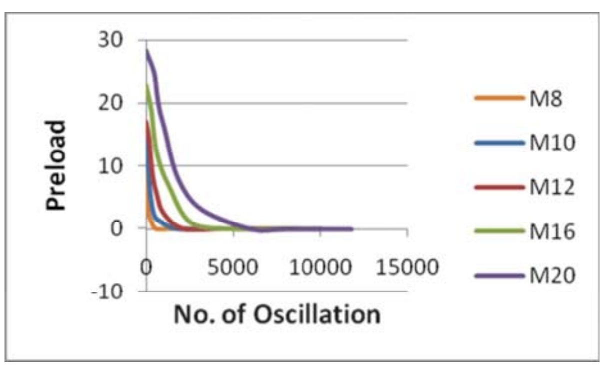


Figure 5. Preload v/s no. of cycles

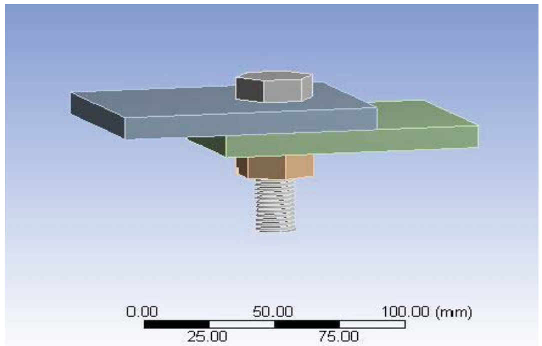


Figure 6. 3D model of nut bolt assembly

### A. *Material Definitions*

The next step after modeling is Analysis is the .IGES format file is imported in ansys workbench. The Contact regions are auto-matically defined in ansys which involved bonded type of interactions within plate and bolt, nut and bolt, plate and nut and plate with bolt. The next task is assigning the materials for plate is mild steel is assign with density 7850 Kg/m3, and also for nut and bolt mild steel with density 7850 Kg/m3 are assign. Proper assignment of various material properties plays an important role in analysis. Another most important part of analysis is the meshing. Fig 7. Shows the meshed generated for M16 nut bolt assembly. Coarse mesh with hexahedral elements is used for meshing. The number of nodes and elements for various models are shown in table.

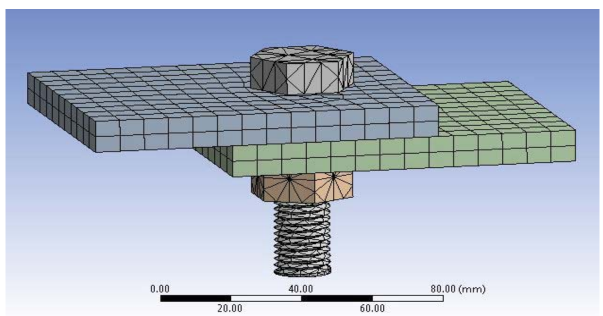


Figure 7. 3D Mesh of M16 Nut Bolt assembly

Table -2 Nodes and Elements for Nut and Bolt meshes

| Sr.No. | Designation | Nodes | Elements |
|---|---|---|---|
| 1 | M8 | 9460 | 3147 |
| 2 | M10 | 10079 | 3697 |
| 3 | M12 | 9432 | 3374 |
| 4 | M16 | 9039 | 3145 |
| 5 | M20 | 9451 | 3401 |

### B. *Boundary Conditions*

As explained earlier preprocessor, processor and post processor are the three main steps of any CAE analysis. Modeling and meshing comes under preprocessor. Next step i.e. processor is applying boundary conditions such as loads and supports which implies the physical condition of the problem for which the problem will be simulated. Fig 8 shows the boundary conditions applied for the model

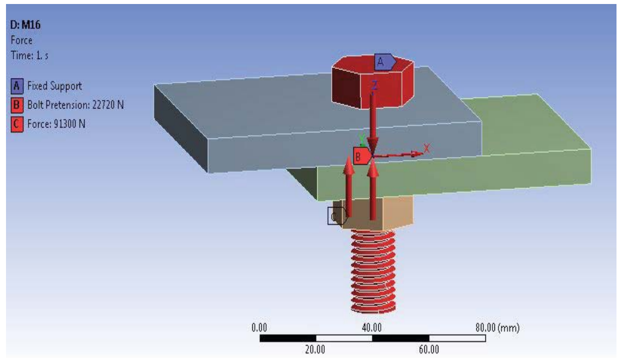


Figure 8. Boundary conditions for analysis

Three boundary conditions are applied for each of nut and bolt assembly. The top surface of the nut is applied as fixed support. The bolt pretension load is applied for bolt body and force is applied to the nut surface which indicated the amount of force required to tight the nut. According to the experimental procedure different pretension loads and force are applied to different nuts and bolts table 1.3 shows the different values of loads for different nut and bolt.

Table -3 Loads for different nut and bolts

| Sr.No. | Designation | Pretension Load (KN) | Tensile Force (KN) |
|---|---|---|---|
| 1 | M8 | 11.36 | 21.5 |
| 2 | M10 | 14.20 | 34 |
| 3 | M12 | 17.40 | 49.2 |
| 4 | M16 | 22.72 | 91.3 |
| 5 | M20 | 28.40 | 141.3 |

### *C. Solutions*

Finally, all the required data for analysis is provided in Ansys. Preprocessor and processor are defined now next step is the solution. As the problem is not dependent on time a static analysis is performed for getting desired results and stress and deformation. Stress tool is selected for results with von-misses stress and deformation is selected for analyzing the amount of deformation for given loading conditions. As the numerical method is same for all the nuts and bolts of designation M8, M10, M12, and M16 the sequence of method for analysis is same except the magnitude of force and bolt pretension. Hence, results for stress and deformation are evaluated for the specified boundary conditions. The contours and animations are obtained after successful completion of solution process in order to get insight on bolt performance at different loading conditions.

### *D. Result and Discussion*

#### *1) Result for Stress in M16 bolt*

Fig 9 show the pretension load applied at 22.72 KN in M16 Nut and Bolt 143.58 MPa stress value is obtained.

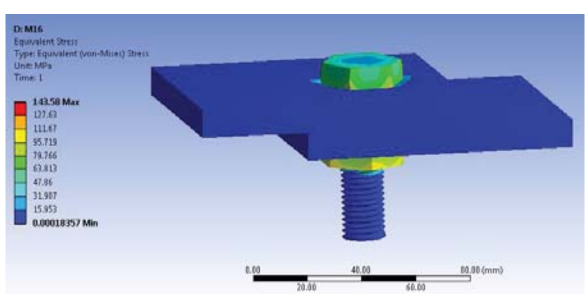


Figure 9. Stress analysis for M16 bolt

### 2) *Result for Deformation in M16 bolt*

Fig.10 shows the pretension load applied at 22.72 KN in M16 Nut and Bolt 2.82 mm deformation value is obtained.

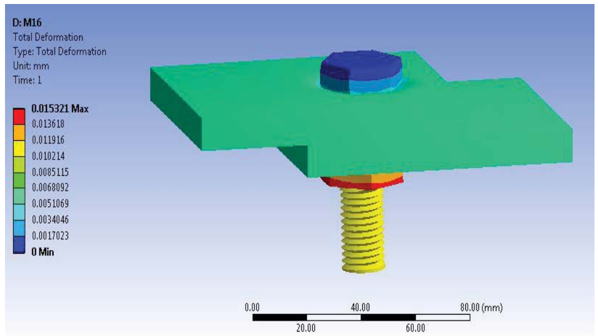


Figure 10. Total deformation for M16 bolt

### 3) *Simulations of difference fasteners assembly*

Table -4 Results for stress and Deformation in M16 bolt

| Bolt Size | Pitch | Maximum Stress N/mm$^2$ | Maximum Deformation in mm |
|---|---|---|---|
| M8 | 1.25 | 307.32 | 0.92 |
| M10 | 1.5 | 240.65 | 1.87 |
| M12 | 1.75 | 198.23 | 2.04 |
| M16 | 2.0 | 143.58 | 2.82 |
| M20 | 2.5 | 111.87 | 2.98 |

## V. RESULTS AND DISCUSSIONS

The results recorded during the experiments are limited only to displacement, applied load. While in the finite element model, we have a greater flexibility in exploring the results of the analysis. For example, stress contours can be plotted in places difficult to monitor during the actual tests.

1. In these work using the ISO Metric thread of difference bolt size and difference pitches determine the total load and deformation factors.

2. Comparing the result of Experimental and Numerical methods of the final stress in the thread verses bolt size, and total deformation verses bolt size.

3. And they also check the self loosening performance of difference sizes of fasteners.

### A. *Comparing Final Stress vs. Bolt size*

Fig 11 shows the comparing final stress vs. biolt size. In this graph it is found that result obtained for final stress by experimental and numerical are vary to 3.36% for M8 bolt also for M10,M12, M16,M20 are 6.00, 5.60,7.96, and10.50% respectively from table 5.

Table -5 Comparison of Experimental and Numerical Stresses

| Bolt size | pitch | Experimental stress | Numerical stress | Error |
|---|---|---|---|---|
| M8 | 1.25 | 318 | 307.32 | 3.36 % |
| M10 | 1.5 | 256 | 240.65 | 6.00 % |
| M12 | 1.75 | 210 | 198.23 | 5.60 % |
| M16 | 2 | 156 | 143.58 | 7.96 % |
| M20 | 2.5 | 125 | 111.87 | 10.50% |

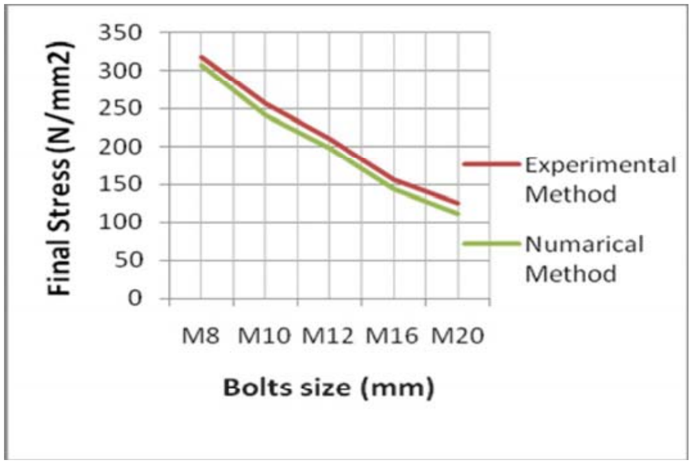


Figure 11. Final Stress vs. Bolt size

### B. *Comparing Final Deformation vs. Bolt size*

From fig 12 shows comparing final deformation vs. Bolt size. this graph it is found that result obtained for final stress by experimental and numerical are vary to 19.23% for M8 bolt also for M10, M12, M16, M20 are17.86, 13.43, 5.48, 2.50 respectively from table 6.

Table -6 Comparison of Numerical and Experimental Stresses.

| Bolt size | pitch | Experimental Deformation | Numerical Deformation | Error |
|---|---|---|---|---|
| M8 | 1.25 | 0.052 | 0.042 | 19.2% |
| M10 | 1.5 | 0.056 | 0.046 | 17.8% |
| M12 | 1.75 | 0.067 | 0.058 | 13.4 % |
| M16 | 2 | 0.073 | 0.069 | 5.48 % |
| M20 | 2.5 | 0.08 | 0.078 | 2.50% |
| | | | | 2.51 |

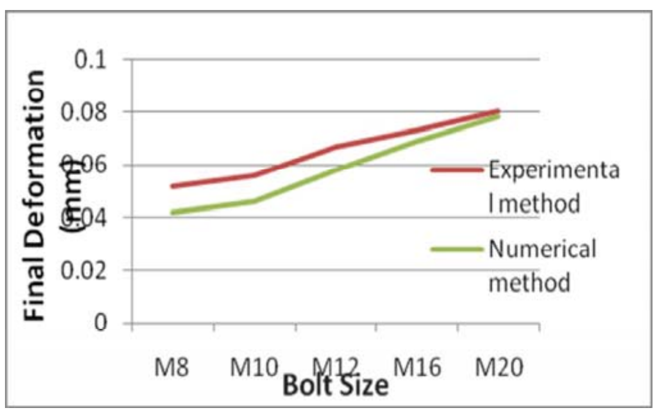


Figure 12. Final Deformation vs. Bolt sizes

## VI. CONCLUSION

In this work, experimental method and numerical techniques are used for calculation of failure load, nut and bolt pretension, stress, deformation and loosening on nut and bolt. ISO Metric thread of M8, M10, M12, M16, and M20 of bolt size with 1.25, 1.5, 1.75, 2 and 2.5 pitches respectively are considered for Investigation of the modeling technique of the structure of the bolted joint while taking into account pretention effect and the behavior of bolted connection using ANSYS workbench version 14.Using the Experimental Set up the effect of self loosening performance of difference bolt size with different pitches are studied. FEA output for stress and Deformation are finding with failure criteria to predict failure using the ANSYS workbench version 14.Experimental setup was evaluated for validation of above FEM results.

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