# A study on the bolt modeling with pre-load for field application

Han Deok Hee[1], Kim Dong Hyeon[1], Kim Young Joon[2],

Lee Kyoung Teak[3], Ahn Yi Moon[3]

[1]DAS Co., Ltd. CAE Solution Team
[2]DAS Co.,Ltd. Future Mobility Lab
[3]Korea Simulation Technologies Co.,Ltd.(KOSTECH) R&D Team

## Abstract

When fastening a structure with a bolt, an axial force is generated by the tightening torque of them. This axial force acts as a friction force by the friction coefficient of the fastening part, and becomes a factor that directly affects the deformation of the fastening part. For this reason, there have been many studies on how to make the bolt models for applying preload and users are using various methods. What is common is the construction and evaluation of bolt models with preload requires a lot of working by user. So this study was conducted because it was necessary to easy and exact method for with preload bolt models.

The research consists of two main parts. The first main is to validate the proposed bolt modeling method. We used *initial_stress_section keyword as the main. The checklist is as follows : First, whether target preload is applied. Second, whether there is a problem in the progress of FEA while preloading is applied. Third, whether there is any problem with the configuration of the fastening part of the bolt.
The second main is the easy pre-processing and post-processing. We made some rules and used them to automate pre and post processing. The commercial software used is LS-DYNA & Hypermesh.
The bolt modeling method in the pre-processing was made possible by simple selection through the GUI and we were able to have results by automatic when analyzing the results in post-processing.

By applying our research to the field, we were able to reduce the work time of making modeling by more than 90%, excluding human errors at pre-processing. At the same time, we were able to get the results intuitively in the post-processing process.

## Introduction

Depending on the method used for bolt modeling, the analysis results, such as strength and deformation patterns of the same analysis model, can vary. Bolts generate axial forces at the fastening points due to tightening torque, and these axial forces create frictional forces through contact with the structure when external forces are applied. The frictional forces of bolts affect the behavior of the contact regions, leading to differences in the deformation of the structure. For this reason, there have been many studies on modeling methods to apply pre-stress to bolts in the fastening regions.[1)]

This study is divided into two main parts. In the first part, it presents a method for bolt modeling with applied axial forces and discusses key considerations during model construction. In the latter part, the focus shifts to automating the pre-processing of bolt configurations and post-processing for a comprehensive overview of the results.

*Fig.1: Failure modes bolt models*

## The fundamental concept of bolt modeling

Bolt modeling can be approached in three ways, as illustrated in Fig.2: Type a), where the bolt is inserted, and the nut is tightened; Type b), where the nut portion is welded to the plate before bolting; and Type c), where threads are created on the plate, allowing direct bolting without a separate nut.

If section force can be utilized to assess bolt failure and the desired axial force can be achieved through the initial stress of the cross-section, all types (a, b, c) of bolt models can be configured similarly to the shape depicted in Fig.3. Following this rationale, the research was conducted by constructing bolt models using solid mesh elements based on CAD models.

Type a) Type b) Type c)

*Fig.2: Bolt fastening types*

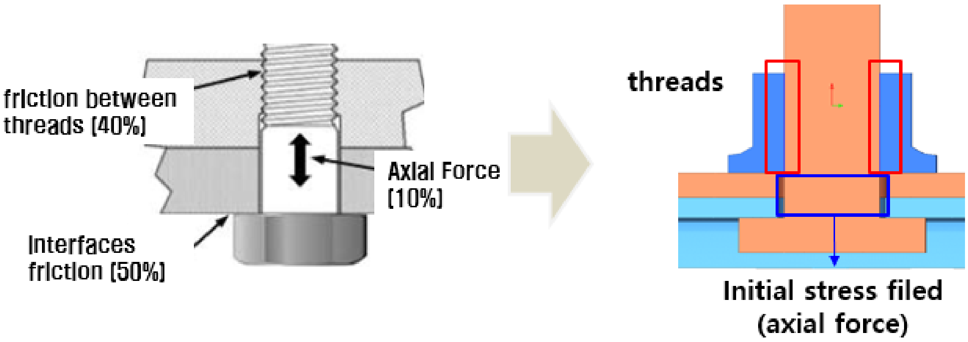
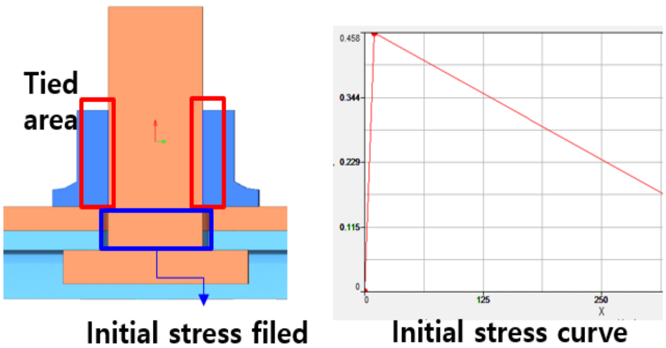



*Fig.3: Definition of bolt modeling methods*

## Bolt pre-processing modeling

In order to obtain the desired magnitude of axial force, the calculated sectional stress was used as an input value for the analysis. The results showed that, compared to the theoretically calculated 21.885 kN, a load of 20.550 kN, which corresponds to approximately 94%, was applied to the section as the axial force.




| | | | |
|---|---|---|---|
| Input | | Dia.(mm) | 7.800 |
| | | Area (mm^2) | 47.784 |
| | | stress(Gpa) | 0.458 |
| Output | Theory | Load (kN) | 21.885 |
| | Analysis | Load (kN) | 20.550 |

*Fig.4: Comparison of Analysis and theoretical result*

The difference in the applied axial load was observed depending on the ratio of hourglass energy to internal energy measured in the bolt. It was observed that the magnitude of distortion varied in some nodal points on the section where initial stress was applied, depending on this ratio.

When the ratio of Hourglass energy is lowered too much, severe distortions were observed in some nodes within the section where initial stress was applied, leading to mesh deformations. Depending on mesh quality and contact conditions, element formulation, and other factors the result can vary, but it was confirmed that setting that energy ratio to around 5-10% eliminates local deformations in some nodes and applies appropriate initial pressure.

Furthermore, since loads are applied based on stress, depending on the condition of the mesh in the section where initial stress can generate effective strains, deformations that should not occur may be observed.

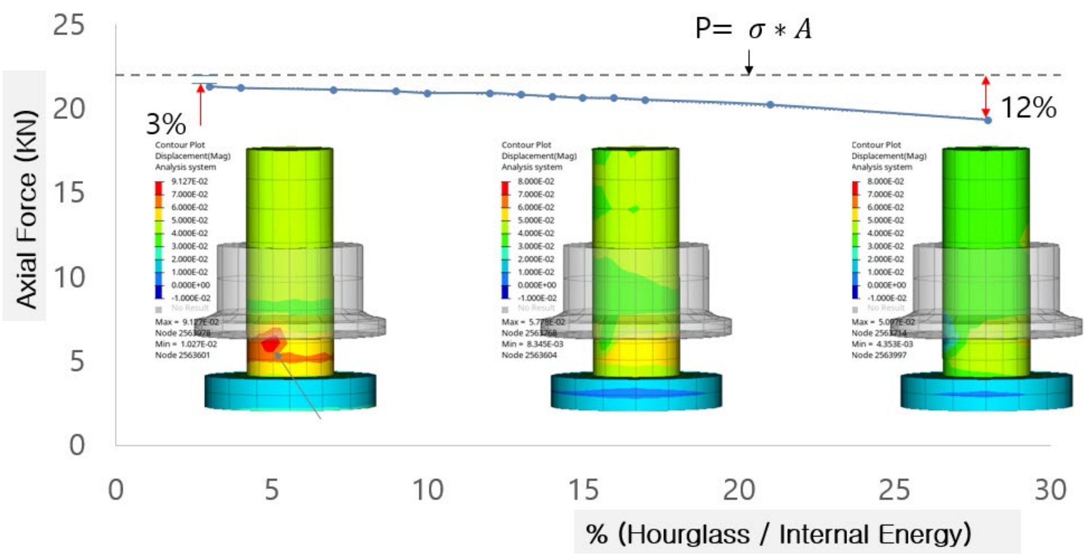



*Fig.5: Axial force based on the hourglass energy ratio*

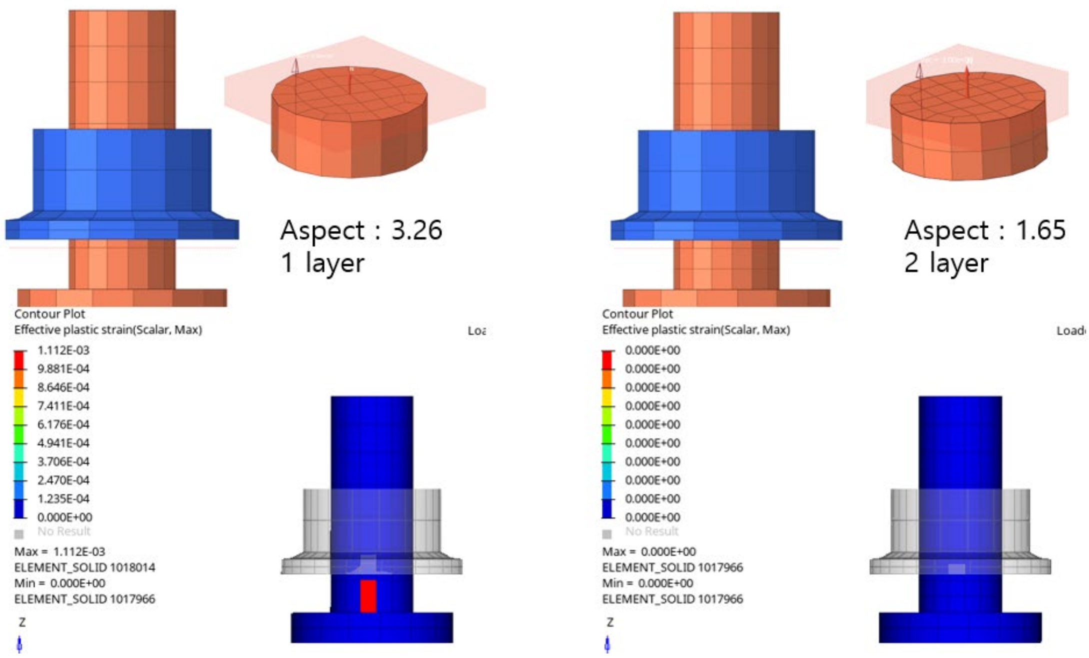



*Fig.6: Stress based analysis – sensitive to mesh quality*

When defining contact for the threads of a bolt, it's crucial to separate it into axial and shear directions. This is because the axial direction of the bolt, as shown in the figure, locks, but when subjected to shear loads in the transverse direction, it can lead to deformation in the thread portion, resulting in a gap on the opposite side. To implement this, the contact region can be defined using the *CONTACT_TIEBREAK_SURFACE_TO_SURFACE card, and the results can be compared.

In cases where thread holes are created in a plate without a separate nut, there can be instances of thread hole failure due to excessive loads. Therefore, the evaluation results can vary significantly based on the configuration of the thread portion.

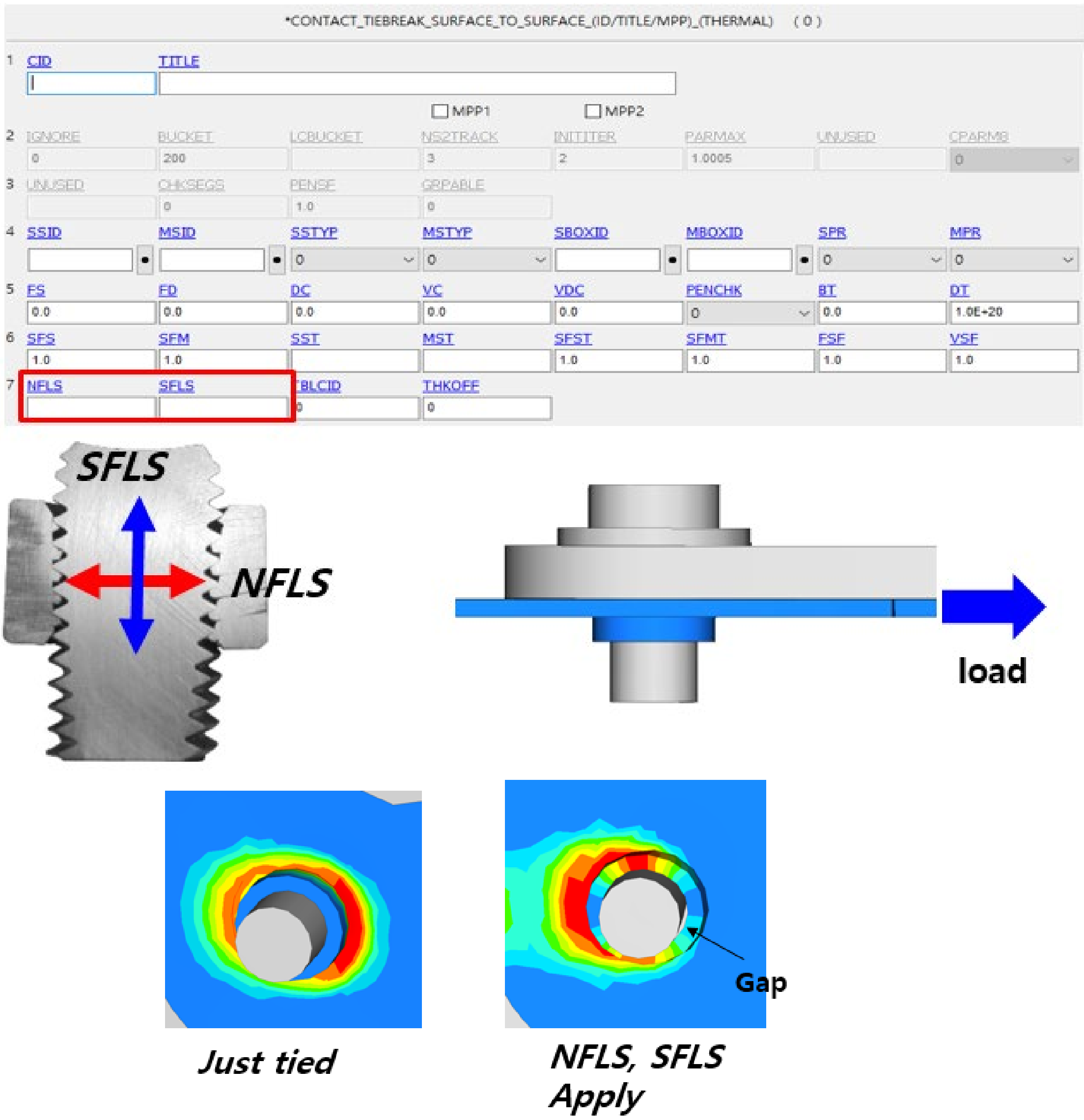



*Fig.7: thread method ( the reason – contact_tiebreak )*

As mentioned earlier, it was proposed that bolt failure can be assessed for the entire system based on the loads acting on the bolt cross-sections. To achieve this, it is crucial to record the loads acting on the bolts in the section force (secforc). Therefore, when creating coordinates along the center of the bolt to update section forces in local coordinates, you should set the FLAG parameter to 1 as shown in Fig.8. This ensures that section forces are properly updated in the local coordinate system along the bolt's center.

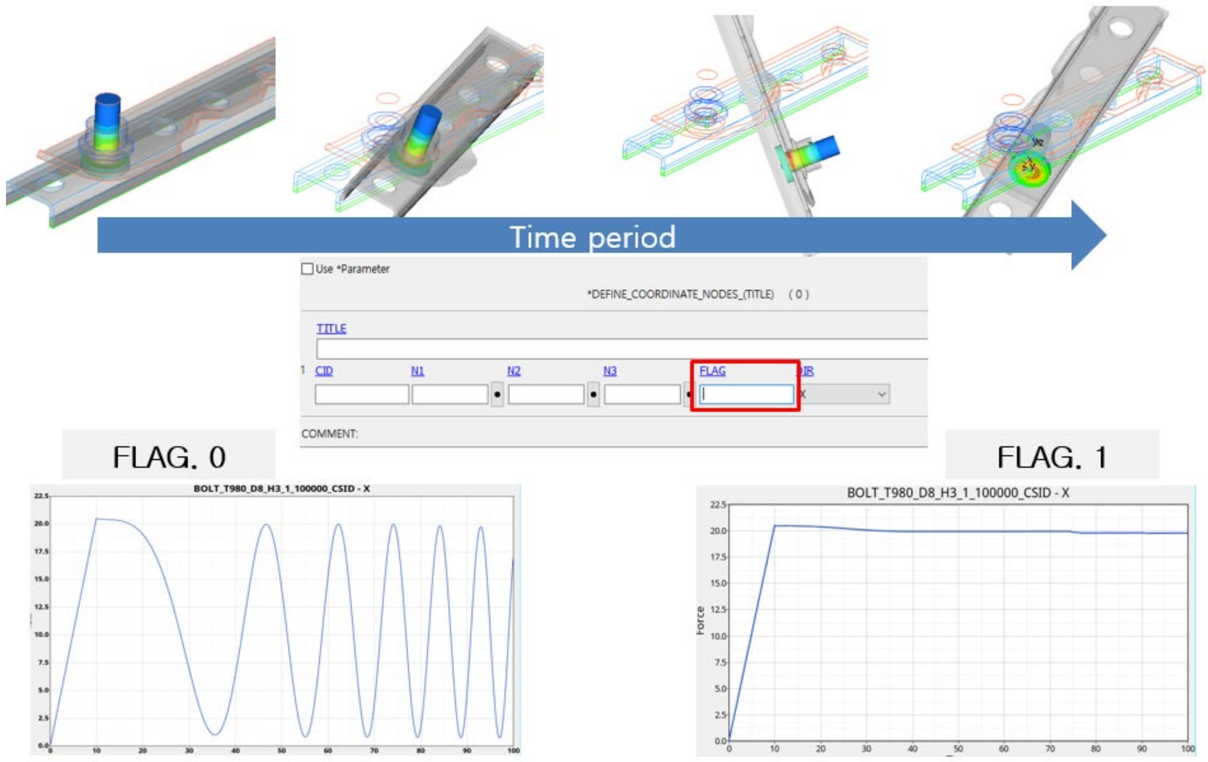



*Fig.8: Consideration when setting local coordinate*

## Problems in the pre-processing

The pre-processing phase for bolts can be summarized as the creation of node-based coordinate systems and inputting cross-sectional information. However, this pre-processing phase can be labor-intensive because it often requires the manual specification of node points in different directions, which demands a significant amount of effort from the user.

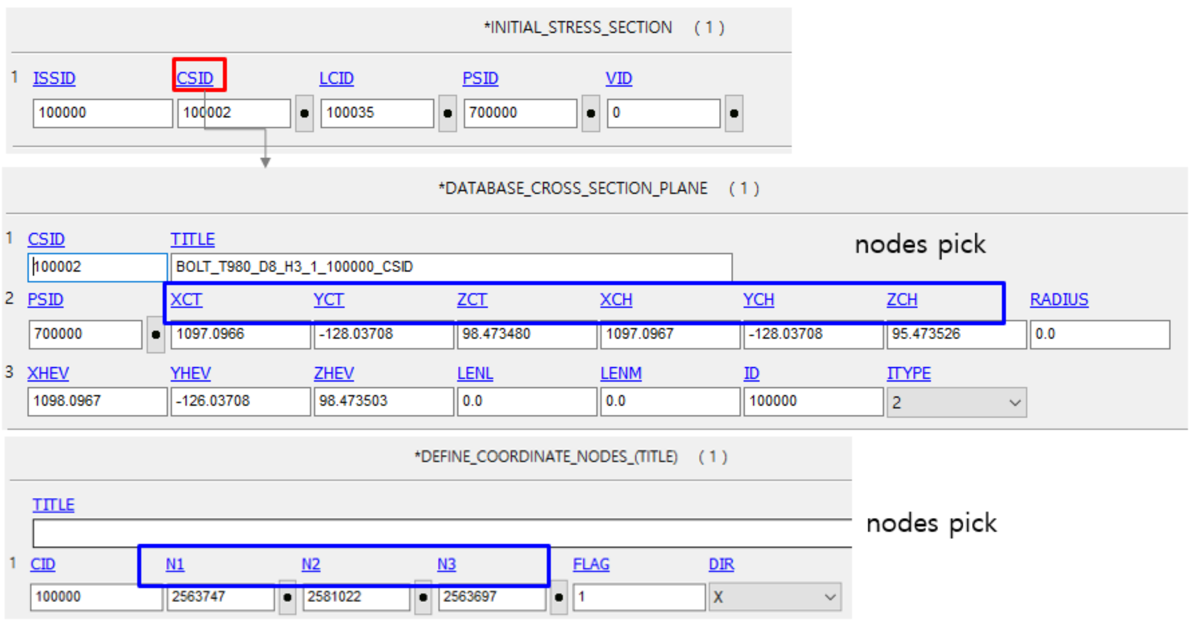



*Fig.9: Basic cards to apply for pre-stress*

Furthermore, bolt failure is defined based on the section force. However, when external loads are applied, as shown in Fig.10, if the vulnerable section of the bolt differs from the section plane set as the cross-section, predicting bolt failure becomes challenging. Therefore, additional cross-sections are needed to measure the loads on sections accurately. In practical pre-processing work, multiple cross-section load data may be required, and these pieces of information are used as input for each node set and solid set. This means that users often spend more time on modeling.

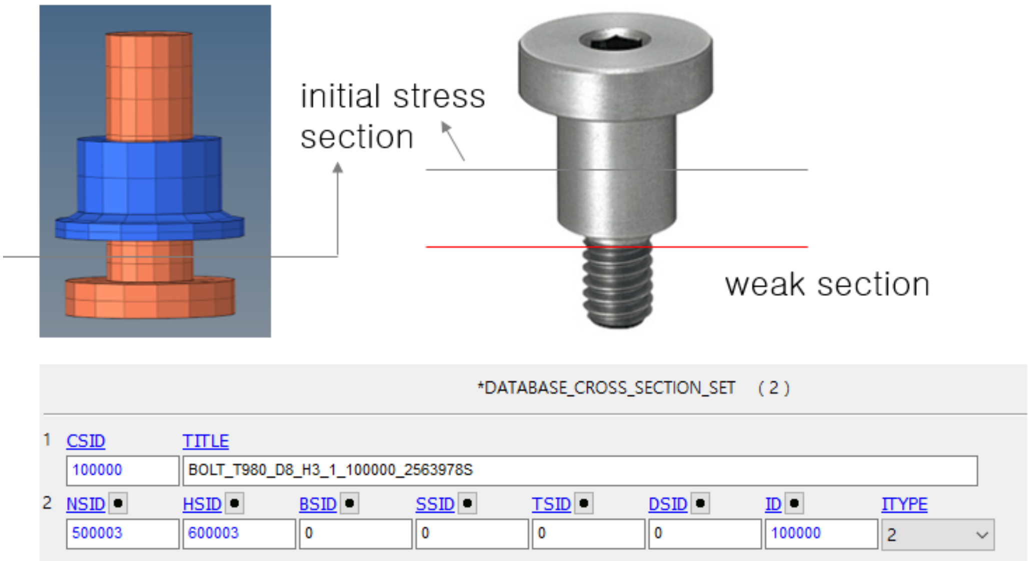



*Fig.10: The necessity of additional card*

## A module for automating bolt modeling

Despite proposing a straightforward bolt modeling method, the pre-processing modeling process still required significant effort. Therefore, we developed a module integrated with a pre-processing tool, as shown in Fig.11. Through this module, we were able to easily manage both pre-processing and post-processing stages of bolt modeling.

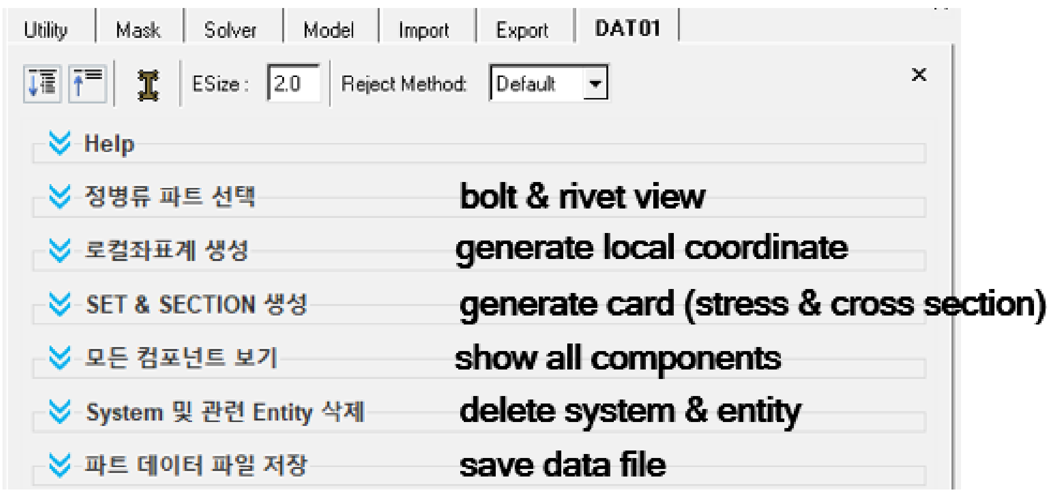



*Fig.11: Module for automation (DAT01 – DAS Automation Tool)*

The module's primary content, involving local coordinates and related keywords, is illustrated in Figure 12. With just a few nodes picked, one can generate LS-DYNA cards, significantly reducing the time required for the pre-processing phase of bolt modeling.

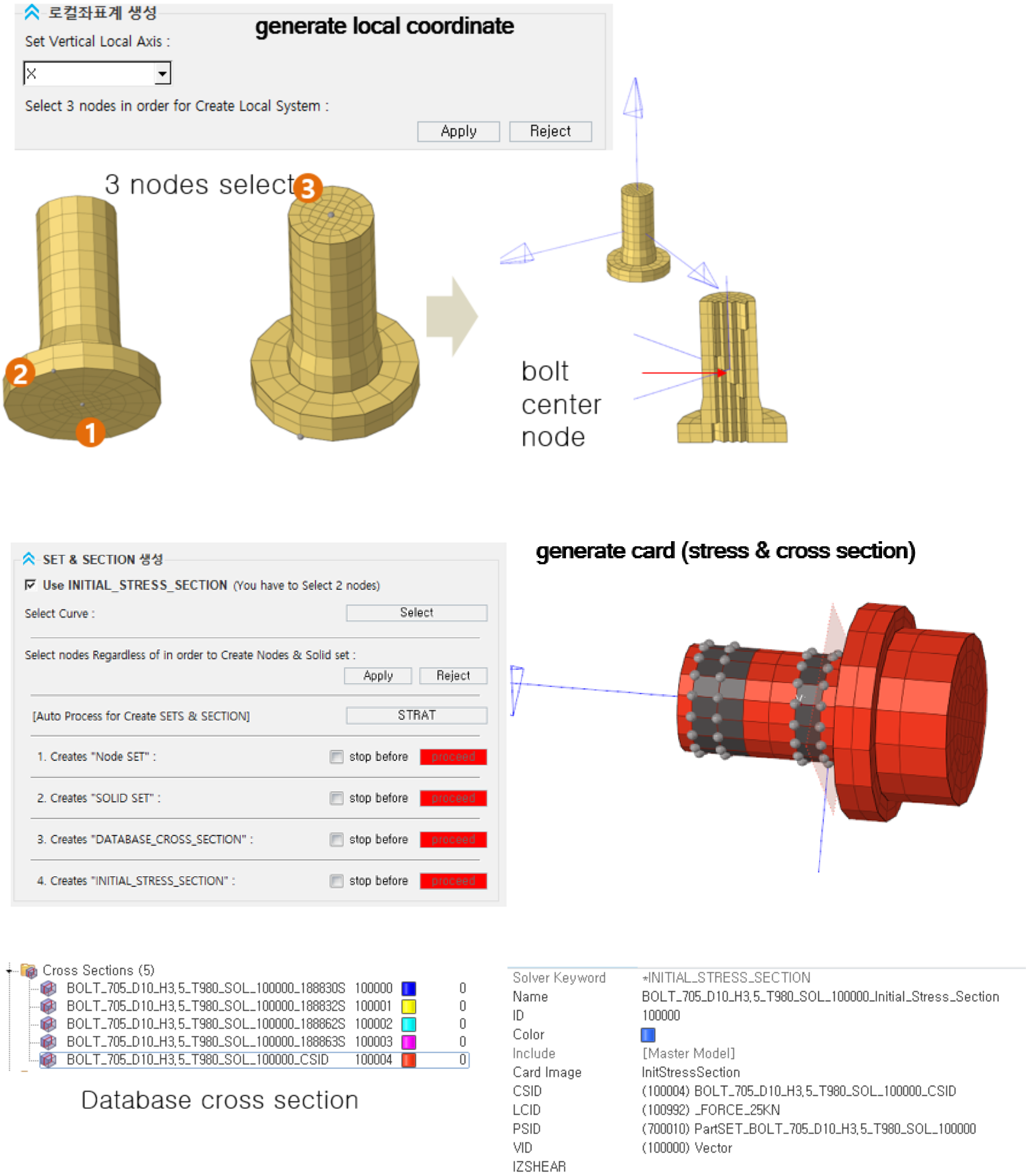



*Fig.12: Generating card for pre-stress application (by Module DAT01)*

After measuring the modeling time per bolt model, it was found that using this module reduced the pre-processing time by approximately 15% compared to the conventional method, with a 10% reduction in overall time. Considering the potential for user errors and reduced productivity due to decreased concentration during repetitive tasks, it is estimated that the actual work efficiency could be increased by more than tenfold when performing the same repetitive tasks.

| No. | Item (work) | basic | | Module (DAT01) | |
|---|---|---|---|---|---|
| | | clicks (number) | Time (s) | clicks (number) | Time (s) |
| 1 | Local coordinate | 8 | 8 | 6 | 6 |
| 2 | Vector | 7 | 5 | 2 | 2 |
| 3 | Part set | 4 | 2 | 0 | 0 |
| 4 | Node set | 24 | 45 | 2 | 3 |
| 5 | Element set | 24 | 45 | 0 | 0.5 |
| 6 | Database cross section plane | 7 | 15 | 0 | 0.5 |
| 7 | Initial stress section | 5 | 7 | 5 | 7 |
| 8 | Additional database | 21 | 60 | 0 | 0.5 |
| Total | | 100 | 187 | 15 (15%) | 19.5(10%) |

*Table 1: Comparison of workload and time*

The review of bolt failure is set up to be automatically organized in Excel, as shown in Fig.13. For each bolt, among the specified cross-sections in the database, the points where tension, shear, and bending moment are maximized, along with the load direction, are highlighted. The safety factor is represented in this format. By clicking on the safety factor, the Excel sheet for that particular bolt is displayed, allowing you to check which part of the overall system has safety concerns.

| MaxTime | PartID | SetID | DBXsectionSet | AllowLoad | MaxLoad | S/F |
|---|---|---|---|---|---|---|
| 68.20 | 100701 | 600017 | BOLT_SETA_03_T980_D6.5_H3_100006_112027S_AxialF | 23.50 | 15.26 | 1.54 |
| 67.30 | 100701 | 600016 | BOLT_SETA_03_T980_D6.5_H3_100006_113749S_ShearF | 16.45 | 5.92 | 2.78 |
| 68.20 | 100701 | 600017 | BOLT_SETA_03_T980_D6.5_H3_100006_112027S_Head_Damage | 42.03 | 15.26 | 2.75 |
| 68.60 | 100701 | 600017 | BOLT_SETA_03_T980_D6.5_H3_100006_112027S_Bending | 16.56 | 31.57 | 0.52 |
| | | | Section check | 60.29 | 31.57 | 1.91 |
| 81.40 | 100702 | 600019 | BOLT_SETA_04_T980_D6.5_H3_100007_111208S_AxialF | 23.50 | 3.58 | 6.56 |
| 83.20 | 100702 | 600018 | BOLT_SETA_04_T980_D6.5_H3_100007_112012S_ShearF | 16.45 | 4.95 | 3.32 |
| 81.40 | 100702 | 600019 | BOLT_SETA_04_T980_D6.5_H3_100007_111208S_Head_Damage | 42.03 | 3.58 | 11.74 |
| 83.00 | 100702 | 600019 | BOLT_SETA_04_T980_D6.5_H3_100007_111208S_Bending | 16.56 | 21.73 | 0.76 |
| | | | Section check | 60.29 | 21.73 | 2.77 |

Summary | RIVET_LINKA_02_T440_D10_H2 | RIVET_LINKB_01_T440_D6_H3 | RIVET_LINKA_01_T440_D10_H2 | RIVET_RAILA_0

| MaxTime | PartID | SetID | DBXsectionSet | AllowLoad | MaxLoad | S/F |
|---|---|---|---|---|---|---|
| 68.20 | 100701 | 600017 | BOLT_SETA_03_T980_D6.5_H3_100006_112027S_AxialF | 23.50 | 15.26 | 1.54 |
| 67.30 | 100701 | 600016 | BOLT_SETA_03_T980_D6.5_H3_100006_113749S_ShearF | 16.45 | 5.92 | 2.78 |
| 68.20 | 100701 | 600017 | BOLT_SETA_03_T980_D6.5_H3_100006_112027S_Head_Damage | 42.03 | 15.26 | 2.75 |
| 68.60 | 100701 | 600017 | BOLT_SETA_03_T980_D6.5_H3_100006_112027S_Bending | 16.56 | 31.57 | 0.52 |

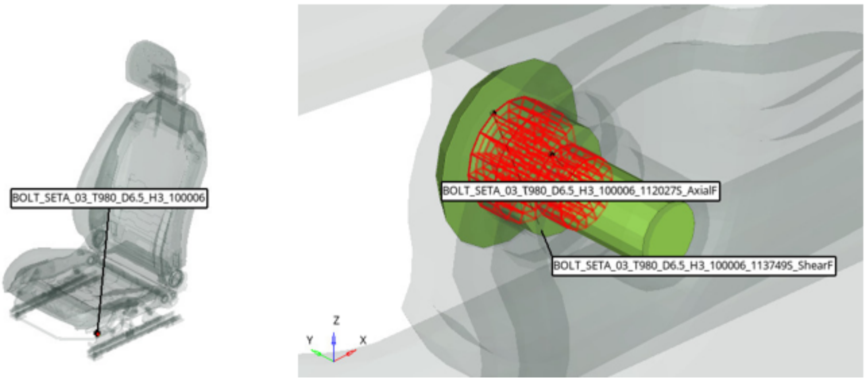



*Fig.13: Results of bolt failure review (by Module DAT01, file type; excel)*

The allowable load for calculating the safety factor of bolts is automatically determined based on the material information, diameter, and head height of the bolt model name. In cases where there is a result of insufficient safety factor, as seen in Figure 13, it could be due to bolts with two different diameters, Φ6.5 (effective diameter Φ5.5) and Φ10.0. While the section force was measured at Φ10.0, the safety factor calculation is based on the bolt's name. Therefore, when reviewing the results, it's essential to double-check whether the safety factor is indeed insufficient in the sections where it's indicated.

Analyzing the failure load of bolts in structural scenarios where external forces are applied can be complex, and automating this process in Excel may not always be efficient. However, if you can analyze and generate a report for around 30 bolts within approximately 3 minutes, it can be considered a valuable tool in real-world tasks.

| No. | Post process (Bolt) | Module (DAT01) | |
|---|---|---|---|
| | | clicks (number) | Time (s) |
| 1 | Open & modification section force graph | 4 | 15 |
| 2 | Analysis the results | 0 | 10 |
| 3 | Job Excel sheet | 1 | 250 |
| 4 | Result check (manual) | 2 | 30 |
| Total | | 7 | 305 |

*Table 2: Workload and time of post-processing*

## Summary

There have been various studies on bolt modeling, but in practical field applications, complex modeling is often avoided due to time constraints. A proposed approach is to simplify bolt modeling, focusing on two key elements: applying axial forces and analyzing section loads. Additionally, suggestions for improving the efficiency of this proposed modeling method are presented.

Our company has undertaken model automation, resulting in a significant reduction of over 90% in the pre-processing time. Furthermore, in the post-processing phase, it became much easier to review the results of all the bolts.

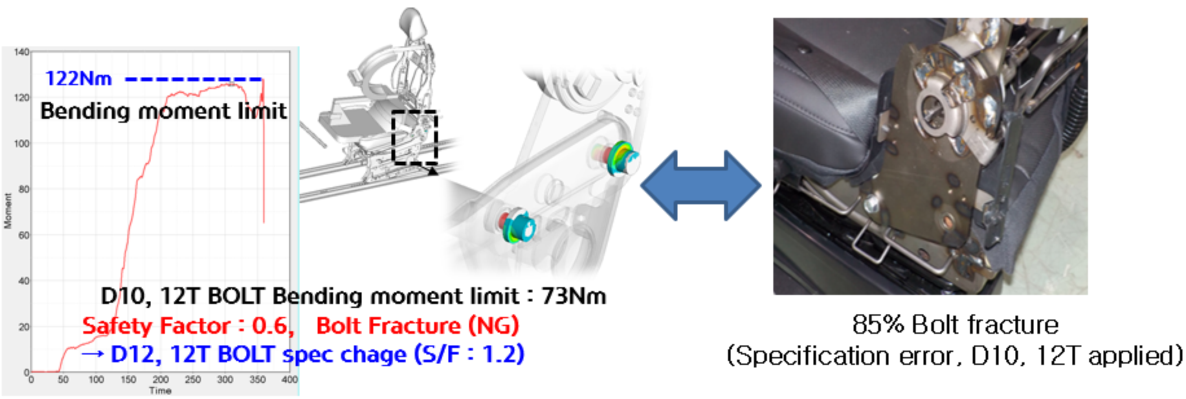



*Fig.14: Analysis validation - Bolt failure by bending moment*

## References

[1] Nils Karajan, Alexander Gromer, Thomas Borrvall, Kishore Pydimarry, : "Modling bolts in LS-DYNA using explicit and implicit time integration", 15th International LS-DYNA Users Conference, Dearborn, Michigan, USA, 2018
[2] Meyer,M.: "Development of an improved screw model at Faurecia", Proceedings of the 11th European LS-DYNA Conference, Strassburg, France, 2011
[3] Narkhede, S; Lokhande, N,; Gangani,B. and Gadekar, G. : "Bolted joint reprentation in LS-DYNA to model bolt pre-stress and bolt failure characteristics in crash simulations", Proceedings of the 11th International LS-DYNA Conference, Detroit, USA, 2010.
[4 Sonnenschein, U.: "Modeling of bolts under dynamic loads" Proceedings of the 7th LS-DYNA Forum, Bamberg, Germany, 2008