Compression test of TBM thrust jack for validation of bucking strength under inclined loading condition

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ABSTRACT: This paper studies a consecutive excavation technique to enhance the shield TBM advance rate. Helical type segments are considered for one solution for the continuous excavation of shield TBM. When using helical segments, the thrust jacks compress on the inclined side wall of the segments. The inclined contact can induce the side force and bending moment of the hydraulic cylinder, which can arouse oil leak or plastic deformation of rod and cylinder parts. The study examined the buckling reliability of thrust jack against to the compressive force on the inclined surface of helical segment. A numerical simulation was conducted for analyzing the structural stability. The reliability testing code was established and the testing specimen of jack and loading jigs were manufactured for the compression test of the jack. After the compression test was conducted, the testing results are summarized for validation.

Keywords: Shield TBM, Thrust jack, Helical segment, Inclined surface, Compression test.

1 INTRODUCTION

The shield TBMs (tunnel boring machine) applications are increased in Korean tunneling sites. A research project is ongoing to enhance the TBM advance rate by reducing the non-operation time during the segment installation. Helical type segment (Rostami, et al., 2019) is considered for one solution for the continuous excavation of shield TBM.

Generally, TBM thrust jacks have the role to advance the cutter head by providing a normal force on to the side wall of segments. If using helical type segments, the TBM thrust jacks have to compress on the inclined wall of the segments because the helical segment has a pitch angle (Figure 1). The inclined contact can induce the side force and bending moment of the hydraulic cylinder, which can arouse oil leak or plastic deformation of rod and cylinder parts. To guarantee the buckling strength of cylinder and seals parts, structural safety has to be precisely examined before the full scale tunneling test (Kongshu et al., 2019).

To investigate the structural stability, a numerical analysis of thrust jack was simulated under normal contact and inclined contact conditions. The stress level of cylinder, ram, frame and pedestal parts were analyzed (Sugimoto et al., 2019). To confirm the reliability of the simulation, a series of compression test was carried out. The testing results were analyzed and the buckling strength and stability of the thrust jack were evaluated.

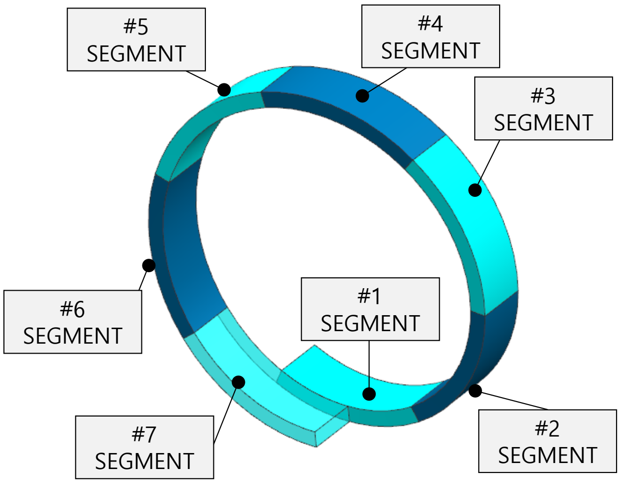


Figure 1. An example of helical type TBM segment.

2 COMPRESSION TEST

2.1 Testing condition

Although the numerical analysis confirmed the stability of thrust jack, the real data from the testing is necessary to validate the simulation results. Thus, a series of compression test was planned to determine the buckling strength and safety of the thrust jack compression stress. In addition, it was difficult to measure the data of excessive TBM thrust jack in the field condition, a test bench and testing jigs were designed and set up to provide the exact condition (i.e., inclination angle of the pedestal, offset between cylinder axis to pedestal center position).

Before the test, the thrust jack is set horizontally on the test equipment and is about 98 % of the maximum management distance. The pedestal comes into contact with the jig designed for compressed loading. It also supplies pressure to the cylinder so that it works as a load of 980.7 kN. The formula for supplying pressure is listed as following Equations (1-3). After two minutes of pressurization, abnormalities such as leaks, deformation, and damage were precisely observed.

Cylinder inner diameter $$D = 275\ mm \tag{1}$$

Cylinder cross section $$A = \frac{D^2 \cdot \pi}{4} = 59{,}395.7\ cm^2 \tag{2}$$

Cylinder supply pressure $$P = \frac{F}{A} = \frac{980{,}665\ N}{59{,}395.7\ cm^2} \times 10 = 165.11\ bar \tag{3}$$

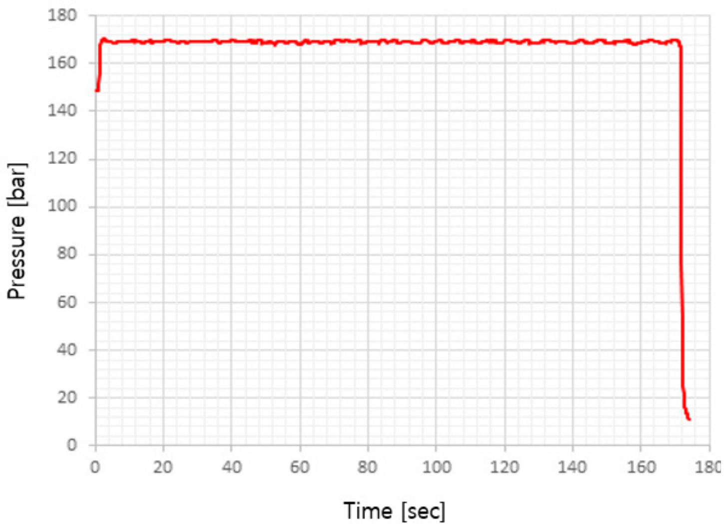
2.2 Test equipment set-up

The test bench is set-up to conduct a compression and durability test using a hydraulic system (Figure 4). The jig was designed to provide a compressed load reaction to simulate the on-site conditions of the thrust jack. The inclination angle (i.e., the pitch angle of helical segment) of the pedestal was set up for 0 to 3.0 °.

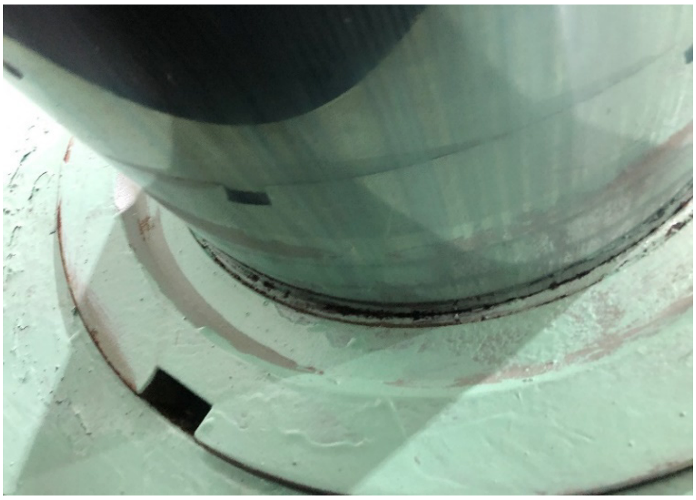
Figure 2. Testing equipment for thrust jack compression test.

2.3 Test result

According to the Equation (3). The test pressure 165 bar for reaching 980.7 kN was applied to the thrust jack and the compression test was conducted. As a result, the maximum pressure was recorded up to 169 bar which can produce 1004 kN of driving force (Figure 5(a)). At the maximum load, oil leakage, and distortion of the seal were not observed (Figure 5(b)). In addition, there was no plastic deformation and damage between the road and the pedestal. The stability of the assembly were validated by the compression test.



(a) Thrust jack pressure data



(b) No leakage of seal part observed

Figure 3. Compression test results.

3 NUMERICAL ANALYSIS

3.1 Numerical model and boundary conditions

A real size thrust jack assembly, including jack cylinder, tube, frame, bracket, and pedestal was modeled according to the drawing (Figure 2). Ansys mechanical was used for the simulation (Ansys, 2022). The material properties of jack tube was defined as STKM13C, and those of the rod and pedestal were determined as the S45C material model.

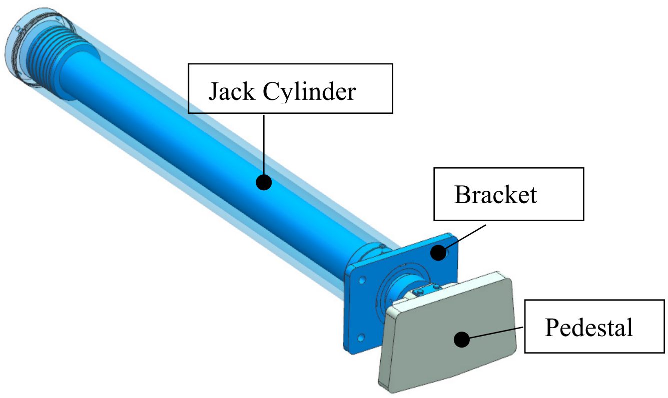


Figure 4. 3D model of TBM thrust jack assembly.

The normal force of the thrust jack acting on the segment during TBM advance. The acting and reacting forces have to be installed on the both side of the assembly model. A hydraulic power was applied to move the cylinder rod forward, a pressure (34.3 MPa) was applied to the inside of the cylinder tube (i.e., B spot in Figure 2). In addition, the thrust force was loaded on the contact surface of pedestal and segment (i.e., A spot in Figure 2). The bracket plate connected to the TBM middle body to provide the thrust force, fixed support boundary condition was set to the bracket plate (C in Figure 2).

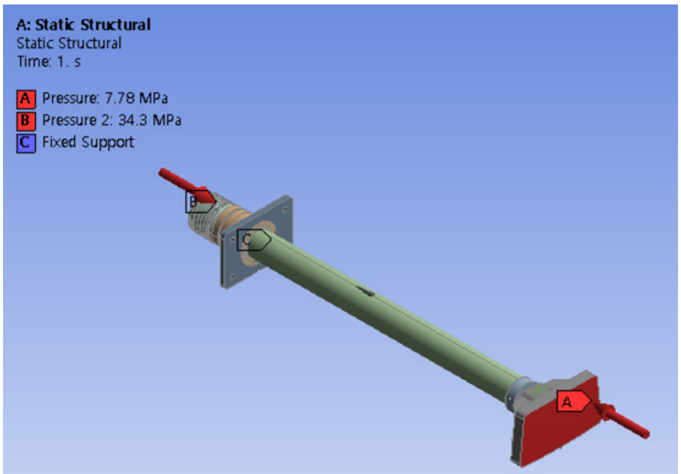


Figure 5. Boundary conditions and acting force on the model.

3.2 Analysis result

Von-Mises stress level was obtained from the static analysis (Figure 3). The stress level of tube of the thrust jack was very low, which means no deformation will occur by the thrust force. But, the stress is concentrated on the end part of the rod. The maximum Von-Mises stress was 182.64 MPa. The maximum stress of the rod was 37.3% of the yield strength of S45C material (Table 1). The resulting displacement was confirmed to be a maximum of 0.7mm. In addition, the maximum stress of STKM13C, which is the material of the tube, is 3.98 MPa. Thus, it was confirmed that no plastic deformation will occur in the assembly.

Table 1. Maximum stress values for each thrust jack component when compressive load is applied.

Material and part	Tensile Strength	Yeild Strength	Max. Stress	Max for yield strength. stress level
Cylinder Tube (STKM13C)	510 MPa	380 MPa	3.98 MPa	1.05 %
S45C (Rode, Piston, Cover)	686 MPa	490 MPa	182.64 MPa	37.3 %

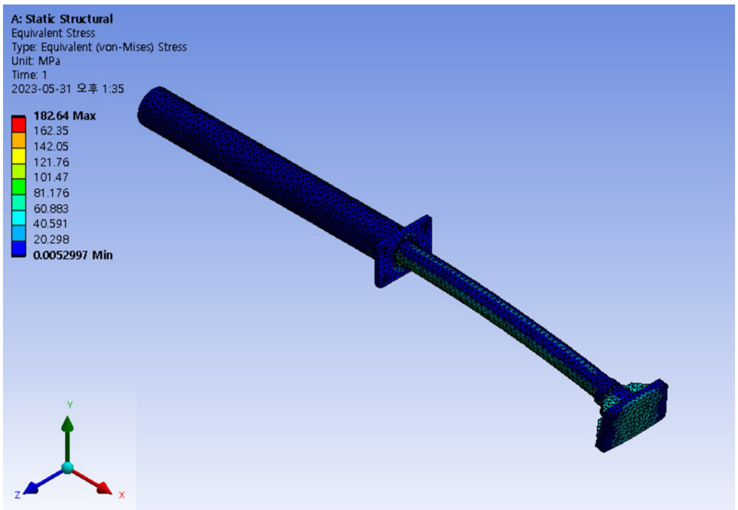


Figure 6. Results of stress distribution for compressive loads.

4 CONCLUSIONS

The study examined the buckling reliability of thrust jack against to the compressive force on the inclined surface of helical segment. A numerical simulation was conducted for analyzing the structural stability. The reliability testing code was established and the testing specimen of jack and loading jigs were manufactured for the compression test of the jack. After the compression test was conducted, the testing results are summarized

1. A real size thrust jack assembly was modeled and the static analysis was conducted. The maximum Von-Mises stress was 64.6% of the yield strength of the part material, thus no plastic deformation or failure will occur in the assembly.
2. The test bench is set-up to conduct a compression test for the thrust jack assembly. The jig was designed to provide a compressed load reaction to describe the on-site conditions of the thrust jack.
3. At the maximum load, which is 1004 kN of driving force, oil leakage, and distortion of the seal were not observed. The numerical results were validated by the compression test.

For the long time validation of consecutive type thrust systems, an inclined compression tests and durability tests are planned. The results will be updated and presented in the ISRM2023 congress.

ACKNOWLEDGEMENTS

We would like to acknowledge the financial support from the Consecutive Excavation Technological Development Project of Tunnel Boring Machine funded by Ministry of Land, Infrastructure and Transport of Korean government of Republic of Korea (Grant: RS-2022-00144188).

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