Investigation of Radial Expansion of Hollow Tubular Devices for Support of Underground Mining Excavations

N.Tshitema
Department of Mechanical and Induistrial Engineering Technology
University of Johannesburg
Johannesburg, South Africa
email: ndalamo001@gmail.com

D. V. V. Kallon
Department of Mechanical and Induistrial Engineering Technology
University of Johannesburg
Johannesburg, South Africa
email: dkallon@uj.ac.za

O. T. Laseinde
Department of Mechanical and Induistrial Engineering Technology
University of Johannesburg
Johannesburg, South Africa
email: otlaseinde@uj.ac.za

Abstract

Undergromd mining activity continues to contribute a huge part of the South African gross domestic product and as much as it is profitable, there are high risks involved in these kinds of mining operations. The safety of working personnel and equipment is of high importance to ensure it remains profitable. This report investiages how the safety of working personnel and equipment can be further improved by designing a yielding bolt under seismic activity. The principle of operation of the yield bolt is based on the science of radial expansion of hollow tubes in tension to provide intergrity to underground excavations. The reults shows how the principle can be used to mitigate the risks caused by seismic activity on mining operations.

Keywords: Underground mining,dynamic, mining operations, personnel safety, yielding bolt,fricton and risk mitigation.

1. Introduction

Most underground excavations require ground support to maintain excavation stability and to ensure a safe environment for the working personnel and equipment. A suitable ground support design which is capable to withstand various loads caused by underground seismic activity (Plouffe, et al., 2007) is of paramount importance. In reality, dynamic seismic activity are very difficult to anticipate and study their behaviour in order to determine the occurance and behaviour of the nesxt activiy. (Plouffe, et al., 2007). When properly accounted for, well-designed dynamic/yielding ground support systems can dramatically improve the excavation stability. The importance of the appropriate ground support selection and design is crucial to ensure personnel safety in seismically active areas.For static gradual down fall of ground,there various sufficent instruments to measure and support the ground.For dynamic seismic activity,due to its unpredictability and varying magnitudes there is need for designing sufficient yielding ground support elements in highly stressed, burst-prone or high deformation environments (Plouffe, et al., 2007).

2. Experimental Approach to Ensuring Excavation Stability Problem

To determine the demand placed on the ground support by dynamic loading activity, it is assumed that a certain volume of rock will be subject to vibrations for which the intensity can be characterized by an acceleration or a velocity (Plouffe, et al., 2007). To effectively maintain a safe working environment, the ground support must be able to withstand the additional loads and displacements in order to dissipate the energy (demand) released by the dynamic event. All mining excavations will have different geomorphic and sedimentary rock layouts,this is means that every excacation needs to be assessed individually to determine the required ground support elements. Overall,the magnitude, nature,frequency and distance between the excavation and epicentre of seismic activity make it very difficult to ensure an appropriate design (Plouffe, et al., 2007). The worst case scenario will be simulated using a hydraulic press which will pull (tensile) the yielding bolt at a speed of 3 m/s similar to seismic activity and rock bursts in dynamic events. The yielding bolt is designed to absorb this energy for a length of 600 mm. In order to successfully maintain structural integrity underground, the Rocbolt needs to yield at 20 tons (Nissen, 2019) as required by the mining industry.

2.1 Concept

Research is being conducted on how to use the solid expandable tubular undergoing rapid radial expansion to ensure the intergrity of underground excavations. The idea is to allow for the controlled energy absorption of these underground dynamic events. Figure 1 (Al-Abri & Pervez, 2013) shows how a mandrel is pushed through a tube,the energy from a dynamic event will be absorbed by the mandrel thus ensuring a rigid excavation by yielding the tube.

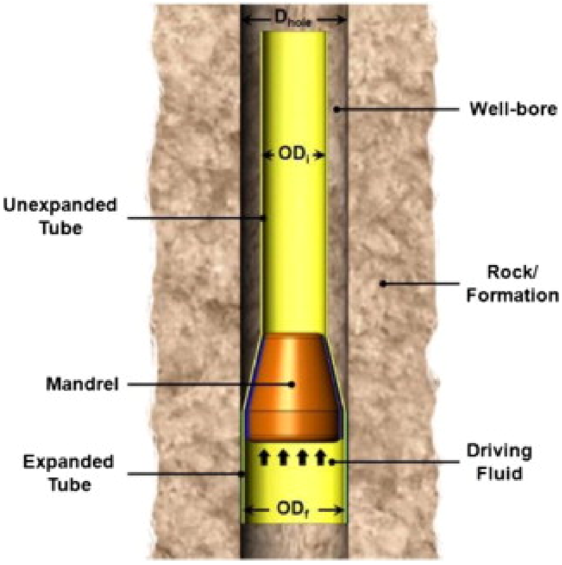

Figure 1: Mandrel radially expanding a hollow tube.

2.2 Theorectical calculations

The following calculations are conducted to find the theoretical results of the force on the cone when yielding the tube (Al-Abri & Pervez, 2013):

Cone angle in degrees [φ]:

$$\frac{\alpha(180)}{\pi}$$

$$= \frac{0.035(180)}{\pi}$$

$$= 2.01°$$

Lateral area of cone [A_l]:

$$\pi(R + r) * [(R - r)^2 + L_c^2)]\text{^}0.5$$

$$= \pi(20.125 + 17.2) * [(20.125 - 17.2)^2 + 88.5^2)]\text{^}0.5$$

$$= 10\ 383.2\ mm^2$$

Surface area of cone:

$$A_l + \pi[(R^2 + r^2)]$$

$$= 10\ 383.2 + \pi[(20.125^2 + 17.2^2)]$$

$$= 12\ 585\ mm^2$$

Stress on cone:

$$\frac{S_{yt} * 2 * t}{R + r}$$

$$= \frac{355 * 2 * 0.005}{0.020125 + 0.0172}$$

$$= 95.11\ MPa$$

Force on cone:

$$surface\ area * pressure$$

$$= 12\ 585 * 95.11$$

$$= 1\ 196.96\ kN$$

Static Frictional force component:

$$\mu * force\ on\ cone$$

$$= 0.15 * 1\ 196.96$$

$$= 179.54\ kN$$

Dynamic Frictional force component:

$$\mu * force\ on\ cone$$

$$= 0.09 * 1\ 196.96$$

$$= 107.72\ kN$$

Yielding force for static :

$$\text{Horizonatal force component on cone} + \text{frictional force}$$

$$= 41.77 + 179.54$$

$$= 221.31\ kN$$

Yielding force for dynamic :

$$\text{Horizonatal force component on cone} + \text{frictional force}$$

$$= 41.77 + 107.72$$

$$149.49\ kN$$

The expected static and dynamic yield forces are 22.13 and 149.49 tons,respectively.

2.3 Experimental Setup and Equipment for Testing

Five specimens have been manufactured for experimental dynamic testing, these are shown in the image below:

Figure 2: Manufactured dynamic testing bolts.

The Rocbolts pictured in Figure 2 will each be inserted into a hydraulic press for testing. There will be two types of tests conducted namely: static and dynamic. Two bolts were inserted into a 100 ton horizontal hydraulic press used for static testing.A load cell will record the force to radial expand the tube, extension of the tube and velocity of the mandrel radially expanding the tube. Therefore bolt is threaded to a load cell on the front end and fixed on the rear end in order to place it in tension. The load cell is attached to a hydraulic cylinder which moves in a forward and backwards motion.When testing begins, the hydraulic cylinder starts to pull on the threaded rod which is attached to the mandrel inside the tube. The force, extension and velocity readings are plotted on a screen as the test proceeds. After the test is complete, a vernier caliper is used to measure the change in outer diameter after yielding, see Table 1 for specifications.

Table 1: Specifications of the specimens

Specification	Quantity
Pipe OD	45 mm
Wall Thickness	5 mm
Pipe length	400
Cone OD	40.25mm
Cone angle	2 degrees

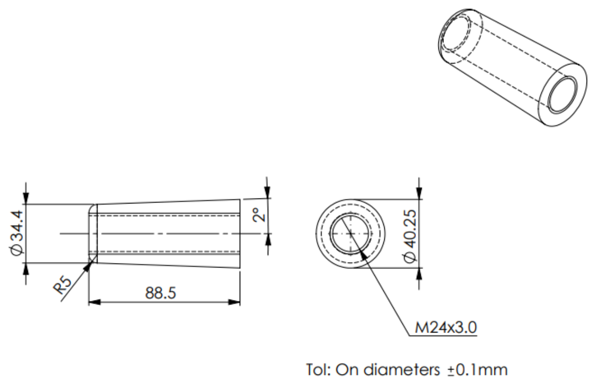

Figure 3: Dimensions of the cone inside the Rocbolts used for hollow tubular expansion.

For dynamic testing,three bolts will be each inserted into a vertical hydraulic press with a capacity of 60 ton.The bolt is inserted in a similar manner to the horizontal press but in the vertical position. The vertical hydraulic cylinder of this press is capable of rapidly pulling the threaded rod at speeds of upto 3m/s in order to simulate seismic underdround activity of an earth quake, rock fall or burst, Figure 3.

3. Results

3.1 Theoretical Results

The theoretical expected yield force from the experiment is 24.04 tons at 2 degrees yield angle as shown in excel template was created which shows the theoretical results of altering the cone angle, length of cone and the thickness of tube in order to obtain the desired yield force of 20 tons. This excel template was created from the theoretical calculations and assists in modeling the different scenarios possible and to understand the relationship between all parameters. Figure 4 is extracted from the excel template used to determind the best parameters and it justifies the parameters of cone design:

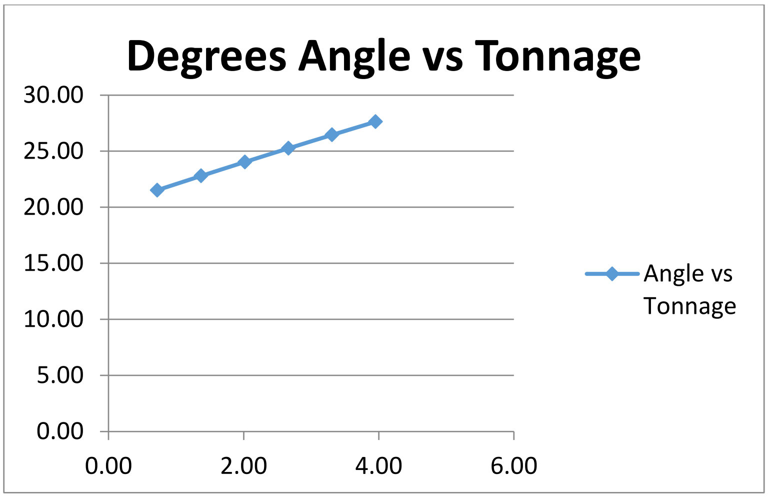

Figure 4: Plot of angular displacement versus tonnage.

In order to select the required safe working tube parameters, from the excel template: the following relationship is shown between tonnage and area yield percentage.The overall cross-sectional percentage yield of the tube will be 25% which requires a yield force above 20 tons as shown in Figure 5:

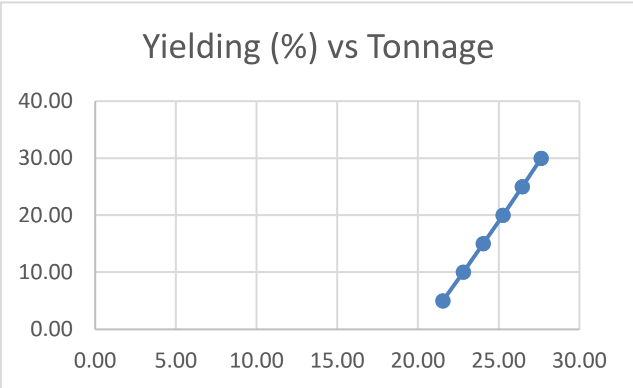

Figure 5: Plot of yield against tonnage.

3.2 Test Results

Figure 6 shows the practical results obtained from tests conducted:

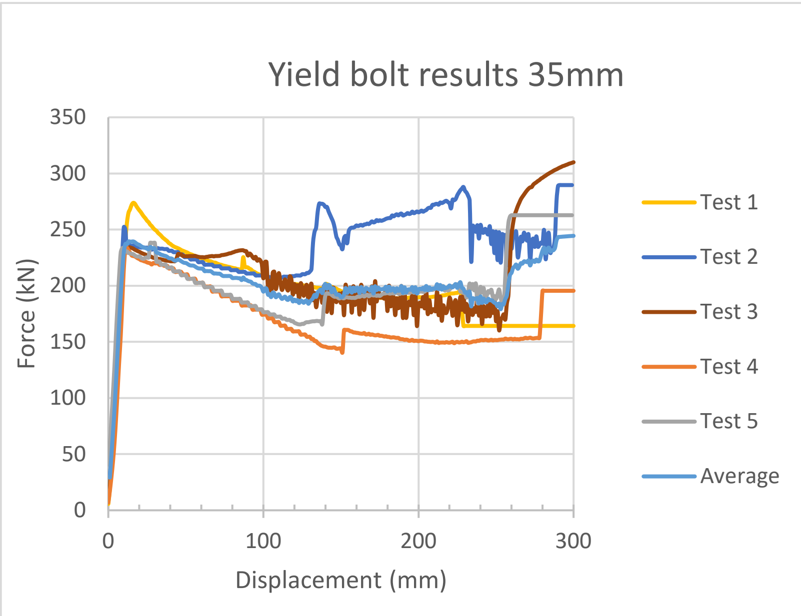

Figure 6: Force against displacement.

The five tests conducted are plotted into one graph showing the displacement of the mandrel within the tube and the force produced when radially expanding the tube. Overall the graphs follow the trend similar to that of a stress-strain graph for tensile strength testing. However, the graphs have a longer permanent plastic deformation(strain hardening) region because the tube is hollow. After the initial yield point of the tube, the force starts to drop since the dynamic friction is less than static friction. When the cone reaches the end of the test,the force starts to rapidly increase and provides the ultimate tensile strength of the bolt.

4. Discussion

From the practical results obtained, the design parameters selected do yield accurate results from practical testing. It is evident that all tubes yield above 20 tons. The average yield of tests 1 and 2 is above 19 tons, this is accurate due to the tests being static and correlates to a static friction factor of 0.15 between the cone and tube. In test graphs 3,4 and 5 the yield tonnage drops lower than in tests 1 and 2. This is due the tests being dynamic at speeds of 3 m/s and thus the applicabe friction factor is kinetic friction of 0.09. It is important to note that the tubes are lubricated within the inner diameter to reduce the effects of the 2 friction factors as the test progresses and ensure that recorded yield force is entirely due to the expansion of tubes. Towards the end of the test, the cone is allowed to continue being pulled against the tube even though there is no more length of tube to yield. This is done in order to determine a safety factor and see if the welding, tube or rod will fail, thus the measurable quantities after testing are considered unrealiable as the destructive testing distorts all dimensions. This failure test has shown that the tube may split as seen by test 1.

5. Conclusion

The report is succesfull in showing the behaviour of a tube under going radial expansion by a mandrel. This working principle is incapusled in a bolt design to be used in underground mining excavations.It uses graphs,diagrams and descriptive analysis to explain this behaviour. The concept is to be used for ensuring the integrity of underground mining excavations as mineral extractions reach deeper under lengths. Due to the unpredictable nature of underground rock seismic activity, it is important to account for the worst case scenario.It was found that the performance of a yield bolt will differ depending on the nature of the seismic activity.The load bearing of the bolt is more consistent in the event of static seismic activity and tends to drop during dynamic activity.

For this report, the tube is placed in tension during radial expansion. Similar studies have been conducted and placed the tube in compression,thus making it prone to buckling. Furthmore, the yielding force was not an important parameter because the concept of radial expansion of tubes was used to line drilled holes for oil extraction underground, the lining prevents soil and other foreign substances from contaminating the extracted oil with the benefit of keeping the soil intact on the sides as they drill deeper.

6. References

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