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Variation in anchorage performance of a high capacity modified bulb cable bolt under differing conditions in a weak confining medium

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VARIATION IN ANCHORAGE PERFORMANCE OF A HIGH CAPACITY MODIFIED BULB CABLE BOLT UNDER DIFFERING CONDITIONS IN A WEAK CONFINING MEDIUM

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ABSTRACT: Cable bolts are increasingly being used for ground reinforcement due to their high load carrying capacity, tendon length and flexibility that affords easy installation. There are a variety of cable bolt designs on the market and while many have been tested, few studies have examined anchorage performance in a weak confining medium that approximates behaviour in coal. This paper presents the results of testing a high capacity cable bolt, the MW9 indented cable bolt, in weak material of differing borehole diameters and grout strengths. Both the standard recommended borehole diameter of 42 mm and an oversize borehole of 52 mm were examined in combination with the standard high strength grout strength of 80 MPa and a lower strength of 62 MPa. In weak grout, borehole diameter had minimal effect on the peak load carrying capacity with only a 6% reduction in capacity from an increase in borehole diameter from 42 mm to 52 mm. However, with the strong grout, there was a 7% increase in peak load carrying capacity with borehole diameter. In the standard borehole diameter, increasing grout strength reduced the peak load carrying capacity by 4% whereas there was a 10% in the oversized borehole. In the vast majority of tests, failure occurred at the bolt/grout interface.

INTRODUCTION

Cablebolts usually consist of multi-wire strands that provide additional flexibility over traditional solid bar rockbolts. Commonly one or more steel cablebolt strands are inserted into boreholes of varying diameter and grouted using either a cement-based or resin material (Hutchinson and Falmagne, 1999). Cablebolts are considered as versatile, easy to install and can be installed from spaces with limited headroom (Hutchinson, 1992).

One of the major developments in recent times has been the development of modified cablebolts such as the bulbed cables. The Megabolt MW9 is one type of modified bulb cablebolt that comes in lengths ranging from 4 m to 11 m with a load carrying capacity from 60 tonnes to 80 tonnes (Megabolt, 2016). Even with the development of these high capacity cablebolts, failure of the cablebolts and/or ground still occurs. As reported by Hutchinson and Diederichs (1996), there are five types of failure modes that can occur in a cablebolt system. These include:

- Failure at cable and grout interface,
- Failure of surrounding rock mass,
- Failure of the grout,
- Failure of grout and rock interface, and
- Rupture of the wire of the cable bolt.

Laboratory pullout tests are often used to assess the load carrying capacity of a cablebolt. The testing apparatus is used to simulate *in situ* conditions in the laboratory. Various advancements have been made in the area of laboratory pullout testing apparatus. The initial split-pull testing apparatus developed by Fuller and Cox (1975), consisted of grout and cablebolts confined in steel split pipes. However, it was found that the properties and confinement provided by a steel tube is different to that

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experienced in field conditions and consequently influenced anchorage response and behaviour (Hagan *et al.,* 2015).

Since 1975 various modifications have been made to the initial split-pull testing apparatus. The latest development in the area of pullout testing has been the development of UNSW modified laboratory short encapsulation pull-test (LSEPT) as reported by Chen *et al.* (2015). This new modified axial testing facility as shown in Figure 1 was used to analyse the performance of MW9 bulbed Megabolt.

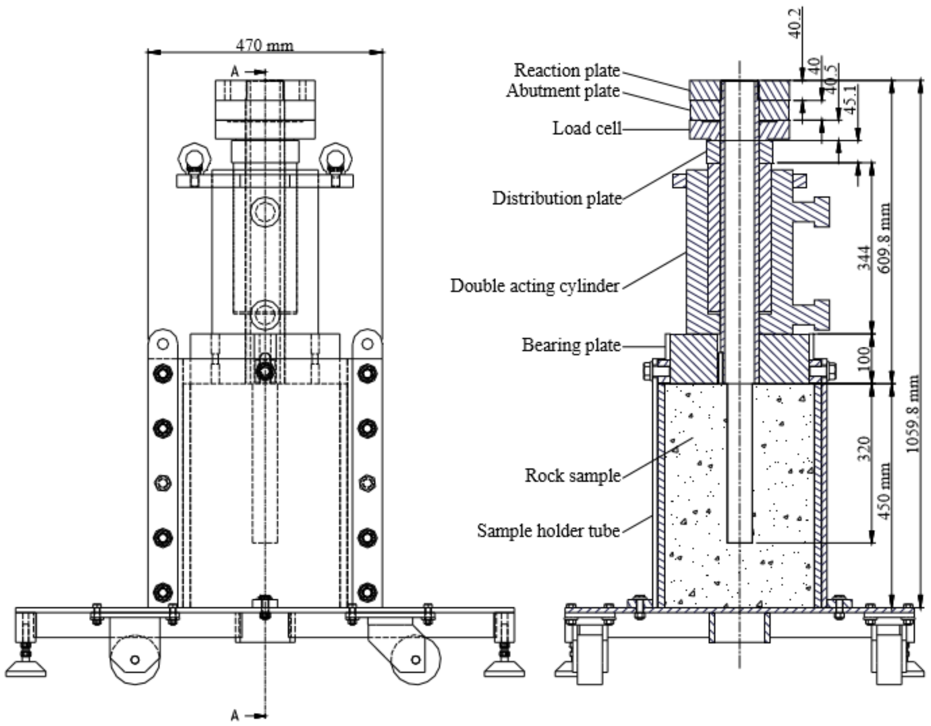

Figure 1: Front and side view of the new axial testing facility (Chen *et al.,* 2015)

The material properties of the grout used to anchor the cablebolt and the borehole diameter impact the performance of cablebolts. Robinson and Sharrock (2010) investigated the effect of borehole diameter on the pullout capacity of the cablebolt using the standard single embedment test. This involved borehole diameters of 42 mm, 52 mm, 81 mm and 106 mm. They found that when used with a cement grout that diameter had little effect on the peak pullout load of the cablebolt whereas water content in the grout mixture ratio and bulb frequency had a more dominant role on cablebolt behaviour. They varied the water to cement ratio between 0.35 and 0.45 and found that with a 0.35 W:C ratio more samples failed via rupture than with a 0.45 W:C sample. A similar trend was observed by Hyett *et al.* (1992).Chen *et al.* (2015) reported on the development of a modified version of the laboratory short encapsulation test (LSEPT), a new axial testing facility capable of assessing the performance of modified cablebolts. As part of this project, a study was undertaken on the effect of borehole diameter on the performance of MW9 Megabolt. The larger borehole diameter achieved a near 25% larger peak load than the standard borehole diameter as shown in Figure 2.

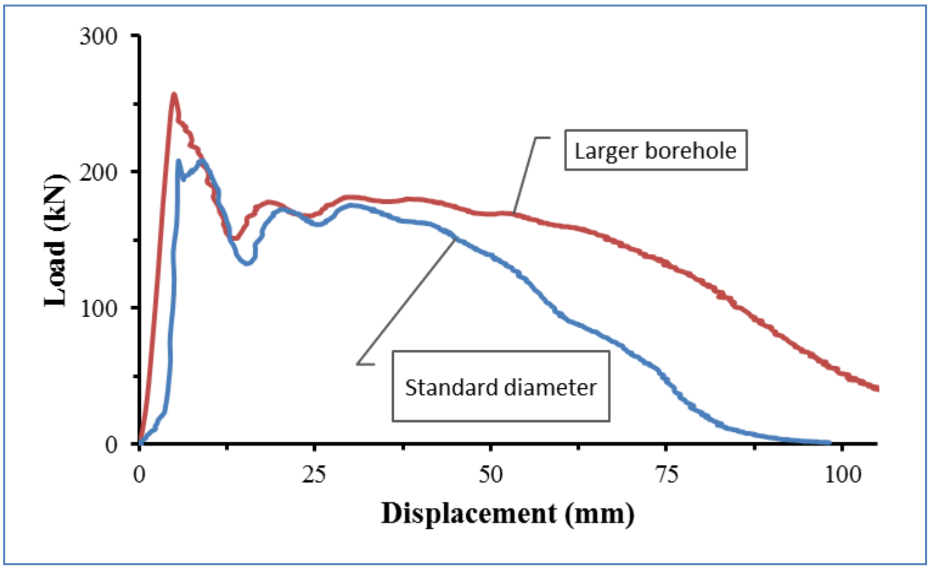

Figure 2: Effect of borehole size on load carrying capacity of MW9 (Hagan and Chen, 2015)

METHODOLOGY

Laboratory testing was carried out using the newly modified LSEPT axial testing facility at The School of Mining Engineering UNSW.

Sample preparation

A total of 20 low strength test samples were prepared as the confining medium in which a cablebolt was embedded. The test samples were prepared from a cement-based material cast into 300 mm diameter cylindrical moulds. Rajaie (1990) first studied the effect of sample diameter size on the pull out strength of plain strand cable bolts. The study found that there was minimal change in the load carrying capacity of the bolts for sample diameter within the range of 200 – 300 mm. Recent study by Ur-Rahman, Hagan and Chen (2015) observed the same trend as reported by Rajaie (1990).

In preparing the moulds, PVC pipes were used to create varying boreholes with diameters of 42 mm and 52 mm. The PVC pipes were wrapped with plastic tube to create a constant manufactured rifled effect in the borehole as is shown in Figure 3.

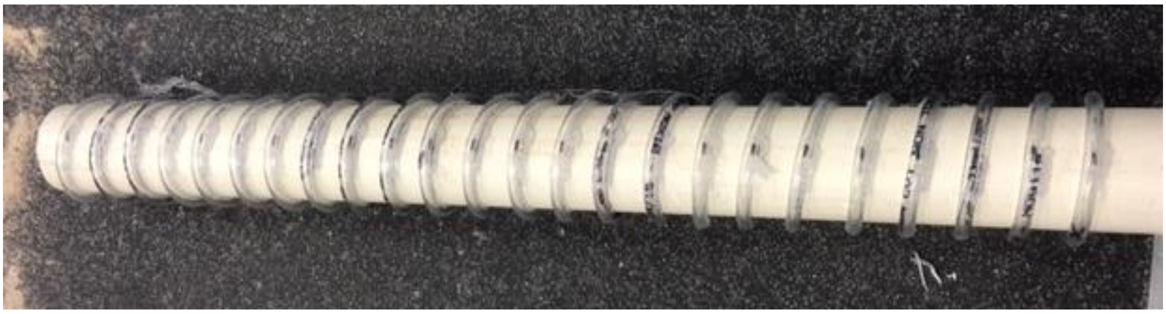

Figure 3: PVC pipe wrapped with plastic tube

Sample moulds were fabricated from Ezytube^{TM} fixed onto fibre board sheets in the centre of which was fixed a PVC pipe as shown in Figure 4. A single batch of low strength concrete was then poured into the 20 moulds. The material had a measured UCS of 10.9 MPa.

Figure 4: Prepared moulds to create the test samples (left) and pouring of cement mixture into moulds (right)

After 24 h, the PVC pipe and plastic tube was removed and the cardboard mould discarded. The test sample confining medium was left to cure for a minimum of 28 days. Lengths of MW9 indented cablebolt was prepared with the lower 90 mm wrapped in PVC heat shrink tube, this was done to ensure a constant embedment length during the pullout test. The cablebolt was then grouted into each confining medium. Ten samples had a grout strength of 80 MPa, the recommended grout strength and, a further ten samples had a strength of 62 MPa representing a grout mixture with a higher water content. Anchor tubes were then installed and grouted over the remaining exposed cablebolt above the confining medium. Anchor tubes are used to stop the cable bolt from unwinding during the pullout process and secure the free section of the cable bolt (Hagan and Chen, 2015). Anchor tube has a key slot with a locking key as shown in Figure 5 which prevents the whole section of the cable bolt from unwinding during a test.

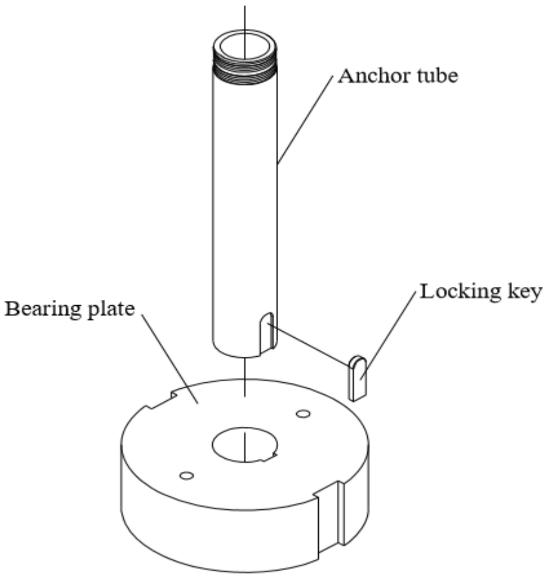

Figure 5: Anchor tube, bearing plate with locking key that prevented rotation during a test (Hagan and Chen, 2015)

Test setup

Each test arrangement involved placing a paired set of split steel tubes around the confining medium. Prior to a test, the bolts on the split tubes were tightened to a constant torque of 50 N.m and the test sample assembly was ready for testing. Laboratory testing was carried out in the newly modified axial testing facility at UNSW that is suited to the testing of a range of modified cablebolt designs. The testing apparatus consists of double acting hydraulic cylinder which provided the axial pull-out force at a displacement rate of 0.27 mm/sec.

RESULTS AND ANALYSIS

A total of 20 test samples were used to assess the variation in axial load carrying capacity of MW9 indented cable bolt under:

1. varying borehole diameter; and
2. varying strength of the grout used to anchor the cable bolt.

Borehole diameter of 42 mm and 52 mm was chosen to assess the axial load carrying capacity of the Megabolt MW9 indented cable bolt. 42 mm represents a standard borehole diameter as recommended by the cablebolt manufacturer. A 10 mm oversize borehole diameter was also chosen. Cablebolt grout strengths of 62 MPa and 80 MPa were used. In total four parameters were varied, each with five samples. 15 samples were tested at a confining torque of 50 Nm. The remaining samples were tested at a confining torque of 40 N.m. Samples tested at 40 Nm confining torque was as follow:

- two samples from 52 mm borehole size with grout strength of 62 MPa;
- two samples from 42 mm borehole size with grout strength of 62 MPa; and
- one sample from 42 mm borehole size with grout strength of 80 MPa.

Analysis of borehole diameter

Standard borehole diameter of 42 mm and oversized borehole diameter 52 mm were used to analyse the effect of changes in borehole diameter on the load carrying capacity of MW9 indented cable bolt system.

62 MPa (weak) grout strength samples

Ten samples were tested at the grout strength of 62 MPa. For analysis purposes, three of the most consistent results with confining torque of 50 Nm were chosen. These results are shown in Figure 6 for 42 mm and 52 mm borehole size respectively.

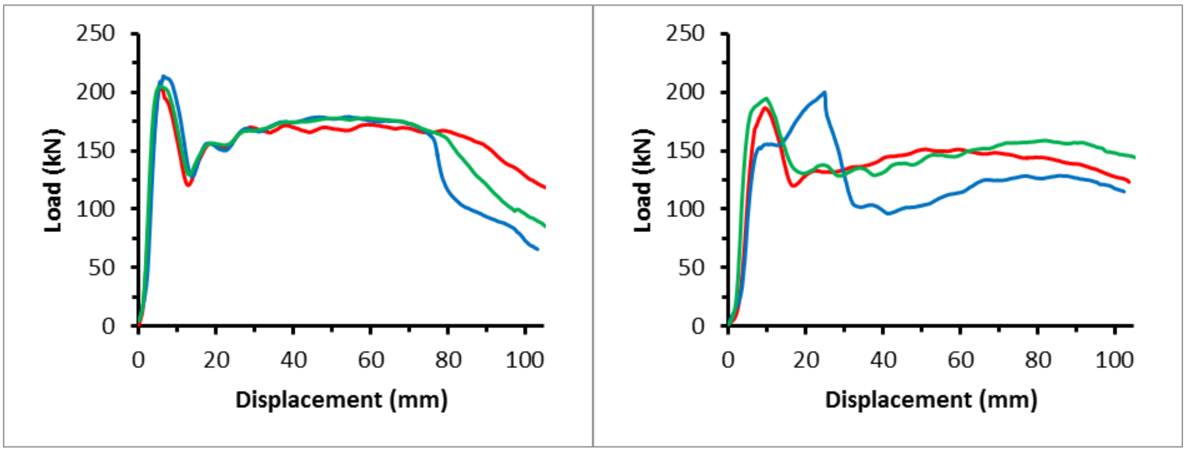

Figure 6: Results of testing with a 62 MPa grout in a 42 mm (left) and 52 mm (right) diameter borehole

The graphs indicate little substantial difference in performance between the two borehole diameters, which indicates that the performance is not sensitive to a small change in borehole diameter in weak grout. Residual stress follows the same pattern with a reduction in load post-peak. However there does appear to be greater evidence of cyclic “slip-lock” behaviour in the smaller diameter borehole. Table 1 shows the 42 mm borehole diameter had on average a 6% higher load carrying capacity than the 52 mm borehole. As the borehole size was increased, peak load carrying capacity decreased by 6%. Maximum peak load was 6 % lower as the borehole size was increased from 42 mm to 52 mm.

Table 1: Performance parameters for the cablebolt for varying borehole diameter in 62 MPa grout

	42 mm borehole	52 mm borehole	Difference
Average Peak Load (kN)	206	193	-6%
Maximum Peak Load (kN)	213	200	-6%
Average initial stiffness (kN/mm)	65.0	47.6	-27%
Maximum initial stiffness (kN/mm)	72.2	61.9	-14%

In terms of stiffness of the support system, an increase in borehole diameter size resulted in 27% reduction in the average initial stiffness. Maximum initial stiffness also fell by 14 % as the borehole size was increased. In the majority of cases, failure occurred at the grout/cablebolt interface and was consistent across both 42 mm and 52 mm samples as shown in Figure 7.

Figure 7: Dominant failure mode was between the grout and cable bolt (left) except in one 52 mm sample where failure occurred at the rock/grout interface (right)

80 MPa (strong) grout strength samples

Borehole diameter was varied in both strong and weak grout. Figure 8 shows graphs of the results for the 42 mm and 52 mm borehole diameters respectively.

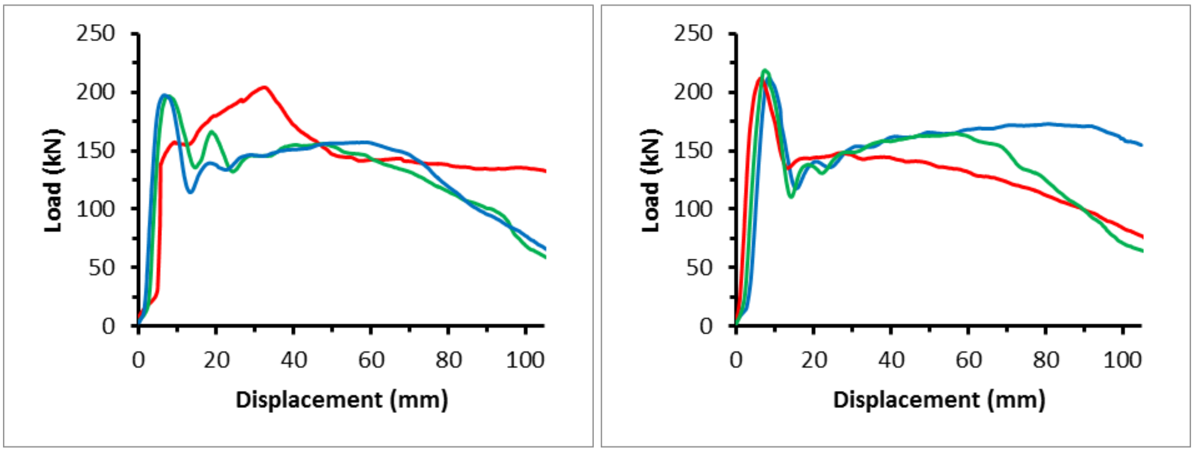

Figure 8: Results of testing with an 80 MPa grout in a 42 mm (left) and 52 mm (right) diameter borehole

Comparing the two graphs in Figure 8, it can be noted that load carrying behaviour for MW9 indented cable bolt was again consistent between the two borehole diameters in strong grout. Slip/lock behaviour was more prominent in the stronger grout. Table 2 shows the trend was reversed with the stronger grout with a 7% increase in average peak load with an increase in borehole diameter. Maximum peak load was also 6% higher in the larger borehole. This could be attributed to better bond strength offered by strong grout. Interestingly, the peak loads were the same for both grout strengths.

Table 2: Performance parameters for the cablebolt for varying borehole diameter in 80 MPa grout

	42 mm borehole	52 mm borehole	Difference
Average Peak Load (kN)	199	212	+7%
Maximum Peak Load (kN)	204	216	+6%
Average initial stiffness (kN/mm)	64.9	55.7	-14%
Maximum initial stiffness (kN/mm)	95.7	62.8	-34%

There was again a reduction in the system stiffness of 14% as the borehole size was increased in strong grout. Initial stiffness values for 52 mm samples were more consistent than 42 mm samples. This is due to the difference in failure modes between 42 mm and 52 mm samples. All three samples with 52 mm had failure at the grout/cablebolt interface. Whereas in the smaller borehole, different failure modes were observed in the three test samples, these being failure at the:

- rock/grout interface;
- bolt/grout interface; and
- combination of bolt/grout and rock/grout interface.

Increasing borehole diameter in both weak and strong grout had a negative impact on the initial stiffness for indented MW9 cable bolts.

Analysis of grout strength to anchor the cable bolts

Grout strength is another important parameter that can affect the load carrying capacity of the MW9 indented cablebolt. A weak grout with strength of 62 MPa and strong grout with 80 MPa were used to analyse the effect of the change in grout strength on the load carrying capacity of the MW9 indented cablebolt system.

42 mm (standard) borehole diameter samples

Graphs of the performance curves for 62 MPa and 80 MPa grout strength are shown in Figure 9. Comparing the graphs in Figure 9 it can be noted that there is minimal change in the peak load carrying capacity of MW9 indented cable bolt as the grout strength is increased in standard borehole samples. Residual stress follows a similar profile in both scenarios with a sharp reduction in load carrying capacity post-peak. This reduction is followed by a gradual increase in the load followed by a gradual decline near the end of sample testing.

Table 3 summarises the change in peak load as the grout strength is varied for the standard borehole diameter samples.

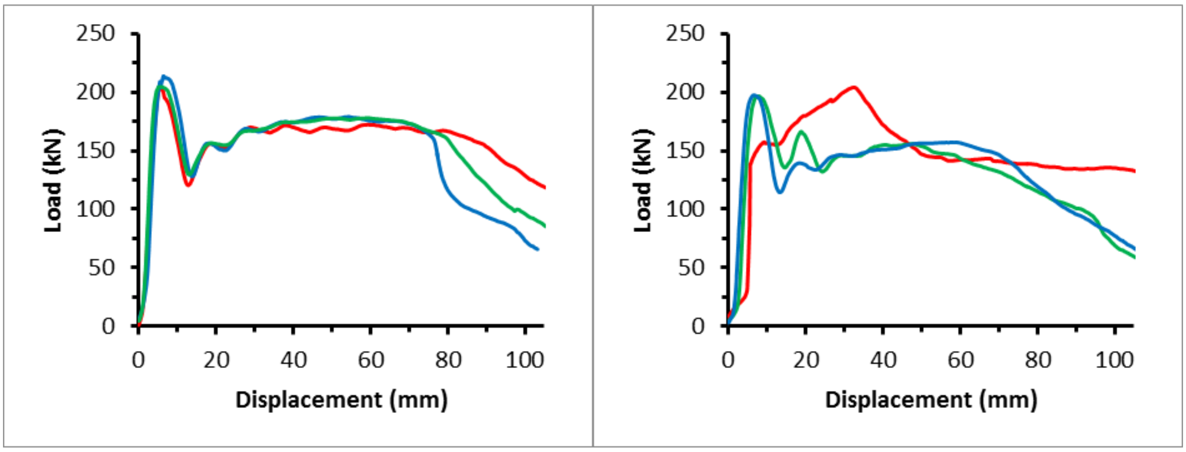

Figure 9: Results of testing in standard borehole of 42 mm with a 62 MPa grout (left) and 80 MPa grout (right)

Table 3: Performance parameters for the cablebolt for varying grout strength in standard 42 mm borehole

	62 MPa grout	80 MPa grout	Difference
Average Peak Load (kN)	206	199	-4%
Maximum Peak Load (kN)	213	204	-5%
Average initial stiffness (kN/mm)	65.0	64.9	0
Maximum initial stiffness (kN/mm)	72.2	95.7	+33%

The peak load carrying capacity for strong grout was 4% less than that of weak grout in standard borehole diameter. Maximum peak load was also 5% lower in the strong grout samples when compared with weak grout. Although the peak load carrying capacity decreased for the strong grout, the change was minimal. These results are contrary to the study done by Robinson and Sharrock (2010), which concluded that higher grout strength results in higher pull out load.

In terms of stiffness, the average initial stiffness was observed to be similar in both grout samples. However, in the 62 MPa grout samples, the values for initial stiffness were constant and less variable when compared with 80 MPa grout samples. This is due to the difference in failure modes. In 62 MPa grout samples the failure was between the bolt and the grout interface for all the 3 samples. Variable failure modes were observed in 80 MPa grout samples. These consisted of failure at:

- rock/grout interface;
- bolt/grout interface; and

52 mm (oversized) borehole diameter samples

Graphs comparing the results for the 62 MPa and 80 MPa grout strength in the oversized borehole are shown in Figure 10.

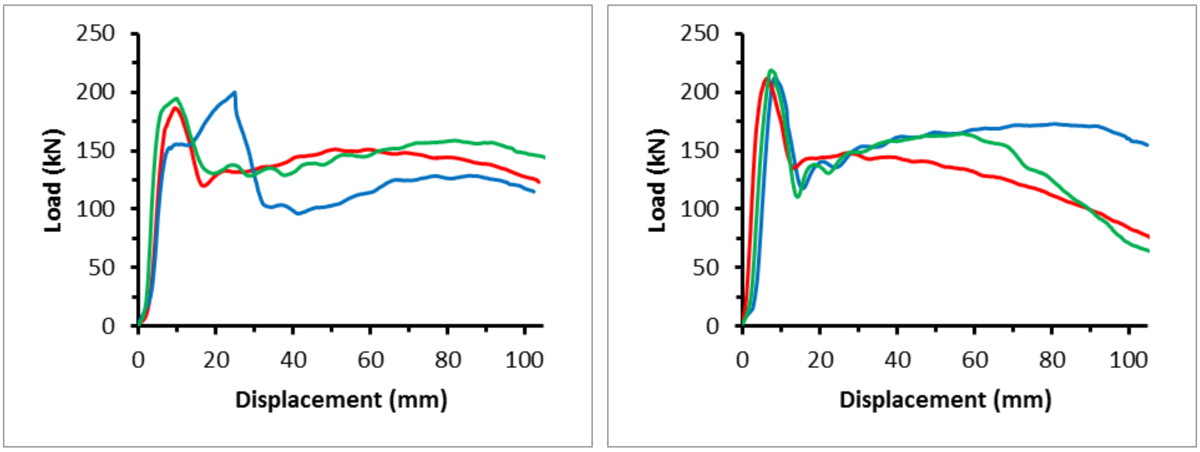

Figure 10: Results of testing in oversized borehole of 52 mm with a 62 MPa grout (left) and 80 MPa grout (right)

A higher peak load carrying capacity was observed in the oversized borehole samples. This is opposite to the results obtained from varying grout strength in standard borehole samples. Table 4 summarises the comparison in peak load for varying grout strength in 52 mm diameter samples.

Table 4: Performance parameters for the cablebolt for varying grout strength in oversized 52 mm borehole

	62 MPa grout	80 MPa grout	Difference
Average Peak Load (kN)	193	212	+10%
Maximum Peak Load (kN)	200	216	+8%
Average initial stiffness (kN/mm)	47.6	55.7	+17
Maximum initial stiffness (kN/mm)	61.9	62.8	+1

Comparing strong and weak grout in oversized borehole it was found that the stronger grout achieved a 10% higher average peak load than that of weak grout. This is contrary to the results achieved in standard borehole size where average peak load was decreased by 4% in strong grout. Results achieved from varying grout strength in oversized borehole are more in line with those of Robinson and Sharrock (2010).

Average initial stiffness increased by 17% for strong grout in oversized borehole diameter samples. This is different to the results obtained from standard borehole size where initial stiffness largely remained unchanged for varying grout strength. Failure mode occurred between bolt and grout interface across weak and strong grout samples. However, one sample was observed to have failed between rock and grout interface in weak grout.

Analysis of confining torque

A number of tests were undertaken to assess the impact of varying the initial torque loading of the bolts used in the split tubes. A total of five samples were tested at a lower torque of 40 Nm compared to the standard 50 Nm used in the majority of tests. A reduction of 13% was observed with the lower torque in the average peak load with the 52 mm borehole with 62 MPa grout. However the initial stiffness was 20% higher. This indicates that the level of confinement through tightening of the bolts is an important factor in determining the performance of MW9 indented cable bolt system. A similar trend was observed with smaller 42 mm borehole and 62 MPa grout strength. 40 Nm confining torque sample resulted in a reduction in the average peak load of 15%.

CONCLUSION

A study was undertaken to analyse the impact of varying grout strength and borehole diameter on the performance of MW9 indented cable bolt in weak confining medium. The effect of a change in the torque of the bolt assembly was also investigated.

Borehole diameter was found to have minimal impact on the peak load carrying capacity of MW9 indented cable bolt in weak grout. Increasing borehole diameter from 42 to 52 mm led to a 6% reduction in peak load carrying capacity. In strong grout, the opposite effect was observed with a 7% higher peak load in the larger borehole. While the differences are not significant, it can be concluded that when using a strong grout, greater benefit can be gained with an oversized borehole. Increasing borehole diameter in both standard and oversized borehole samples decreased the average initial stiffness. Residual load followed the same with cyclic slip/lock behaviour with the borehole regardless of the borehole diameter.

Increasing grout strength in standard borehole reduced the peak load carrying capacity by 4%. However, increasing the grout strength in oversized borehole led to 10% increase in peak load carrying capacity. Therefore, the study confirmed that oversized borehole diameter should be used for strong grout to improve the peak load carrying capacity of the MW9 indented cable bolts.

A number of tests were undertaken at a lower bolt torque of 40 N.m. The reduction in confining torque led to a significant reduction in peak load carrying capacity for MW9 indented cable bolt. In the majority of cases, the failure mode in the test samples was at the bolt/grout interface.

The study offers insights into the effect of varying borehole diameter, grout strength and confining torque on the performance of MW9 indented cable bolts. Results achieved are consistent and reliable. These results will help the industry make informed decisions in relation to optimum selection of ground reinforcement systems. This will lead to improve safety standards in civil and mining industry.

ACKNOWLEDGEMENTS

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