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SAMPLE SIZE AND SAMPLE STRENGTH EFFECTS ON TESTING THE PERFORMANCE OF CABLE BOLTS

Hao Zhai, Paul Hagan and Danqi Li

ABSTRACT: This paper presents the results of a study on the effect of test sample diameter on the peak load carrying capacity of cable bolts in varying conditions. It was previously found that peak load varies with the diameter of test sample up to 300 mm and further that confinement has a significant impact on load. In this study test samples were varied over a larger range of diameters up to 500 mm in test samples having strengths of 32 MPa and 66 MPa using a plain strand Superstrand cable bolt and a nutcage high capacity MW9 cable bolt. The test work confirmed that there are differences in anchorage performance in material of different strength between the two cable bolts and importantly that a 300 mm diameter sample size is required when comparing different types of cable bolts design.

INTRODUCTION

Cable bolts are widely used for ground support in both the civil construction and mining industries. They are used to prevent movements of joints by transferring loads from the failing side of the discontinuity plane to the intact side of the discontinuity plane (Hutchinson and Diederichs 1996).

Considering the importance of cable bolts in this role, a systematic method of determining and comparing the performance of different types of cable bolts is important in optimising the selection in differing ground conditions. Over the years, a variety of testing methods such as “split-pull/push” test, single embedment test, double embedment test and Laboratory Short Encapsulation Pull Test (LSEPT) have been developed to better understand the load transfer mechanism of cable bolts (Hagan et al., 2014). The study by Thomas (2012) revealed several deficiencies in the LSEPT developed in the UK that had been adopted as the industry standard test method. As a result, an Australian Coal Association Research Program (ACARP) sponsored project was undertaken at UNSW to develop a new cable bolt testing facility.

In testing cable bolts, the primary variables include the design and form of cable bolt and properties and dimensions of the test sample in which the cable bolt is anchored. Previous research reported by Rajaie (1990) using a plain strand cable bolt found the peak load increased with the diameter of the test sample up to around 200 mm and thereafter remained largely unchanged. With the development of high capacity, modified cable bolts since that time, it was not known whether this diameter was still applicable or whether sample strength had any effect on anchorage performance. Recent studies have been undertaken on the basis that test results might be compromised if load capacity of a cable bolt was a function of test sample size used in anchoring the cable. This paper examines the influence of changes in the diameter of the test sample on the peak pull-out load in two strengths of test samples and two types of cable bolts. A series of pull tests was undertaken with samples varying over a range of diameters up to 500 mm in high strength and low strength materials when using a plain strand Superstrand cable bolt and a nutcage high capacity MW9 cable bolt.

BACKGROUND AND OBJECTIVES

An earlier study by Rajaie (1990) involved 295 tests with test samples in the unconfined state, that is test sample cylinders without any lateral constraint with diameters ranging between 100 mm and 300 mm. A 15 mm diameter plain strand cable bolt was used in the tests with grout used as the binding material for cable bolt installation. As is shown in Figure 1, the peak load carrying capacity increased with sample diameter until it reached a plateau at around 200 mm. Beyond this diameter there was little further change in load. Based on this observation, Rajaie recommended that test sample diameter used for pull out tests should be at least 250 mm.
Subsequently, there have been many developments in cable bolt design leading to large diameter high capacity cable bolts and it is conjectured that the minimum diameter of test sample recommended by Rajaie may no longer be applicable due to the much higher stresses induced in the test sample (Hagan and Chen 2015). Holden and Hagan (2014) replicated Rajaie’s work using a high capacity bulbed cable bolt and confirmed that the peak load carrying capacity continued to increase with test sample diameters in excess of 200 mm.

Ur-Rahman et al. (2015) reported a subsequent study on the peak load carrying capacity and the sample diameter relationship using a bulbed Sumo cable bolt with a diameter of 28 mm. As shown in Figure 2, the threshold value of sample diameter was found to be much larger at 300 mm. It should be mentioned that tests at some diameters were not replicated to account for variability and hence there was some scatter in results. A major development since Rajaie’s study is the introduction of confinement to test samples. The LSEPT test method uses a biaxial cell to apply a constant stress condition during testing. More recently Hagan and Chen (2014) reported on the use of a steel barrel or cylinder to simulate the confinement of a rock mass that provides passive confinement in reaction to any stress induced in the test sample during or as a consequence of load being applied to the cable bolt. However, the stress state in the surrounding rock mass may not be consistent under loading by a cable bolt (Thomas 2012). To overcome this issue, a split steel cylinder was used where the bolts joining the two halves of the split cylinder were torqued to the same level to provide a consistent level of sample confinement.
The main objectives of this study were to:

- determine whether there were any differences in the peak load/sample diameter relationship for plain Superstrand and nutcaged MW9 cable bolts;
- compare the results for peak load in test samples of different strength; and
- recommend a minimum test sample diameter for pull-out tests applicable over the range of cable bolts currently in use.

**METHODOLOGY**

The testing methodology developed by Ur-Rahman et al., (2015) was used as the basis of this study. However, the embedment length, rifling intervals and the level of confinement were altered in line with the development of the UNSW pull test facility. Furthermore, polyester resin was replaced by high fluidity grout to ensure consistency in cable bolt installation.

**Sample preparation**

An MW9 nutcage cable bolt and a Superstrand plain cable bolt were selected to represent a high and low performance bolt respectively. Both types of cable bolt used in the tests were 1200 mm in length of which 270 mm was grouted in the test sample and 930 mm was left free for gripping as shown in Figure 3. For the MW9 cable bolt, the nutcage section spanned nearly 180 mm. The centre of the nutcage was positioned 140 mm from one end of the cable bolt leaving some 50 mm of unmodified cable bolt. The Superstrand cable bolt is 21.8 mm in diameter and has a solid king wire (the central wire) whereas the MW9 diameter is 32 mm in the plain section and 36 mm in the nutcaged section. The king wire in the MW9 is hollow to allow for grout injection in the field.

![Figure 3: Designs of Superstrand (upper) and MW9 (lower) cable bolts](image)

The test samples were prepared as a bulk-pour from an aggi-truck to ensure consistency in material properties. The high strength and low strength samples were cast in two batches. The cementitious material was poured directly into fibre glass and cardboard compound casting cylinders each having a height of 320 mm and inner diameters ranging from 200 mm to 500 mm. To create smaller 150 mm diameter test samples, casting moulds were made from PVC pipe. Pre-split lines were cut along the length of the PVC pipes to allow for easy demoulding sealed on the inside with duct tape to prevent leakage. The material was left to cure for a minimum of 28 days.

The casting moulds were glued onto 2 m by 2 m Medium Density Fibre Boards (MDF Board) using waterproof silicon glue as show in Figure 4. PVC pipes with 28 mm and 42 mm outer diameters were used as the rifled borehole moulds for Superstrand and MW9 cable bolt respectively. As shown in Figure 5a, a 5 mm diameter soft plastic tube was wound around the PVC pipe with a 20 mm pitch to promote the interlocking between grout and rock. The plastic rifling tubes were mounted on the PVC moulds by medium adhesive strength hot glues to ensure easy detachment in demoulding. The PVC
tubes were filled with foam on one side of the rifling tube to increase the contact surface area for glue application.

![Figure 4: Assembled casting moulds](image)

Figure 4: Assembled casting moulds

![Figure 5: a) Assembled PVC tube used as mould to create borehole rifling effect (left) and b) foam fill tube (right)](image)

Figure 5: a) Assembled PVC tube used as mould to create borehole rifling effect (left) and b) foam fill tube (right)

When the casting moulds were fully assembled with the rifling tubes, the cement grout was poured directly into the moulds as shown in Figure 6. A mechanical vibrator was used to remove any trapped air bubbles.

![Figure 6: Test samples after pouring](image)

Figure 6: Test samples after pouring

After 24 hours, both the outer cardboard mould and inner PVC pipe were removed and each test sample was then left to cure for 28 days fully submerged in tap water as shown in Figure 7. The top surface of each sample was covered by wet rugs which were moisturized on a daily basis.
As the borehole was cast to the full length of the test sample, the borehole was sufficiently backfilled with a cement mixture to leave a remaining 270 mm length for grouting of the cable bolt.

Both the Superstrand and MW9 cable bolts were installed into fully cured samples after at least 24 hours of backfilling. The same 60 MPa grout strength using a 0.42 water to cement (w:c) ratio was used as the binding material in both the strong and weak test samples. The cable bolt installation involved the following steps.

1. Insert the cable bolt into the fully cured sample;
2. Pour well mixed grout with 0.45 w:c ratio in the annulus between the cable bolt and the borehole wall;
3. Shake and rotate the cable bolt to remove trapped air inside the grout;
4. Support the cable bolt with alignment clamps and metal plates.

An example of cable bolt installation is shown in Figure 8.

Confinement of the test sample was by means of a split steel cylinder assembled using four bolts as shown in Figure 9. The cylinder was designed to allow for a 10 mm annulus between the test sample and the steel cylinder that was backfilled with general purpose cement with a w:c ratio of 0.45. A thin
layer of foam was inserted between faceplates to prevent mortar leakage. After 24 hours of curing, each of the four bolts were tightened with a micrometre torque wrench to 40 N·m.

![Figure 9: Assembled split steel cylinder in place with sample ready for testing](image)

**Test procedures**

The testing system used for this test is presented in Figure 10 and 11. The test system comprises sections: the bolted section at the bottom and pull section at the top. During each test, a load was applied to the cable bolt by an hydraulic ram acting against a steel bearing plate on top of the test sample. The magnitude of applied load was measured using a load cell while displacement was measured using a Linear Variable Differential Transformer (LVDT) and a laser displacement sensor. During a test setup, the locations of the LVDT and laser displacement sensor had to be carefully adjusted because of the limited reading range.

![Figure 10: Testing system design](image)
RESULTS AND ANALYSIS

Strength UCS tests

UCS strength tests were conducted on 50 mm cubic samples of the cable bolt grouting material and test samples one day before the pull tests began. Material strengths were derived from the average of five UCS test replications. Test results are presented in Table 1 with the mean values for strong and weak test samples as well as the grout being 66.2 MPa and 31.5 MPa respectively, representing a near 50% difference in material strength between the two samples. The strength of the material used to grout the cable bolt in the test sample was 53.7 MPa.

Nutcage MW9 cable bolt in strong test sample

Figure 12 shows the variation in measured peak load of the MW9 cable bolt with diameter of test sample using the strong cement material. In most cases, three test replications were undertaken at each level of test sample diameter. The data is a plot of the average of the three load measurements and indicates the range of standard deviation.
Table 1: Results of UCS strength tests

<table>
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<tr>
<th>Material</th>
<th>Test Number</th>
<th>UCS (MPa)</th>
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<tr>
<td>Strong test sample</td>
<td>1</td>
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<tr>
<td></td>
<td>2</td>
<td>66.52</td>
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<td></td>
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<td>67.97</td>
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<tr>
<td>mean</td>
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<tr>
<td>Weak test sample</td>
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<tr>
<td></td>
<td>2</td>
<td>31.61</td>
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<td>31.58</td>
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<td>mean</td>
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<tr>
<td>Cable grout mix</td>
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<tr>
<td>mean</td>
<td></td>
<td>53.7</td>
</tr>
</tbody>
</table>

Figure 12: Variation in peak load with sample diameter for MW9 in strong test samples

Over the range of diameters studied, there was a near 30% increase in load bearing capacity of the MW9 cable.

The lowest load of 238 kN was attained with the 150 mm diameter sample, the smallest of test samples. Load increased with diameter until approximately 300 mm when it reached 305 kN at which point the load had effectively plateaued indicating sample size at this turning point of 300 mm no longer had any influence on the load bearing capacity of the cable bolt. In should be noted that only one sample was tested at the larger diameters because of issues in casting the test samples.
NUTCAGED MW9 WEAK SAMPLE

Similar to the strong sample, there was a trend of increase in load with diameter in the weaker material up to approximately 300 mm as shown in Figure 13. The load at a diameter of 150 mm was 194 kN or nearly 80% of the load achieved in strong material. Again a turning point was reached at 300 mm with a load of 230 kN. The value of the peak load at this turning point in the lower strength test material was only 75% of that achieved in material nearly twice its strength.

PLAIN SUPERSTRAND STRONG SAMPLES

As shown in Figure 14, the range of sample diameter effecting peak load when using the Superstrand cable was much less extending to between 200 mm and 250 mm. The load at 150 mm was 145 kN or around 60% of the load achieved with the MW9 cable in the same strength sample. The maximum load that could be achieved was only 170 kN. This result of a much smaller diameter is consistent with the findings of Rajaie (1990).
Plain Superstrand weak samples

In tests with the Superstrand cable in weak material shown in Figure 15 a similar trend was evident with the turning point in diameter between 200 mm and 250 mm. The lower strength material did not appear to have any impact on the turning point diameter, only use of the lower capacity cable bolt. The value of the peak load was only 125 kN at and beyond the turning point. Interestingly, there seemed to be more variability in this combination of parameters than in any of the other tests with consistently more scatter in the mean values as well as larger standard deviations.

Figure 15: Variation in peak load with sample diameter for Superstrand in weak test samples

Analysis

The values for maximum load bearing capacity as well as the peak load for the Superstrand and MW9 cable bolts are compared in Figures 16 and 17 for strong and weak test samples respectively. It can be seen that different cable bolts have different sample diameters for turning points. For the Superstrand and MW9 cables, the turning points occurred at 200 mm and 300 mm respectively.

Rajaie (1990) stated in his work with plain strand cable bolts, the threshold value of sample diameter should be between 200 mm and 250 mm where the samples were tested in the unconfined condition. Rajaie’s finding is similar to the result for the Superstrand cables where the samples were tested in the confined condition.

Figure 16: Comparison of cable bolt load bearing capacity in strong test samples
Figure 17: Comparison of cable bolt load bearing capacity in weak test samples

The earlier work reported by Ur-Rahman et al., (2015) who used Sumo cable bolts, a similarly modified high capacity bolt, reported peak load continued to increase beyond a diameter of 250 mm and only plateaued at 300 mm as shown earlier in Figure 2. This suggests that when testing only plain strand cable bolts, a sample size of 250 mm is sufficient but when comparing performance with higher capacity bolts the minimum sample diameter needs to be at least 300 mm in order to eliminate any effect of sample size on measured performance.

Moreover, both the peak loads and turning point sample diameter of modified cable bolts are significantly greater than conventional plain cable bolts. Hence this emphasises the observation by Hagan and Chen (2015) that as cable bolts have evolved over recent decades, so too the parameters used in tests need to be reviewed because of the potential effects they can have on measured performance.

In comparing the performance of the two cable bolts shown in Figures 18 and 19, while strength of the test material had little perceptible effect on the turning point sample diameter, it had a marked effect on the peak load in each instance. Hence it is important when reporting test results to state the strength of the test sample used and as much as possible ensure consistent material properties when comparing the performance of different types of cable bolts.

Figure 18: Peak loads and material strength comparison for the MW9 cable bolt
CONCLUSIONS

It was found that within a certain range of test sample diameters used in performance testing of cable bolts, diameter has a marked effect on anchorage performance. In the case of the modified high capacity MW9 cable, a doubling in test sample diameter up to the turning point of 300 mm resulted in a nearly 30% increase in measured peak load. Beyond 300 mm there was no perceptible increase in load observed. With the plain strand Superstrand cable bolt, the range of diameters only extended up to the turning point of between 200 and 250 mm beyond which there was no further increase in measured load. It is likely that when load is applied to the cable bolt the stress induced within the test sample can result in premature failure of the confining material, hence limiting the load that can be applied to the cable bolt. As diameter of the test sample increases, so does the level of stress necessary to fail the test sample.

Strength of test sample had little or no effect on the turning point of diameter. With a doubling in material strength from 32 MPa to 66 MPa, the turning point diameter was unchanged for both types of cable bolt though it had a marked impact on the peak load that could be attained in each instance.

The results are consistent with the findings by Rajaie (1990) who used a plain strand cable bolt and the more recent work reported by Ur-Rahman et al.,(2015) who used another type of modified bulbed cable bolt.

It is therefore recommended that the minimum diameter of test sample necessary when testing different types of cable bolts be at least 300 mm. Moreover it is important that as strength of the test sample has a marked impact on performance, controls are put in place to ensure consistent strength of the test samples. No one strength of test sample is recommended however, work by Hagan and Chen (2015) indicates failure mode varies with strength of test material and hence it plays an important role when understanding the differences in anchorage performance in different rock types such as coal and sandstone.

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