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THE INFLUENCE OF CONCRETE SAMPLE TESTING DIMENSIONS ON ASSESSING CABLE BOLT LOAD CARRYING CAPACITY

Ibad Ur-Rahman, Paul Hagan and Jianhang Chen

ABSTRACT: This paper presents the results of a study into the influence of size of the test sample on the maximum load carrying capacity of cable bolts. As part of the design for the standardisation of the laboratory pullout test, it was previously found that the size of the sample in which the cable bolt is embedded can influence the behaviour of the cable bolt in terms of the peak load carrying capacity. This testing was done with a low capacity plain strand cable bolt with the sample in an unconfined state. Confinement of the sample during testing better simulates the *in situ* condition of the interaction between the cable bolt and surrounding rock mass. A test program was undertaken to assess whether there was any significant difference in the load carrying capacity with varying diameter of test samples and at different levels of confinement. A series of pull-out tests were conducted on cable bolts embedded into samples varying between 150 mm and 500 mm in diameter that were placed within a steel cylinder to provide confinement to the test samples. It was found maximum load varied with the test sample diameter up to some threshold diameter but that confinement pressure also had a significant effect on the load carrying capacity of a cable bolt.

INTRODUCTION

The application of cable bolt systems has advanced rapidly in recent years due to better understanding of the load transfer carrying capacity mechanisms and the advances made in cable bolt system technology. Cable bolts are used as part of temporary and permanent support systems in both civil tunnelling and mining operations throughout the world. In mining they are used for slope stability applications in surface mining and a variety of ground support purposes in underground operations such as stoping, roadway development and shaft sinking. Cable bolts are used to prevent the movement between discontinuity planes by transferring load across the discontinuity when relative strata layer movement takes place with separation.

The most common type of failure mechanism identified in the field is failure at the cable-grout interface (Hyett, Moosavi and Bawden, 1996; Singh *et al.*, 2001). This type of failure is common due to insufficient frictional resistance between the cable strand ridges and the grout material usually due to poor ground conditions and/or poor quality control at installation which leads to weak shear bond strength at the interface. This will often result in premature failure of the system before the steel capacity is mobilised. Due to the vast majority of failures being identified at the cable-grout interface, it can be concluded that a standardised testing methodology should focus on failures at the cable-grout interface (Rajaie, 1990; Hutchinson and Diederichs, 1996)

As reported by Hagan, Chen and Saydam (2014), a range of testing methods has been developed over the years including the double embedment and more recently the Laboratory Short Encapsulation Pull Test (LSEPT). The latter overcomes many of the deficiencies in the earlier tests. An issue with the LSEPT method highlighted by Thomas (2012) is the use of a small diameter test sample of approximately 142 mm placed within a pressurised Hoek cell arrangement and its inability to withstand the torsional loads generated during a pull-test. Rajaie (1990) reported a study on the anchorage strength of cable bolt and the effect of the diameter of the test sample. Nearly 300 pull-tests were conducted using test samples in an unconfined state in order to define the characteristic and behaviour of the cable bolt element using conventional grout and grout-aggregate. The cable bolt used was a plain strand cable with a diameter of approximately 15 mm in test samples having a constant embedment length and borehole diameter. Tests were conducted in test rock samples having diameters ranging between 100 mm and 300 mm. As the results in Figure 1 show, the load carrying capacity of the cable bolt varied with sample diameters up to 200 mm beyond which there was no change. This phenomenon was due to the stress generated with the test sample as a result of the load transfer between the cable bolt, grout and rock. Rajaie recommended that pull out tests be standardised to test samples having a diameter of 250 mm.

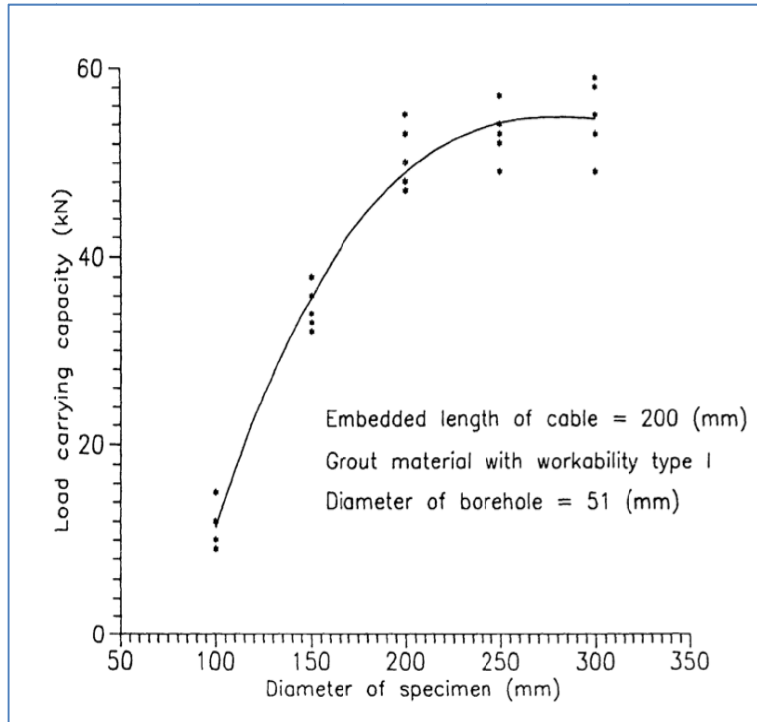


Figure 1: Variation in load carrying capacity with sample diameter (Rajaie, 1990)

Since that time, there have been a number of significant developments in the design of cable bolts including the availability of modified bulbed cable bolts having much greater load bearing capacity than the plain strand cable bolts as used by Rajaie. These higher capacity cable bolts are likely to generate much higher stresses in the surrounding rock mass when tested to full capacity. Subsequent work reported by Holden and Hagan (2014) repeated the work by Rajaie using a high capacity cable bolt. They report the pull-out load continued to increase beyond the 200 mm diameter limit as shown in Figure 2.

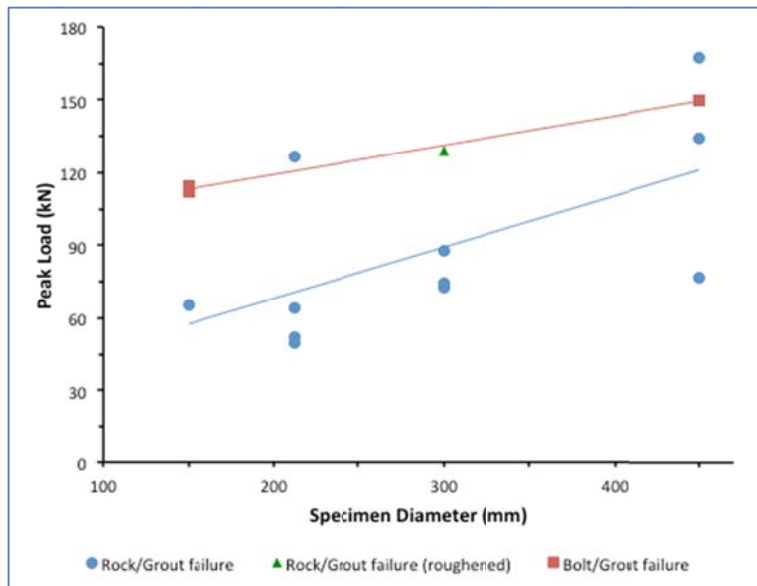


Figure 2: Variation in peak load with composite medium diameter (Holden and Hagan, 2014)

The approach used for cable bolt embedment and test sample confinement has also changed. In tests such as the double embedment tests, the cable bolt is grouted in a small bore steel tube. Confinement within the tube creates a constant stiffness-testing environment that inhibits any dilation effect otherwise induced by the cable bolt when under load due to load transfer. As Thomas (2012) noted, this arrangement does not allow assessment of the rock to grout interface. In the LSEPT test method, the cable bolt is grouted within a sample of rock that itself is confined within a biaxial cell pressurized to

10 MPa. The use of a biaxial cell creates a constant stress environment that “is not necessarily a true and consistent reflection of the underground environment in that (1) very little is known in regard to the *in situ* magnitude of borehole closure in underground coal mines and (2) it is almost certainly a dynamic variable that will vary both along the length of the cable and during the ‘life’ of the cable” (Thomas, 2012). To overcome this issue, the LSEPT was modified in the test program of Thomas with the sample instead grouted in a thick-walled steel cylinder.

METHODOLOGY

In line with the developments in testing methodology, the work of Holden and Hagan (2014) was repeated, but in this case instead of the test sample being unconfined, the samples were confined within a steel cylinder for each sample diameter. To ensure a more consistent mode of failure, the borehole in which the cable bolt was grouted was rifled to provide better and more consistent bonding between the grout and test sample.

Sample preparation

For testing, the test samples were made from a cement-based material cast in moulds ranging in diameter from 150 mm to 500 mm with an overall length of 320 mm and borehole diameter of 42 mm. An indented Sumo strand cable bolt, manufactured by Jenmar Australia, was selected as it is a high load transfer capacity cable bolt commonly used in the underground coal mining industry. Figure 3 shows the bulb design Sumo strand cable bolt as used in the tests.



Figure 3: Sumo strand cable bolt

The Sumo stand cable bolt was chosen as it represents the worst-case scenario in terms of the high loads generated and hence high stresses induced within the test sample as a result of load transfer. Hence the findings would be equally applicable to lower capacity cable bolts. Preparation involved the following:

1. Preparing moulds (including a rifling mould) and pouring of mortar to create test samples;
2. Initial curing for 24 hr at which time the rifling mould and the casting mould were removed and the test sample allowed to cure for the remainder of the 28 day period under fully saturated conditions; and
3. Grouting a cable bolt into the test sample using a polyester resin.

The test samples were cast in moulds made from thick walled cardboard cylinders with a height of 320 mm and diameters ranging between 150 mm and 350 mm. The cardboard moulds were glued to the base of a wooden board as shown in Figure 4a using industrial silicone to ensure the moulds retained its round shape and prevented any leakage during the cement pouring stage.

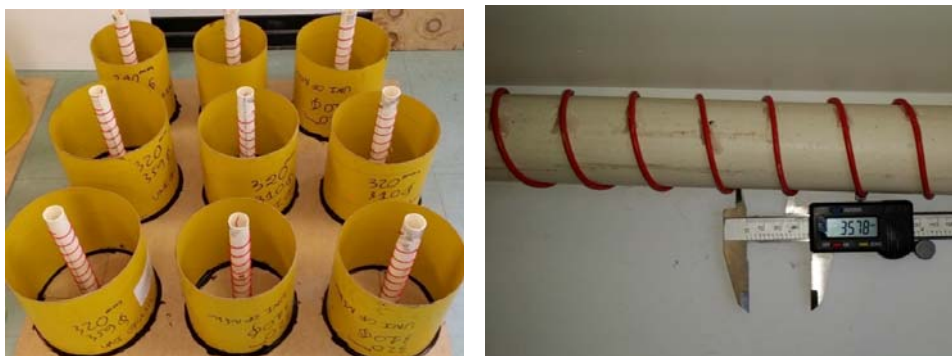


Figure 4: a) Prepared moulds prior to pouring of cement (left) and b) PVC tube used to create borehole with rifling effect (right)

The manufactured rifled boreholes were prepared from a hollow PVC tube around which were wrapped 3 mm electrical wire at a pitch of 36 mm as shown in Figure 4b. The purpose of the wire was to create the rifling effect in the borehole wall that would better promote interlock with the infill resin simulating the load transfer mechanism between resin and rock.

The cement based product used to prepare the sample had an ultimate compressive strength of 32 MPa. Once the silicone dried and set, cement was poured into the moulds as shown in Figure 5. A mechanical vibrator was used to remove air bubbles in the cement during the mixing stage.



Figure 5: Post the pouring of cement into the casting moulds

Within 24 hours of pouring the mortar, both the middle PVC tube and the outer cardboard mould were removed leaving a test sample with the rifled borehole as shown in Figure 6: .



Figure 6: Test sample (left) with rifling borehole (right)

After removing the outer cardboard casting mould and the rifling PVC tube, the samples were left to cure fully submerged for 28 days in either a large holding tub or plastic bags as shown in Figure 7.



Figure 7: Test samples fully submerged in water for curing

After curing of the rock cylinder samples, a cable bolt was grouted into each rock cylinder using a slow set resin with a setting time of 20 to 25 min. The resin and oil based catalyst were mixed for 13 min. An electric mixer was employed to combine the two components to ensure a thorough and even distribution of catalyst throughout the resin, which is imperative in achieving the ultimate strength of the cured resin. The mixed resin was poured into the boreholes to a height 50 mm below the collar of the borehole. This allowed room for displacement of the resin after the cable bolt was installed into the borehole. Excess resin was removed from around the rim of the borehole. The resin was left to cure for a day before it was used for testing. An example of the cured resin with cable bolt and rock is shown in Figure 8.



Figure 8: Cable bolt embedded in test sample using a slow set resin

Test arrangement

The setup arrangement for the tests is illustrated in Figure 9. The cable bolt was grouted in the test sample shown in the lower section of Figure 9 and load applied to the cable bolt using hollow hydraulic cylinder acting against a steel plate located on the top surface of the test sample. The level of applied load was measured using a pressure transducer and load cell and, the displacement was measured using a Linear Variable Differential Transformer (LVDT).

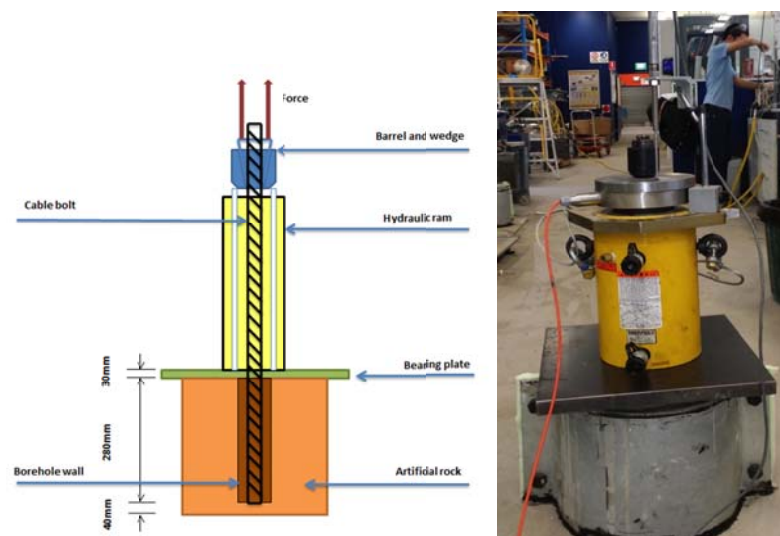


Figure 9: a) Test arrangement (not to scale) (left) and b) fully assembled test arrangement (right)

Prior to each test, the test sample was placed within a split steel cylinder as shown in Figure 10 and the narrow gap or annulus between the sample and cylinder backfilled with cement. A 15 mm gap was left

between the faceplates that were bolted together to join the two halves of the steel cylinder. This gap was filled with foam to prevent spillage of cement during backfilling. To ensure a consistent level of contact between the test sample, cement and steel cylinder that might otherwise alter the maximum pullout load, pre-confinement was applied to the steel cylinder and test sample by tensioning the bolts with a micrometre torque wrench.



Figure 10: a) Test sample placed in assembled steel cylinder (left) and b) gap filled with foam and bolts on side of cylinder that were tensioned before a test (right)

Test variables

Tests were undertaken to determine the size effect of the test sample on pull-out load under:

- unconfined conditions;
- confined conditions with zero torque;
- confined conditions with 40 N□m; and
- confined conditions with 80 N□m.

RESULTS AND ANALYSIS

Unconfined conditions

The peak load carrying capacities of each size of test sample in the unconfined state is plotted in Figure 11. Three test replications were undertaken at each level of sample diameter.

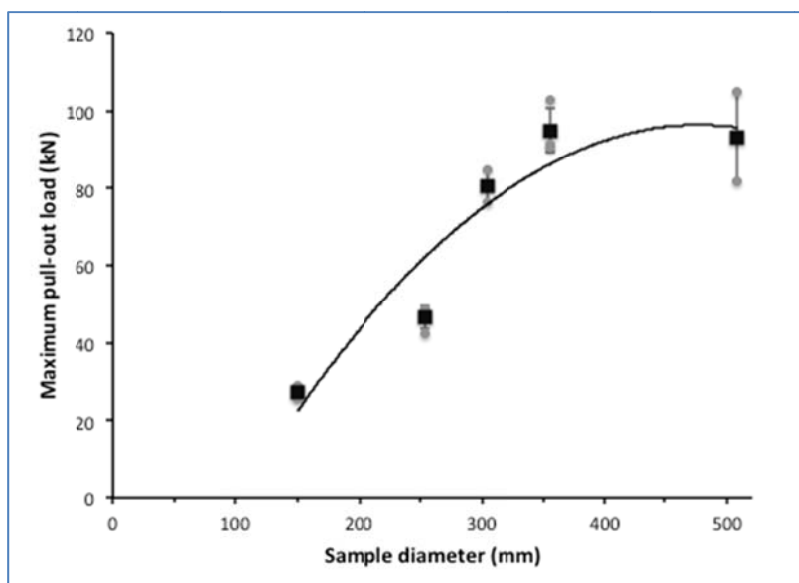


Figure 11: Variation in maximum pullout load with test sample diameter in the unconfined state

There was a near three-fold variation in maximum pull-out load from approximately 30 kN with the smallest size of sample up to over 100 kN achieved in the largest of test samples. This reaffirms the earlier findings by Rajaie (1990) and Holden and Hagan (2014) of the sensitivity of changes in pull-out being dependent on sample size in any laboratory determination of cable bolt performance.

The maximum pull-out load increased with size of the test sample until some threshold value was reached beyond which there was no further increase in load. This is in line with the observation made that in the unconfined condition, the smaller size samples tended to dilate creating two or often three fracture planes as shown in Figure 12. The larger test samples generally remained intact after testing. The general trend is similar to that reported by Rajaie (1990) except the threshold value of sample diameter was in this case in the order of 400 mm, much larger than the diameter of 250 mm as recommended by Rajaie.



Figure 12: Typical failure mode of test samples with two or three fractures

Confined with zero torque

In this series, the test samples were all placed in a steel cylinder that was intended to provide confinement to the sample similar to that experienced by a rock mass surrounding a cable bolt *in situ*. The maximum pull-out load in this confined condition of the test samples is plotted in Figure 13. In this case no torque was applied to the bolts joining the two halves of the steel cylinder.

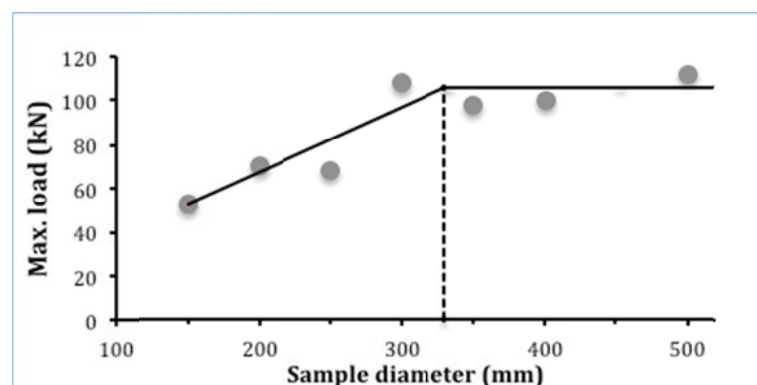


Figure 13: Variation in maximum load with test sample diameter with sample contained in steel cylinder

Similar to the unconfined tests, the maximum pull-out load was sensitive to changes in sample diameter. The main effect of confinement was that it reduced the threshold size above which there was little change in load. In this case the threshold diameter was found to be in the order of 330 mm, down from the 400 mm observed in the unconfined tests.

Confinement with a bolt torque of 40 Nm

In this series, the samples were again placed in a steel cylinder, but in this case the joining bolts were tightened with a torque wrench to a torque level of 40 Nm are shown in Figure 14. A similar result was achieved with a reduction in the threshold diameter with confinement in the steel cylinder.

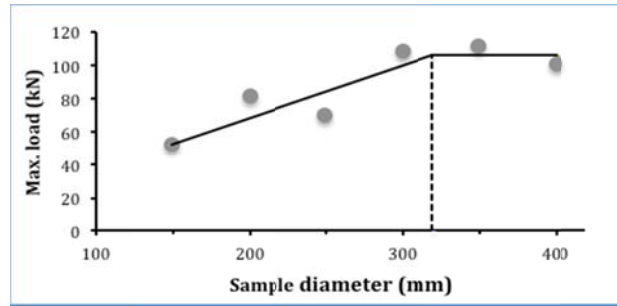


Figure 14: Variation in maximum load with test sample diameter at a bolt torque of 40 Nm

Confinement with a bolt torque of 80 Nm

The variation in load with sample diameter in the case of tightening the joining bolts to a torque level of 80 Nm is shown in Figure 15. A doubling in the level of bolt torque of the bolt did not appear to have any significant effect in reducing the threshold diameter.

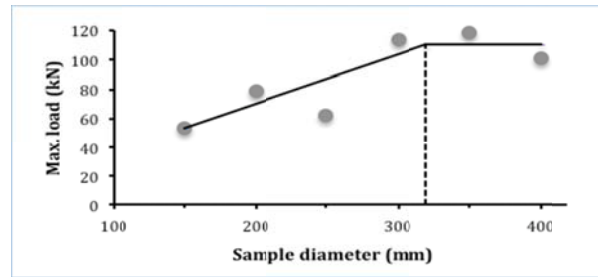


Figure 15: Variation in maximum load with test sample diameter at a bolt torque of 80 Nm

Further analysis

The results from the unconfined test combined with the three different scenarios of confinement are plotted in Figure 16. The graph shows a definite upward shift in the maximum pull-out load attained with the confined test samples especially for test samples with diameters less than 300 mm. The difference, however, reduces as the diameter approaches 400 mm. Interestingly, the pull-out load is insensitive to the level of confinement, at least over the range of confinements investigated in this test program in terms of both the maximum pull-out load of approximately 100 kN and threshold sample diameter of 300-330 mm as there is very little apparent difference.

Overall it can be concluded that consistent pull-out test results can be obtained with a test sample that is in the confined condition with a diameter of at least 300mm. Moreover while the maximum pullout load varies little with the amount of confinement, a tangible amount of confinement provided by tightening the joining bolts to the same low level of torque of 40 Nm will provide a standardized testing environment and hence is more likely to provide more consistent results.

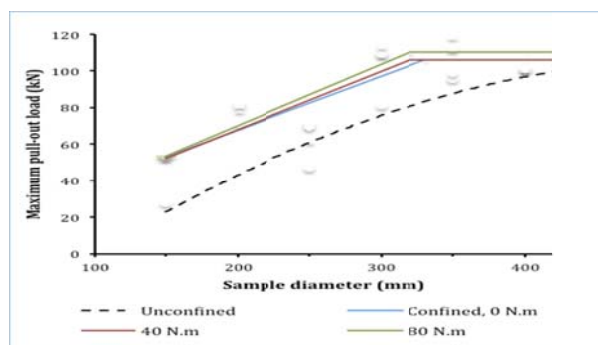


Figure 16: Comparison of the effect of varying levels of confinement on the maximum pull-out load for different sample diameters.

CONCLUSIONS

The results obtained from performance testing a high capacity modified bulb Sumo cable bolt embedded in test samples in an unconfined state found a similar trend to that reported by Rajaie (1990) in that there is an increase in the maximum pull-out load with diameter of the test sample up to some limiting or threshold diameter. Beyond this threshold diameter there is little change in the load of the cable bolt. Rajaie stated the threshold to be around 200 mm in tests that used a low capacity plain strand cable bolt, whereas with the high capacity cable bolt used in this project the threshold is nearly double at 400 mm. Confinement of the test sample by placing it in a rigid steel cylinder was found to reduce this threshold diameter to around 300 mm. Interestingly, over the range of confinement levels studied, the performance of the cable bolt was essentially insensitive to the actual level of confinement. In order to provide a standardised testing environment for the range of cable bolts now available it is recommended that the test sample in which the cable bolt is embedded is placed within a split steel cylinder of at least 300 mm diameter and the bolts that join the two halves of the cylinder be tightened to a torque of 40 Nm to ensure a consistent level of confinement.

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