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Prabhdeep Singh Bajwa
University of New South Wales

Paul Hagan

Danqi Li

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A COMPARISON BETWEEN RESIN AND A CEMENTITIOUS MATERIAL IN THE GROUTING OF CABLE BOLTS

Prabhdeep Singh Bajwa[1], Paul Hagan and Danqi Li

ABSTRACT: The mining and civil underground construction industries have increasingly become reliant over recent decades on the use of grouted cable bolts for ground support especially in difficult ground conditions. Despite this there are still some key areas of cable bolt performance that are poorly understood. This paper details an investigation that compared the anchorage performance of a plain strand cable bolt that was grouted in a confining medium using in one case a resin grout and in a second case a cementitious grout. The impact of borehole diameter on the performance of the two grout types was also studied. The investigation involved a series of twenty pull-out tests with a plain strand bolt using the UNSW modified Laboratory Short Encapsulation Pull-out Test. In tests with the standard borehole diameter of 27 mm, it was found that the resin grout exhibited a lower average peak load carrying capacity than the cementitious grout. By contrast, with the larger diameter of 37 mm, the resin grout outperformed the cementitious grout in terms of average peak load carrying capacity. With a cementitious grout, an increase in borehole diameter size from 27 mm to 37 mm decreased the average peak load while the load doubled when using the resin.

INTRODUCTION

Cable bolts have been used extensively in the civil and mining industry since the 1960's to support ground excavations. A geotechnical engineer must select from cable bolts of differing length, shape, diameter, strand-configuration, strand surfaces and structural modifications including bulbs, bird-cages, etc. The performance of a cable bolt can alter significantly with these design variations. An engineer must also take into account factors including borehole diameter, embedment length and the type and strength of grout used, etc. which also contribute to the performance of the cable bolt.

The function of cable bolts has been defined as active excavation reinforcement through the use and conservation of the "inherent strength of the rock mass surrounding the excavation" (Villaescusa, Windsor and Thompson, 1999).

Failures of a cable bolt in axial loading can be divided into four categories as illustrated in Figure 1. The first type of failure is failure of the cable-grout interface. The mechanical interlock between the grout and bolt depends largely upon the surface roughness of the bolt. This type of failure is the most common type of failure observed in-situ and during pull out tests (Rajaie, 1990; Hutchinson and Diederichs, 1996; Hyett *et al*, 1995; Hyett, Moosavi and Bawden, 1996; and, Singh *et al.*, 2001). The second type of failure is the material failure of the grout. This is governed by the strength of the grout. The third type of failure is caused by the failure of the mechanical interlock between the grout and face of the borehole wall. The fourth type of failure occurs when the rock mass immediate to the cable bolt is unable to support the load developed in the cable bolt.

As reported in Hagan, Chen and Saydam (2014), a variation of testing methodologies have since been developed. The latest axial testing methodology is referred to as the UNSW laboratory short encapsulation pull-test (LSEPT) developed by Hagan *et al* (2015) and overcomes a number of disadvantages of previous testing methodologies. Li (2016) has additionally incorporated shrink wrapping to approximately the bottom 90 mm of the cable bolts to ensure constant embedment length as the cable bolt is pulled out during testing.

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[1] *School of Mining Engineering, UNSW Australia, Sydney, Australia*

Hoek, Kaiser and Bawden (2000) reported on load-deformation results obtained by Li and Stillborg (1999) on steel rebar rockbolts comparing cement grout with resin grout. Li and Stillborg (1999) found both cement grouted and resin grouted steel rebar to have same maximum load and deformation at failure – 15 t and 1.5 mm respectively. The results are shown in Figure 2. This study offers early insights into possible failure styles of cable bolts in resin versus cementitious grout.

This also aims to identify and analyse the effect of borehole diameter on the performance of a cable bolt when using different types of grout. Thomas (2012) as well as Hagan *et al.* (2015) studied the impact of changes in borehole diameter and both concluded that an increase in borehole diameter increased the pull-out load capacity of modified cable bolts. Conversely, an increase in borehole diameter decreased maximum load carrying capacity of plain strand cable bolts in both studies. Thomas (2012) and Hagan *et al.* (2015) used cementitious grout.

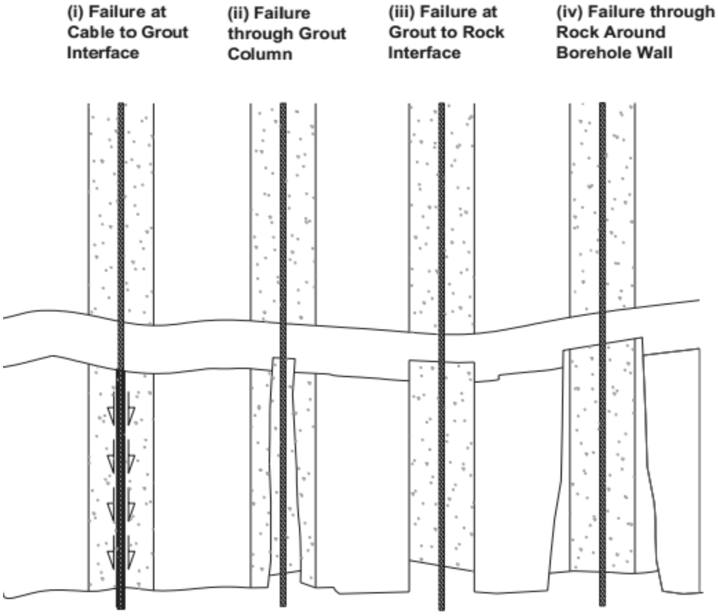

Figure 1: Four modes of cable bolt failure (Thomas, 2012)

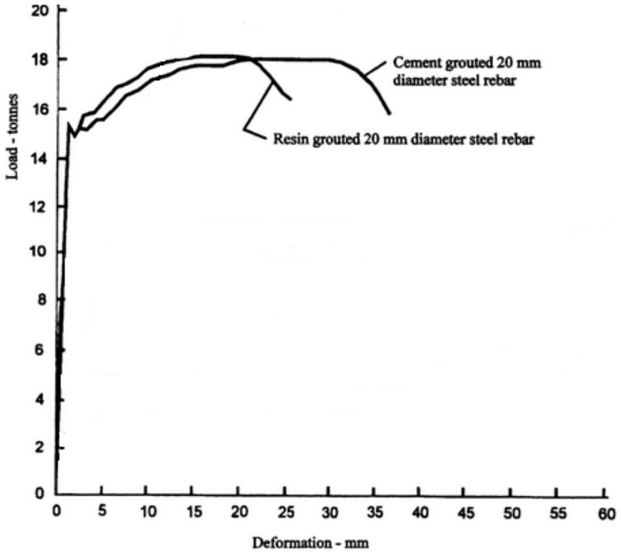

Figure 2: Load-deformation results by Li and Stillborg (1999) comparing resin *vs.* cement grouted steel rebar (Hoek, Kaiser and Bawden, 2000)

In contrast, Mosse-Robinson and Sharrock (2010) and Rajaie (1990) also studied the impact of borehole diameter in cable bolt performance. Their results found little impact on the peak load capacity of a cable due to borehole diameter. Hutchinson and Diederichs (1996) modelling also concludes that borehole diameter should have a negligible effect on cable bolt performance.

METHODOLOGY

To compare the performance of a plain strand cablebolt anchored with a cementitious grout and a resin grout in two size boreholes using the UNSW modified LSEPT after Hagan *et al.* (2015) was used. The addition by Li (2016) of utilising heat shrink wrap along the bottom of the cable bolt to maintain constant embedment length was also incorporated into the tests.

Sample preparation

A total of 20 samples were prepared for testing. The first task was to prepare the moulds for casting the confining medium in which the cablebolt is embedded. The effect of sample size was studied by Rajaie (1990) and more recently studied by Ur-Rahman (2014) and Zhai (2015). Rajaie (1990) reported that sample size diameter does not have an effect on maximum pull-out load beyond 200-250 mm while Ur-Rahman (2014) concluded the inflection point was 300-350 mm. Zhai (2015) found the effect of sample size to be negligible beyond 200 mm and 300 mm for Superstrand plain cable bolts and nutcaged MW9 cable bolts respectively. A 300 mm sample diameter was chosen after taking into consideration the above studies. To construct the exterior formwork for the mould a product called 'Spiral Tube' from Ezytube™ was used.

PVC pipes of length 500 mm with the same exterior diameter as the borehole sizes required, 27 mm and 37 mm, were prepared. These were then wrapped with 5 mm silicone tubing as shown in Figure 3. The silicone tubing would create the desired rifling effect on the borehole walls as seen in the field. The rifling effect is essential in achieving an adequate interlock between the grout and borehole walls. Figure 4 shows the PVC pipes and the moulds being affixed to the fibreboard using a high strength silicone adhesive.

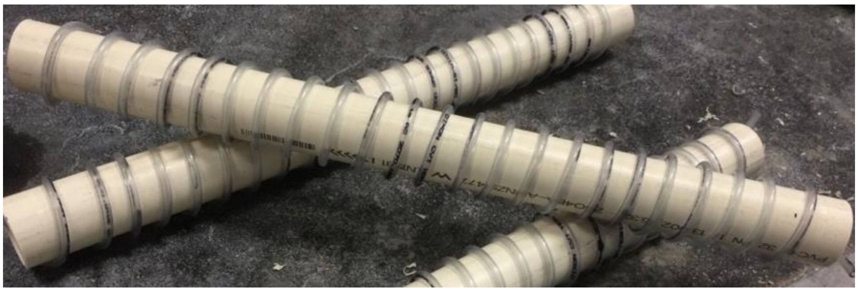

Figure 3: Silicone tubing wrapped around PVC pipe to create a consistent rifling effect in borehole

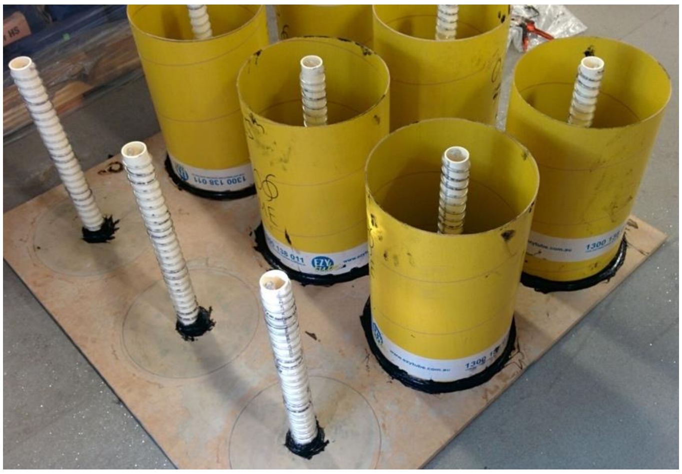

Figure 4: Completed moulds ready for casting

The next step in the preparation process was to cast the confining medium. The cement-based material that was to be used was special ordered with a strength of 10 MPa. Figure 5 shows the cement-based material being pumped into the prepared moulds and the moulds immediately after casting.

Figure 5: Cement-based material being pumped into moulds (left) and, samples immediately after casting (right)

Following this the cable bolts were prepared for grouting by applying the PVC heat shrink wrap to the bottom 90 mm of the cable bolt. The next step was to grout the cable bolts into the samples. The 10 cement grout samples were prepared using Minova Stratabinder HS at water to cement ratio of 0.45. The water to cement ratio was chosen to ensure the UCS of cement grout is the same as the UCS of resin grout as specified by the manufacturer of the resin grout. The resin grout used was 'XXSlow Resin Premix' by J-lok Resins Jennmar. It was prepared as per recommendations by the manufacturer. The catalyst to grout ratio was 93% XXSlow Resin Premix to 7% supplied oil catalyst. The prepared grout was then poured into the boreholes.

The next step was to affix the anchor tube. The steel anchor tube is a rigid terminating device that transfers the applied tensile load from the hydraulic ram to the cable bolt being tested. The anchor tube also forms part of the device that constrains the cable bolt against rotation during the test. The latter is achieved with a 4 mm deep and 70 mm long key slot, cut into the lower section of the anchor tube, as shown in Figure 6. The key of 8 mm thickness, also shown in Figure 6, is inserted between the anchor tube and the bearing plate and prevents rotation of the cable bolt during testing.

Figure 6: Machined anti-rotation key slot in the anchor tube (top) and, locking key (bottom)

To affix the 610 mm long anchor tubes to the cable bolt the anchor tube was filled with grout. The grout used was Minova Stratabinder HS with a water to cement ratio of 0.4. After grouting the anchor tubes the samples were cured for a minimum of 30 days.

Test setup

To confirm the strength of the confining medium, two types of UCS tests were conducted. Firstly, while the samples were being cast, 50 mm cubic grout samples were prepared and cured in identical fashion to the test samples and tested at the time of the pull-out tests. Additionally, after pull-out testing was completed the 50 mm core samples were drilled in the confining medium and tested.

The first step in setting up the test facility was to place the assembled cablebolt and anchor tube within a matched pair of half steel tubes. The tube is meant to provide confinement, reacting against any radial stresses generated in the confining medium as a result of the axial load applied to the cablebolt. The split tubes were placed around the in the confining medium with nuts and bolts used to secure the two halves hand tightened. The 10 mm annulus between the sample and split tubes was filled with grout made using 'General Purpose' (GP) cement at water to cement ratio of 0.5:1. The grout was left to cure for one day before testing.

On the following day and prior to a test, the securing bolts for the split-tube were tightened to a constant torque of 50 N·m. Figure 7 shows a test sample placed in the confinement split-tube have been placed and the bolts being tightened to the required level of torque.

Figure 7: Confinement split-tubes grouted around sample (left); and, confinement torque being applied (right).

The complete assembly was then placed in the testing facility consisting of a 100mm thick bearing plate to distribute the reactive load evenly across the surface of the confining medium; a hollow hydraulic cylinder placed over the anchor tube that provided the axial pull-out load; a load cell placed on top of the cylinder to directly measure the applied force of the hydraulic cylinder; and a reaction plate screwed to the top of the anchor tube to transfer the load from the cylinder to the anchor tube. Displacement of the cable bolt was measured using a Micropulse linear position sensor. The setup is illustrated in Figure 8. A hydraulic pump was used to power the hydraulic cylinder ensuring a constant displacement rate with full extraction of 100 mm cablebolt within approximately 15 mins.

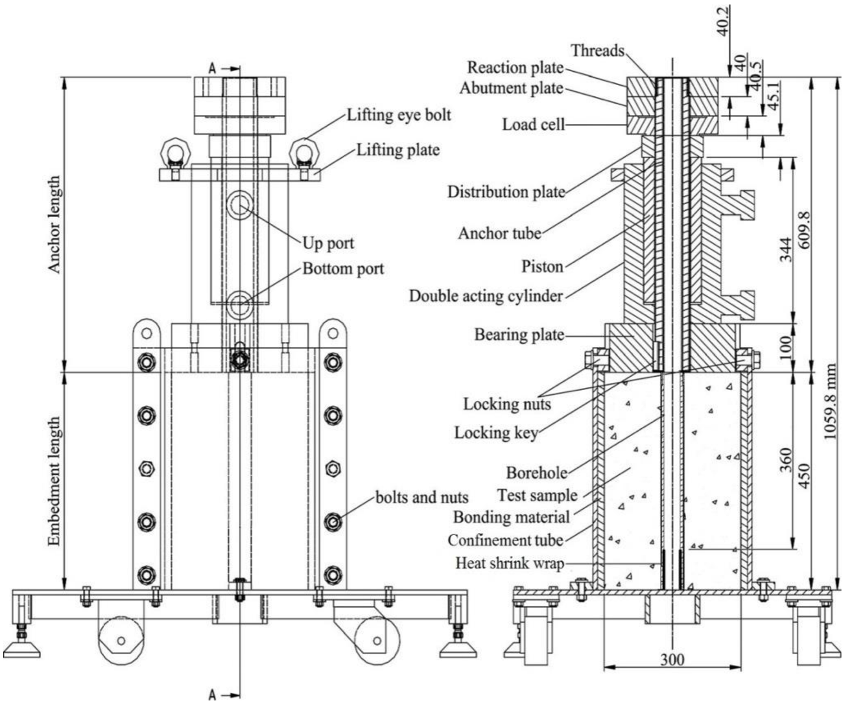

Figure 8: Illustration of testing facility (illustration adapted from Hagan, Chen and Saydam (2015))

RESULTS AND ANALYSIS

In total, 20 pull tests were conducted with a plain strand cablebolt; 10 test samples using a cementitious grout and 10 with a resin grout. In each case, half the test samples had a borehole diameter of 27 mm while the remaining half had a borehole diameter of 37 mm. In all cases, the failure mode was at the bolt/grout interface.

Strength tests conducted on the confining medium found the average UCS measured of three diamond cored specimens was 10.9 MPa while that of the three cast 50 mm cubic specimens was 8.4 MPa. This strength level was intended to be representative of a weak rock type such as coal.

COMPARISON OF CEMENTITIOUS AND RESIN GROUTS

27 mm borehole diameter

The objective of this investigation was to identify and analyse the difference in performance of the cable bolt when using two different grouting materials, namely resin and cementitious grout in samples having a 27 mm diameter boreholes, this being the supplier’s recommended borehole diameter for the cablebolt. Figure 9 shows the results for the cementitious grout and the resin grout with the best three results highlighted in a darker shade. The red curve in each case represents the generalised shape of the performance curve.

Comparing the graphs it is clear that cementitious grout system achieved a significantly higher ultimate peak load. As Table 1 indicates the average peak load for the cementitious grout was on average 40% greater than the resin grout. Both grout types achieved full load resistance over a comparatively short displacement of around 5 mm though the stiffness of the cementitious grout system was nearly 23% greater than the resin grout.

Also, the shape of residual loading curve is unique to each grout material. The load of the cementitious grout continued to increase with displacement over the range of constant embedment length of 90 mm whereas the load remained largely unchanged over the same range of displacement.

The average residual load after 90 mm displacement with the cementitious grout was 47% larger. Interestingly there was more variability in the performance with the resin grout as indicated by higher values for coefficient of variation, conversely the cementitious grout produced more consistent results.

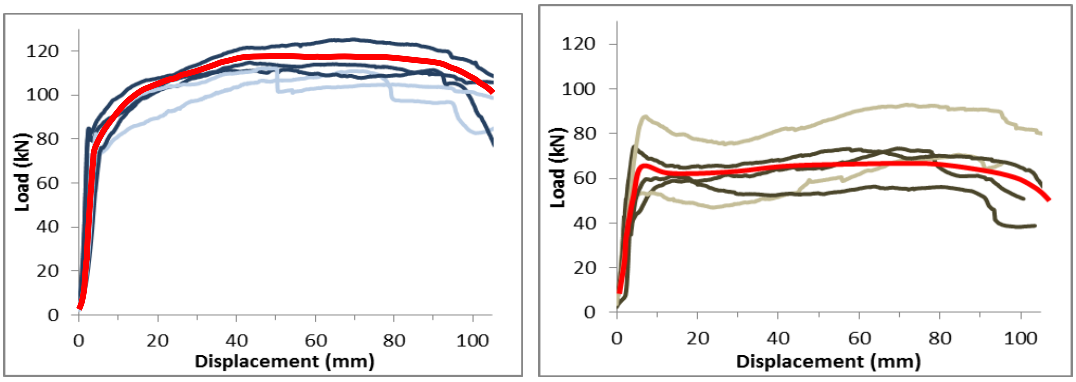

Figure 9: Pullout performance in a 27mm borehole with the cementitious grout (left) and resin grout (right)

Table 1: Analysis of the anchorage performance characteristics for the 27mm diameter borehole

Statistical Parameter	Peak Load (kN)				Load @ 90 mm (kN)				Initial Stiffness (kN/mm)		
	Cement	Resin	diff.		Cement	Resin	diff.		Cement	Resin	diff.
average	117	70	-40%		114	61	-47%		43	33	-23%
maximum	125	74	-40%		121	69	-43%		58	38	-34%
minimum	112	61	-46%		110	53	-52%		22	29	+31%
Coefficient of Variation	5%	9%	-		4%	11%	-		36%	11%	-

37 mm borehole diameter

A second set of tests were conducted with a 10 mm larger borehole diameter to examine the sensitivity of diameter on anchorage performance. Figure 10 shows the results for the 37mm cementitious grouted and resin grouted samples.

In this case the performance is reversed with the ultimate peak load for the resin grout sample being much higher. Again, the characteristic shape is unique to each grouting material with the load bearing capacity for the cementitious grout again increasing with displacement up to around 60 mm.

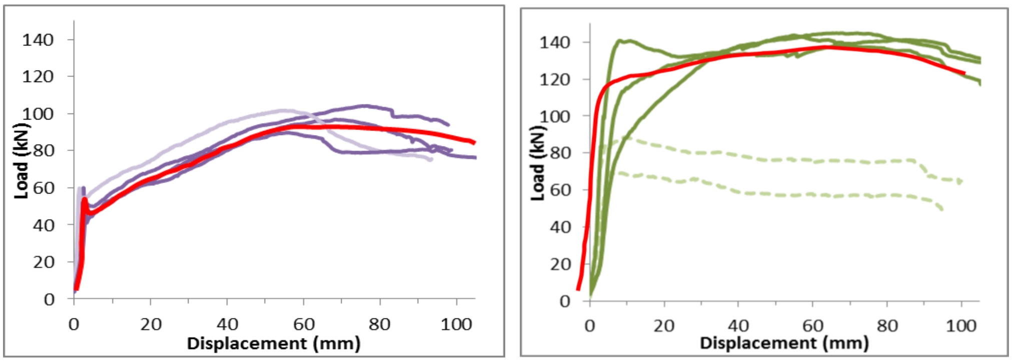

Figure 10: Pullout performance in a 37 mm borehole with the cementitious grout (left) and resin grout (right)

Table 2 shows the average ultimate peak load with the larger borehole was 43% higher with the resin grouted sample. Also the residual load at 90mm was 53% higher with the resin grout. It should be noted that the results tended to be less consistent with the resin grout as is evident by the graph in Figure 10 that shows the results for tests were much less than the other three and on par with the results achieved with the cementitious grout. Alternatively, this indicates more consistent results might be achieved when using cementitious grout though this would need to be confirmed with a larger number of test replications.

In terms of stiffness, there was little difference between the two types of grout material, being of the same order as the stiffness measured in the 27 mm with the resin grout.

Table 2: Analysis of the anchorage performance characteristics for the 37mm diameter borehole

Statistical Parameter	Peak Load (kN)			Load @ 90 mm (kN)			Initial Stiffness (kN/mm)		
	Cement	Resin	diff.	Cement	Resin	diff.	Cement	Resin	diff.
average	97	143	+47%	88.3	137.3	+55%	32	31	-3%
maximum	104	145	+39%	98.5	140.9	+43%	51	43	-16%
minimum	90	141	+57%	80.5	132.3	+64%	23	20	-13%
Coefficient of Variation	6%	1%	-	9%	3%	-	40%	30%	-

EFFECT OF BOREHOLE DIAMETER

Cementitious grouted samples

Comparing the effect of borehole diameter on anchorage performance when using a cementitious grout, it can be seen that performance is degraded as shown in Figure 11.

The two graphs show that increasing the borehole diameter reduced both the initial peak load peak and the ultimate peak load. This is accordance with the results obtained by Thomas (2012) and Hagan *et al*. (2015). It can also be seen that the initial load peak is more prominent in the 37 mm results. The shape of the residual loading also changes. The 27 mm samples reached 90% of their maximum peak load after approximately 40 mm of displacement while in the 37 mm samples, the ultimate load was achieved after around 60-70 mm displacement. In-field this would result in a larger roof displacement if a plain strand cablebolt were installed in a larger 37 mm diameter borehole.

Table 3 summarise the effect of changing borehole diameter on cementitious grouted samples. The average ultimate peak load decreased by 17% and the average initial stiffness decreased by 26% with an increase in borehole diameter. The load at displacement of 90 mm was decreased by 22%.

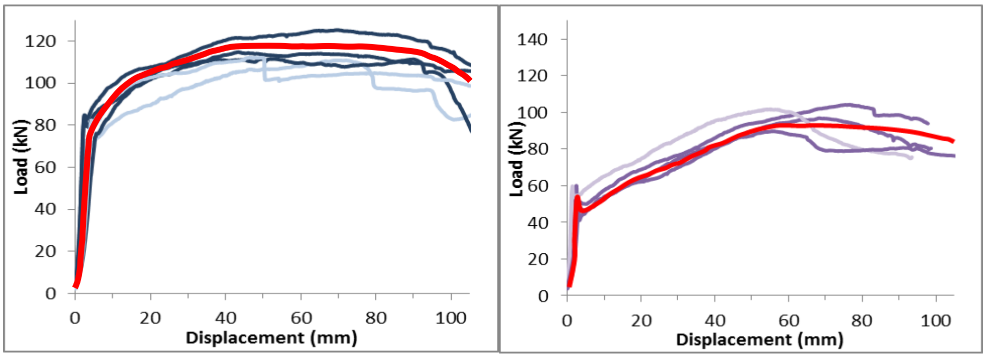

Figure 11: Performance with the cementitious grout in a 27mm borehole (left) and 37 mmborehole (right)

Table 3: Analysis of the anchorage performance characteristics with the cementitious grout

Statistical Parameter	Peak Load (kN)			Load @ 90 mm (kN)			Initial Stiffness (kN/mm)		
	27 mm	37 mm	diff.	27 mm	37 mm	diff.	27 mm	37 mm	diff.
average	117	97	-17%	114	88	-22%	43	32	-26%
maximum	125	104	-17%	121	99	-19%	58	51	-12%
minimum	112	90	-20%	110	81	-26%	22	23	+5%
Coefficient of Variation	5%	6%	-	4%	9%	-	36%	40%	-

Resin grouted samples

Figure 12 shows the performance graphs when using resin grout in samples with borehole diameters of 27 mm and 37 mm. In contrast to the cementitious grouted samples, increasing the borehole size significantly increased the load carrying capacity of the cable bolt. The initial peak load and the ultimate peak load capacity. However unlike the cementitious grout, the change in borehole diameter did not affect the residual loading behaviour of the cablebolt.

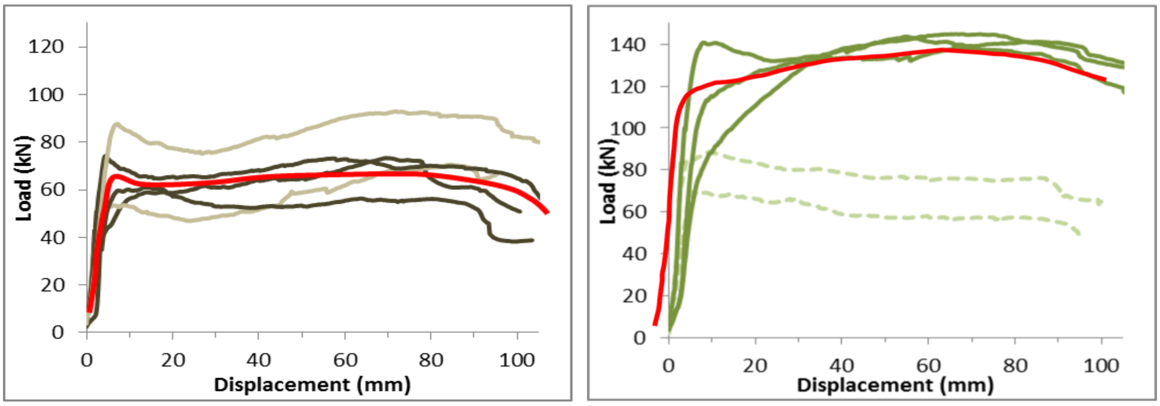

Figure 12: Performance with the resin grout in a 27mm borehole (left) and 37 mm borehole (right)

Table 4: Analysis of the anchorage performance characteristics with the resin grout

Statistical Parameter	Peak Load (kN)			Load @ 90 mm (kN)			Initial Stiffness (kN/mm)		
	27 mm	37 mm	diff.	27 mm	37 mm	diff.	27 mm	37 mm	diff.
average	70	143	+104%	60.8	137.3	+125%	33	31	-6%
maximum	74	145	+96%	69.0	140.9	+104%	38	43	+13%
minimum	61	141	+131%	52.5	132.3	+152%	29	20	-31%
Coefficient of Variation	9%	1%	-	11%	3%	-	11%	30%	-

Table 4 summarises results for the 27 mm and 37 mm resin grouted samples. Comparing the two borehole diameters it was found that the 37 mm oversized borehole diameter increased the average initial peak load capacity by 104%. Also, the average ultimate load, at displacement of 90 mm, was increased by 125% in the oversized borehole. There was little change in the initial stiffness though of the resin grout system with borehole diameter.

CONCLUSION

The objective of this study was to determine what influence, if any, the type of grout material had on the load bearing characteristics of a plain strand cablebolt and further whether this was influenced by a change in borehole diameter.

In total, the project entailed a multi-factorial study involving four variables, namely a cementitious and a resin grout and, embedment in the recommended standard borehole diameter of 27 mm and oversized borehole of 37 mm. Each arrangement was replicated five times. The confining medium in which the cablebolt was anchored was prepared in one batch from a cement-based material having a measured compressive strength of 10.9 MPa that is equivalent to a low strength rock such as coal.

In the 27 mm borehole diameter samples, the cementitious grouted samples achieved a 40% higher average initial peak pullout load and a 47% higher ultimate peak pullout load after 90 mm displacement than the resin grouted samples. By contrast, the situation was reversed in the larger borehole with the resin grout having a higher initial peak load and ultimate peak load at 90 mm of 47% and 55% respectively.

Overall in terms of load bearing capacity, the optimum performance was by far achieved with the resin grout in the oversized borehole with average initial peak load and ultimate peak load at 90 mm of 143 kN and 137 kN compared to 117 kN and 114 kN with the cementitious grout in the standard borehole. The results appeared to be less consistent when using the resin grout.

In both cases when using the cementitious grout, the pullout load tended to increase gradually with displacement beyond the initial peak load that was achieved in most cases after nearly 5 mm. In all cases with the resin grout, the pullout load remained relatively constant over the constant embedment length of 90 mm.

Considering stiffness, there was little difference between the different combinations of anchorage systems except in the case of the cementitious grout in the standard diameter borehole which was approximately one third greater than the other combinations.

In all cases, failure was observed to occur at the cable/grout interface. This was largely due to the plain strand cable bolt offering minimum amount of friction between the grout and cable bolt compared to what can be achieved when using a modified cablebolt.

The results offer the industry a more accurate decision making opportunities regarding grout use, leading to enhanced safety and productivity. This project will also contribute towards ACARP led effort to standardise the laboratory pull-out test procedure.

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