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COMPARISON OF THE PERFORMANCE OF RESIN AND CEMENTITIOUS GROUTING MEDIA FOR CABLE BOLTS

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ABSTRACT: Cable bolting systems are an integral part of ground support designed to improve the stability of underground excavations. As geotechnical conditions vary, each component in the cable bolt system must be optimized to maximise the efficiency of the system. This study examined the performance of cable bolts with two different types of grouting agent – a standard cementitious material and a resin-based grout; in two strengths of confining material; and, in two different borehole diameters. Performance was quantified in terms of peak load, residual load and stiffness. The UNSW modified Laboratory Short Encapsulation Pull-out Test (LSEPT) facility was employed where an axial load was applied to a high capacity modified cable bolt. Results of the study indicated significant differences in the performance of the cable bolt between being grouted in strong and weak materials with the former resulting in the highest average peak loads of 406 kN and 397 kN respectively for the cement and resin grouts respectively indicating both grouts were just as effective in load transfer. The average peak load in the weak material was about 24% less at around 315 kN and in one case 207 kN with cement grout in the standard borehole diameter. In general, peak load was slightly higher when grouted in the standard borehole diameter in strong material but this trend was reversed in the weak material. Interestingly in terms of residual load, or the load bearing capacity after 90 mm displacement, the reduction from the peak load was much less at just 35% in the weak material to 203 kN whereas the reduction in the strong material was 63% to 145 kN. Little difference was observed in the stiffness between all test scenarios.

INTRODUCTION

Ground support is an essential element in ensuring the stability of underground excavations. Cable bolts are one example of ground support developed originally during the 1940's in North America that began to be used in Australia during the 1960's (Bouteldja, 2000). Despite extensive research being undertaken on the effectiveness of cable bolt systems, most recently by Chen, Hagan and Saydam (2016) roof failures still continue. For example, Mark, Molinda and Doliner (2001) reported that each year in the U.S.A., some 1,500 reportable non-injury roof falls occur.

This paper aims to improve understanding of the performance of cable bolts in different conditions. The testing program was undertaken using the UNSW modified Laboratory Short Encapsulation Pull Test (LSEPT) facility which applies an axial load to the cable bolt with the aim of determining the effect of changes in grout material, borehole diameter and strength of rock on the peak load, residual load and initial stiffness of a cable bolting system.

This was achieved by comparing the performance of a high capacity modified cable bolt grouted into a confining material using a Jennmar 'standard single speed' oil-based resin and a Minova 'Stratabinder HS' cementitious grout. A Megabolt MW9 spiral wire cable bolt was grouted in weak and strong confining media having UCS values of approximately 15 and 50 MPa respectively and, in standard (42 mm) and oversized (52 mm) diameter boreholes.

TEST PROCEDURE

The UNSW modified LSEPT facility is based on the British Standard BS7861-2:2009 that has been modified to overcome deficiencies when testing high capacity modified bulbed cable bolts on the market and used in the Australian underground coal industry. In the modified test, a cable bolt is embedded in a confining medium with an external diameter and length of 300 mm and 450 mm respectively, these being nearly twice the dimensions specified in the

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BS test design. Earlier work by Chen, Hagan and Saydam (2017) found the pull-out load of a high capacity modified cable bolt varied with the diameter of the confining medium in which the cable bolt is embedded up to 300 mm beyond which there was little further change in pull-out load as shown in Figure 1.

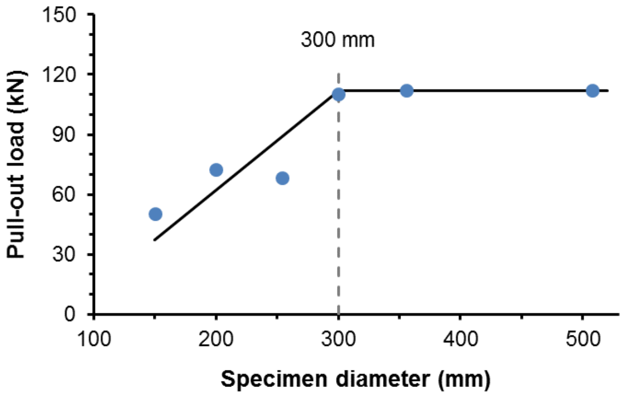

Figure 1: The effect of sample diameter on peak load of a cable bolt (Ur-Rahman and Hagan, 2015).

The test program consisted of eight different combinations of strength of confining medium (weak and strong); grout type (resin and cement); and, borehole diameter (standard and oversized) as detailed in Table 1. The program allowed for each combination of test parameters to be replicated five times and, as per the British Standard, the three best results have been reported.

Table 1: Details of parameters in test program.

Confining medium	*Borehole diameter*	*Grout type*
Weak	Standard	Resin
(15.7 MPa)	(42 mm)	Cement
	Oversized	Resin
	(52 mm)	Cement
Strong	Standard	Resin
(49.2 MPa)	(42 mm)	Cement
	Oversized	Resin
	(52 mm)	Cement

The fully assembled test arrangement shown in Figure 2 comprised a cable bolt embedded in a cylindrical cement-based confining medium. A bearing plate was placed on top of the confining medium with a centre hole that allowed the cable bolt to extend up through a hollow hydraulic actuator and load cell with a barrel and wedge assembly attached to the end of the cable bolt. A hydraulic actuator was used to apply the load to the cable bolt with a pull-out displacement of 100 mm. The load cell and an LVDT were used to measure the applied load and the resultant displacement of the cable bolt. The confining medium was placed within a split-steel cylinder which was bolted together and the bolts pre-tensioned to 40 N·m prior to testing. Changes in the anchorage performance of the cable bolt were assessed in terms of the average peak load attained during pull-out, the initial stiffness of the cable bolt up to the point of peak load and the residual post-peak load that could be sustained by the cable bolt after 90 mm displacement.

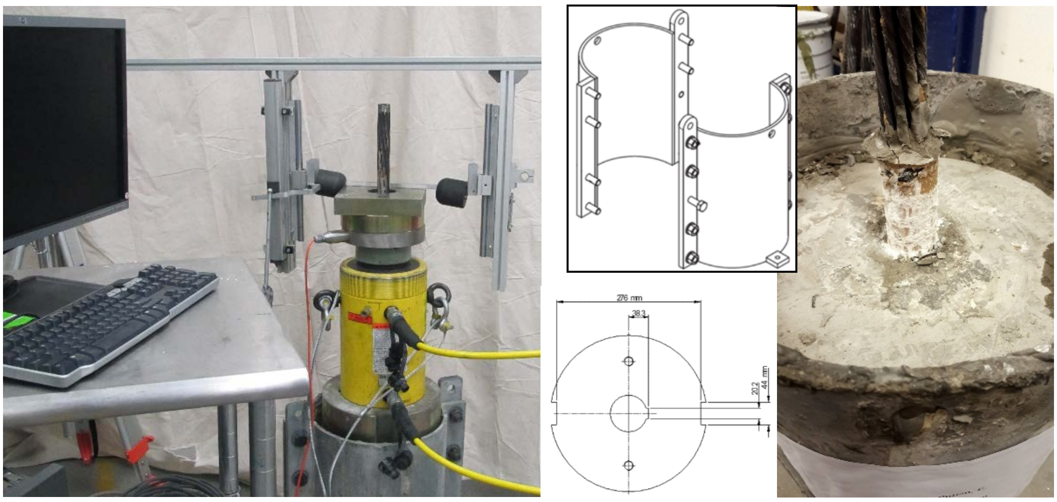

Figure 2: The assembled modified LSEPT testing facility and measurement instrumentation (left); split-steel confining cylinder (upper centre); bearing plate (lower centre); and, confining medium showing 100 mm of extruded cable bolt after completion of a test (right).

STRENGTH OF TEST MATERIALS

Strength tests were undertaken of the two batches of confining medium used in the program; oil and water-based resin products; and, five mixes of Stratabinder, the cement-based material used as the cement grout, at varying water to cement ratios. The results of the strength tests are shown in Figure 3.

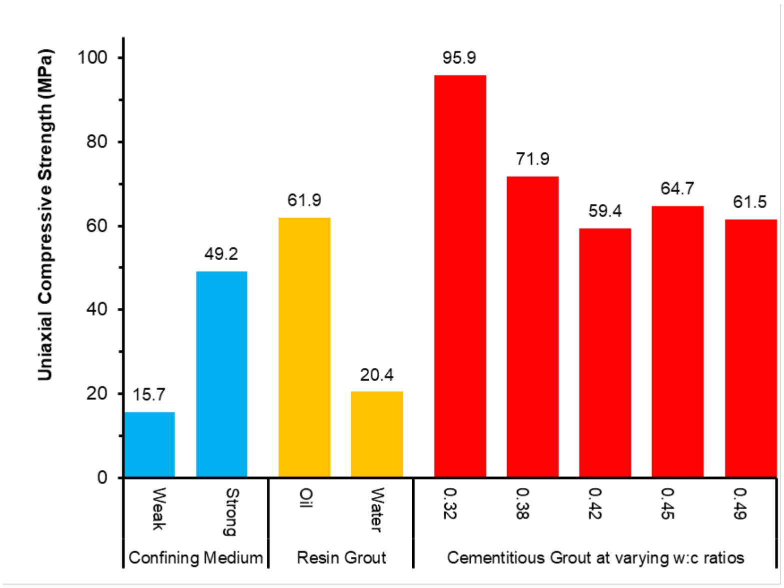

Figure 3: Results of strength tests on confining media, resin grout and cement grout.

The strength tests showed there was a three-fold difference in strength between the weak and strong confining media (15.7 *vs.* 49.2 MPa respectively) and, a three-fold difference between the water-based resin and oil-based resin (20.4 *vs.* 61.9 MPa). As it was found that the water-based resin had a very low strength, only the oil-based material was used as the resin grout material. A water to cement ratio of 0.49:1 was used for the cement grout being equivalent to the strength of the oil-based resin.

LOAD TRANSFER BEHAVIOUR IN A WEAK CONFINING MEDIUM

Standard borehole diameter

As indicated in Figure 4, there was on the whole consistent repeatable performance observed with the resin grout used to embed the cable bolt in the standard manufacturer's recommended borehole diameter of 42 mm and in the 15.7 MPa weak confining medium both with regard to the peak pull-out load and residual load. With respect to the resin grout, the peak load varied between 279 and 333 kN, with an average value of 306 kN. There was somewhat slightly more variability in the peak load with use of the cement grout varying between 165 and 265 kN with an average peak load of 207 kN. The corresponding displacement to peak load was similar for both grout types at between varied between 20 and 30 mm.

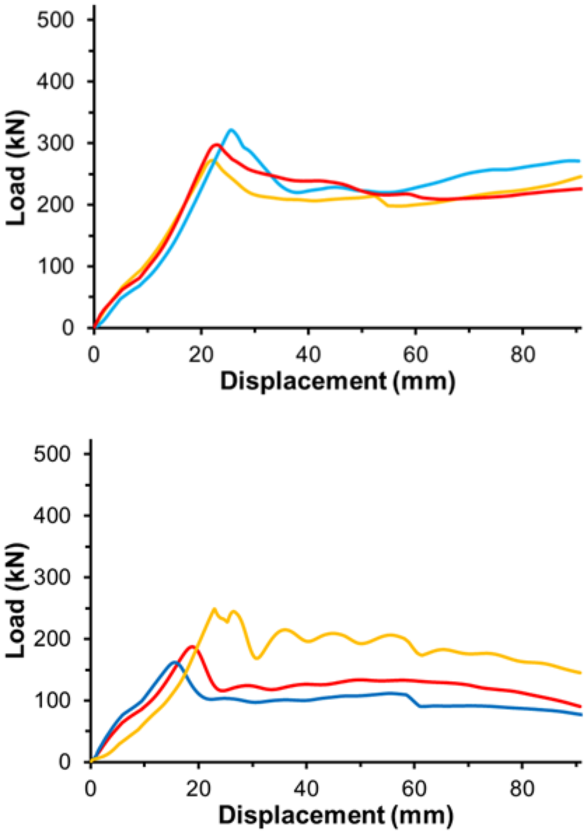

Figure 4: Load transfer behaviour of a cable bolt with resin grout (left) and cement grout (right) with a standard borehole diameter in a weak confining medium.

There was a marked difference in the behaviour between the two grout types in nearly all tests. In the case of the cement grout tests, there was very often a sudden reduction in the post-peak load bearing capacity approaching 60% in many instances. Also, the "slip-lock" phenomenon was observed in the post-peak region more often with the cement grout.

Table 2: Comparison of test results between resin and cement grout in weak confining medium.

				Residual strength at 90 mm	
Borehole diameter	***Grout type***	***Peak load (kN)***	***Stiffness (kN/mm)***	***(kN)***	***% peak load***
Standard	Resin	306	9.2	224	80%
(42 mm)	Cement	207	8.3	121	57%
	change	**48%**	**11%**	**85%**	**40%**
Oversized	Resin	364	15.2	257	70%
(52 mm)	Cement	358	9.9	138	38%
	change	**2%**	**54%**	**86%**	**84%**

Note: Residual load is defined as the load that can be sustained by a cable bolt after 90 mm displacement

As indicated in Table 2, there was much less of a reduction in the residual load with the resin grout compared to the cement grout indicating the former tended to maintain its integral shape whereas the cement grout was found to crumble offering less resistance as it was drawn through the confining medium. The stiffness was in the majority of test results of the same order for the resin and cement grout averaging 10.5 kN/mm. There was a marked difference observed in the failure pattern between the two grout types in the weak confining medium. As shown in Figure 5, failure with the resin grout tended to occur at the grout to rock interface whereas with the cement grout, failure occurred at the cable to grout interface.

Figure 5: Typical failure in the weak confining medium at the grout/rock interface with the resin grout (left) and failure at the cable/grout interface with a cement grout (right).

Oversize borehole diameter

The 10 mm larger borehole diameter in the weak confining medium resulted in an increase in performance with both grout types. In the case of the resin grout, there was an improvement in anchorage performance with much higher average peak load, residual load and stiffness than in the standard borehole diameter, these being 364 kN, 257 kN and 15.2 kN/mm respectively as shown in Table 2.

While peak load was fairly consistent between the tests, there was much more variability in the residual load with the resin grout than that observed in the standard borehole diameter as can be seen in Figure 6. There was in general more consistent behaviour with use of the cement grout in the oversized borehole and a substantial increase in average peak load from 207 kN in the standard diameter to 358 kN in the oversized borehole. However, there was little substantial change observed in residual load and stiffness.

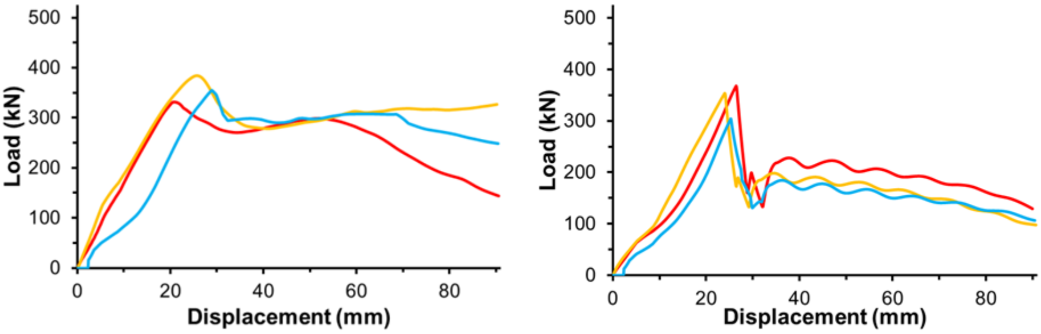

Figure 6: Load transfer behaviour of a cable bolt with resin grout (left) and cement grout (right) with an oversized borehole diameter in a weak confining medium.

LOAD TRANSFER BEHAVIOUR IN A STRONG CONFINING MEDIUM

Standard borehole diameter

In all instances in the strong confining medium, failure occurred at the cable to grout interface.

Overall, embedment in the stronger confining medium led to substantial increases in the average peak load with both grout types though there was little change in the stiffness. There was also much closer alignment in the peak load between the resin and cement grout as shown in Table 3. The highest peak loads were achieved with the resin and cement grouted cable bolt in the standard borehole diameter and strong confining medium with average peak load of 397 and 406 kN respectively. The residual strength in this scenario was quite variable as shown in Figure 7 and much lower than in the weak confining medium at 99 kN.
With the cement grout there was again close alignment between each of the test replications. The average peak and residual loads were much higher in this instance at 406 kN and at 216 kN respectively.

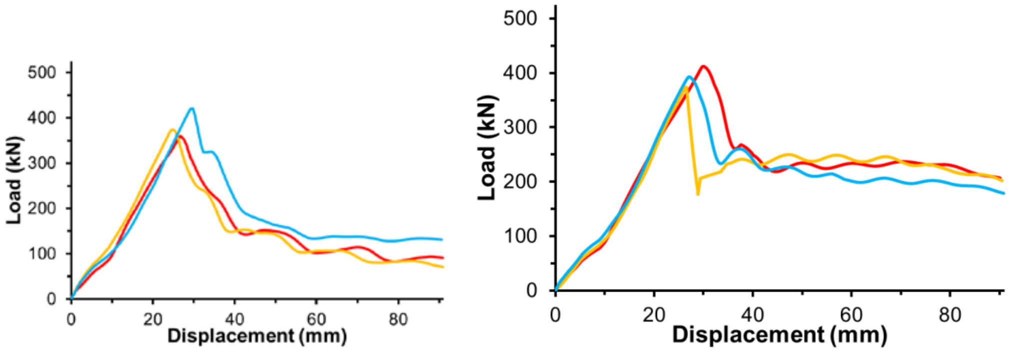

Figure 7: Load transfer behaviour of a cable bolt with resin grout (left) and cement grout (right) with a standard borehole diameter in a strong confining medium.

Table 3: Comparison of test results between resin and cement grout in strong confining medium.

				Residual strength at 90 mm	
Borehole diameter	*Grout type*	*Peak load (kN)*	*Stiffness (kN/mm)*	*(kN)*	*% peak load*
Standard	Resin	397	10.5	99	25%
(42 mm)	Cement	406	10.3	216	53%
	change	**2%**	**2%**	**118%**	**112%**
Oversized	Resin	374	9.9	96	26%
(52 mm)	Cement	382	9.8	170	44%
	change	**2%**	**1%**	**77%**	**69%**

Oversize borehole diameter

The oversized borehole tended to have a more beneficial impact on the peak load anchorage of the cement grout than the resin grout and there tended to be less variability in the results for the resin and cement grout as shown in Figure 8. Despite this and unlike the performance observed in the weak confining material, the peak loads with both grout types was not as great in the oversized borehole. The average peak and residual loads reached 374 kN and 96 kN respectively, the latter being the lowest average residual load with use of the resin in the test program.

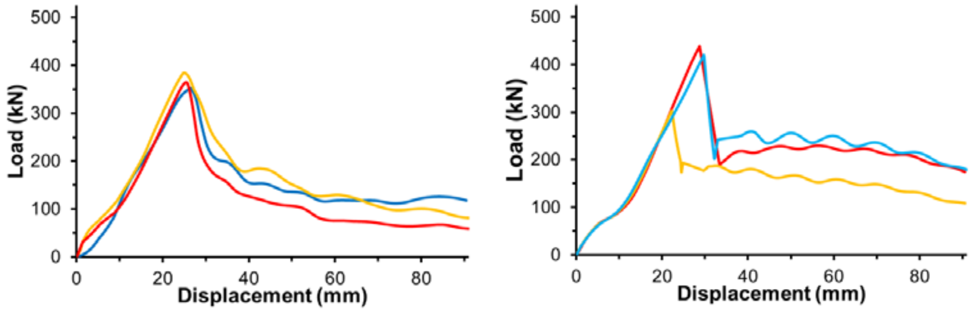

Figure 8: Load transfer behaviour of a cable bolt with resin grout (left) and cement grout (right) with an oversized borehole diameter in a strong confining medium.

The cement grout in an oversize borehole achieved an average peak load of 382 kN. The residual load as well as stiffness was of a similar level as measured in the other instances.
While there was larger variation in the peak load with the cement grout, the variation in residual load was greatest with the resin grout.

EFFECT OF BOREHOLE DIAMETER

On the whole, borehole diameter had little effect on anchorage performance in the strong confining medium with peak load being on average 6% higher in the standard borehole diameter for both the resin and cement grout as shown in Table 4.
Conversely in the weak confining material, the increase in borehole diameter resulted in substantial increases in peak load, residual load and stiffness. In the case of peak load, there were differences of 73% and 27% due to the increase in diameter for the cement and resin grouts respectively.

Table 4: Comparison of test results between resin and cement grout with different borehole diameters in weak and strong confining media.

					Residual strength at 90 mm	
Confining medium	Grout type	Borehole diameter	Peak load (kN)	Stiffness (kN/mm)	(kN)	% peak load
Weak	Resin	Standard	306	9.2	224	80%
(15.7 MPa)		Oversized	389	16.3	328	84%
		change	**27%**	**77%**	**46%**	**5%**
	Cement	Standard	207	8.3	121	57%
		Oversized	358	9.9	138	38%
		change	**73%**	**19%**	**14%**	**50%**
Strong	Resin	Standard	397	10.5	99	25%
(49.2 MPa)		Oversized	374	9.9	96	26%
		change	**6%**	**6%**	**3%**	**4%**
	Cement	Standard	406	10.3	216	53%
		Oversized	382	9.8	170	44%
		change	**6%**	**5%**	**27%**	**20%**

EFFECT OF STRENGTH OF THE CONFINING MEDIUM

Strength of the confining medium had more of an effect in the standard borehole diameter with increases of 30% and 96% in peak load for the resin and cement grouts respectively as shown in Table 5. The change was less significant in general in the oversized borehole.

Table 5: Comparison of results between weak and strong confining media with a resin and cement-based grout.

					Residual strength at 90 mm	
Borehole diameter	Grout type	Confining medium	Peak load (kN)	Stiffness (kN/mm)	(kN)	% peak load
Standard	Resin	Weak	306	9.2	224	80%
(42 mm)		Strong	397	10.5	99	25%
		change	**30%**	**14%**	**126%**	**220%**
	Cement	Weak	207	8.3	121	57%
		Strong	406	10.3	216	53%
		change	**96%**	**24%**	**79%**	**8%**
Oversized	Resin	Weak	364	15.2	257	70%
(52 mm)		Strong	374	9.9	96	26%
		change	**3%**	**54%**	**168%**	**169%**
	Cement	Weak	358	9.9	138	38%
		Strong	382	9.8	170	44%
		change	**7%**	**1%**	**23%**	**16%**

MEASURE OF STIFFNESS

Athanassiou (2016) and Hagan and Li (2017) reported values for stiffness in the order of 60 - 80 kN/mm. Their results are significantly higher than the stiffness reported in this study that is in the order of 10.5 kN/mm. This difference can be attributed to changes made in the procedure used in this test program. In both earlier cases, the test procedure provided for a constant embedment length in the pull-out test with 90 mm of shrink wrapping applied to the far end of the cable bolt before grouting. Further their tests involved grouting the entire free end of the cable bolt lying outside the confining medium within a thick-walled steel tube as opposed to fastening a bail and anchor at the end of the cable bolt as used in this program.

The former arrangement not only minimises the chance of any slippage during loading but also minimises the free length of cable bolt over which load is applied by the hydraulic actuator thereby the measured stiffness is of the grouted cable bolt section only.

CONCLUSIONS

The cement-based grout and resin grout were found to be equally effective in load transfer achieving the largest measured peak loads when placed in the high strength confining medium as shown in Figure 11. In the standard diameter borehole of 42 mm, the three-fold increase in strength of the confining medium from 15.7 MPa to 49.2 MPa resulted in 30% and 96% increases in average peak load with the resin and cement grouts to 397 and 406 kN respectively as shown in Table 6. Little differences were observed in the stiffness between all the test scenarios.

The resin grout tended to produce more consistent results with changes in borehole diameter and strength of confining medium. The cement grout was found to achieve a much lower average peak load in the weak confining medium and standard borehole diameter of 207 kN though there was a higher degree of variability observed between the test results in this condition.

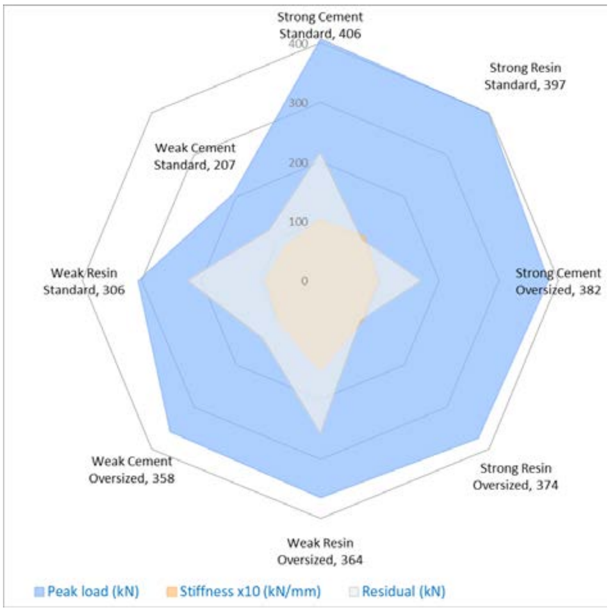

Figure 11: Summary of test findings indicating the highest load capacity was observed in the strong confining medium, the type of grout having little impact on the magnitude of the peak load. A larger diameter borehole had most effect in the weak confining medium only resulting in an increase in average peak load.

Table 6: Comparison of the effect of various test parameters sorted by peak load.

			Residual strength at 90 mm	
	Peak load (kN)	Stiffness (kN/mm)	(kN)	% peak load
Strong Cement Standard	406	10.3	216	53%
Strong Resin Standard	397	10.5	99	25%
Strong Cement Oversized	382	9.8	170	44%
Strong Resin Oversized	374	9.9	96	26%
Weak Resin Oversized	364	15.2	257	70%
Weak Cement Oversized	358	9.9	138	38%
Weak Resin Standard	306	9.2	224	80%
Weak Cement Standard	207	8.3	121	57%
mean	**349**	**10.4**	**165**	**49%**

Note: Strong and weak refer to strength of the confining medium.
Standard and oversized refer to borehole diameter.

A 10 mm change in borehole diameter had less of an effect in the strong confining medium whereas in the weak material, an increase in borehole diameter increased average peak and residual loads. In practise, it is recommended that when installing a cable bolt in weak ground such as coal that the borehole diameter be increased slightly as this is more likely to improve the performance of the cable bolt to levels comparable to that observed in stronger rock such as sandstones and shale. The impact of the change in diameter in weak ground was found to be more acute with the use of cement grout than the resin grout.

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