

# Performance of Cable Bolts in Small- and Large-Scale Laboratory Pullout Tests

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## Abstract

Various testing methods have been proposed and conducted on cable bolt pull out in the last century. Large and small scale tests have both provided valuable information about the behaviour of the cable bolts. This study compares large scale and small scale pull out experiments with similar cables, bonding agents (grout and resin), and loading paths (monotonic and cyclic) to juxtapose the unique characteristics of each test. The results suggested that small scale tests in grout tend to have lower repeatability compared to large scale test while large scale test typically provide a stiffer behaviour with higher initial peak loads. In cyclic loading, large scale testing tended to have most of their cycles in the first 5 mm whereas small scale test loading and unloading cycles were more spread. In resin cases, bulbed cables had similar behaviour whereas the unbulbed cables had various load values suggesting the presence of bulbs overshadows other characteristics.

Keywords: Cable Bolt, Pull out, Grout, Resin, Large Scale, Small Scale, Monotonic, Cyclic

## Highlights

- Small scale pull out tests tend to have less repeatability
- The reduction in peak load going from large to small scale test is not just a function of the encapsulation length
- Large scale pull out tests have higher initial stiffness compared
- Compared to the small scale setup, cyclic tests in large scale setup have most of the load/unload cycles in the early displacements
- Although small scale pull out tests can adequately gauge the performance of the cable bolting system, large scale and small scale pull out tests provide two different unique perspectives and should coexist

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# 1 Introduction

Efficient use of cable bolts in engineering practice largely depends on our understanding of them. Multiple experiments have been proposed over the years to study the axial performance of the cable bolts. Large scale tests can be categorized as tests in which the cable is encapsulated with a bonding agent inside a rock or concrete confining medium (Rastegarmanesh et al. 2022, 2023). On the other hand, small scale test lacks the rock/concrete confining medium, and the bonding agent acts as the confining medium. This makes small scale tests less expensive and faster to run, however, the lack of a large separate brittle confining medium around the bonding agent leads to more resistance to dilation and, thus higher loads at shorter embedment lengths (Rastegarmanesh et al. 2024a). In both types of tests, the samples are usually confined with an external metal tube to provide constant radial stiffness or pressure, and maintain integrity during the tests.

One of the earliest systematic studies was done using Spline-Pipe Pull Test (SPPT) which consisted of two grouted pipes in which a single high tensile steel tendon was encapsulated using cement-based grout. Special attention was paid to stopping the rotational movement (Fuller and Cox 1975; Nguyen et al. 1986). Double Embedment Pull Test (DEPT) in which the apparatus comprised two same length tubes which when pulled, failure could occur at either part of the gap (Goris 1990, 1991; Hutchins et al. 1990). Modified Hoek cell (MHC) was a setup that enabled a constant radial pressure on the sample during the pull out test, and multiple iterations of it were used to study cable and rock bolts (Hyett et al. 1992, 1995a, b; MacSporran 1993; Moosavi et al. 2005).

Having control over radial stiffness and pressure during the pull out has been used extensively (Martin 2012; Thenevin et al. 2017). The Laboratory Short Encapsulation Pull Test (LSEPT) consisted of a sample confined in a biaxial cell that could apply various radial pressures during the test. The setup consisted of an embedment and an anchoring section (Clifford et al. 2001). The Laboratory Double Embedment Tensile Test (DETT) consisted of two anchored internally rifled 125 mm sections with no gap in between. The rotation was stopped using a pin between the two sections (Reynolds, 2006; BS7864-1). The original design later inspired various other small scale pull out setups (Aziz et al. 2016; Li 2019). Later, the British Standard (BS7861-2) was modified to use the original setup (based on DEPT) for nutcage cables. Such designs were inherently double embedment tests. Bigby and Reynolds (2005) believed the Double embedment is “artificial” and cannot model rock interface fully. As for single embedment tests, in the Single Embedment Pull Test (SEPT) a cable bolt is encapsulated into a metal pipe on one end, and restrained with a barrel and wedge at the other end (Hutchinson and Diederichs 1996; Forbes and Vlachopoulos 2016). Meanwhile, rock or concrete for pull out tests can also be utilized in various embedment styles (Hagan 2004; Chen 2016; Hagan and Li 2017)

As mentioned above, while there is no shortage of small and large scale pull out tests on cable bolts, there seems to be a lack of comparison data between them. Juxtaposition of the two types of experiment can shine a light on the differences between them, which in turn can provide more insight on the axial performance of the cable bolts in the laboratory and field. Also, the results can potentially help breach the gap between the two scales of the tests and increase confidence in interpreting the result of one in the absence of the other. In the following sections of this research, large scale and small scale pull out experiments involving cable bolts encapsulated with cementitious grout and chemical resin are briefly introduced. Then the differences in the results are then delineated and interrogated before drawing conclusions on the performance of the two test types.

## 2 Experiment Design

In this section, two pull out experiments are briefly introduced. Similarities between these two experiments provide relatively fair ground for comparisons later on. In both setups, the cable/grout(resin) interface is tested.

### 2.1 Large Scale Laboratory Test

Large scale laboratory testing apparatus as seen in Rastegarmanesh et al. (2022, 2023) included a concrete cylinder confined passively in a thick steel pipe (Figure 1). The cables were encapsulated in the rifled boreholes using Stratabinder grout and Carbothix resin (Figure 2). The experiment particularly investigated the role of the anti rotation setup and the torque on the external confinement split pipe. The vertical pull out displacement of the cable bolts was recorded alongside the displacement of the barrel and wedge during a 120 mm pull out length with 6 mm/min rate. The barrel and wedge displacement was then deducted from the total vertical displacement (Rastegarmanesh et al. 2024b).

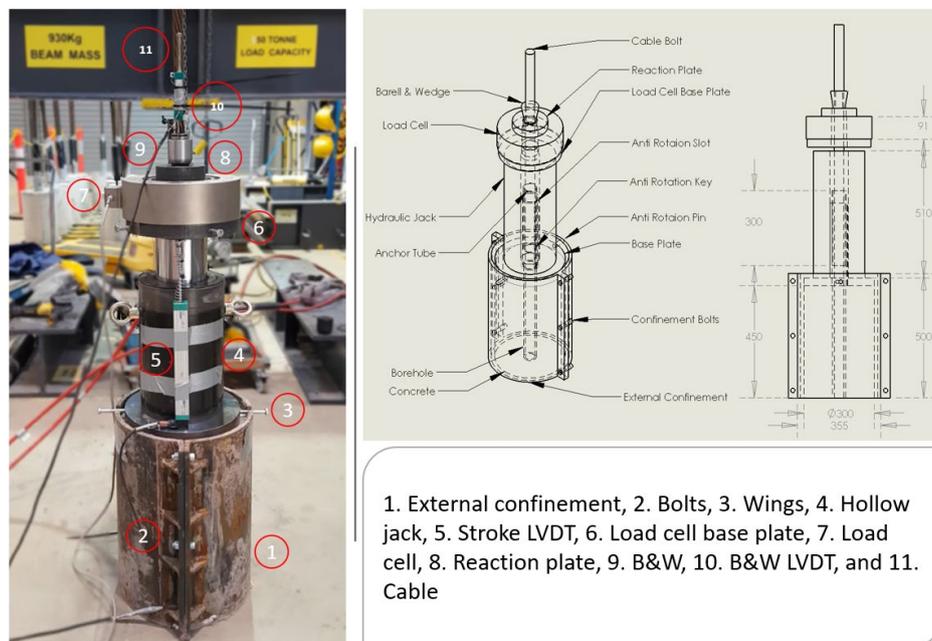


Figure 1 Apparatus schematic and various testing components mid-test (Rastegarmanesh et al. 2022)

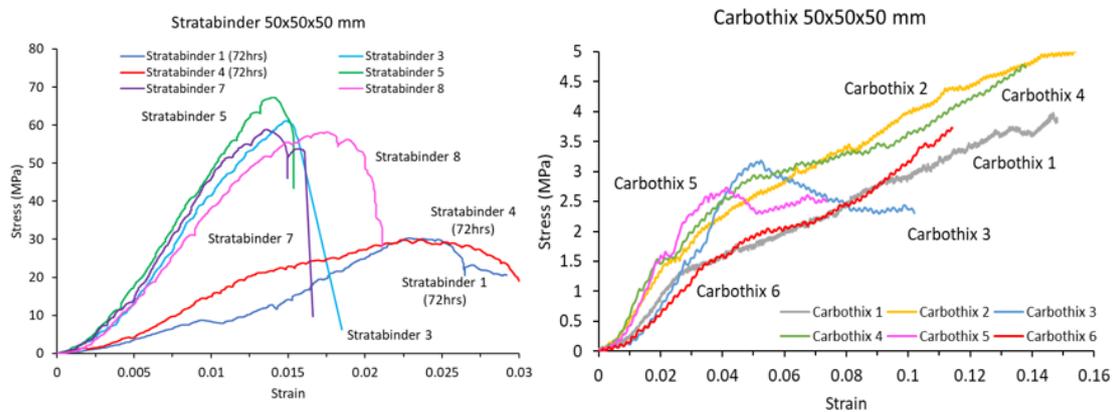


Figure 2 Left: Stress-strain behaviour of Stratabinder 50mm cube samples under uniaxial compressive strength testing. Right: Carbothix stress-strain graph

## 2.2 Small Scale Laboratory Test

The Small scale (sleeve) laboratory pull out test as outlined in Rastegarmanesh et al. (2024a) included a 150 mm long, 50 mm wide sleeve with 4.5 mm wall thickness bonded around cables with Stratabinder grout (Figure 2) and GeoFlex resin (Figure 3). The internally rifled sleeves used an anti rotation setup to inhibit the exit point rotation during the test (Figure 4). The cables were fixed with the jaws of a tensile loading machine and during 120 mm pull out length with load and displacement read through the testing machine. In the case of bulbed cables, the bulb was placed around 50 mm away from the cable entry point during pull out to provide at least 100 mm of bulb movement in the annulus. Figure 5 exhibits the small and large scale sample before the experiments, and Figure 6 presents the cut samples after the test.

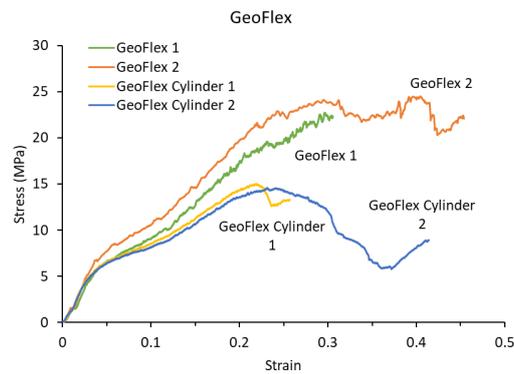


Figure 3 GeoFlex UCS test results

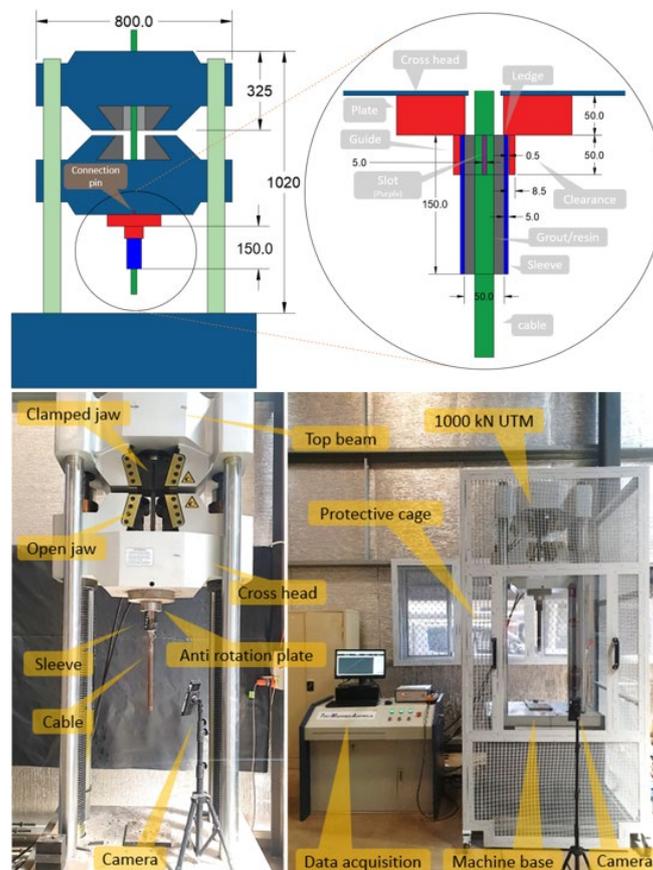


Figure 4 Sleeve pull out schematic (dimensions in millimetres) (Rastegarmanesh et al. 2024a)

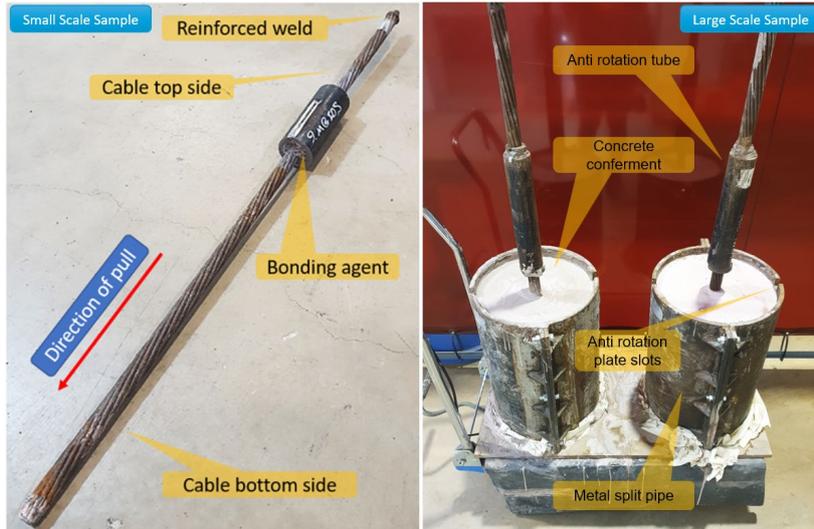


Figure 5 Small and large scale samples



Figure 6 Left: 10 strand cable after the test, Right: Opened 12 strand sample with restricted rotation

Both experiment scales described above were conducted on the same set of cables used in the mining industry. Table 1 presents the cables used and their respective codes (abbreviations) used herein for brevity. To avoid confusion, in this article, a “bulb” is a structural modification along the cable length in the form of enlarged sections, while modifications on the surface in terms of small patterns are called "indentation". A cable without any modification is called a “plain” cable while a cable without “indentation” is referred to as “smooth”. A cable (bolt) is made of various “strands” wound together.

Table 1 Cable specification (Jennmar Australia 2020)

Cable Type	Code	Strand Diameter (mm)	Breaking Point @Strands (KN)	Breaking Point @B&W (KN)	Steel Area (mm <sup>2</sup> )	Elongation at Failure (%)	Bulb Diameter (mm)
Goliath	Gol	28.6	970	>800	532	5-7	-
12 strand	12S	31	705	640	-	5-7	36
10 strand	10S	31	705	640	-	5-7	36
9 strand	9S	28	635	540	-	5-7	35
Superstrand	SS	21.8	590	520	313	6-7	-
Indented Superstrand	IDS	21.8	570	450	313	6-7	-

### 3 Result Analysis and Discussion

In the following sections, while the main points of comparison are Scale and Bonding Agents, various other comparisons are also made on the basis of the type of test, cable type, and loading type. As a reminder, in the following graphs, # represents a rotation permitted (absence of the anti rotation plate) and *G* and *R* refer to grout and resin, respectively. Also, where relevant torque values on the split pipe for the large scale grout samples are also mentioned (60 Nm and 80 Nm).

#### 3.1 Comparison of Large Scale Monotonic Pull out in Grout versus Resin

This section presents the results gained from the large scale pull out tests conducted on cementitious grout and fast set resin detailed in Rastegarmanesh et al. (2022, 2023). As seen in Figure 7, there is a good agreement between the Superstrand cable in resin and grout. It is evident that the effect of the indentation is much more pronounced in the grout samples. In the grout, indentation increases the load by up to approximately five times the smooth cable, whereas this contribution for the resin is limited to a maximum of twice the load. As seen in Figure 7, the initial stiffness of both cases is very similar, and the maximum initial peak occurs at almost the same displacement.

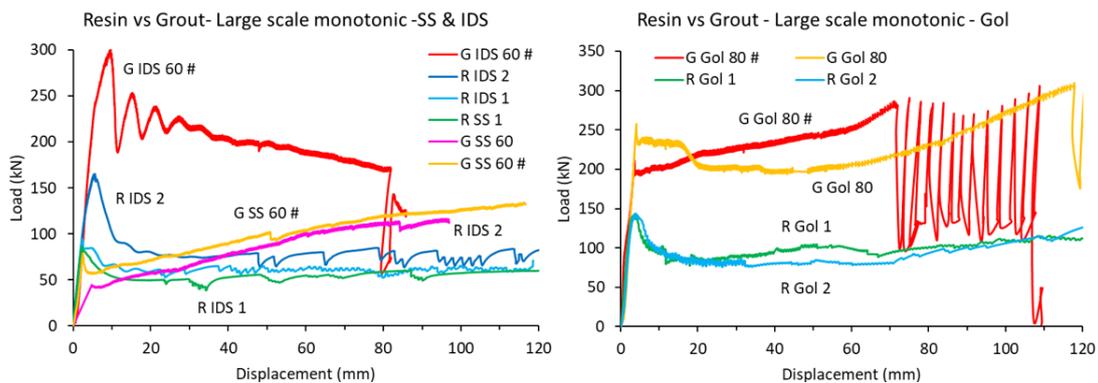


Figure 7 Left: Large scale monotonic Superstrand and indented Superstrand cables in grout and resin (# = rotation allowed), Right: Large scale monotonic Goliath cable in grout and resin (# = rotation allowed)

For the bulbed cables, a series of identical observations are made. Figure 8 illustrates that the resin cables could only carry as little as 30% of the load of the 80 Nm torque grout samples. In all bulbed cables, the perfectly plastic behaviour of the resin cables is juxtaposed against the strain softening or rather brittle behaviour of the grout

cables. Additionally, for each bonding agent, all the bulbed cables resulted in similar outcomes suggesting Carbothix could not differentiate between the bulbed cable types.

This finding suggests that the presence of the bulb, regardless of the size, can be enough to utilize the mentioned benefits of bulbs. With bulbs, the other properties of the cable are not as important, because 9, 10 and 12 strand cables for both grout and resin do not differ significantly, especially in the resin tests. Comparing Figure 7 and Figure 8 suggest high repeatability for the resin sample compared to the grout samples and almost identical initial load peak up and stiffness.

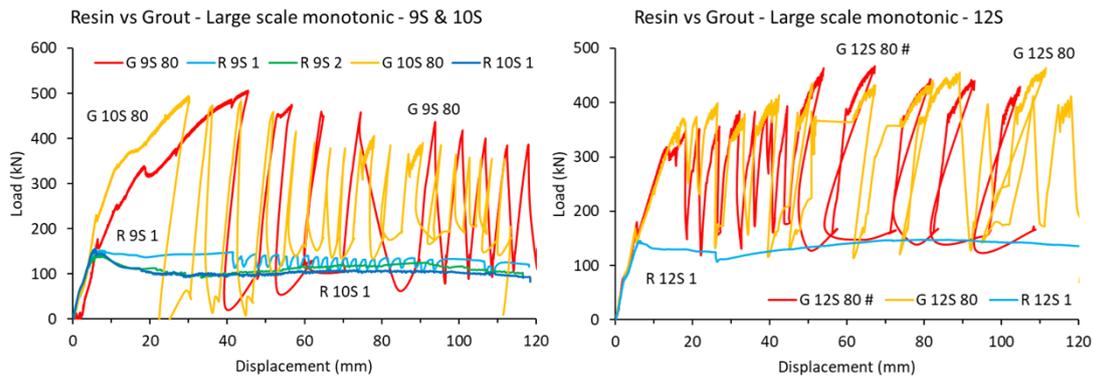


Figure 8 Left: Large scale monotonic 9 and 10 strand cable in grout and resin, Right: Large scale monotonic 12 strand cable in grout and resin (# = rotation allowed)

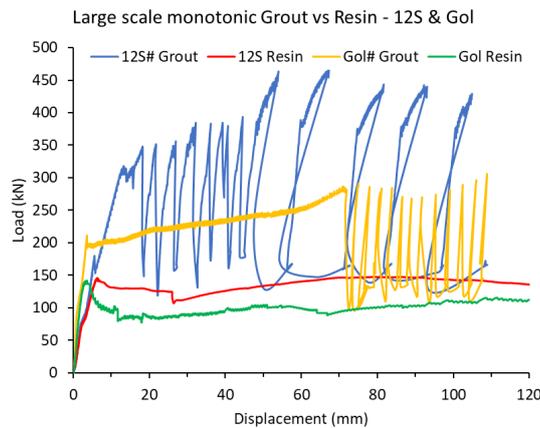


Figure 9 Comparison between resin and grout for 12 strand and Goliath cables (# = rotation allowed)

### 3.2 Comparison of Small Scale Monotonic Pull out in Grout versus Resin

In this section, the performance of tested cables in resin and grout in the small scale pull out experiments are compared as detailed in Rastegarmanesh et al. (Rastegarmanesh et al. 2024a). As seen in Figure 10, the load in the resin samples is much lower than in the grout samples. In the case of the Goliath cables, although the two grout tests themselves are fairly different from each other, the resin test shows around 20-40% of the grout sample peak load. In the case of the 9 strand cables, the resin sample only reaches 30% of the grout’s ultimate load, while in both cases it is evident that the initial stiffness is much higher in the grout samples. From all the graphs, the behaviour can be inferred as almost strain softening or perfectly plastic, except for the resin Goliath cable which is a smooth plain cable.

Figure 10 illustrates the comparison between the 10 and 12 strand cables in the monotonic small scale tests. In both cases, the resin samples perform at only 20-30% of the load of the grout samples. The difference is greater for the 12 strand cables compared to the 10 strand cables. The resin samples portray a better consistency relative to the grout samples, however tests results for identical cables vary significantly between tests. The grout cables clearly illustrate their signature post peak oscillations, and similar to the Goliath and 9 strand cables, the resin behaviour tends to be less stiff than grout with a gentler load curve with the maximum load at a higher displacement.

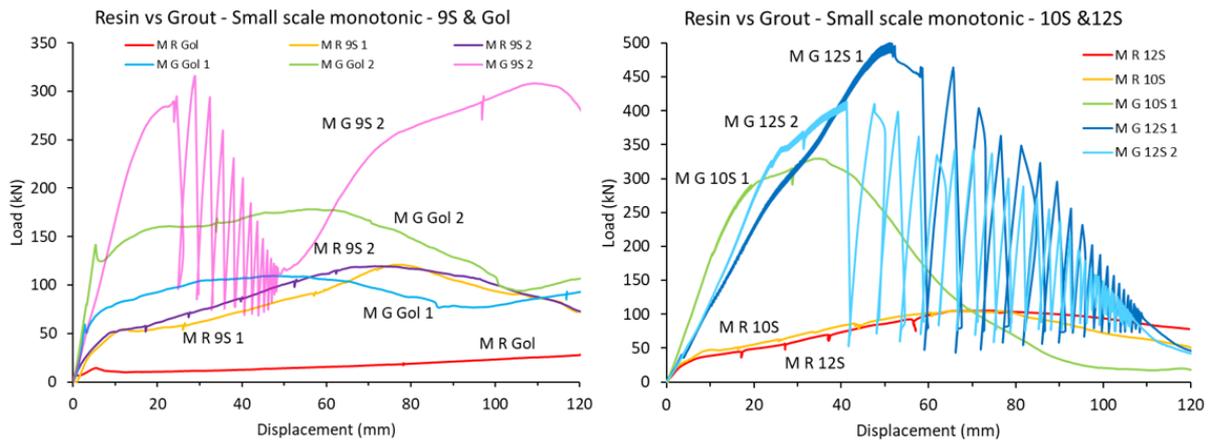


Figure 10 Left: Resin vs grout for 9S and Goliath cables in monotonic small scale pull out, Right: Resin vs grout for 10S and 12S cables in monotonic small scale pull out

Lastly, Figure 11 shows the comparison between the two types of Superstrand cables. The indented Superstrand cables in resin show significantly less loading capacity than the grout tests, with less than 10% of the load, performing even more poorly than the smooth Superstrand cables in grout. However, only one resin test was conducted on the Superstrand cables so the results cannot be taken to be conclusive.

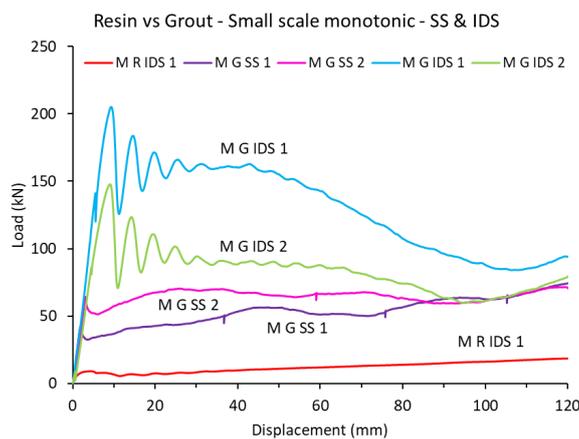


Figure 11 Resin vs grout for Superstrand and indented Superstrand cables in monotonic small scale pull out

### 3.3 Comparison of Grout Encapsulated Pull out in Small versus Large Scale

This section compares the small scale (sleeve) and large scale pull out tests in grout. The tests were all performed under monotonic loading. It should be noted that the large scale tests' encapsulation length was 300 mm compared to the 150 mm of the small scale tests. The hash key (#) denotes the lack of anti-rotation in this section and the

prefixes *S* and *L* represent small and large scales, respectively. Furthermore, unless mentioned specifically, all the large scale tests were conducted at 80 Nm of torque.

Figure 12 represents the results for the indented Superstrand and Goliath cables in grout. In both cases, the large scale tests result in up to a 50% higher load with a stiffer response. However, the overall behaviour of the tests is reasonably similar, and unchanged between the two testing types. The repeatability of the tests in both cases is low, with the small scale tests performing at a lower load.

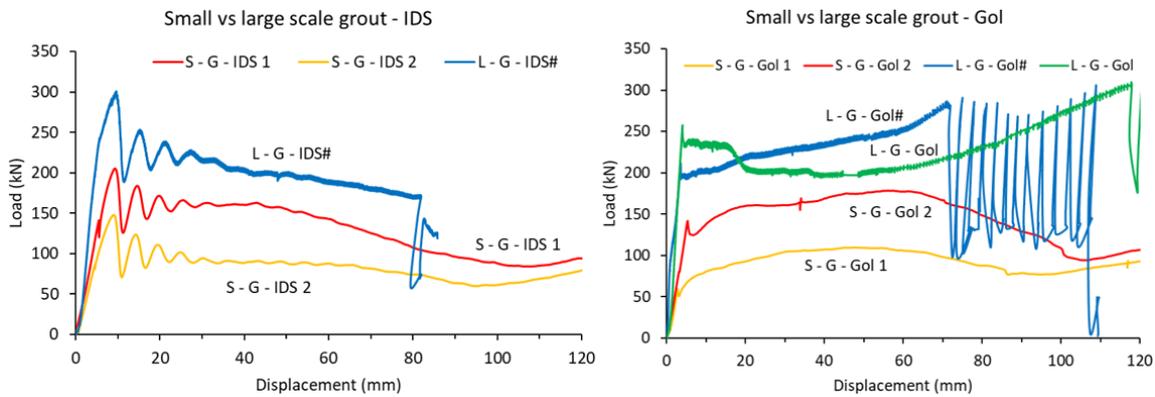


Figure 12 Left: Small and large scale indented Superstrand pull out tests in grout – 60 Nm of torque, Right: Small and large scale Goliath pull out tests in grout

Figure 13 covers the results for the 9 and 10 strand cables. As can be seen in the case of the 9 and 10 strand cables, the small scale tests tend to be in more accordance with the lower torque (60 Nm) large scale tests. This is counterintuitive as the sleeves were filled with high strength grout rather than 40 MPa concrete. Also, the sleeves were radially constrained with a metal pipe at 50 mm diameter rather than 330 mm. The 60 Nm torqued bolts were an attempted analogy to the lower radial stiffness compared to the 80 Nm torqued tests. In the case of the 9 strand cable, the small scale test achieves approximately 30% less load with almost similar initial stiffness, whereas in the 10 strand cable, the load value is almost similar, with the small scale test clearly showing less stiffness.

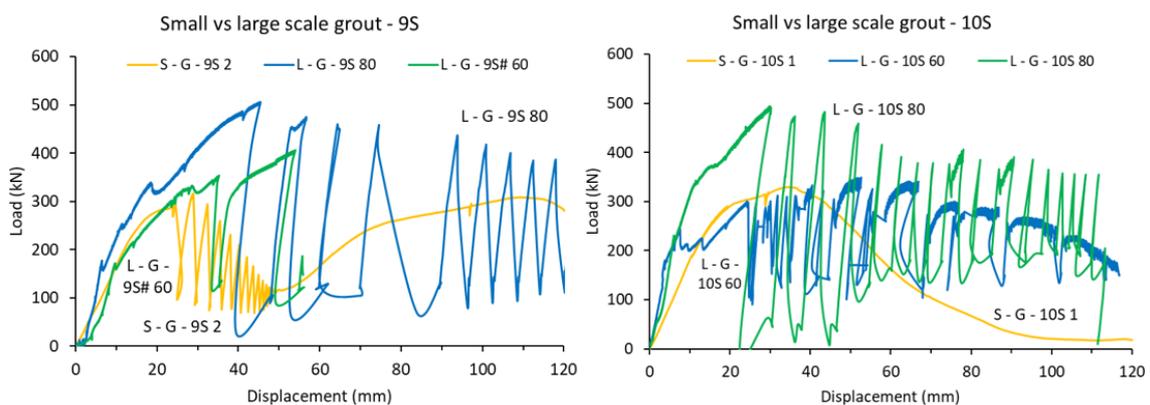


Figure 13 Left: Small and large scale 9 strand pull out tests in grout, Right: Small and large scale 10 strand pull out tests in grout

For the 12 strand cable (Figure 14), the small and large scale test loads are in reasonable agreement with each other. The values appear to match the 80 Nm torque test, contrary to the 9 and 10 strand cable, and are similar to all the other cables (except for 9S). The large scale test has a stiffer initial response. The 12 strand cable, similar to the 9 and 10 strands, shows the same post peak oscillations as the large scale test, albeit in a diminishing manner.

This decline is due to the shorter length of the encapsulation in the small scale test which causes the bulb to significantly damage a large portion of the annulus and exit out of the sleeve.

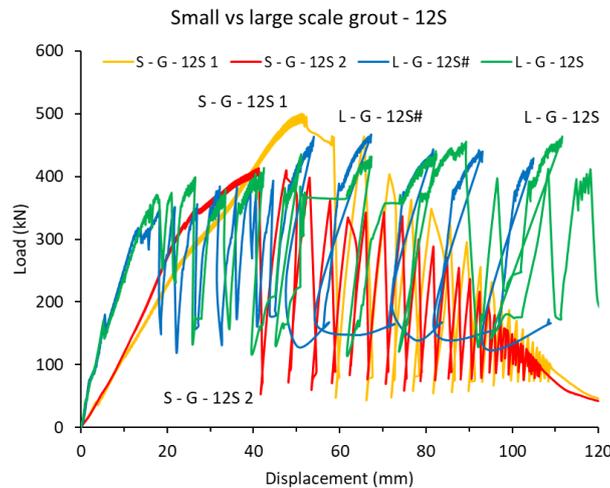


Figure 14 Small and large scale 12 strand pull out tests in grout

### 3.4 Comparison of Resin Encapsulated Pull out in Small versus Large Scale

This section presents the performance differences in the small and large scale resin pull out experiments. The tests were conducted in both monotonic and cyclic loading. The small scale tests had half the encapsulation length of the large tests (150 mm compared to 300 mm). The resin used for the large scale tests was Carbothix while the resin used in the small scale testing was GeoFlex. Although the two resins were similar chemically (Urea Silica), they possessed different mechanical characteristics and properties, as shown by their UCS tests earlier (Figure 2 and Figure 3).

Figure 15 illustrates the results for indented Superstrand and Goliath cables. In both cables, not only do the large scale tests show higher values than the small scale tests by a significant margin, but the behaviour of the tests has also changed from strain softening to hardening. Moreover, the 9 strand cable also shows a less stiff behaviour with around 20% load loss between the tests. However, the extent of the load loss is far from the unbulbed cables in Figure 15 (indented Superstrand and Goliath).

Figure 16 presents the 10 and 12 strand cables. The tests at both scales show acceptable repeatability, and the performance of the cables at both scales is similar regardless of cable type. The small scale tests perform around 30% lower in terms of peak load, however, the peak load occurs at a much higher displacement. A comparison between Figure 15 and Figure 16 shows an almost identical load range and behaviour for both large and small scale tests. This suggests that the bulbed cables respond similarly to both of the resins used in this study. This indicates that the significant effect of a bulb on a test tends to dominate other properties such as cable type or geometrical characteristics such as diameter.

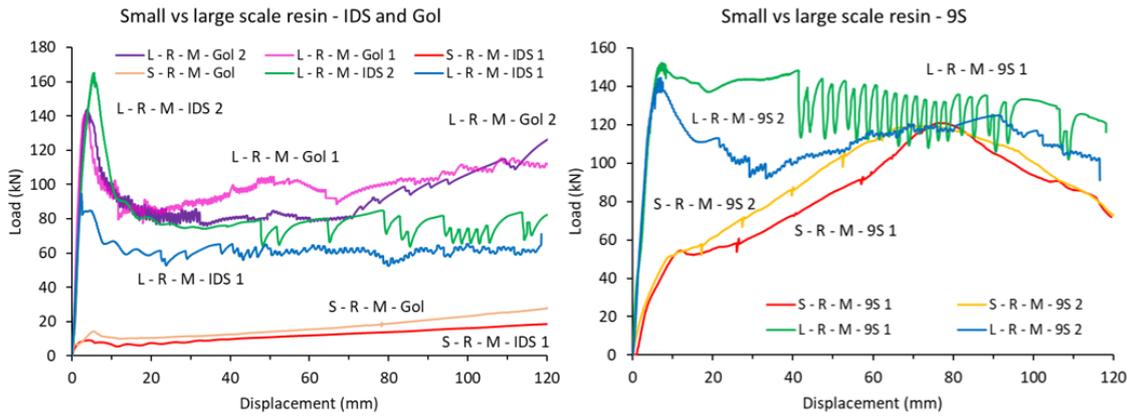


Figure 15 Left: Monotonic small and large scale pull out test in resin for indented Superstrand and Goliath cables, Right: Monotonic small and large scale pull out test in resin for 9 strand cable

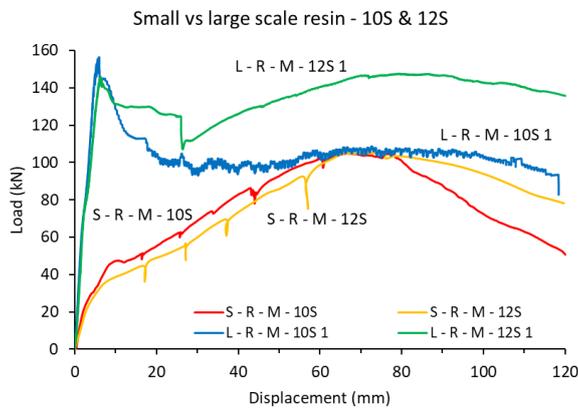


Figure 16 Monotonic small and large scale pull out test in resin for 10 and 12 strand cables

Finally, Figure 17 exhibits the results of the cyclic loading of small and large scale samples. The Goliath (plain smooth cable) shows the greatest load decline with up to 90% load lost, while the bulbed cables all experience a 50-60% load loss between the two scales. The other obvious observation is that, in the large scale tests, the load cycles all occur before the peak load and in a very small displacement range (usually the first 10 mm), whereas in the small scale tests, the cycles are more widely spread apart, but the overall conclusions drawn are similar to the monotonic tests.

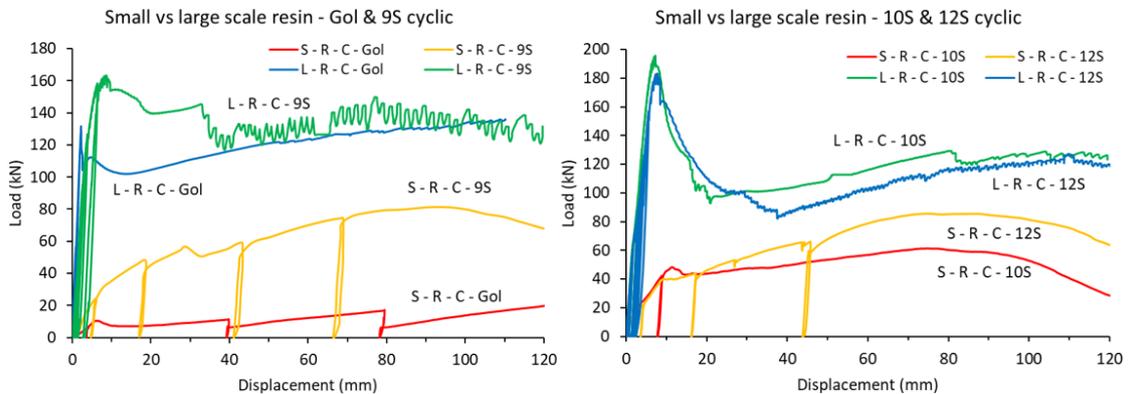


Figure 17 Left: Cyclic small and large scale resin pull out tests for Goliath and 9 strand cables, Right: Cyclic small and large scale resin pull out tests for 10 and 12 strand cables

## 4 Conclusion

Comparison between grout samples in the small and large scale tests showed that the small scale tests in grout have lower repeatability whilst the large scale tests have higher initial stiffness and higher peak loads. This might be counterintuitive considering the metal encapsulation and higher strength confining medium of the small scale tests. Perhaps a more rigid sleeve (thicker tube) could result in higher initial stiffness. Apart from that, the overall behaviour of the tests was similar for both scales. Going from large scale to small scale, while grout samples have on average around 0-50% less load (commensurate with their encapsulation length of 150 mm compared to 300 mm), resin samples had a relatively more substantial decrease.

Comparisons between the resin samples in the small and large scale tests for the unbulbed cables clearly showed a significant difference between the load values. This difference was much smaller in bulbed cables, suggesting once again that the presence of bulbs in small scale tests was a highly influential factor. At both scales, the bulbed cables had higher repeatability and resulted in similar load values. For both resin types, all of the bulbed cables performed similarly. This means that the presence of a bulb was enough to overshadow the other key properties such as diameter and lay length.

Finally for the cyclic tests, with both bonding agents, the load dropped to much lower values when changing the scale of the tests from large to small. A unique behaviour of the large scale cyclic tests was that the cycles all happened in the first 10 mm of displacement whereas, in the small scale tests, the cycles were spaced further apart.

Small scale tests are a more accessible, cost-effective, and sustainable substitute for large scale tests. Ideally, having enough data points for both large scale and small scale tests can possibly lead to a function to map the two. Perhaps a standard of testing for both the small and large scale pull out tests could be beneficial, so a uniform database of cable bolt pull out tests could be stabilised, and more substantial statistical analysis could be conducted. Other limitations that can be investigated are unwanted factors such as lack of control or quality on grouting/resin, adhesion, aging, water presence, fine particles slicken coating in the external interface etc. In conclusion, the authors believe that while both experiments can be used to compare cables, small scale tests cannot produce “identical” results to the large scale tests, and thus cross comparison is not advised until more raw data is available to establish correlation coefficients. The two tests are different in nature, however, investigating the unique behaviours seen in each test provides the opportunity to look at the pull out behaviour of the cable bolts from two valuable perspectives.

## Acknowledgement

The authors wish to acknowledge the help and in-kind support of Minova and Jennmar Australia, and their provision of the samples used in this research. In particular, Robert Hawker, Peter Craig, Tom Meikle and Arya Gao.

## Statements and Declarations

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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