GRANIT®: non-destructive Anchorage Testing and Monitoring System

AMEC and the University of Aberdeen describe the latest developments in GRANIT- the new non-destructive non-invasive testing system designed to assess anchor integrity.

Introduction

GRANIT is the world’s first rapid, effective, multiple capability, non-destructive anchor integrity testing system for rockbolts for mining, tunnelling and other civil engineering ground anchorage systems. This new technology incorporates the latest in artificial intelligence, signal processing and engineering design [1]. GRANIT provides a major contribution to the safety of anchorage re-enforced structures that are in daily use, by permitting the rapid establishment of the condition and integrity of the anchors.

GRANIT can be applied to most types of anchor and does not need any special preparation of the anchor, and the anchor proximal end may be threaded or unthreaded.

GRANIT is lightweight, self contained, non destructive and non invasive and is able to be operated by one person.

GRANIT can be developed specifically for a particular site and is readily adaptable because of its simplicity of operation. Modification for adapting to widely varying size of anchor head and type is quick and easy.

GRANIT is used for quality control, exception testing, load and effective free length diagnosis, bond verification and troubleshooting of anchors.

GRANIT can be applied to any anchor from 10mm up to 75 mm diameter and lengths up to 40m.

GRANIT can be applied to bar or strand anchors.

GRANIT is a highly productive system enabling-for example-a large number of mining bolts or conventional anchors to be tested in a single shift by one operator. The system is deployable in a manner that typically will not interfere with operations or production.

GRANIT is readily applicable in a variety of anchoring/bolting situations including mining, tunnelling and general civil engineering. This includes existing and newly installed anchors as well as during the process of anchor installation for Quality Assurance and Quality Control purposes.

This article concentrates mainly on mining type applications.
How does GRANIT work?
The system works by first attaching a purpose built pneumatic impact device to the head of the anchor. This device applies a small tensile impulse to the anchor being tested. An accelerometer and data acquisition system then captures the resulting vibration response signal. The impulse applied is small enough to ensure no damage occurs to the bolt or encapsulation. The vibration response signal is processed and fed into a neural network which has previously been “trained” to recognise characteristics of the signal and interpret these to provide diagnosis of load and free length. Figure 1 shows a schematic of the system.

Fig 1: Schematic of the GRANIT system

A major advantage of GRANIT is that the device simply screws or clamps onto the section of the anchor protruding beyond the plate and is locked in place prior to testing. No special preparation of the anchor head is required. The device is simply clamped on where screw threads are not present, with an in-built collet type clamping arrangement, which can be tailored to suit. The frontispiece illustrations of this article show the device being attached to a roof bolt at Thoresby Colliery, and response data recording in progress on the field computer.

Need for integrity testing-Mining
Current roofbolting practice in UK mines specifies that the bolts should be fully encapsulated with the materials in accordance with BS 7681. The installation must also be in accordance with the code of practice and applicable regulations [2]. Similar regimes operate in other countries.

Increasingly, regulatory authorities are demanding that managements fulfil their safety obligations regarding the application of anchor systems by regular periodic testing and provision of hard data on which to base determinations of safe condition.

Safety
It is important from purely safety considerations that there is some method of confirming that the specified bolt/anchor installation quality is being achieved and that the bolts are performing to specification. There is no visual way of detecting bolt system out of specification installation or incipient malfunction—except when this results in visible movement in the strata above (tell-tales) or actual deformation of the bolted roadway. Obviously any warning of this would be advantageous as timely remedial measures can be taken, enhancing safety and assisting in the avoidance of interruptions to production while remedial measures are undertaken.

As an example of the need for adequate anchor encapsulation and bonding, a recent survey of roof falls in deep South African mines [3] showed that over 70% occurred with thicknesses of fallen material of less than 0.5m. In such cases it is obviously critical that the bolt is fully bonded and/or pre-tensioned to ensure that such shallow falls are minimised. In particular, poor encapsulation/bond at the proximal end of the bolt is likely to predispose the roof to this type of shallow fall—especially where little or no pre-tension has been applied to the bolt.

Laboratory Testing
GRANIT has been developed over a number of years to address these problems by enabling assessment of unbonded length and load under the head of the rockbolt. This development has been underpinned by extensive laboratory testing and computer modelling on unbonded/free length [4] and load diagnosis [5]. Laboratory testing used full scale anchors bonded in concrete in steel gun-barrels, of various sizes and lengths. Testing was carried out on a wide variety of anchor head hardware.

Computer Modelling
A computer model has been developed at the University of Aberdeen which enables the accurate mathematical modelling of a wide variety of anchorage types. The model can be used to predict the likely responses of anchorages to GRANIT testing and to verify real field data.

The model can also be used to generate data for the initial training of neural networks, without the need for extensive field data, which is time consuming and can be expensive to obtain. This mathematical model is a very important and useful part of the overall GRANIT system, and it is being further refined to broaden its capability.

Proving Trials
Prior to its first full scale application, the GRANIT system was used on surface in a set of proving trials at AMEC’s purpose built test sites at Swynnerton UK. These trials were designed to replicate as closely as possible the conditions found in applications such as mines and tunnels that use resin bonded bolting systems. Further extensive trials were also undertaken at another purpose built site at Kibblestone UK where the anchors were designed to replicate single strand anchors often found in mines and tunnels, and in civil engineering sites generally.

The aim of the trials was to establish the accuracy to which GRANIT could estimate unbonded length and load under the head of the bolt and to verify exception testing. Some of the results from these trials can be seen in Table 1 and Figure 2 respectively.

Results of Proving Trials
As can be seen from Table 1 the GRANIT equipment can be used to diagnose the unbonded length of the bolt highly accurately. These three results are typical of the accuracy obtained in tests at the Swynnerton test site. The bolts were installed in a manner as close as possible to typical mine installation methodology.

<table>
<thead>
<tr>
<th>Actual Unbonded length (mm)</th>
<th>Diagnosed Unbonded length (mm)</th>
</tr>
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<tbody>
<tr>
<td>280</td>
<td>285</td>
</tr>
<tr>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>300</td>
<td>285</td>
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Table 1: Diagnosis of unbonded length

Many thousands of load diagnosis tests were carried out on mine rock bolts and other anchorages installed in the test site at Swynnerton and at the natural sandstone site at Kibblestone.
Figure 2 shows the diagnosis of load in one of the test bolts. Again the GRANIT system is able to diagnose the load level with good accuracy over a large load range. This test programme gave confidence that the GRANIT system could be used to diagnose the unbonded lengths of the bolts in the roadway of coalmines and the load under the head of these bolts.

Full Scale Trials at UK Coal

Having proved that the GRANIT system could accurately determine unbonded length and load, the system was tested underground on a large scale at UK Coal’s Thoresby Colliery, in a Longwall main access roadway and panel main gate. Tests were undertaken in two sectors of the mine and at different distances along the roadways in the two sectors. In one sector the bolts had been installed about two months prior to the testing. In the other sector the bolts had been installed about 30 months prior to testing. The aim was to see if there was any substantive difference between the two regions with different ages of bolts.

Data was taken to allow diagnosis of the unbonded lengths of the bolts in the roadway of coalmines and the load under the head of these bolts.

Unbonded Length

The results of the tests to ascertain unbonded length showed that there was a large distribution of values of unbonded lengths, which was inconsistent with the design specification required for coal mining practice [2].

As can be seen in Figure 3, in this region of the mine, there is a wide variation in unbonded lengths. In fact two of the bolts have unbonded lengths of around 500mm. The reason for these large unbonded lengths may be due to fissuring in the rock resulting in leakage of the resin into the fissures during installation, resin loss at the mouth of the hole during or shortly after installation or simply oversize drilling causing short-run of the displaced resin down the hole.

This is a very important result for two reasons. Firstly it shows that, although these bolts visually met the design criterion for total/full length encapsulation, full bonding had not been achieved over the full length. This is important for the prevention of shallow roof falls. Secondly it shows that GRANIT can be used as an effective tool for the monitoring of the installation practice of the rockbolts. The use of the GRANIT system in this way will enable bolts that are outwith specification to be identified and any necessary remedial action taken. Economies in cost and lost production could be gained as a result of remedial action being taken based on hard data and hence firm knowledge.

Difference in unbonded length distributions in different areas of the mine

In addition to the fact that some bolts were identified as possessing large unbonded lengths, further examination of the data showed that there appeared to be differences in the bolt characteristics in different parts of the mine. This can be seen clearly in Figure 4. This plot shows the distribution of unbonded lengths in 3 sections along a roadway. The mean unbonded length in each section is circled, and the length of the horizontal line indicates the spread of the data in the region.

Exception testing

GRANIT tests were also taken on bolts to determine load. Once a number of bolts had been tested it is possible to identify bolts which are significantly different from the others in the vicinity i.e.: exception testing. It is then possible to look at related factors to deduce cause, such as local geology, adjacent workings or installation practise and procedures, as a basis for remedial action.

In this context, exception testing at Thoresby resulted in the identification of a number of bolts with inordinately long unbonded lengths low loads and bolts diagnosed as having very high loads. A
picture of the loading in the roadway can be built up by plotting response frequency/load against location of the bolt(s) in the roadway and this approach is shown in figures 5 and 6.

In another aspect of these trials, two different groups of bolts of different age were tested to determine the effect of bolt age on vibration response-if any. The bolts tested in the main access roadway were approximately 30 months old and those in the panel roadway approximately 2 months old. The vibration response signatures were seen to be internally consistent in both age groups and there was no discernible difference in signature between the two groups, except where unbonded length is concerned-as noted above.

Discussion and Implications

By monitoring the bolts in a region of a mine, the data produced by the GRANIT system can be used to assess changes in the loading pattern of the bolts, which would give indications of incipient roof movement. Regions of higher indicated load can then be checked on a more regular basis-with the potential for improved safety.

One of the early indications from the testing of 264 bolts in the two different area of Thoresby Colliery was the fact that although the bolts were seen to be in compliance with installation quality control criteria and with regulations, GRANIT proved conclusively that there was a high proportion of bolts with a measurable free length, notwithstanding full encapsulation to the mouth of the hole.

These bolts were not intended to be passive bolts but in practice were acting as such. Also, perhaps not coincidentally, these bolts were clustered in an area of roadway showing marked deformation and heavy loading. In civil engineering practice, active bolts would be specified for typical roof support bolting/anchoring system, with a significant degree of pre-stress applied to the anchors or bolts.

It should be noted that the benefits of pre-stress can still be obtained, even though full encapsulation to allow transmission of the horizontal stress field at all horizons in the bolted zone is required.

The use of GRANIT has shown that this is an issue the industry needs to address, as the current non pre-stress anchor methodologies are not gaining the full degree of possible support mobilisation which is obtainable by the application of pre-stress.

Recent Developments

The system described in this article is being continuously developed for use both in mining applications and also in other main-stream civil engineering applications. Tests on single tendon strand anchorages similar to the cable bolts used in mining and elsewhere have proven successful [6]. Testing has also taken place at a number of sites to assess the application of GRANIT to large bar bolt anchorages and the initial results show the system is applicable.

The system has been streamlined to make it easily portable/operable by one man. The impact device has been reduced in size and weight to improve handling, ease of connection to the bolt/anchor head and to improve productivity. This will also reduce air consumption and allow the system to be run readily from small compressed air bottles. In parallel, the data acquisition system is being miniaturised by replacing the laptop computer used currently, by a handheld device with sufficient memory to allow data from several shifts to be stored before down-loading.

For hazardous conditions, intrinsically safe handheld devices are available.

As can be seen, it is clear that GRANIT can identify the most critical cases of high load, indicating potential roof movement and can identify long unbonded lengths with the associated concerns of shallow falls.

Figs 5 & 6 also show clear trends of increasing response frequency along the roadway. These corresponded precisely with increasing visible loading in the roadways and associated increasing deformation along the roadways in those locations.

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cracking are possible causes. Research work and practical experimentation is proceeding into determination of tendon length by the GRANIT system and early results are very promising. Work is also proceeding into the application of GRANIT to the detection of loss of section due to corrosion.

The scope and accuracy of the mathematical model are being continuously improved and expanded.

At the practical level, development is taking place to reduce the size of the kit still further, and to further improve the productivity of the system in terms of anchorage test cycle times.

The system is easy to use, is very portable and is in practice a one man operation, applicable over a wide range of bar anchorage types and of strand anchorages. The productivity of the system in terms of number of anchorages able to be tested in a typical day or shift is high. Thus the system is a major step forward in anchorage condition monitoring. It complements and enhances the monitoring spectrum-between visual examinations and lift off tests and/or special instrumented anchorages. In any case, instrumented anchors give only a snapshot of conditions in their immediate vicinity and in quantity they are inordinately expensive and difficult to deploy. GRANIT can enhance and/or reduce the need for these costly techniques.

GRANIT can assist managers and owners of facilities employing anchorage systems in the provision of hard data on their installation quality and on-going performance. The importance of this with regard to the discharge of statutory and corporate responsibility in terms of safety and profits cannot be overstated.

GRANIT is now available to conclusively determine anchor characteristics and provide hard data on quality and performance, in a rapid, productive and low cost environment. This is done non-destructively and non-invasively and without dislocation or disruption to on going operations.

GRANIT is being continuously developed in order to be able to offer a comprehensive capability to provide all the information needed to satisfy stakeholders concerned with the safe and efficient application of anchorage systems.

For all enquiries regarding the application of GRANIT to bolts in mines or anchors generally, please contact:

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