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INNOVATIONS IN MINE ROADWAY STABILITY MONITORING USING DUAL HEIGHT AND REMOTE READING ELECTRONIC TELLTALES

David Bigby¹, Keith MacAndrew¹ and Ken Hurt¹

ABSTRACT: Rockbolting telltales are now an internationally established means of providing preemptive warnings of roof falls. The dual height telltale, providing an immediate visible measurement distinguishing between movement above and below the rockbolted height, is the most widespread version. The dual height telltale was first developed by British Coal in the early 1990's as rockbolting was introduced to replace steel arch support and the success of this support system in deep coal mines has been widely ascribed to the use of this safety device. Since its adoption, many permutations and improvements on the basic design have been developed and applied worldwide to suit different mining circumstances; for instance, triple height telltales are commonly used where a combination of roofbolts and longer tendons are installed at the face of the heading. The choice of appropriate movement action levels is vital for safety. Experience has also shown that systematic management of the application of the telltale warning system is required to ensure that appropriate action (usually the installation of additional support) is taken in time when action levels are exceeded. In Australia, this is exemplified in the TARP approach. Another major development has been an intrinsically safe remote reading dual height telltale system which allows up to 100 electronic telltales to be connected with a twin core cable and read, using either a portable readout, from the end of the roadway, or a surface PC via a telephone cable connection. In the latter configuration, a real time display of roof condition is obtained whilst retaining the immediate visual indication underground. A recent development is the “Autowarning” telltale. This provides a warning of impending goafing in depillaring operations via high visibility, flashing LEDs. The paper describes these and other telltale developments and provides case histories of their application worldwide, including UK, India, and USA.

INTRODUCTION

The term ‘telltale’ is used to denote a strata extensometer which incorporates a visual indication of strata movement into an excavation and is intended to provide a visible warning of excessive ground deformation.

The application of telltales is primarily in rockbolt supported mine roadways to give warning of excessive roof or rib movement. Rock Mechanics Technology (now part of Golder Associates (UK) Ltd) has developed telltale devices ranging from the simplest mechanical types through to the latest electronic and auto warning configurations. These products and their applications worldwide are described in this paper.

DEVELOPMENT AND APPLICATION OF THE MECHANICAL STRATA MOVEMENT TELLTALE

Single height telltales

The principal application of telltales is to monitor strata deformation in rockbolt supported roadways. This is necessary because visual indications of excessive movement are not always present.

At its simplest, a mechanical telltale consists of a strata movement indicator (usually with coloured bands and/or graduations) positioned in the mouth of a drilled hole and attached to an anchor installed up the hole. The earliest telltales were simply longer bolts, point anchored above the support bolt horizon, and left protruding from the roof to indicate movement within the bolted horizon. These suffered from the disadvantages of limited monitored height and false readings caused by roof shear, which can result in the telltale bolt being trapped along its length and pulled down with the roof. A

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typical single height telltale now consists of a reference tube, an indicator tube, a stainless steel wire and a spring anchor positioned at twice the bolted height, as shown in Figure 1.

![Figure 1 - The single height telltale](image1.jpg)

One of the problems with purely mechanical telltales installed in the roadway roof is the difficulty in reading the graduated scale in high roadways. This problem has been overcome for single height telltales by developing the Rotary Telltale (Figure 2). The device converts roof movement into rotation of a pointer round a dial and magnifies the movement by a factor of fifteen. This has been developed to meet a South African requirement for a routine monitoring system that is easy to install, easy to read, accurate to better than 1 mm and low cost. Small movements can be read easily with the reading visible from below, even in a 5 m high roadway. The dial face is subdivided into coloured bands corresponding to chosen action levels. These rotary telltales are currently being used in several South African mines. The rotary principle has been patented and a low cost design is currently manufactured under licence in RSA.

![Figure 2 - The rotary telltale](image2.jpg)

**Dual height telltales**

A shortcoming of single height telltales is that they do not provide information on the position of any movement occurring within the monitored length. Movement above the rockbolted height is an important parameter, which can indicate that the bolt system is failing to provide effective support. The type of additional support required in response to movement above the bolted height will usually differ from that needed for deformation within the bolted height (long tendons or standing support for the former compared with additional bolts for the latter), and ideally a telltale should distinguish between movement in these zones.
Telltale with two or more anchor positions, including the most commonly used types in Australia, have been introduced to do this. However, although it is possible to determine the movement magnitudes above and within the bolted height using additional anchor positions, without the concentric indicator arrangement described below, it is still necessary to compare and subtract the readings in order to do this. This defeats the primary role of the telltale in providing an immediate visible warning, particularly of movement above the bolted height.

In order to facilitate the introduction of rockbolt support into UK coal mines, staff working for British Coal overcame this problem by devising the dual height telltale, which in 1992 was patented in Britain and coal mining countries worldwide, including Australia (Figure 3). The key feature of the dual height telltale is that it directly indicates movement both within and above the bolted height. This is achieved using two anchor positions in conjunction with the concentric design of the movement indicators (Figure 4).

The anchorage arrangement means that the A indicator directly displays roof deformation within the bolted height and the B indicator suspended below directly shows deformation above the bolted height, without any necessity for calculation by the observer. The A indicator anchor is normally positioned approximately 0.3 m below the top of the rockbolts to coincide with the boundary of the fully reinforced zone. The B anchor position is typically at least twice the rockbolted height. A full description of the development of this device is given by Bigby and DeMarco.

In the UK, dual height telltales are installed at maximum intervals of 20 m along all rockbolted roadways, with the B indicator anchored at least twice the bolted height above the roof horizon. The telltales are observed by the District Official at least once during his shift and any indicating excessive movement noted on his statutory report. Similar practices have been adopted elsewhere where rockbolting is used in relatively difficult mining conditions involving weak roof and/or high local rock stresses, for example in Europe and Canada. A ground control safety procedure based on the use of telltales has been widely credited as a major factor in the successful introduction of rockbolting in these conditions.

**Telltale action levels**

The use of telltales as an effective safety warning device requires procedures detailing how they should be deployed and read and specifying what action should be taken, depending upon the level of roof dilation measured. This is embodied in the Australian TARP (Trigger Action Response Plan) concept.

In the UK specific guidance is provided in a document published by the UK Health and Safety Executive (HSE). This document recommends that the Colliery Manager should specify procedures for auditing of routine monitoring devices in rockbolted roadways, actions to be taken and the person...
responsible for taking the action. There must also be a “Schedule of measurement zones and measurement frequency”. In “Inbye” areas, telltales should be observed and reported each shift and measured and recorded at least weekly. In areas of known or suspected instability they need to be measured and recorded at least daily and in other areas they should be measured and recorded at least once each month. Figure 5 shows a typical graph of a set of weekly Dual Height Telltale data for a gateroad, showing where remedial action has been taken.

Since their introduction the coloured bands on standard UK dual height telltales have been green (0-25 mm), yellow (25-50 mm), red (50-75 mm) and, by default, action to provide additional support has to be taken after each 25 mm of movement on either indicator. The rationale behind these action levels was drawn from a number of sources. Firstly, there was French experience that 100 mm of total roof movement could be tolerated before roof failure. Thus a warning at 25 mm and action at 50mm would seem appropriate for an unstable time trend (as described by Stillborg). This was supplemented by sonic extensometer data from Australian mines, provided by ACIRL during the introduction of rockbolting to the UK, which indicated similar levels of movement prior to roof falls developing. Secondly, it takes into account the typical strain level to failure of coal measures rocks of around 4 mm/m. This translates into 10 mm displacement on either indicator for a 2.4 m rockbolt, if the strain were spread throughout the monitored height. The 25 mm transition to yellow thus indicates a mean strain of 10 mm/m throughout the monitored zone, which would indicate that significant zones of softening are likely to be forming in the monitored column.

As experience with rockbolting in the UK developed and, in particular, a large quantity of sonic extensometer and telltale data was gathered, more site specific action levels were developed. Examples of determining site specific action levels are given by Kent, Cartwright and Bigby. Although standard dual height telltales still use 25 mm coloured bands, some mines find it necessary to take remedial action at deformation levels below 25 mm and in these cases, specialised telltales with different widths of coloured band may be used. Lower action levels have been needed, particularly for the B indicator, where the roof is more brittle than usual and/or where the levels of in-situ horizontal stress are low. In lower horizontal stress conditions, loosened roof is less likely to be clamped in place by roof shortening in the way that it is under high horizontal stress, leading to a danger of roof falls at lower levels of roof dilation.
Shear detection

Although the wire used in the dual height telltale to suspend the indicators is less susceptible to being trapped by roof shear than the rod type telltales formerly used, this can still happen in actively shearing strata, resulting in false readings. A shear detection facility is now incorporated as standard in Golder RMT mechanical telltales to allow any trapping of the wire in high shear conditions to be easily detected. The addition of a spring attachment at the wire/anchor joint allows the indicators to be pulled downwards slightly, following which they should return to their initial position. If they resist this downward pull, then the wires are trapped.

Other mechanical telltale types

Since the adoption of the mechanical telltale, many permutations and improvements on the basic design have been developed and applied to suit different mining circumstances. The Triple Height Telltale (Figure 6), for example was developed in response to the increasing use in the UK of steel wire strand flexible rockbolts as an additional support to standard full column resin anchored rockbolts. A typical UK roof bolting pattern employing flexible bolts would include a mixture of 2.4 m full column resin anchored rockbolts (at a minimum density of 1 bolt per square metre) and 4 m, 90% column, resin anchored, flexible bolts. As its name suggests, the Triple Height Telltale has an additional concentric indicator when compared to the Dual Height Telltale. The A indicator (nearest roof) is anchored 0.3 m below the top of the rockbolts, the B indicator (middle) is anchored 0.5 m below the top of the flexible bolts and the C indicator (lowest) is anchored a minimum of 5 m above the roof horizon or 1m above the flexible bolts if they are longer than 4 m. This allows the mine personnel and particularly the support engineer to easily determine whether any measured roof dilation is occurring within the bolted height (A indicator), in the roof zone reinforced by flexible bolts alone (B indicator), or above the reinforced height (C indicator) and so allows the most appropriate type of remedial support to be applied where required.

Figure 6 - The triple height telltale

Many other permutations of the telltale are in use in smaller quantities for specialised applications. These include special extended reference tube designs to bring the indicators to a lower height in high roadways. The ribside indicator telltale is an example. Here a Bowden cable type mechanism is used to transfer the dual height indicators to the ribside to enable easy reading. In addition to a wire for each indicator position, a third wire is used within the cable sleeve to indicate the reference tube position. This eliminates any error due to wire/sleeve expansion or contraction.

With conventional telltales, wire tensioning relies on the weight of the indicator. This makes them less suitable for use in deforming ribsides and consequently spring loaded versions have been developed for this purpose.

Worldwide applications

Over the last twenty years the mechanical telltale has been adopted in a large number of deep coal mining industries worldwide, both in its standard dual height form and in a number of alternative forms developed to meet the specific local mining and geotechnical environments. They are now in use in a significant number of US mines. This includes the triple height telltale, used where multiple lengths of
reinforcement are installed concurrently. The Single Height Rotary Telltale is used widely in South African room and pillar coal mines where low levels of movement in high roadways must be identified and reacted to. The mechanical dual height telltale is also being used in significant numbers in Indian, Indonesian and Norwegian coal mines.

THE ELECTRONIC DUAL HEIGHT TELLTALE

Concept

Although the introduction of the dual height mechanical telltale represented a significant step forward in mining ground control safety practice, it is limited by the need for frequent visual reading and the associated difficulty in obtaining consistent and accurate readings especially in high roadways. In addition there is a requirement for remote monitoring of potentially unstable or inaccessible areas. Consequently Golder RMT has developed an intrinsically safe electronic extensometer and telltale system which includes an electronic version of the dual height telltale. The contactless electronic telltale combines high accuracy with low cost and local or remote reading options.

The design specification for the Golder RMT Remote Reading Telltale (RRTT) system contained a number of essential features, namely;

- low cost transponders and connectors, such that the overall cost of ownership remains acceptable,
- simple installation, preferably by the heading team, and as similar as possible to standard telltales,
- dual height transponders,
- retention of the visual reading characteristics of standard telltales, both by observation of the colour bands and reading of a millimetre scale,
- no batteries or separate power supplies for individual transponders,
- underground diagnostic features to allow easy identification of faulty transponders
- easy replacement procedures for faulty transponders and avoidance of the necessity to carry large stocks of spares
- automatic system recognition of additional transponders when they are connected
- automatic generation of warnings when action levels are exceeded.

The final system design achieved all the above requirements.

Measurement principle

The basic measurement principle used is that the inductance of a coil varies depending upon the position of a ferrite rod within that coil. The on-board electronics convert the inductance to a frequency which is transmitted down the line when the transponder is addressed. This has the advantage over potentiometric devices of being contact-less, requiring very low power and not being susceptible to moisture. The signal conditioning electronics are well suited to an analogue, frequency based interrogation system. Numerous forms of this electronic extensometer are available based on a single basic transponder design with a range up to 75 mm at 0.1 mm resolution. Transponders can be interrogated remotely or locally with a portable readout unit which also provides the power source. They can be read separately, or connected together by a single cable to a central monitoring point.

Telltale transponders

The telltale transponders (Figure 7) are available in single height or triple height versions as well as dual height. They are designed to fit into 35-45 mm diameter boreholes with a stainless steel wire attached to each borehole horizon using a simple spring anchor. These wires transfer the relative axial displacement of the rock to the measurement mechanisms located within the transponder body. They incorporate concentric visible indicators with 25 mm coloured bands and millimetre scales to allow
direct visual reading, as well as the electronic measurement system. In each transponder the two ferrite rods are directly connected to the A and B indicators respectively as shown in Figure 7.

Electronic telltale transponders are outwardly similar to Golder RMT’s visual telltales and are designed to be used in vertical holes only. The alternative wire extensometer transponders do not have the visual reading facility but have the advantage of a spring tensioning mechanism, allowing them to be deployed in non-vertical boreholes. These are available in one, two and four height models.

![Figure 7 - The electronic telltale transponder](image)

**Remote reading system**

The remote reading dual height telltale system allows up to 100 electronic telltales to be connected with a twin core cable and are read using either a portable readout, from the end of the roadway, or by a surface PC, via a telephone cable connection (Figure 8). A highly reliable frequency based system is used by the local communications unit to address and interrogate each transponder. Each transponder has a specific address represented by a tone. When that tone is placed on the line by the interrogation unit, the relevant transponder responds with two tones representing the A and B indicator readings.

The transponders can be installed using a simple crimp connection without the need for specialist staff. Underground, the only power supply required is a 12 volt supply to the interrogation unit. Individual transponders draw their low power requirements from the same line that carries the reading and addressing data signals. There can be up to 2 km of cable between the underground reading position and the most distant transponder. The remote PC can be up to 10 km from the underground monitoring unit. One PC can monitor up to 4 sets of transponders. In this configuration, a real time display of roof condition is obtained whilst the immediate visual indication underground is retained. The one, two and four height roof and rib extensometers and convergence meters can also be interfaced to the system.
Figure 8 - Remote reading telltale system

Instrument reading and data analysis

The main function of the RRTT system is to provide real time data on the state of all the connected telltales to allow remedial action to be taken before a roof fall develops. However it also acts as a data logger allowing historical data to be stored for subsequent analysis. This is achieved in a number of ways. The raw frequency data is stored in both text file and random access formats at the configured scan rate. This data can be accessed by the “Boltmon” software program running on the surface PC or read into an Excel spreadsheet for plotting and analysis. The Boltmon program obtains readings consecutively from the system transponders and, once configured, continues to run in the background with no need for further operator intervention. “Boltmon” also provides a graphical display of selected transponder readings in real time and other diagnostic tools.

The main user interface is provided by the “RRTelltales” program. This accesses the frequency data stored by “Boltmon”, converts readings to millimetres of movement and displays them on the screen in tabular form. The “RRTelltales” program also stores the recorded data in a random access file which can be accessed for subsequent uploading into a database by a purpose written program. An “alarm” level can be set for each of the monitored telltale indicators, for both absolute movement and rate of change. This is achieved through a set of global, default values set for the whole system which can be overridden with a local set of values for each individual telltale.

Intrinsic safety certification

The system received European ATEX Intrinsic Safety Approval in mid 2000 and has just received Australian IECex approval for use in potentially explosive atmospheres.

Application examples

German coal mine roadway

The first full-scale application of the system, employing 67 telltales, was in a 1300 m longwall maingate access tunnel in a German coal mine in 2001. This was a rectangular section rockbolted roadway serving a retreating longwall face. The Remote Reading Telltale System was used in order to obtain detailed information on roof behaviour in the front abutment area and to help to understand the performance of the roof and support system behind the longwall. This particular configuration differed from a “classic” RRTT system installation in that:
The transponders were not installed at the face of the roadway during development, but in several batches after the roadway had been driven. However the existing monitoring systems (mechanical telltales) indicated that very little roof movement had occurred prior to installation.

The desire to maintain readings behind the face meant that great care would be needed to prevent damage to the transponders and cable in the face-end area.

An initial pilot installation with 10 transponders allowed any unforeseen problems to be identified and corrected prior to the full installation.

Following this, the full system was installed during June 2001 with a total of 67 transponders installed between the 123 and 1108 metre marks. The face commenced production on 25th June 2001. The face passed the last transponder on the system in October 2002. During the period of operation the scan rate was set at 20 minutes such that the system display was updated and data was recorded from all connected telltales 72 times a day.

An example of the main “RRTelltal es” screen from this site is shown in Figure 9. The connected telltales are shown in the first column under “Telltale Details”. In this case the roadway name (1830) and the metre mark where each telltale is installed are shown. The right hand half of the screen shows the current condition of each telltale. This is shown in terms of A, B and Total movement in millimetres, rate of movement (ROM) for A and B, in millimetres per hour, and the alarm condition for A, B, Total and ROM. The background colour in the A and B reading columns corresponds with the visible coloured band on the transponder itself (< 25mm green, < 50mm yellow >25mm, red >50mm). The readings on this display are updated at the scanning rate set for both “Boltmon” and “RRTelltal es”. The remaining columns on the left hand side of the screen show the roof displacements for each telltale for previous days during the current week. The operator can scroll back for up to one week to allow recent trends to be examined.

Maingate roof conditions ahead of the longwall were excellent throughout the face retreat. The face did not generally begin to affect the roof until it was less than 20 m away. Figure 10, which shows detail of telltale data from Station 52 at 862 m, indicates that movement did not begin in this case until the face was some 16 m away. This graph shows each 20 minute data point and it can be seen that this level of detail shows several interesting aspects of roof movement which could only be observed with a monitoring system of this type. In particular, the “B” telltale shows roof movement occurring in several
distinct steps of up to 4 mm. The “A” indicator also shows these steps but, except for the 4 mm step on 7th January, they are generally of a lesser degree.

![Figure 10 - Remote reading telltale data – station 52 German coal mine roadway](image)

This first trial demonstrated the potential of the new system in obtaining data on roof deformation processes as well as acting as a real time warning system to prevent roof falls in strategic rockbolted roadways.

Relatively sudden steps in movement as the face approached were seen on many of the telltales in the roadway and similar patterns of movement have since been observed at other sites, confirming that they are a real phenomenon. An example from a current application site, where the telltales are scanned every 10 minutes, is shown in Figure 11. Here, a sudden immediate roof displacement of approximately 8 mm occurred, followed 70 minutes later by a second displacement of another 6 mm. No additional movement above the bolted height occurred.

**UK Coal Mine – Monitoring of Sealed Access Road**

A remote reading telltale system, comprising 13 dual height telltales, was installed in July 2005 to monitor a faceline access road at 800 m depth in a UK mine. This roadway was to be temporarily sealed until required to prevent spontaneous combustion and the system was needed to remotely monitor the condition of the sealed section of rockbolted maingate.

The installed system operated reliably over the period when the roadway was inaccessible and the relatively low movements, confirming stable conditions, allowed the mine to leave the sealed off face unsalvaged until the face equipment was required.

The previously sealed lengths of gate road and face line were re-accessed during April 2006, allowing the telltale visual readings to be checked against those displayed on the surface PC. This confirmed that the system had maintained its accuracy to within a millimetre over the 9 month operational period during which the roadway had been sealed. The maximum movement in the rockbolted maingate had occurred 5 m outbye the face line junction. This was 46.5 mm on the A indicator (bolted height) and 1.1 mm on the B indicator (above the bolts). The face was successfully salvaged following re-access of the district and the installation of long tendon support in the face end junctions.
Figure 11 shows data for four of the telltales over the 9 months when the roadway was sealed, again illustrating short term increases in movement rate presumed to be caused by the failure of individual strata units.

**Indonesian room and pillar coal mine**

Remote reading telltales are currently being used to monitor partial pillar extraction operations in an experimental Indonesian room and pillar coal mine. In this case the portable readout is used to connect to the chain of transponders underground. The readings are then transferred to a spreadsheet for plotting.

The depth of working is 100m and the seam thickness 2.5 m. The mine is being developed as linked main roadways off which angled run outs are driven. Additional coal is obtained by mining out "pockets" from one side of the run outs. The stability of the run outs and laterals is being monitored as this process continues.

The support being installed consists of 2.1 m rockbolts with additional long tendons in junction areas, and the telltale anchors in the roadways are being installed to 1.8 m (A) and 8 m (B). Figure 13 shows the position of the instruments in the run outs and Figure 14 typical telltale results as mining proceeds. The Figure shows additional movement within the bolted height developing and then stabilising as pocketing of successive run outs takes place. No significant movement above the bolts has taken place.

**US gas storage cavern**

A remote reading dual height telltale system is currently being used to monitor roof stability during development of a gas storage cavern in the USA. Sixty four telltales have been installed at 15 m intervals in a room and pillar type layout. The system is currently live and can be monitored by the engineers in real time on the internet. Figure 15 shows a screen shot taken at Golder RMT of some of the telltale readings on 10th November 2009. The instrument readings confirm good stability with very low readings and none above action levels.
Figure 12 - Monitoring results from sealed access road in a UK coal mine

Figure 13 - Monitoring plan including remote reading telltales – experimental Indonesian coal mine
Figure 14 - Remote reading dual height telltale data – experimental Indonesian coal mine

Figure 15 - Screenshot of telltale data – US gas storage cavern

THE AUTO WARNING TELTTALE

The auto warning telltale is a development of the electronic telltale concept, still meeting intrinsic safety requirements, and providing an additional high visibility warning of roof movement via flashing light.
emitting diodes (LEDs). Intended applications include pillar extraction areas in room and pillar workings to give warning of impending goafing. This is based on the premise that goafing events are preceded by smaller scale roof dilation which will be detected by the telltale. It is used in preference over roof to floor convergence monitoring which is susceptible to triggering by floor heave. In order to incorporate this additional warning, the telltale design includes a 1.5 volt alkaline primary cell supply and LED configuration housed within the existing telltale’s plastic drip tray moulding (Figure 16).

Figure 16 - Auto warning telltale

The Autowarning electronic module powers the LEDs in a flashing sequence when a pre-set level of telltale movement is reached. A minimum of two LEDs are employed in the latest version with an option for four LEDs for well lit areas. The flasher module has an operational ‘flashing’ life of over a month.

The auto warning telltale is currently being used in the first fully mechanised pillar extraction bord and pillar mines in India. Telltales are being installed in each junction and roadway midpoint prior to extraction operations (Figure 17). The telltales used are single height types with the anchor position at 10 m into the roof and a trigger level of 5 mm. This combination of large monitored height and low trigger level is intended to ensure that the telltale warning is triggered prior to a major goafing event. The auto warning telltales are reported to be working as planned with the LEDs flashing as roof failure commences.

SUMMARY

The rockbolting telltale has been a major contributor to ground control safety since it was developed in its present form almost twenty years ago. The more recent development and proving of the electronic telltale, with its remote reading capability and improved accuracy, allows intensive monitoring of bolted roadway deformation to be undertaken automatically. The information gained, if properly assessed and used, can play a major role in ensuring safety, optimising support design and confirming the stability of strategic roadways. There is no doubt that the role of mining geotechnical instrumentation of this type will continue to grow, with the ultimate aim of eliminating all falls of ground.
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