Recent Experience Using Telltale Roof Monitoring Systems

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ABSTRACT

Extensive arrays of telltale roof monitoring instruments were recently installed in a Mexican copper mine and a large underground mined storage facility in the eastern U.S. The data were used to evaluate roof stability during development and retreat mining and after installation of supplemental supports. Both manual-reading and automated systems were employed and consisted of up to 64 instruments. This paper will discuss the practical issues involved with installation and monitoring, including reliability and maintenance. Examples will be given for telltale response in relation to known events affecting roof stability, including nearby pillar extraction roof caving, installation of supplemental cable bolts, and separation of the immediate roof layer. The strategy for processing the large quantity of data, presenting the data for review, monitoring the system remotely, and identifying and reporting critical events will be described.

INTRODUCTION

Telltales have been used for many years with many varied applications. They are relatively inexpensive, easy to install and interpret, robust, and adaptable. The term "telltale" generally denotes a strata extensometer that incorporates a visual indication (and warning) of strata movement. The most common dual-height telltale (Figure 1) was developed by British Coal in the early 1990s as roof bolting was replacing steel arch support (Bigby, 2001). Dual-height telltales provide immediately visible measurements, distinguish between movements above and below the bolted height, and are an established means for providing preemptive warnings of roof falls.

Many improvements and modifications on the basic design have been developed to adapt to different mining conditions. For example, triple-height telltales are commonly used where roof bolts of different lengths are installed. The standard manually-read telltales are limited by the difficulty of obtaining frequent, consistent, and accurate readings, especially in high openings. The instruments may also be located in unstable or inaccessible areas. Consequently, an intrinsically safe electronic telltale system was developed that combines high accuracy and both local and remote reading options. The system supports a network of up to 100 dual-height telltales on each of four separate branches. The instruments are connected with a two-conductor cable and can be read both underground, using a portable readout, and on a surface computer (Figure 2). The automated system still provides the visual warning indication underground.

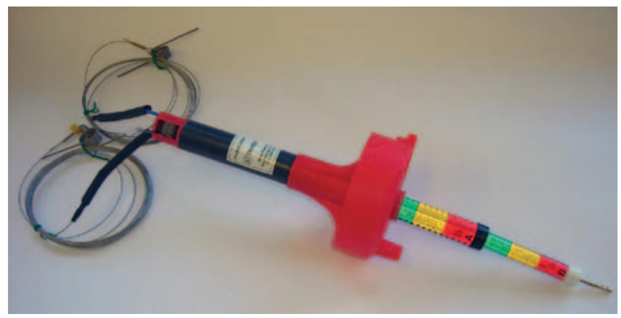

Figure 1. Dual-height telltale.

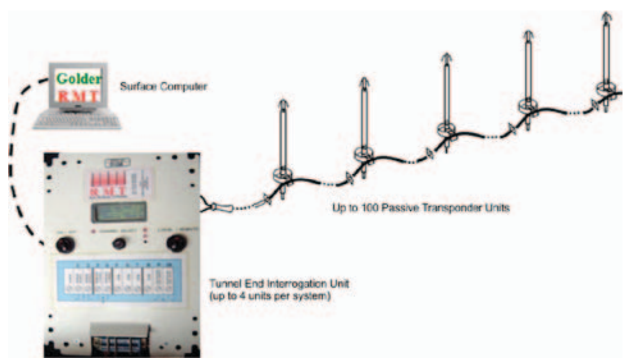

Figure 2. Automated telltale network installation.

At its simplest, a mechanical telltale consists of one or more strata movement indicator tubes (usually with colored bands and/or graduations) nested at the collar of a vertical borehole and attached by wires to anchors installed up the hole. The dual-height telltales were developed to detect movement both within and above the bolted interval, since movement above the bolted height can indicate that the bolts are failing to provide effective support.

Although conventional multi-point borehole extensometer (MPBX) instruments can identify these same movements between anchors, it is necessary to compare and subtract the readings. The nested telltale indicators provide this comparison automatically, without the necessity for calculation by the observer.

The default range of movement of the colored bands on standard dual-height telltales are green (0–25 mm 0-1 in), yellow (25–50 mm (1-2 in)), and red (50–75 mm (2-3 in)). Prior French experience indicated that 100 mm (4 in) of roof movement could be tolerated before roof failure; thus a warning level at 25 mm and action level at 50 mm (2 in) seemed appropriate. The typical strain level at failure of coal measure rocks is around 0.004, which translates into 10 mm (0.4 in) of displacement on either indicator for a 2.4-m (7.9-ft) rock bolt. Thus, the 25 mm (1 in) transition to yellow corresponds to a strain of 0.01, which would indicate that significant softening is occurring in the monitored interval between anchors. The default color ranges should not be relied on exclusively, and different site-specific criteria may be more applicable at different locations.

The electronic telltales are installed using the same anchors and in the same size boreholes as the manual instruments. They incorporate the same concentric, visible indicators with colored bands and scales to allow direct visual reading, as well as the electronic measurements. The basic measurement principle is the change in inductance of a coil depending upon the relative displacement of a ferrite rod within the coil. The inductance value is transmitted as a frequency along a simple two-wire cable. The remote reading system allows up to 100 electronic telltales within a 2 km (1.2 mi) area to be connected to an underground interrogator and power supply unit, then to a surface computer via a telephone cable connection. The monitoring software offers a variety of features but basically displays real-time data (including alarms) on the screen and saves the data to the hard disk.

INSTALLATION AND DATA ANALYSIS

Recent projects include a secondary extraction copper mine in Mexico and a room-and-pillar storage cavern being constructed in shale in West Virginia. The copper project involved three-position manual telltales installed in and around a test section to monitor the effects from pillar extraction mining. The storage cavern involved two-position manual telltales initially and was upgraded to a more extensive automated system once the initial development was completed. The telltale data were combined with other convergence measurements, numerical modeling studies, and visual observations to better understand the behavior of the roof and effects from mining and various roof support systems.

The two monitoring sites represent very different conditions, owing to different rock types, opening sizes, mining procedures, and time scales. The following sections will describe specific conditions at each site and relevant events that occurred during installation and monitoring of the instruments.

Site 1—Copper Mine

The instrumentation was installed in a test mine as part of a mine feasibility evaluation of a planned copper mine located in Baja, Mexico. Figure 3 is a map of the test section showing instrument locations relative to development cuts and retreat wing cuts. Also shown are the dates when the various excavation stages occurred. Access to the mine was achieved through a horizontal adit, and the cover depth over the test section was about 100 m (328 ft). Development mining was accomplished using a roadheader machine, and the instruments were installed near the face, as soon as possible after the roof support was installed. Openings were 5 m (16 ft) wide by 4 m (13 ft) high. Roof supports consisted of 2.1-m (6.9 ft) full-length resin-grouted bolts installed on 1.2-m (3.9 ft) centers with steel straps and mesh. Figure 4 shows a typical installation of a triple-height telltale. The instrument locations were selected to monitor both pillared and non-pillared areas. The anchors were installed at depths of 1.8 m (5.9 ft) (within the bolted zone), 4 m (13 ft), and 6 m (20 ft).

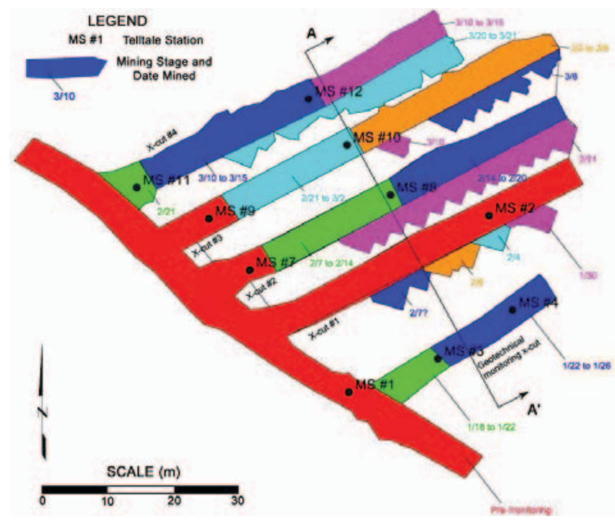

Figure 3. Mine layout and telltale locations – Copper Mine.

Figure 4. Typical installation of triple height telltale.

The stations were read daily for about 1 week immediately after installation and for another week during pillaring operations. The data were entered into Excel™ for archiving, analysis, and plotting. Figures 5 and 6 show typical roof movement plots for the development and pillaring periods. The data show increased movement between anchors when the side drifts were developed and the pillars retreated but do not show a significant change when pillaring was conducted. Figure 7 shows the same data set as Figure 5 but with entry closure also plotted. The entry closure was substantially greater than the roof movement (sag), and surveyed floor elevations do not show any floor heave. Thus, the room closure was due almost entirely to deformation of the pillars. The roof and pillar material was a breccia with a high clay content and exhibited significant plastic deformation over time, eventually flowing into the entries. The telltale data showed movement between all anchors, consistent with uniform squeezing of a massive, non-laminated roof.

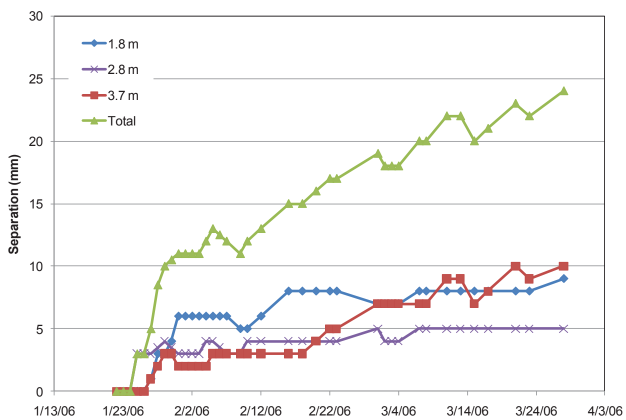

Figure 5. Plot of roof movement for station 3 – Copper Mine.

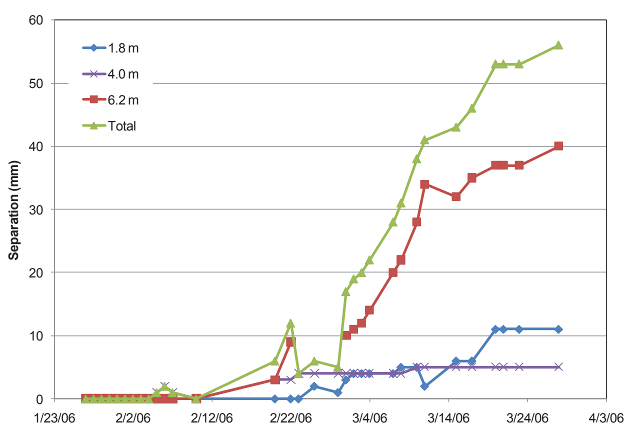

Figure 6. Plot of roof movement for station 9 – Copper Mine.

There was some concern regarding possible anchor creep in the soft clay material; however, the data appear stable over the duration of the monitoring period and no creep behavior was detected. The greatest difficulty was in obtaining consistent readings, and the data variations were generally caused by personal biases, awkward reading angles, and data-sheet recording errors. There were no instrument failures or unusual difficulties with either the installation or operation of the telltales. The data were used to calibrate numerical models which were ultimately used for the design of production pillar sizes (Conover, 2009).

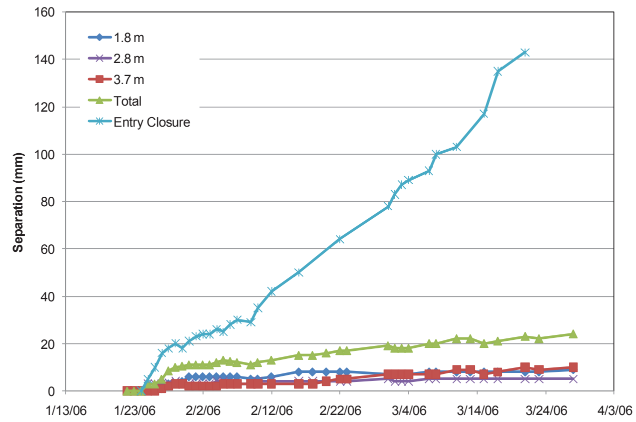

Figure 7. Combined roof movement and entry closure for station 3.

Site 2—Storage Cavern

A large cavern is currently being developed in West Virginia using a room-and-pillar configuration with shaft access at the center of the cavern. A main crosscut was developed in both directions from the shaft to the cavern boundaries, and side drifts were then developed on both sides of the crosscut (but primarily to the north) at uniform intervals, as shown in Figure 8. The immediate roof rock is a bioturbated shale with moderate laminations and bedding. Cover depth is uniform at about 120 m (394 ft). The openings are about 6.1 m (20 ft) wide by 4.6 m (15 ft) high and were excavated using drill-and-blast techniques. Roof support initially used 1.8-m (6-ft) resin-grouted bolts on 1.5-m (5-ft) centers with wire mesh. Several areas were reinforced with secondary supports, including additional and different-type bolts, shotcrete, and injection grouting.

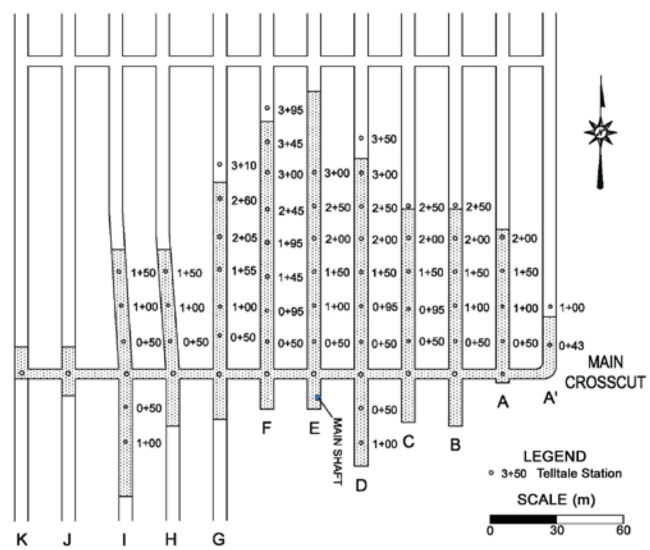

Figure 8. Mine layout and telltale locations – storage cavern.

Initially, manual reading two-position telltales were installed in the centers of the intersections along the main crosscut and at

15-m intervals along the side drifts. The lower "A" anchors were installed 1.8-m (6-ft) above the roof line, and the upper "B" anchors were installed at depths of either 3.6 or 4.6 m (12-15 ft). The instruments were read initially at approximately 1-day intervals, increasing to weekly intervals after about 1 month. After 1 year, an automated system was installed, with two-position telltales installed adjacent to the existing manual instruments and with the same anchor depths as the manual stations. The data cable was routed through the shaft to a computer on the surface that performed all control functions, including instrument polling, real-time data display, and data storage to hard disk. The computer has an internet connection, and data are user/password accessible from remote locations, specifically, Agapito Associates, Inc.'s (AAI's) office in Colorado and Golder RMT's office in England. The automated data are continuously scanned and are stored every 10 minutes. Alarms are raised at the surface computer, but since personnel are present on the surface during underground operations, the alarms are not linked to a remote notification system.

The data files are entered into a database and are immediately available for examination; for example, to determine the exact time of a sudden movement or to determine if apparent movements are real or caused by electronic noise. The data are also transferred to AAI's office weekly and entered into a semi-automated Excel™ workbook file. The data for the automated telltales were appended to the earlier manual readings to provide a continuous record of roof movement from the time of the first installation. The data are examined and plotted to identify any accelerating movement or other conditions requiring attention.

Shortly after the manual telltales were installed, mining operations at the site were put on standby and no development has occurred for the last 21 months. A number of different conditions were noted during the monitoring period: instrument noise, collar anchor slippage, equipment component failure, ventilation effects, roof falls, installation of additional support, and instrument replacement.

Figure 9 shows the data plot for the telltale at the intersection of "A" Drift and the main crosscut (MCC). The initial manual readings are variable, until the automated system was installed in February 2009. The plot shows a common pattern of roof movement where the rate of movement decreases over time and either stabilizes (zero movement) or continues to move at a small rate. Because of these continuous small movements and underground observations that indicated possible instabilities, a number of additional longer bolts were installed in most of the intersections and other priority areas. Some installations were not effective in controlling roof movement, as shown by the virtually unchanged trends plotted in Figure 9. Other stations did show immediate improvements. Another typical behavior shown in the figure is the slight increases that occur periodically and then return to the initial level. These fluctuations correspond to temperature and humidity changes that occurred when the ventilation fan was turned on during on-site inspections of underground conditions that were performed every 1 to 2 months. The manual telltales were also read during these inspections as a check of the accuracy of the automated system. In all cases, the data from the manual and automated stations have been in agreement.

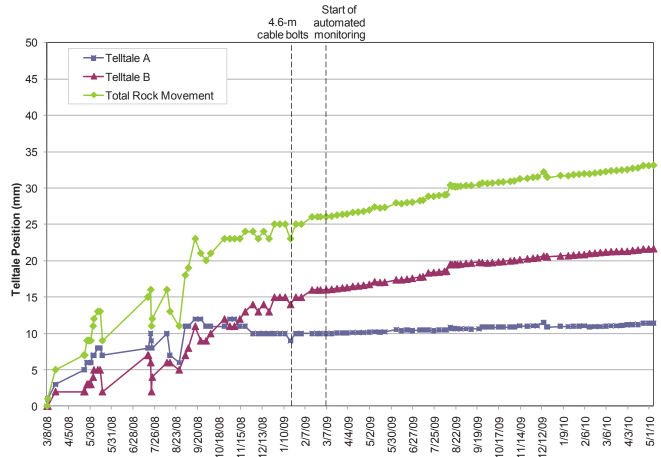

Figure 9. Roof movement for station A MCC.

Figure 10 shows the data for station "E 1+00," 30 m (98 ft) north of the MCC. This plot shows typical instrument response from slabs forming around the collar anchor, becoming completely detached and falling against the wire mesh. In many cases, the slabs could be broken and the collar anchor reinstalled in the borehole; however, in other cases, the anchor unit was damaged and had to be replaced with a new transponder.

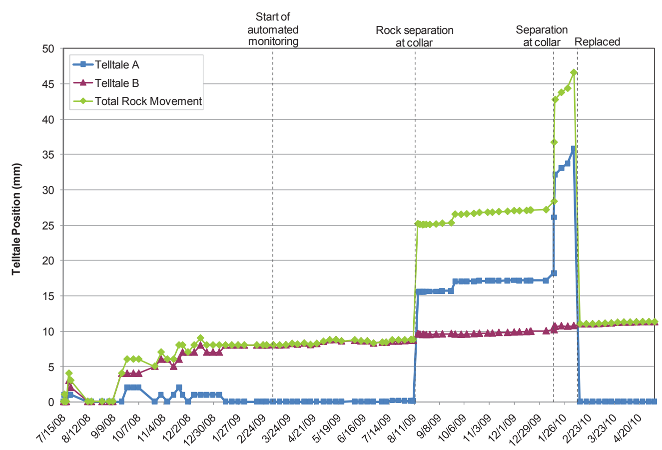

Figure 10. Roof movement for station E 1+00.

Figure 11 shows station "E 2+50," 75 m (246 ft) north of the MCC. This station represents the greatest movement and the area considered the most unstable of all the monitored areas. Prior to the start of monitoring, a large roof fall occurred approximately 30 m (98 ft) north of the station and significant additional support was installed in the area as indicated by the notation regarding steel sets shown in the figure. Cable bolts, 3.6 m (12 ft) long, were installed around the station shortly afterward, in January 2009, and the roof movements appeared to stabilize. However, movement continued to occur and in November 2009, 6.7-m (22 ft) long cable bolts were installed. Movement of the lower strata subsequently stabilized; however, the upper strata continue to move and the area is closely watched during the monthly inspections. Movements between the two anchors are past the 25-mm (1 in) range normally considered as warning levels, and total movement is approaching the 100-mm (4-in) rule-of-thumb estimate for the maximum stable displacement. However, the installations of cable bolts effectively "reset" the alarms and neither the 25-mm (1 in) nor the 100-mm (4 in) level has been reached subsequent to their installation. Based on underground observations of ground conditions and evidence of instability, these levels are considered to be in the appropriate range for providing an early warning of possible roof failure. A related topic is the use of deformation rate to trigger alerts in addition to deformation magnitudes. It is difficult to specify what alert levels are appropriate owing to the wide variety of rock types and conditions that may be encountered. For conditions at the cavern site, the maximum deformation rate shown in Figure 11 immediately before the installation of the 3.6-m (11.8 ft) cable bolts is about 0.3 mm/day (0.01 in/day). This rate corresponds to deteriorating conditions and represents an upper limit for setting an appropriate alert level.

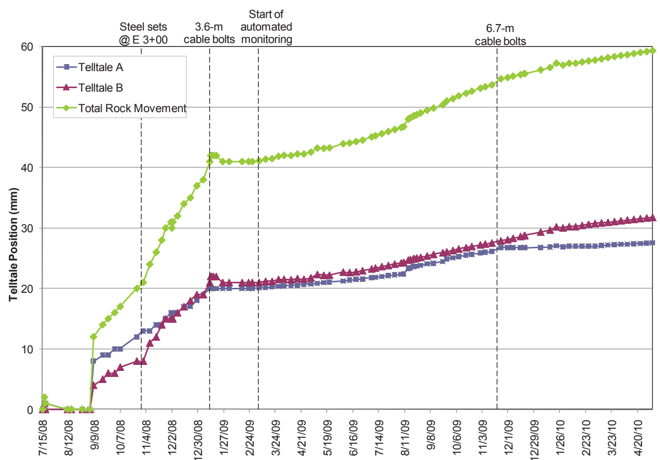

Figure 11. Roof movement for station E 2+50.

Figure 12 shows the data for the station at the intersection of "H" drift and the MCC. Again, the installation of supplemental support shows initial stabilization followed by continued movement. The movement is decreasing over time, and it is expected that the area will stabilize without requiring additional support. There is a sudden apparent decrease in the movement of the "A" anchor in January 2010 which corresponds to manual repositioning of the collar anchor during the monthly inspection. Such unusual occurrences show the need to maintain complete and accurate records of any factors that might affect the instrument accuracy or response.

There were a few short interruptions of the automated system caused by equipment difficulties. Some erratic (noisy) readings were recorded for a few instruments and the problem was solved by adjusting the interrogation unit to account for the large number of network branches in the cavern layout, compared to a single gate-road entry, for example. The multiple nodes required in the cavern configuration presented a major challenge to a system designed originally for a single "daisy chain" arrangement. In addition, three transponders malfunctioned and one was damaged by near-surface rock delamination, requiring replacement of the transponders and editing of the software configuration. The internet connection permitted remote software updates, which greatly reduced the required number of on-site maintenance trips. Another small rock

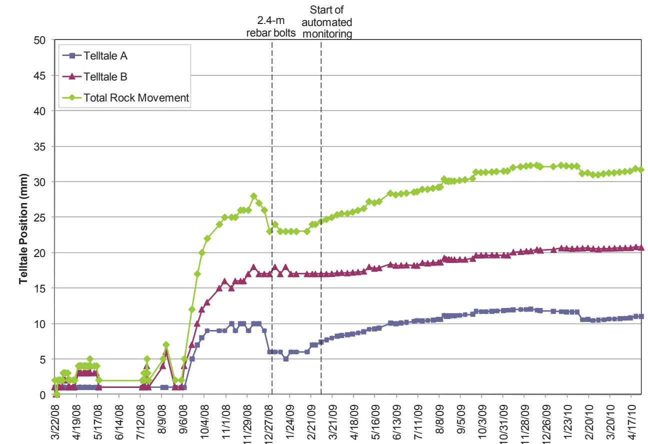

Figure 12. Roof movement for station H MCC.

fall pulled the cable apart at a splice, which would have been a simple repair had someone been on-site full time, but required a special troubleshooting trip to locate and repair the damage. In general, the system has proven to be reliable and accurate, and has provided the information needed to assess the cavern stability and further support requirements.

CONCLUSIONS

Two successful installations of telltale monitoring instruments were recently conducted. Both manual and automated instruments were installed and, overall, the equipment performed very well. No mechanical difficulties were encountered with the manual reading instruments, which is to be expected owing to their relative simplicity and long development history. However, some data errors occurred that were attributed to the manual reading procedure. The automated system presented a few interruptions of data, but was generally reliable and repairs were made quickly with no significant loss of data. The system is continually being updated, and the initial problems experienced at the storage cavern project have been addressed in the current versions of hardware/software. The automated system provided much smoother and more consistent data than the manual system, as it eliminated human reading and recording errors. The availability of the data across the internet provided true remote monitoring and permitted software updating from anywhere in the world.

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