SUGGESTED METHODS FOR MONITORING ROCK MOVEMENTS USING TILTMETERS

(International Society for Rock Mechanics)

1. (a) A tiltmeter consists of a housing containing a gravity operated sensor which detects static or dynamic angular movements at a point. Normally a portable tiltmeter is temporarily located on a reference plate (Fig. 1) cemented or bolted to intact rock at the ground surface or in a tunnel or adit[1]. Periodic measurement of the surface tilt of each plate enables determination of the magnitude and rate of angular deformation.

(b) Nonportable tiltmeters are also available which may be used for static or dynamic angular measurement and can provide continuous monitoring[2]. These sensors are enclosed in a waterproof housing and cemented or bolted and grouted directly to the rock surface. Local access for reading may be utilized or remote reading facilities may be installed.

(c) The tiltmeter, unlike the probe or fixed-in-place inclinometers, only measures the tilt at a discrete, normally accessible point. It does not operate at depth along a borehole although in certain situations it can be permanently buried.

(d) The reference plate must be anchored on a surface which properly reflects movements of the rock mass under investigation. The weathered initial few meters at the surface can often be avoided by locating the reference plate on a pipe or concrete pillar founded on intact rock 1 to 2 meters below the surface. The monument must be free from contact with the upper 1 to 2 meters of rock. Failure to protect the reference plate from the effects of surficial temperature and moisture variations may result in erroneous readings.

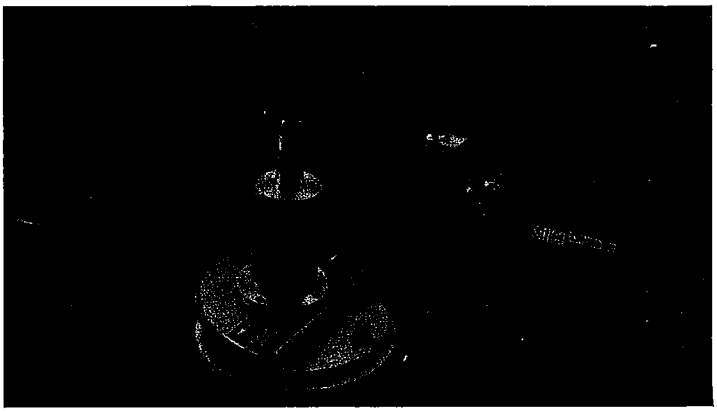

Fig. 1. Portable tiltmeter, reference plate and readout.

Apparatus

2. Surface preparation and drilling equipment including:

(a) Hand tools or bush hammer or jack hammer for surface cleanup, leveling and preparation of a fresh dust-free surface.

(b) A rock drill to give drillholes 15 to 40 mm in diameter, up to about 300 mm deep for fixing bolts.

(c) A rock drill to give a shallow drillhole of the required diameter for a steel anchor tube 70 to 150 mm in diameter, up to 3 m long. Core drilling should be used, but if no core is available, a borehole periscope may be used to inspect the hole.

(d) A rock drill to excavate a large diameter shallow hole for an isolated concrete pillar. Blasting should be avoided.

3. Surface reference plates and installation equipment:

(a) The surface reference plate on which the portable tiltmeter sensor is periodically located should be made of dimensionally stable metal, ceramic or rock. The reference surface should be corrosion-free, easy to wipe clean and not easily damaged. The surface of the reference plate should incorporate a precise positioning system compatible with

the portable sensor and which locates the sensor in two mutually perpendicular directions. The positioning system must permit the sensor to be reversed through 180 deg to enable zero errors in the portable sensor to be eliminated. Inaccurate replacement may be the greatest source of error with a sensitive tiltmeter.

(b) Epoxy or polyester resin cement, Portland cement or similar grouts for fixing the reference plate directly to prepared rock surface or steel plate.

(c) Anchor bolts where additional anchorage is needed.

(d) A steel tube 70 to 150 mm in diameter, up to 3 m long to be grouted into a shallow hole and isolated from the weathered initial 1 to 2 meters of rock at the surface. The tube should have an integral reference plate welded in place.

(e) Materials for constructing a concrete pillar or monument founded below the rock surface and isolated from the weathered initial 1 to 2 meters of rock at the surface.

4. Tiltmeter sensor and readout (for example, Fig. 1) including:

(a) If a portable tiltmeter sensor is to be used this should comprise a housing containing a sensing device[3], and with a reference surface incorporating a precise positioning system compatible with the fixed reference plates. The reference surface on the portable sensor should be corrosion-free, easy to wipe clean and not easily damaged. The electrical sensing device is connected by a cable to a compatible portable readout box[4].

(b) If a nonportable tiltmeter is to be used, this should comprise an electrically operated sensor[3] enclosed in a waterproof corrosion resistant housing designed for direct and permanent fixing to the rock surface. The electrical sensing device is connected by a permanently installed cable to a compatible monitoring and readout system. The tiltmeter housing should preferably incorporate a reference surface suitable for a portable tiltmeter which is used periodically to check the permanently installed tiltmeter for zero drift or other malfunction.

(c) The measuring range, sensitivity and accuracy of the tiltmeter with its readout system should be specified according to the requirements of the project. The range and resolution of tiltmeters varies considerably; ±30 deg and 10 seconds, ±0.7 deg and 2 seconds are typical specifications.

(d) The equipment should be designed to ensure that the specified accuracy is maintained irrespective of normal mechanical handling, water pressures, and corrosive environments encountered in use.

5. Calibration equipment including:

(a) A calibrating device to enable initial checking of fixed tiltmeters or routine on-site checking of the portable sensor and readout unit. The device should allow the sensor to be set in its normal operating position and should be adjustable from horizontal to the maximum operating angle of the sensor, with at least one intermediate setting either side of the horizontal. The calibrator should ideally have an independent angle measuring accuracy better than the resolution of the portable tiltmeter sensor[5].

Procedure

6. Preparatory investigations:

(a) The site and project characteristics should be considered in detail in order to specify the performance requirements of equipment to be used.

(b) Tiltmeter locations should be selected on the basis of a study of the geotechnical features of the site, taking into consideration the directions and magnitudes of anticipated ground movements and the nature of other instrumentation to be installed.

(c) The amount and depth of weathering of the rock surface should be investigated so that the tiltmeter is located on or anchored in intact rock. Failure to eliminate the influence of localized surficial movements or inhomogeneities may entirely invalidate the tiltmeter measurements especially if the true subsurface movements are small. If extensive weathering exists, subsurface location in a tunnel or adit is desirable.

7. Installation:

(a) If suitable fresh, hard, unweathered, sound rock exists at the surface, minimal cleanup is required to form a dust-free, level surface.

(b) Holes should be drilled for fixing bolts when the grout to rock adhesion is unreliable. Alternatively, a shallow hole should be drilled or excavated to install a tubular steel anchor or to construct a concrete pillar, isolated from the weathered near-surface rock and founded on fresh rock.

(c) The underside of the reference plate or of the nonportable tiltmeter, thoroughly cleaned and abraded, is oriented to correspond with the required direction of measurement and is then cemented or grouted in place on the rock, anchor or pillar and leveled. The azimuth should be recorded to an accuracy of ±3 deg.

(d) A protective cap or cover should be installed over the exposed reference plate or tiltmeter to prevent damage.

8. Readings:

(a) The nonportable tiltmeter should be calibrated prior to installation.

(b) The portable tiltmeter should be checked on site both before and after each day's readings. Instrument errors should be promptly investigated and corrected and a diary of calibrations and adjustments should be kept. Unnecessary adjustment must be avoided.

(c) Several sets of initial readings should be taken immediately after the cement or grout has set. These readings are averaged to provide a baseline for all subsequent observations. Thereafter, readings should be taken at intervals specified by the project engineer on the basis of site requirements. A set of readings with the portable tiltmeter should comprise, as a minimum, steps 9(d) and 9(e) below.

(d) The reference plate and portable tiltmeter are wiped with a clean dry cloth and inspected for dirt or damage. The tiltmeter is accurately located on the reference plate and a reading taken. The tiltmeter is removed, the contact surfaces rewiped and replaced. This procedure is repeated three or four times until consistent readings

are obtained. The tiltmeter is then rotated through 180 deg and the readings repeated, rewiping the contact surfaces each time.

(e) The procedure 9(d) is repeated with the tiltmeter located at 90 deg to the initial position.

(f) A permanently installed tiltmeter may be read manually or automatically at suitable time intervals. It should, where feasible, be periodically checked by a portable tiltmeter as in 9(d) and 9(e).

Calculations and Data Processing

9. (a) Unless otherwise specified all data should be processed within 24 hours of readings being taken[6].

(b) The field data are scrutinized and obvious errors marked on the field data sheet. If corrections are made, these should be clearly noted.

(c) Pairs of opposite face readings obtained with the portable tiltmeter are averaged to correct for face error. The direction of angular rotation must be carefully checked and recorded.

(d) Single face readings obtained with the permanently installed tiltmeter may be corrected for zero error, based on intermittent portable tiltmeter readings on both faces.

(e) Corrected readings are compared with initial readings at the same location to determine the incremental change in angle or displacement.

(f) Graphs of angular change or displacement versus time are plotted for each reference plate location (for example, Fig. 2).

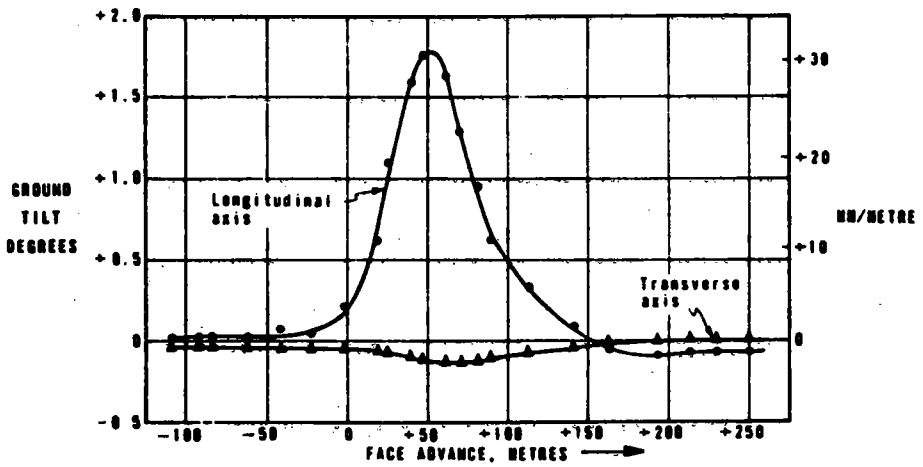

Fig. 2. Tilt at ground surface due to longwall mining face advance at depth.

Reporting of Results

10. Results should, unless otherwise specified, be presented in two forms of report: an Installation Report giving basic data on the instrumentation system at the time of installation; followed by Monitoring Reports presenting periodically the results of routine observations. The Monitoring Reports will generally be required at frequent intervals to minimize delay between the detection of adverse behavior and the implementation of any remedial measures that may be necessary.

11. The Installation Report should include the following:

(a) A description and diagrams of the monitoring equipment used including detailed performance specifications and manufacturers' literature.

(b) A station location plan with details of the reference plates, their surveyed positions and elevations.

(c) Details of methods used for tiltmeter installation, calibration, and monitoring; reference may be made to this ISRM Suggested Method stating only departures from the recommended procedures.

(d) For each station, a diagram showing the geotechnical characteristics of the ground and the position of the reference plate. The azimuth of reference plate guides should be reported clearly stating conventions adopted for the sign of movement and angle directions.

(e) For each station, a tabulated list of initial tiltmeter readings.

12. The Monitoring Reports should include the following:

(a) A set of field monitoring result tabulations; the set to cover all observations since the preceding report.

(b) Graphs of angular change or displacement versus time, sufficient to show clearly the magnitudes, rates, and directions of all significant movements.

(c) A brief commentary drawing attention to significant movements and to all instrument malfunctions occurring since the preceding report.

Notes

[1]Tiltmeters may also be installed on structures founded on rock, for example on concrete dams or turbine foundations.

[2]In addition, there exist very sensitive and narrow range tiltmeters designed to resolve angles as small as 1×10^{-8} radians, used mainly for detecting earthtides and other geodetic or seismic events.

[3]The sensing device may, for example, include an electrolytic spirit level, a pendulum actuated vibrating wire or closed loop servo-accelerometer or alternatively a precise spirit level with a manual mechanical-optical micrometer system, which is not suitable for automatic recording.

[4]The readout box may for example include a direct reading voltmeter, a manual null-balance bridge circuit, a digital voltmeter, or an automatic null balance bridge with digital display and an integrating circuit to sum incremental displacements. Units are available that allow recording on magnetic or paper tape.

[5]It is recognized that this may be difficult to achieve if a narrow range tiltmeter with a resolution of one or two seconds of arc is used, and some compromise will be necessary.

[6]Data processing may be manual or with the aid of a computer; however, the various stages of computation must in either case be fully supervised and checked for reading or transcribing errors and to ensure that the significance of any anomalous behavior is fully appreciated. For example, it is often difficult to distinguish between anomalies due to ground behavior and those due to instrument malfunction.