Suggested Methods for Surface Monitoring of Movements Across Discontinuities

TECHNICAL INTRODUCTION AND SUMMARY

1. Monitoring of rock movements provides input to understanding the behaviour of a rock mass and to an assessment of its stability. Observations of fracturing on a rock surface can provide useful information concerning behaviour at depth, and surficial monitoring is usually far less expensive than borehole instrumentation or other techniques for subsurface monitoring.

(b) The use of wooden wedges driven into open fractures and observing when wedges loosen has been a traditional method used by mining personnel, but more sophisticated techniques are often required. Table 2 indicates some of the available methods, with major advantages and limitations and approximate accuracies. The following four suggested methods are a sampling of available techniques. These suggested methods are not intended to be recommended methods: they are merely samples to be used as a guide when adopting the method most applicable to a particular project.

(c) Simple optical and mechanical methods should be used, wherever possible, in preference to electrical methods, as electrical methods tend to be less reliable for long-term monitoring unless the physical environment (moisture, dust, temperature, vibration) is suitably controlled.

Typical applications include monitoring tension cracks behind slopes, and monitoring cracks in concrete structures, pavements or tunnel linings, or discontinuities in rock.

METHOD 1: SUGGESTED METHOD FOR MONITORING MOVEMENT ACROSS DISCONTINUITIES USING GLASS PLATES

Scope

1. This method provides a simple and direct means of monitoring movement across discontinuities. It consists essentially of cementing glass plates across discontinuities and observing breakages, supplemented as necessary by measurement and recording of crack separation and direction of relative movement.

Apparatus

2. (a) Spray paint, brightly coloured to contrast with the surface to which it will be applied.

(b) Glass plates, approximately 80 x 20 x 2 mm.

(c) Epoxy resin, polyurethane resin or cyanoacrylate adhesive.

(d) Waterproof felt marking pens.

(e) Ruler.

Procedure

Installation

3. (a) The area to be monitored for crack movements is thoroughly inspected, and all existing cracks marked with paint along their full length.

(b) The surfaces to which the glass plates are cemented must be hard, for example hard rock, or concrete, in order to ensure reliable adhesion. When necessary the surfaces should be cleaned and roughened to provide a key for the adhesive.

(c) Glass plates are then cemented across each crack at several locations using epoxy resin adhesive or similar material of strength greater than the glass plate.

(d) Having installed all plates, their positions are marked on plans and cross sections. A number designation is marked clearly and permanently adjacent to each plate and the corresponding designation is also marked on the plans and sections.

(e) During installation, installation record sheets should be completed.*

Inspection and reading

4. (a) Inspection entails observation of breakages. Reading entails use of a ruler to measure crack separation and direction of relative movement. Reading accuracy should be approximately ± 1 mm.

(b) The frequency of inspection and/or readings should be related to site activity and to the rate at which deformation is occurring.2

(c) Data should be recorded on specially prepared field data sheets.3

(d) Where a glass plate has been broken by movement, it is often helpful to cement a new plate alongside the broken one, to check whether movement is continuing.

Calculations4

5. If readings have been taken, they should be converted into movements in a timely manner, using specially prepared calculation sheets.5

Reporting of Results

6. An "installation report" should be prepared on completion of plate installation.6
Table 2. Methods for surface monitoring of crack and fault movements

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1 ISRM Suggested Methods are in preparation for survey triangulation, levelling, offset and electronic distance measurement (EDM).

*All require access by monitoring technician to the reading location.

'Suggested Method is included in this text. These four suggested methods are not intended to be recommended methods; they are merely samples to be used as a guide when adopting the method most applicable to a particular project. Simple optical or mechanical methods should be used wherever possible.

Method is similar to glass plate method, but using gypsum plaster instead of glass plates and adhesive. The plaster is applied with a flat trowel.

A wire is stretched across the discontinuity between a pin on one side and a pulley mounted to a measurement station on the other side. A weight on the wire below the pulley maintains tension. A scale is attached to the measurement station behind the wire, and a reference mark made on the wire. Observation of the reference mark position with respect to the scale provides movement data. A trip block can be added to the wire, arranged to contact a trip switch on the scale when a predetermined movement occurs. This can be connected to an alarm if required.

A portable steel tape with punched holes, or a stainless steel wire, is attached to a pin on one side of a discontinuity, and passed through a measurement station on the other side. A mechanical indicator ("Potts extensometer") is mounted on the measurement station, and the tape or wire attached to the indicator. The indicator is adjusted to apply a constant tension, and mechanical scales on the indicator provide movement data.

The grid tell-tale consists of two overlapping transparent plastic plates, one mounted on each side of the discontinuity. Crossed cursor lines on the upper plate overlay a graduated grid on the lower plate. Movement is determined by observing the position of the upper plate cross with respect to the grid.

Tape extensometers are available from many suppliers of geotechnical instrumentation. They consist essentially of a tape in series with an adjustable spring for tension control, and a dial indicator for measurement of movement. Reference points attached to pins on each side of the discontinuity mate with attachments on the tape extensometer. An ISRM Suggested Method is in preparation for convergence measurements, including use of tape extensometers.

A dial indicator can be attached to a bracket on one side of the discontinuity and arranged to bear against a machined reference surface on the other side. Tri-directional dial indicator systems are also available.

An electrical linear displacement transducer can be attached to a bracket on one side of the discontinuity and arranged to bear against a machined reference surface on the other side. Alternatively, anchor points can be located on either side of a discontinuity and the transducer attached to the anchor points via ball joints. Available transducers include linear potentiometers, linear variable differential transformers (LVDTs), direct current differential transformers (DCDTs), vibrating wire transducers, bonded and unbonded resistance strain gauge transducers, and inductance transducers that form an oscillating circuit with frequency output.
7. A “monitoring report” should be prepared following each set of readings. If glass plates are being used merely for observation of breakages, clearly the monitoring report will not include graphs.

**METHOD 2: SUGGESTED METHOD FOR MONITORING MOVEMENT ACROSS DISCONTINUITIES USING PINS AND A TAPE**

**Scope**

1.(a) This method is intended as a simple technique for monitoring movements using pins set on either side of the discontinuity. Measurements are taken using a steel tape spanning the pins.

(b) Pins are typically set at 1–3 m apart but may extend to 20 m across a single discontinuity or series of discontinuities.

(c) The accuracy required will depend on the application but will typically be approximately ±2 mm. With care, ±0.5 mm accuracy is possible.

**Apparatus**

_Pins and fixing materials_

2.(a) The type and dimensions of the pins and the fixing system to be used should be appropriate to the condition of the ground or structure to be monitored, to ensure the pins are rigidly attached to the surface and will remain attached throughout the monitoring programme.

(b) When the surface is strong rock or concrete unaffected by local cracking, pins are typically 2 cm long, 5 mm dia with a tapered point at one end and a welded base at the other. Epoxy resin is used to fix the base to the surface, or a concrete rivet gun may be used to embed pins.

(c) For soils or soft rocks, pins of 50 cm in length and 1.5 cm dia are typically used where they are to be driven into the formation. Alternatively, pins may be grouted in.

(d) Pins should have pointed tips or alternatively have filed cross-lines on the tip of a flat head.

3. A steel tape graduated in millimetres is typically used to measure displacements.

**Procedure**

_Pin installation_

4.(a) The area to be monitored is first inspected to determine critical discontinuities and the most appropriate number and location of measuring spans. Both shear and normal displacement of a discontinuity can be made by installing a pair of pins on either side of the discontinuity and taking diagonal and normal measurements. The discontinuities may first be monitored visually or with glass plates (Method 1) for sufficient time to establish the general pattern of movements.

(b) Where pins are to be fixed directly to a firm surface, the surface is first cleaned of loose material and dust which might otherwise interfere with adequate bonding of the adhesive. The pin locations are marked approximately, in general equidistant from and perpendicular to the discontinuity. The surface between the pins may require flattening, to remove any irregularities which would otherwise interfere with the correct positioning and operation of the tape. The pins are then cemented to the surface using a strong, fast-setting epoxy resin adhesive.

(c) In soft ground or broken surfaces, pins can be driven to depths of about 10 cm or such that the pins are rigidly positioned. Alternatively, pins may be positioned in boreholes and grouted in.

(d) Having installed all pins, their positions are marked on plans and cross sections. A number designation is marked clearly and permanently adjacent to each pair of pins (measuring span) and the corresponding designation is also marked on the plans and sections. It also may be useful to use brightly coloured paint to mark the structure in the vicinity of the pins so that they can be found without difficulty when taking readings.

(e) During installation, installation record sheets should be completed.

**Reading**

5.(a) Several sets of initial readings are required to establish a reliable base, ideally unaffected by site activity. The frequency of subsequent readings should be related to site activity and to the rate at which the readings are changing.

(b) Where the pin separation is less than about 2 m, measurements can be made to an accuracy of ±2 mm using a steel tape, e.g. standard construction quality product. Temperature and sag corrections are not normally required over this measurement distance. Where the pin separation exceeds 2 m, a survey chain should be used. The end of this chain should be attached to one of the pins to minimize referencing errors and a standard pull should be applied to eliminate the need to apply sag corrections. If the pins are not rigid or are not securely attached to the ground so it is not possible to attach the chain to one pin, then two people will be required to make the measurements, one to hold each end of the chain. A standard pull should be used and temperature corrections applied as required. In all cases, three measurements of pin separation should be made each time sets of readings are carried out, and the average separation calculated. Individual readings should not differ by more than ±2 mm.

(c) Adequate lighting must be provided to ensure satisfactory reading conditions.

(d) The position of pins relative to a fixed reference point should be checked where possible to ensure that the true measurement is being measured.

(e) Readings should be recorded on specially prepared field data sheets, and immediately compared with previous readings to examine for reading errors or instrument malfunction.

**Calculations**

6. Readings should be converted into movements in a timely manner, using specially prepared calculation...
sheets. For each pair of pins, the reading change is calculated by subtracting the initial reading from the subsequent reading, taking note of the positive or negative sign. A positive sign indicates opening, a negative sign indicates closing.

Reporting of Results

7. An “installation report” should be prepared on completion of the installation of pins and after taking the initial readings.

8. A “monitoring report” should be prepared following each set of readings.

METHOD 3: SUGGESTED METHOD FOR MONITORING MOVEMENT ACROSS DISCONTINUITIES USING A PORTABLE MECHANICAL GAUGE

Scope

1. (a) This method is intended for the measurement of variation in distance between two targets, one located on each side of the discontinuity to be monitored. The method requires manual access to the targets.

(b) The targets are typically separated by a distance of between 50 and 250 mm. A portable mechanical displacement gauge is used to take measurements between any pair of targets.

(c) The method is generally employed for accurate determinations of small movements, usually not exceeding ±5 mm.

2. A portable displacement gauge with the following characteristics (e.g. Fig. 1).

   (a) The gauge typically has a fixed gauge length, requiring that targets are mounted at a predetermined separation distance. Typical gauge lengths are in the range 50–250 mm. A suitable gauge length should be selected for the application; for example, when monitoring cracks there is usually a minimum separation of targets that will ensure that the targets do not become loose or damaged in service.

   (b) The portable instrument usually employs a mechanical displacement sensor such as a dial gauge with a lever system to amplify the movements between targets. Typically the instrument has a reading resolution in the order of 0.003 mm.

   (c) The accuracy and repeatability of readings depend on a robust design of instrument and on the avoidance of errors that result from friction or wear in the mechanical amplification system. Repeatability should be on the order of ±0.005 mm for successive readings.

   (d) In general the more accurate the instrument the smaller is its measuring range. Typical ranges are from ±2 to ±5 mm. The instrument should only be employed if the anticipated displacement is consistent with this measuring range.

   (e) The instrument makes contact with the targets through one fixed arm and one pivoted arm connected with the displacement sensor. The contact between points and targets must be precisely reproducible. For example, the points may be conical, locating in conical

Fig. 1. Example of portable displacement gauge. (Photo: W. H. Mayes & Son, Windsor Ltd, England).
depressions in the targets; spherical, locating in spherical depressions; or the targets may themselves be spherical, locating in conical depressions in the points.

**Targets and fixing materials**

3.(a) A design of target should be employed to suit the selected gauge. The target fixing system should be appropriate to the condition of the ground or structure at the measuring location to ensure that the target will remain fixed in place and immovable throughout the programme of measurements.

(b) A setting tool is usually required to ensure that the separation of targets is within the prescribed gauge length of the instrument.

(c) When the surface on which the targets are to be located consists of strong rock or concrete unaffected by local cracking, the targets may be fixed to this surface using a strong adhesive such as epoxy resin.

(d) When the surface is weak or friable or when there is risk of mechanical damage to the targets, the targets should take the form of steel pins, typically 2–5 mm dia and 50–100 mm long, installed in drilled holes using a strong adhesive such as epoxy resin.

(e) In situations such as the monitoring of tension cracks in soil where the material on either side of the crack is weak or friable, the targets should be fixed to deeper anchors, e.g. 20–30 mm dia and 0.5–1.5 m long bars into the ground or installed in drillholes by grouting over their full length.

(f) The targets and adhesives and the anchoring systems where employed should be of strong and corrosion resistant materials to ensure that readings are unaffected by distortion, damage, loosening or dimensional changes during their operating life.

**Calibration equipment**

4.(a) The displacement gauge should be supplied with a calibration bar to permit frequent checks on its calibration, adjustment and correct functioning.

(b) The calibration bar should be robust and corrosion resistant and should incorporate targets of identical design and separation to those to be employed for displacement measurements. Readings on the calibration bar should be reproducible within the specified reproducibility of the instrument. The bar should be kept clean and protected against mechanical damage.

**Procedure**

**Target installation**

5.(a) The area to be monitored is first inspected to determine critical discontinuities and the most appropriate number and location of measuring spans. Both shear and normal displacement of a discontinuity can be made by installing a pair of targets on either side of the discontinuity and taking diagonal and normal measurements. The discontinuities may first be monitored visually or with glass plates (Method 1) for sufficient time to establish the general pattern of movements.

(b) Where targets are to be fixed directly to a firm surface, the surface is first cleaned of loose material and dust which might otherwise interfere with adequate bonding of the adhesive. The target locations are marked approximately, in general equidistant from, and perpendicular to, the discontinuity. The surface between the targets may require flattening, to remove any irregularities which would otherwise interfere with the correct positioning and operation of the gauge. The setting tool is usually needed to ensure correct target separation to suit the make of gauge, adjusting this distance if necessary just before the adhesive sets.10 The targets are then cemented to the surface using a strong, fast-setting epoxy resin adhesive.

(c) When targets are to be fixed in shallow drilled holes, the locations are first marked approximately, the first hole is drilled, and the hole separation is checked before drilling the second location. Dust is removed by blowing through a tube, the holes and target pins are coated with adhesive, and the target pins are installed. The target separation is checked and if necessary adjusted before the adhesive has set.10 When targets are to be fixed to deeper anchors a similar procedure is followed except that anchor posts are installed first, and checked for rigidity. They should not flex or displace and should be located so that they are protected from mechanical damage due to site traffic. The targets may then be fixed to the upper surface of the anchor posts with strong adhesive. If the posts need to be separated by a distance greater than the gauge length, they may be supplied fitted with crossbeams allowing the targets themselves to be at the correct separation.

(d) Check readings are taken between each pair of targets, ensuring that the locating points are free from adhesive and paint and that the targets themselves are securely anchored and at the correct separation distance.

(e) Having installed all targets, their positions are marked on plans and cross sections. A number designation is marked clearly and permanently adjacent to each pair of targets (measuring span) and the corresponding designation is also marked on the plans and sections. It also may be useful to use brightly coloured paint to mark the structure in the vicinity of the targets so that they can be found without difficulty when taking readings.

(f) During installation, installation record sheets should be completed.1

**Reading**

6.(a) Several sets of initial readings are required to establish a reliable base, ideally unaffected by site activity. The frequency of subsequent readings should be related to site activity and to the rate at which the readings are changing.2

(b) Adequate lighting must be provided to ensure satisfactory reading conditions.

(c) Readings should be recorded on specially prepared field data sheets, and immediately compared with previous readings to examine for reading errors or instrument malfunction.3

(d) If at all possible, the same instrument should be used to take readings throughout a project. If it becomes...
METHOD 4: SUGGESTED METHOD FOR MONITORING MOVEMENT ACROSS DISCONTINUITIES USING A REMOTE READING ELECTRICAL JOINTMETER

Scope

1. This method is intended for the measurement of variation in distance between two anchor points, one located on each side of this discontinuity to be monitored. Readings are made from a remote location, hence overcoming the need for manual access to the anchor points.

(b) Two basic arrangements are possible. First, an electrical linear displacement transducer can be attached to a bracket on one side of the discontinuity and arranged to bear against a machined reference surface on the other side. Second, anchor points can be located on either side of a discontinuity and the transducer attached to the anchor points via ball joints. This Suggested Method describes use of the second arrangement.

(c) In this text the electrical device itself is referred to as a transducer, and the transducer, anchor points and attachments are referred to as a jointmeter.

(d) The anchor points are typically located between 10 and 50 cm apart along a line perpendicular to the discontinuity to be monitored.

(e) Depending on the type of transducer, the displacement measurement capacity of the jointmeter ranges from 10 to 100 mm, and can usually be extended by resetting, using extension rods. If the expected direction of movement is unknown, the transducer can be set initially in mid-range.

(f) The jointmeter is intended for precise remote displacement measurements, requiring cable connection of the instrument to an electronic readout unit. For most types of transducer, automatic data logging capability is available, often allowing reading in engineering units.
Apparatus

2. Typical apparatus is shown in Fig. 2.

3. A remote reading electrical linear displacement transducer. Available transducers include linear potentiometers, linear variable differential transformers (LVDTs), direct current differential transformers (DCDTs), vibrating wire transducers, bonded and un-bonded resistance strain gauge transducers, and inductance transducers that form an oscillating circuit with frequency output. The transducer should, unless the particular application requires other characteristics, have the following features:

(a) O-ring or other seals between the sliding bar and transducer housing to protect the transducer from moisture and dirt.

(b) Facility for increasing the length of the sliding bar, by screwing together lengths of extension rods to match the separation distance between anchor points, or to increase the range of the jointmeter after initial displacements have taken place.

(c) An accuracy consistent with specific monitoring needs. Available transducers have accuracies ranging from \( \pm 0.1 \text{ mm} \) to \( \pm 0.002 \text{ mm} \).

(d) If lead wire length is likely to be changed during the monitoring programme, the transducer reading should be insensitive to change in lead wire length.

(e) Insensitivity to temperature variation at the transducer. Alternatively a temperature correction factor should be supplied with the transducer, and the transducer should include a temperature sensor.

(f) Insensitivity to temperature variation along the lead wires.

(g) Ball joints at each end of the transducer, to allow for lateral and rotational movement of the discontinuity without damage to the transducer. The ball joints should be arranged for attachment to the anchor points.

(h) An over-range protection, typically by allowing the sliding bar to move beyond the specified range, by shearing a pin inside the housing without destroying the transducer.

Anchors and fixing materials

4. (a) Selection of an anchor should be made to match the ball joint fixtures provided with the transducer. The anchor fixing system should be appropriate to the condition of the ground or structure at the measuring location to ensure that the anchor will remain fixed in place and immovable throughout the programme of measurements.

(b) Some form of setting tool is usually required to ensure that the separation of anchors is within the prescribed gauge length of the instrument. A ruler may be suitable or, if transducer range is small, a location jig may be needed.

(c) When the surface on which the anchors are to be located consists of strong rock or concrete unaffected by
local cracking, the anchors may be fixed to this surface using a strong adhesive such as epoxy resin.

(d) When the surface is weak or friable, or when there is risk of mechanical damage to the anchors, the anchors should take the form of rebar anchors suitably grouted into drill holes or the form of steel pins, typically 50–100 mm long installed in drilled holes using a strong adhesive such as epoxy resin. The rebar anchors or pins should be machined to accept a threaded member of the ball joint fixture provided with the transducer.

(e) In situations such as the monitoring of tension cracks in soil where the material on either side of the crack is weak and friable, the anchors should be set in deep holes, for example, 20–30 mm dia and 0.5–1.5 m long bars driven into the ground or installed in drilled holes by grouting over their full length. Again, the bars should be adapted to accept the threaded ball joint attachment fixtures.

(f) The anchors and adhesives, where employed, should be of strong and corrosion resistant materials to ensure that readings are unaffected by distortion, damage, loosening or dimensional changes during their operating life.

**Calibration equipment**

5.(a) Each jointmeter should be supplied with a calibration factor and temperature correction factor for calculation of the actual displacement from the readout unit change.

(b) A hand-held calibration unit should be provided for on-site calibration of the jointmeter prior to installation. Readings made with the calibration unit should be reproducible within the specified reproducibility of the jointmeter. The calibration unit should be kept clean and protected against mechanical damage.

**Procedure**

**Anchor point installation**

6.(a) The area to be monitored is first inspected to determine critical discontinuities and the most appropriate number and location of measuring spans. The discontinuities may first be monitored visually or with glass plates (Method 1) for sufficient time to establish the general pattern of movements.

(b) Where anchor points are to be fixed directly to a firm surface, the surface is first cleaned of loose material and dust which might otherwise interfere with adequate bonding of the adhesive. The anchor locations are marked approximately, in general equidistant from, and perpendicular to, the discontinuity. The surface between the anchors may require flattening, to remove any irregularities which would otherwise interfere with the correct positioning and operation of the jointmeter. The setting tool is usually needed to ensure correct anchor point separation. The anchors are then cemented to the surface using a strong, fast-setting epoxy resin adhesive.

(c) When anchors are to be fixed in shallow drilled holes, the locations are first marked approximately, the first hole is drilled, and the hole separation is checked before drilling the second location. Dust is removed by blowing through a tube, the holes and anchors are coated with adhesive, and the anchors are installed. The anchor separation is checked and if necessary adjusted before the adhesive has set. Anchors should not flex or displace and should be located so that they are protected from mechanical damage due to site traffic.

(d) Full advantage of the transducer range can be utilized if the direction of movement is known beforehand. A suitable separation distance for the anchor points should then be selected for the application. For example, if only extension is expected, the sliding bar can be fully pushed in and anchor positions can be selected for extension only.

**Transducer installation**

7.(a) After the anchor points have been fixed in position, the ball joints, sliding bar, transducer, and any necessary extension rods are fixed in position, following the general scheme shown in Fig. 2. Details will depend on the type of transducer and will generally be described in the manufacturer's instruction manual.

(b) It is generally necessary to protect the jointmeter from vandalism and damage, and to protect the cable by burial or by use of conduit.

(c) When a number of jointmeters are to be read at one location, the cables can be connected to a switch box, which in turn is connected to the readout unit. In standard data-logging systems, the cables are terminated to a number of switch modules which are automatically scanned by the data-logger.

**Installation records**

8.(a) Having installed the jointmeters, their positions are marked on plans and cross sections. A number designation is marked clearly and permanently adjacent to each jointmeter, and the corresponding designation is also marked on the plans and sections.

(b) During installation, installation record sheets should be completed.

**Reading**

9.(a) Several sets of initial readings are required to establish a reliable base, ideally unaffected by site activity. The frequency of subsequent readings should be related to site activity and to the rate at which the readings are changing.

(b) Readings should be recorded on specially prepared field data sheets, and immediately compared with previous readings to examine for reading errors or instrument malfunction.

(c) If at all possible, the same readout instrument should be used to take readings throughout a project. If it becomes necessary to change instruments it is advisable to take a duplicate set of readings on the day of change, one set with each instrument, to facilitate determination of a correction factor to be applied to all subsequent readings.

(d) The calibration of the readout unit should be checked on a regular schedule, at a maximum interval of
6 months. This can be achieved by calibration at the manufacturer's facility or at a commercial calibration house, using equipment traceable to a fixed standard. A sticker on the readout unit should indicate the last and next calibration date.

Calculations

10. (a) Readings should be converted into movements in a timely manner, using specially prepared calculation sheets.5

(b) If the transducer is sensitive to temperature, the raw data should be corrected for any temperature variation, using the correction factor supplied by the manufacturer.

Reporting of Results

11. An “installation report” should be prepared on completion of the jointmeter installation and after taking initial readings. It should include the model and serial numbers of the jointmeters and the readout device, and a complete set of calibration readings, together with specifications of the calibration gauge factor and temperature correction factor of the jointmeters.

12. A “monitoring report” should be prepared following each set of readings.7 It should include reading values and calculated values of corrected readings for temperature change and movement. Graphs should be annotated to show any adjustment or repairs to the readout device, and the report should draw attention to any instrument malfunctions, repairs or adjustments since the previous readings were taken.

NOTES

1. During installation a record should be made of all factors that may be relevant to subsequent data interpretation on forms specially prepared for each project. Items to be recorded should include project name, instrument type and number, location in plan and elevation, personnel responsible for installation, installation date, and actual and unusual features of the installation.

2. Too many readings overload the processing and interpretation capacity, whereas too few may cause important events to be missed and prevent timely action from being taken. If construction is in progress, readings should be taken frequently when construction approaches a measurement point, e.g. once a week, once a day, once a shift, or even more frequently in relation to construction activity. It is often wise to increase the frequency of readings during heavy rainfalls. As construction activity moves away from the measurement point or ceases altogether and when readings have stabilized and remained constant, the frequency may then be decreased.

3. It is important that the latest readings be compared immediately with previous readings so that changes can be verified as real or as errors caused by misreading. Space on the sheets should be provided for project name, instrument type, date, time, observer, measurement point number, readings, remarks, weather, temperature, construction activity, and any other factors that might possibly influence the readings. One or more sheets will be used for each date, with later transcription of data to one calculation sheet for each measurement point.

4. The aims of calculations should be to provide a rapid assessment of the data in order to detect sudden changes requiring immediate action, and to summarize and present the data in order to show trends and compare observed with predicted behaviour for determination of the appropriate action to be taken.

5. The raw field data are first transcribed from the field data sheets onto calculation sheets for conversion into movements. Usually this task should be accomplished within 24 hr of taking the readings. Calculation sheets should be prepared specially for each project and instrument to record project name, instrument type and number, date and time of readings, initials of person making and checking calculations, readings transcribed from field data sheets, and any remarks.

6. The installation report should contain at least the following information:

(a) Plans, sections, drawings, photographs, etc. sufficient to show the positions of measurement points and their number designations, together with the positions, orientations, and other characteristics of discontinuities to be monitored, and to show sufficient detail of geology, structural design, etc. as necessary for purposes of interpreting the monitoring results.

(b) Details of the measurement point design, materials and installation procedures employed.

(c) Details and manufacturer of any reading apparatus used.

(d) Initial readings (not applicable for Method 1).

(e) A copy of each field installation record form, as described in Note 1.

7. The monitoring report should contain at least the following information:

(a) An updated tabulation of readings to show the measurement point designation, date, time, temperature and reading change.

(b) Updated graphs of movement vs time, annotated to show the scale of the graph, the sign convention for convergence and divergence, also showing the nature, date and time of any activities which might have contributed to the recorded movements (e.g. excavation, blasting, measurement point repairs).

(c) The monitoring report should identify the technicians taking the readings and should be independently checked and signed by the engineer responsible for the monitoring programme.

(d) The report should be accompanied by a brief written account drawing attention to any significant movements or changes since the previous readings, and to their possible cause.

(e) The principal conclusions of the monitoring report should be communicated verbally where urgency of information transfer is essential. This communication should be followed by a written report within a specified
time period (generally not greater than 1–2 days from the time the readings were taken).

8. Some instruments are designed to allow the possibility of several alternative gauge lengths. The gauge length is, however, not generally adjustable since this would tend to reduce the accuracy of the instrument.

9. If the measuring range is exceeded during the monitoring programme, replacements targets may be installed alongside the initial targets to allow readings to be continued.

10. In some cases it may be easier to fix one target or anchor point in place, then to mark out and fix the second of the pair. If the separation is found to be outside the measuring range of the instrument after the adhesive has set, one of the pair must be replaced.

11. Where the number of replicated readings for any one span is five or more, it is generally preferable to use the median value rather than the average value to represent the span distance. The median value is obtained by deleting highest and lowest values until only one central reading remains, this being the median. If two readings remain (as is the case for an even number of readings), the average of these two is taken as the median value.

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