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ISRM Suggested Methods for rock stress estimation—Part 4: Quality control of rock stress estimation ☆

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1. Introduction

1. This is Part 4 of four new ISRM-suggested methods (SMs) for rock stress estimation:

- Part 1: Strategy for rock stress estimation.
- Part 2: Overcoring methods.
- Part 3: Hydraulic fracturing and/or hydraulic testing of pre-existing fractures (HTPF) methods.
- Part 4: Quality control of rock stress estimation.

These SMs are published together in a Rock Stress Estimation Special Issue of the International Journal of Rock Mechanics and Mining Sciences, 2003, Vol. 40, Issue 7–8, together with a suite of supporting contributions describing various aspects of rock stress estimation.

It is strongly recommended that the new SMs be studied in association with the supporting contributions in the 2003 Special Issue—because these contributions provide a wealth of further detail and measurement case examples.

2. The Client requires information on the rock stress to be traceable, with an accuracy in conformity with his/her specification. This can only be achieved if an adequate quality control system is in place and operated successfully throughout the duration of the work, from original conception to presentation of the results. Accordingly, this Part 4 SM provides guidance on the key issues related to implementing an adequate Quality Control system. Following an overview table of the Technical Auditing issues for stress measurements, a series of detailed tables is presented covering 26 issues under the 10 audit Subject Areas of stress measurement objective and background, stress measurement method, contractual aspects, establishing Quality Assurance procedures, quality aspects for establishing the viability of stress measurements at a given location/depth, measurement procedures, stress data reduction

☆ Please send any written comments on this ISRM Suggested Method to Prof. J.A. Hudson, President of the ISRM Testing Methods Commission, 7 The Quadrangle, Welwyn Garden City, Herts AL8 6SG, UK.

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Table 1
Auditing issues for stress measurements

Overcoring	General and common issues	Hydraulic fracturing/HTPF
Overall aspects for development of a stress estimation/measurement program (also see Table 2)		
	Statement of the measurement objective Statement of the stress measurement background Specification of the stress measurement method Confirmation of method adequacy Availability of a QA procedure Stress measurement protocol Schedule and required resources Auditing requirements and strategy Contractual aspects	
Establishing QA for stress measurement equipment (also see Table 3)		
Procedures for manufacturing the stress cell	Adaptation to the quality system of the organisations	Procedures for manufacturing the packer system elements (Practitioner designs and fabricates the packer system, straddle packer, that will do the job properly at a given location)
Quality of the glue	Routines for storage and maintenance of equipment for stress measurements Quality control of data acquisition systems Establishment and maintenance of QA procedures	Demonstration of the maximum pressure and temperature characteristics of equipment
Quality aspects for establishing stress measurements at a given location (also see Table 4)		
Procedures for drilling the pilot hole and accepting a test location	Decision on test location Functional testing of installation tools, etc. Quality and functional testing procedures of gauges and loggers for data acquisition	Control on the accurate specification of the test location
Quality aspects in measurements and data processing (also see Table 4)		
Procedures for mixing and using the glue Procedures for installation of the stress cell Procedures for overcoring and QA inspection of the core		Procedure for the proper design of a straddle packer Procedure for installation of the packer system Procedures for hydraulic fracturing/HTPF
Biaxial testing procedures	Data acquisition Routine data processing Procedures for draft reporting and decision on continuation or termination of field work Reporting procedures	Procedures to measure the induced fracture Laboratory test procedures (optional)
The Client's review procedures (also see Table 6)		
	Procedures to check all records Review of how the work has actually been carried out Are the assumptions for the method fulfilled? Are the results supported by other information (database, other stress indicators, etc.) Are results realistic based on overall geological information? Auditing conclusions	

and interpretation, continuous evaluation process, validation and presentation, and Technical Auditing conclusions.

3. Any programme involving the collection of field data from a geological medium will include several types of uncertainties, such as heterogeneity and anisotropy,

Table 2

List of audit subjects to be addressed in the development of a stress estimation/measurement program

Audit Subject Area 1: Stress measurement objective and background

1. Statement of the measurement objective
 - What is the purpose of the measurements?
 - What is the accuracy expected?
 - What confirmatory procedures are to be adopted?
 2. Statement of the stress measurement background
 - Have the problems with in situ rock stress measurements been identified?
 - Has a list of the problems been made?
 - Have the most relevant literature references been identified and studied?
 - Has the project been discussed with someone who has practical experience of measuring stresses, and with the specific method to be used?
-

Audit Subject Area 2: Stress measurement method

3. Specification of the stress measurement method
 - What stress measurement method is to be used?
 - What are the physical processes involved?
 - What influence might site conditions have on the results from the method to be used?
 - What problems have been identified in the past?
 4. Confirmation of method adequacy
 - Given the statements produced so far, is the stress measurement capable of measuring the required rock stress?
 5. Availability of a QA procedure
 - Is a QA procedure available for the stress measurement method?
 - If so, has the QA procedure been checked—for both theoretical and practical experience aspects—to ensure that it is adequate, given the objective and the known problems with stress measurements?
 - Is the existing QA procedure adequate?
 - If a suitable QA procedure is not available, can an adequate one be generated?
 6. Stress measurement protocol
 - Is a protocol being developed for the use of the stress measurement method that incorporates the TA and QA aspects?
-

Audit Subject Area 3: Contractual aspects

7. Schedule and required resources
 - What time is available for the stress measurement works?
 - Requirements on the field crew
 - Need for on-site auditing?
 8. Auditing requirements and strategy
 - Conclude auditing requirements based on Subject Areas 1 and 2
 - Establish auditing strategy
 - Establish auditing resources
 9. Roles for Client and Contractor
 - Responsibilities on site
 - Resources provided by the Client
 - Review and evaluation tasks
-

depth dependence of parameter values, scale effects, the method utilised, equipment used for the data collection, and experience with the procedures. The efforts spent to reduce uncertainties in data will vary according to

Table 3

A list of issues to be considered when establishing QA procedures (continuation of Table 2)

Audit Subject Area 4: Establishing QA procedures

10. Adaptation to the quality system of the organisation
 - Level of detail?
 - Compatibility/coincidence with any overall QA system for the organisation?
 11. Manufacturing or assembling of equipment
 - Are the parts used suitable for use?
 - Are stress magnitudes, water pressure and water quality issues considered?
 - Are the parts used of sufficient quality for their purpose?
 - Will spare parts be available?
 - Are the critical activities that may influence the quality of test results understood and sufficient procedures and quality control established?
 12. Routines for storage and maintenance of equipment for stress measurements
 - Are maintenance procedures of the critical equipment components established?
 - Is equipment stored in a safe way when not in use?
 13. Quality control of data acquisition systems
 - Are calibration routines established?
 - Is the lifetime of the components understood?
 - Is the software validated?
 14. Establishment and maintenance of QA procedures
 - Is there a system to follow up on the routines and procedures applied?
 - Are there established and maintained procedures to identify training needs, as well as to provide the training, of personnel carrying out and evaluating the stress measurements?
-

Table 4

List of issues to be considered when establishing the viability of stress measurements at a given location/depth (continuation of Table 3)

Audit Subject Area 5: Quality aspects for establishing the viability of stress measurements at a given location/depth

15. Decision on the test location/depth
 - Is the most recent geological information being used for judgement of the suitability of a test location/depth?
 - Is the proposed test location/depth representative for the site/the planned project?
 - For overcoring—are there specifications on required rock quality in the actual formation stated in advance of the measurements?
 - For hydraulic fracturing—is the influence of any anisotropy on test results understood, and could the least anisotropic sections be chosen?
 - For HTPF—are there suitable closed fractures available?
 16. Functional testing of installation tools, etc.
 - Are procedures followed and checklists used?
 17. Procedures to install equipment at the suitable location/depth
 - For overcoring—what procedures are in place for drilling the pilot hole and accepting the test level?
 - For hydraulic fracturing—what procedures are in place for controlling that the packers are placed at the chosen test level, and are relevant procedures followed and documented?
-

Table 5

A list of items for consideration during measurements and data processing (continuation of Table 4)

Audit Subject Area 6: Measurement procedures

18. Down-hole installations and measurements

- What procedures are in place to ensure that the down-hole operations are fully traceable?
- What procedures are in place to check the actual geological conditions at the test level (e.g. inspection of overcored sample, checking impression packer result)?

19. Data acquisition

- What procedures are in place to check or calibrate gauges used?
- What procedures are in place to check hardware and software?
- What procedures are in place for data storage and backup?

Audit Subject Area 7: Stress data reduction and interpretation

20. Data recording, reliability and reduction

- What procedures are in place to ensure that the data will be recorded accurately and safely?
- Have all the hazards with stress measurements (see Audit Subject Areas 1 and 2) been addressed?
- What procedures are in place to ensure that the raw data obtained are reliable?
- How will the data be reduced?
- What procedures are in place to ensure that mistakes will not occur during data reduction?
- Is there a protocol with a case example available for this Subject Area 7?

21. Data interpretation

- How are the data to be interpreted and the trends identified?

Audit Subject Area 8: Continuous evaluation process

22. Procedures for on-site evaluation and draft reporting

- What procedures are in place for a gradually updating understanding of the results during the measurement process?
- What procedures are in place for a decision on continuation or termination of field works (see Subject Area 2)?

Audit Subject Area 9: Validation and presentation

23. Data validation

- Are results compatible with existing relevant data and trends at the site?
- Are the site conditions within the assumptions for the method used?
- Are the determined elastic properties of the rock realistic?

24. Presentation of stress measurement results

- How are the stress measurements to be presented in a clear form?
- Discussion of the process for uncertainty evaluation
- How is the uncertainty to be presented?

factors such as the nature of the measured parameter, the phase of the project, the project budget and site conditions. It is, however, always important to ensure that a suitable plan of action has been devised (see also Part 1 SM) and that an appropriate record is kept of the

Table 6

A list of items to consider for the auditing conclusions (continuation of Table 5)

Audit Subject Area 10: TA conclusions

25. Stress measurement adequacy

- Have the stress measurements been conducted adequately—given the objective (Audit Subject Area 1) and the existing scientific, practical and site knowledge
- Is the documentation of the quality control during measurement, data reduction and data interpretation reliable (Subject Areas 5–9)?

26. Overall TA statement

- What are the overall TA conclusions given the individual conclusions in Items 1–25 above?
- What recommendations are to be made concerning the work?

work carried out in order to allow for full traceability so that the results can be scrutinised to demonstrate reliability.

4. The requirements enabling traceability will vary according to the method applied. For example, a standardised method frequently used in foundation engineering may be widely known through the standardised description, and the quality control measures will be based on the requirement to follow the standard in question. On the other hand, a specialised method that is not commonly used has to incorporate other quality control aspects as well, such as the following:

- the theory and assumptions for the method must be fulfilled;
- the equipment used must be relevant for the site conditions;
- each component may have separate restrictions for usage or need for calibration, which can cause complex procedures for its usage at the site; and
- the influence of natural spatial heterogeneity in the rock mass on individual results may have to be explored.

5. These aspects for quality control are particularly relevant for in situ stress measurements and the following SM recommendations are focused on the two commonly used methods, overcoring and hydraulic fracturing/HTPF, as described in SMs Parts 2 and 3, but the principles will be applicable to other methods as well. The recommendations cover both Technical Auditing (TA) and Quality Assurance (QA). The term ‘technical auditing’ means examining the technical content of, for example, a measurement procedure or a rock mechanics model or a rock engineering design to establish if it is adequate for the purpose—in this context, the estimation/measurement of rock stress. Note that TA has a wider scope than basic QA because

QA, once implemented, is concerned with following pre-determined procedures.

6. In addition to checking the adequacy of procedures commensurate with the objective, TA ensures transparency of methods used, traceability of analysis methods and associated decisions, and confirms that the investigation of all necessary factors has been implemented. Furthermore, an audit trail is automatically generated. In the case of the technical auditing of rock stress estimation and measurement, an overview of the issues is presented in [Table 1](#). Note that the headings within [Table 1](#) indicate subsequent tables covering the items.

2. Subjects to be addressed when developing a stress estimation/measurement programme

7. During the development of a stress measurement programme, there is a number of issues recommended for the Client in going through the planning process. There should be a check-list prior to initiation of the measurement works. The subject areas proposed deal with the stress measurement objective and background, the stress measurement method(s) chosen and contractual aspects. A list of technical audit issues to be used in the planning process is given in [Table 2](#).

3. Establishing QA procedures for stress measurement equipment

8. A QA strategy for the fieldwork is essential for accurate, repeatable results and reliable records of the work. This shall be compatible with any more systematic overall Quality System in operation by the Contractor. It is the responsibility of the stress measurement Contractor to develop and fully document routines and procedures for the equipment used. All hardware and software used must be documented and specifications developed for any manufacturing or assembly of equipment, calibration of gauges used and the operation of software for data acquisition and processing. This forms the full record of Quality Procedures that also need to be maintained and updated if required. A list of issues to be considered when establishing Quality Assurance procedures is given in [Table 3](#).

4. Quality aspects for establishing the viability of stress measurements at a given location/depth

9. The Client and the Contractor may have a shared responsibility in establishing the viability of stress measurements at a specific level in a borehole. For both the overcoring and the hydraulic fracturing/HTPF methods, is the Client's need for measurements at any specific location/depth limited by the actual ground conditions? Overcoring cannot be carried out in fractured rock, but hydraulic testing can be used if the HTPF technique is applied. There is, however, one major difference between the two techniques: planning for hydraulic testing may be possible to be done based on core or borehole logging; but overcoring is carried out essentially 'blind' during drilling. Only the pilot hole for a 3-D overcoring cell provides rock information. Other information, such as drilling through a significant fracture zone that may have a considerable effect on the state of stress in the vicinity of the structure, has also to be considered. Thus, the best available information on the geological conditions should be considered in the planning and decision process. A list of issues to be considered when establishing stress measurements at a level/depth is given in [Table 4](#).

5. Quality aspects of measurements and data processing

10. The actual measurements and the data processing are under the full responsibility of the Contractor, who must have relevant procedures and check-lists for his/her work. There is, however, a joint responsibility for the Client and the Contractor to continuously review the overall suitability of the site for stress measurements with the method chosen (see Subject Area 2). A list of items for consideration during measurements and data processing is given in [Table 5](#).

6. The Client's review procedures

11. The complete auditing of the stress measurement results is the responsibility of the Client before using the data. A list of items to consider for the auditing conclusions is given in [Table 6](#).