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A Comparative Study of Rock Stress and Property Measurement Equipment

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<p>This is the first Semiannual Technical Report for the reporting period from April 2, 1971 to November 2, 1971.</p> <p>Data accumulation was the only activity. Analysis will follow in a later report. A brief statement of purpose and background is given and specific mention of the more accepted reports on stress and modulus gage theory, design, and very inadequate use description is presented. Brief mention is made of the questionnaire and data collection process with a listing of the number of references, questionnaires, and contacts resulting from the study to date. Little technical information is provided at this time consistent with work plans.</p>			

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Telephone Number: (208) 885-6376
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Technical Report Summary

The purpose of the study is to provide information to engineers on use, cost, time, and other factors relating to rock stress and modulus gages. This information would be oriented toward comparative selection of gages to be used in specific application.

Due to the nature of the project, only data collection through questionnaires, personal contact, and telephone is called for. No equipment purchase or intermediate conclusions have resulted.

The primary interest is directed toward collection of specific use-data on the U. S. Bureau of Mines borehole gage, CSIR "doorstopper", Griswold gage, and the Photoelastic glass plug used for in-situ rock-stress determination; and the Rocha dilatometer, Goodman jack, U. S. Bureau of Mines CPC, and the Menard pressure meter used for in-situ rock-modulus determination. Approximately 800 questionnaires have provided about 240 answers with possibly 70 meaningful sets of data. The data is continuing to come in, and follow-up on incomplete answers is required in most cases. Analysis of the data has started, but results are insufficient to provide useful information at this early date.

The only technical difficulty encountered has been the absence of the principal investigator, C. J. Hall, due to visa clearance. The project director has continued the work plan at a reduced rate pending Dr. Hall's arrival. If the absence continues much longer, it will be necessary to make other arrangements and possibly to request time extension for the project.

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A Comparative Study of Rock Stress and Property Measurement Equipment

Introduction

Engineering design of specific structures requires data on load, area of application of the load, material properties, and use criteria such as failure or deformation specifications. Rock mechanics or the engineering applications of rock is no exception. The major distinction is that the working structure in rock is formed by removal of material from a semi-infinite mass and the resulting skeleton is required to be self-supporting, and possibly support other structures.

Unlike fabricated or constructed structures, the design load is unknown since the semi-infinite mass of rock causes the load through some combination of geologic and gravitational conditions. The resulting effect is an unknown load in an unknown direction applied over a questionable area. To further complicate the problem, most critical conditions relate to stress concentrations due to the opening formed in the rock. The concentrations are a function of geometry and rock properties. The geometry may or may not be well defined because fracture or time-dependent effects may make the visual and effective opening shape quite different. The properties are also poorly defined because of mass effects that exhibit heterogeneity and anisotropy dependent on volume. Controlled laboratory test data on finite samples and field data on a more massive scale often may not

coincide. Due to many factors, realistic measurement of in-situ stress and modulus would appear most needed.

Some development had to be made to provide these data, if a change from artisanship to engineering was to be expected. These were attempted and gradually techniques were developed by many investigators over the past 25 years with increasing frequency and with varying success. Many reports of the theoretical principles, gage design, laboratory application and testing have been written which are listed in the attached references. However, reports of application of these gages in field conditions to get meaningful results are few.

The Purpose of Study

The objectives of the present study are to collect data on field tests in which stress and modulus gages have been used. The gages for measuring stress that are of particular interest are: U. S. Bureau of Mines borehole gage, CSIR "doorstopper", Griswold gage, and Photoelastic glass plug; and the gages for measuring modulus that are of particular interest are: Rocha dilatometer, Goodman jack, U. S. Bureau of Mines CPC, and Menard pressure meter. Other gages were considered whenever possible, and when specifically reported in the questionnaire.

There would appear to be no valid reason for repeating previously chronicled data on theory or design of any gage, but a compendium of use

data such as best application, cost, depth, difficulty, reliability, etc., could be of considerable value to a prospective user. This, then, is the primary reason for the study--to provide information to engineers who are faced with the selection of the most appropriate equipment for a given situation in which the stress and rock modulus must be determined.

Background

During several years work in rock mechanics in which it was frequently necessary to recommend the best way of determining in-situ stress or modulus, the investigators were never able to ascertain adequate information about gage use for comparative decisions. Choice was too often confined to personal opinion or proprietary enthusiasm. This seemed to be a common problem for most potential gage users. The present literature search shows little improvement although some of the individual papers are quite helpful for specific gages.

Leeman ^{1/} described a number of gages with details of design, but did not give adequate information for selecting one gage in preference to another. Obert and Duvall ^{2/} also presented information on theory and design of some gages, but again with limited use data. Woodruff ^{3/} presented some application data as well as theory and design of some gages. Information on individual gages was presented in more detail in separate papers at an early symposium edited by Spokes ^{4/}. Some of the papers were more specific on the problems and costs so that selection could be made more intelli-

gently. It was an improvement over the previous symposium discussion at McGill in 1962 by Panek ^{5/}. An attempt was made by Fairhurst ^{6/} to compile several of these reports in one to provide a ready source of information on the subject. It still did not give adequate data for use selection. Possibly a better presentation for the purpose is the work by Abel ^{7/} in which most of the same gages were examined, but with a different intent. His purpose was to evaluate the gages and instruments for use on the Project Payette. His report chronicled information for one specific application which this investigation is to do for more general use.

Other data accumulated, and in process of accumulation, almost exclusively pertains to individual gages. These are to be compiled and analyzed during the next phase of this project.

Theory

Although the purpose of this study is to explore stress and modulus gage use, it is appropriate to provide information on the theory behind the gages for anyone wishing to compare their use and applicability in more detail.

Reddy's ^{8/} two-dimensional photoelastic investigation of stresses surrounding the pilot hole region during overcoring shows high stress concentration in the potential overcore and an explanation for discing of cores which is a frequent problem in high stress areas. It can be seen that gage positioning and interpretation of deformation becomes important in the complex stress field that results from the process. Mahtab and Goodman ^{9/} have used finite element analysis to investigate nonlinear stress-strain laws at the bottom of well bores at 6000-foot depth. Problems of nonlinearity although effective over only one-quarter hole radius, nevertheless would appear to effect gages dependent on surface measurements at well bottom. Van Heerden ^{10/} shows that fracture around the borehole end can be expected but does not interfere with the doorstopper gage use. After considering both flat and spherical hole bottom configuration, he determined the flat hole bottom ^{11/} was satisfactory for his purposes.

Several authors mentioned previously (1, 2, 3, 4, 5, 6, 7) have investigated two or more gages for comparative purposes. These reports vary from the theoretical to state-of-the-art information with the most complete treatment being given by Fairhurst ^{6/}, Leeman ^{1/}, and Obert ^{2/}. Leeman's treatment while not complete offers the reader the mathematical, description of instru-

ments, and information about the use of several of the devices. His classification of: 1) borehole deformation strain cells, 2) borehole inclusion stressmeters, and 3) borehole strain gage devices are a convenient method of distinguishing between groups of borehole measuring devices to determine stress. No such reports or classification has been found for modulus determinations. It must also be remembered that these instruments have been designed on elastic principles. While many applications are of elastic conditions in which even fractured ground give acceptable elastic response, long term tests on some rock material result in time-dependent-relationships. Some rock exhibits these time-dependent properties under short-period tests. When encountered, devices incorporating rheological principles should be used on rocks of this type.

These theoretical presentations, when appropriate, will be included in the final report for completeness, or will be referred to for easy access. The engineer must be aware of limitations of theory as well as of gage use. For example, several of the gages are designed to determine principle stresses only if the borehole is parallel to the third principle stress. If this cannot be determined for certain in the field, another method of investigation becomes necessary. Other limitations of theory exist and will be presented in the final report.

Investigative Procedure

Initial review of reports on gage use corroborated the author's belief of a tendency toward positive reporting with only a minimum and usually a complete absence of adverse information being included. As negative as well as positive information was part of the purpose of this investigation, it was necessary to collect first-hand comments from users to get a more accurate assessment of operator difficulty, costs, time, and weaknesses. Only with these data and comments would a prospective user be able to make a meaningful selection between gages for his particular condition.

The first step in any investigation is the collection of published information, but in this study authors' addresses were also needed. This resulted in severe complications because a surprising number of professionals have a high rate of migration in a period of five years.

A questionnaire was devised (see Appendix) to get as detailed data as possible from each user. One questionnaire was sent to each operator or anyone believed to have been an operator of any rock-type gage. Duplicate questionnaires were sent to those indicating use of more than one gage. Follow-up after no return of an inquiry is by letter or telephone. If returned unopened, additional effort is made to establish a correct address.

Personal contact was made with individuals separately or during professional meetings to establish additional information, clarify details, or get names of other investigators. In all, approximately 800 questionnaires were sent, both domestic and foreign, with about 240 replies being received.

Most foreign replies have not had an opportunity to arrive yet. Of the 240 replies, only 70 have been informative to any degree, and less than 50 have detailed use data that is of value. Direct contact has netted approximately an equal amount of data, some of it overlapping.

The most difficult part of both written and verbal contact was to arrive at common denominators of cost, ease or difficulty of operation, set-up time, reliability, and problems encountered. Efforts are still being tried to make these more fruitful, as well as continue to gather additional information.

Data Collected

The objective of the study is to get working data on the following gages:

Stress Gage

1. U. S. Bureau of Mines borehole gage
2. CSIR "doorstopper"
3. Photoelastic glass plug
4. Griswold gage

Modulus Gage

1. Menard pressure meter
2. Rocha dilatometer
3. U. S. Bureau of Mines CPC
4. Goodman jack

If information on other gages becomes available, and is appropriate, it will be included also. Since most gages have been described in detail, and their theoretical concepts have been well chronicled, no attempt will be made to repeat this information here. For completeness, it will be included in the appendix of the final report.

Questionnaires received at the time of this report have generally been inadequate in their answers to questions on costs and specific difficulties encountered. The two main reasons for the lack of data are: incomplete

response, which is being given individual follow-up during the next half; and inadequate records of this information by the user. For example, the U. S. Bureau of Mines prime objective is experimental information on feasibility with cost being of secondary importance. Often the user had only limited experience with the gage. In addition to being an unfair reflection on the gage, except possibly the training needed to use it, these data do not establish the critical information sought for comparative purposes. It is expected that continued investigation will amplify these data, mainly through direct telephone or personal contact.

No conclusions will be presented in this interim report nor will it be appropriate to present use charts, recommendations, or selection guides due to the small quantity of information available. These will be left for the final report at the end of the second six-month period.

Information received for the specific gages was:

<u>Stress Gages</u>	<u>Publications</u>	<u>Questionnaires</u>	<u>Personal Discussion</u>
USBM Borehole	23	16	10
CSIR Doorstopper	9	9	2
Photoelastic Plug	8	9	8
Griswold	4	1	2
<u>Modulus Gages</u>			
Menard Pressuremeter	5	1	0
Rocha Dilatometer	2	1	3
USBM CPC	1	6	2
Goodman Jack	11	7	5
<u>Other Gages</u>			
Hast	2	1	0
White Pine Solid Inclusion	3	3	2
CSIR 3-D Cell	17	0	2
Soil Stress Cell	2	0	0
Deformation Gage	2	1	0
Flatjack	4	1	2
Hydraulic Cell	2	2	2
Hydrofract	0	2	4
Photoelastic Coating	0	1	6
SR-4 Strain Gages	2	2	5
Soiltest Unit	1	3	0
Seismic	1	1	5
Sweeny Tescon	1	1	0
Talobre	1	1	0
Terrametries	1	0	1
TiWag Radial Jack	5	0	0
Extensometers	0	2	4
Potts Stressmeter	5	1	1

Attempts to analyze and chronicle these data are starting according to program plans, but are of insufficient value to be presented here. These will be left for the final report.

Conclusions

At this point, the only conclusions that can be made are:

1. It is almost impossible to get specific data on costs and difficulties from operators.
2. Problems of a specific nature such as design errors, malfunctions of gages and performance difficulties are not chronicled by the designer and frequently when reported by the user are omitted from final reports on a project.

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64. Wright, F. H. In-situ Stress in Granite, Project Shoal. Lucius Pitkin, Inc., AEC Report VUF-2600, May 1964, 76 pp.

Appendix

Questionnaire

Sent to all gage users.

Return to: University of Idaho
Bureau of Mining Research
J. R. Hoskins
Moscow, Idaho 83843

Telephone: 208-885-6376

Name: _____

Company or
Affiliation: _____

Address: _____

Telephone: _____

(Please correct the above)

QUESTIONNAIRE

Dear Sir:

I am collecting operational data on rock stress and modulus gages. My principal objective is to learn what gages have been used in in-situ rock or in underground installations for determining stress and modulus and what results have been obtained from these gages. Information concerning the borehole deformation gage, doorstopper, Griswold gage, photoelastic glass plug, Goodman jack, USBM cylindrical pressure cell, and Rocha dilatometer will be especially useful.

Your help in filling out the following questionnaire will be appreciated. It is hoped that the results will provide a ready source of information on gage selection, use, cost, and operational characteristics. If you do not have complete information, please estimate and so indicate and fill out all data wherever possible. Would you please send copies of any articles or papers which you have written on modulus or stress gages?

MODULUS GAGES, STRESS GAGES (PLEASE CROSS OUT ONE)

Have you or any member of your group used the gages? _____ Name of the
gage. _____ How many times have you used the

gage? _____ The number of people required to use it. _____

What crew size do you recommend? _____ Did you get the data desired? _____

How long did it take to get this data? _____

Did you have difficulty? _____ What were these difficulties? _____

Is any type of rock (i.e., granite, quartzite) more difficult than another? _____

What kind? _____ Why? _____

What kind of training was required in order to get satisfactory data? _____

How long does this training take? _____ Are there special techniques needed? _____

Are there difficulties in getting data at depth? _____

What are these? _____

Are there difficulties due to rock conditions? (i.e., moderately fractured rock)

What are these? _____

What is the maximum depth at which you have gotten information? _____

What is the limiting depth for this method? _____

How much does it cost to get information at 5-foot intervals? _____

Does it cost more with depth? _____

How much per 5-foot intervals to 20 feet? _____ to 50 feet? _____

to 100 feet? _____ to 200 feet? _____

How accurate are your results? _____

Have you checked your data by other methods? _____

Do you use other intervals and hole depths? _____ What are these? _____

Is there an optimum depth of hole to get reliable data? _____

Is there an optimum hole depth for practical use of the instrument? _____

Where can the instrument be purchased? _____

Cost of the instrument \$ _____ Cost of calibration of the instrument? _____

Cost of preparing for a test at the site \$ _____

Material and labor costs for conducting the test \$ _____

Please describe the field procedure used. _____

Please describe the limitations of the instrument. _____

What do you consider to be the instrument's best points and best application?

What do you consider to be the instrument's weak points? _____

What are the recommendations for improvement of the gage? _____

Do you have information on other gages of the rock stress or modulus type? _____

May I send you another questionnaire? _____ How many _____

Can you give the name and address of one or more investigators who have used these or other gages in underground investigations?

Name: _____ Name: _____

Address: _____ Address: _____

Telephone: _____ Telephone: _____

Name: _____ Name: _____

Address: _____ Address: _____

Telephone: _____ Telephone: _____