SERATA GEOMECHANICS CORPORATION

Automatic Stress/Property Measurement for Earthwork Optimization

CATEGORY 1 OVERVIEW OF NEW ERA

— Serata Stress Technology for In-Situ Optimization of Earthwork —

SERATA STRESS TECHNOLOGY (SST)

Causes	Computerized Relationship	Result
S x **P**	**R** →	**D**
Stress, Properties	In-Situ	Deformation/Destruction
Measurement by Serata Probe	Modeling by Serata Software	Measurement by Conventional Methods

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Serata Stress Technology for In-Situ Optimization of Earthwork

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An innovative next-generation technology of stress/property (S/P) measurement (Serata Probe) has been developed by Shosei Serata based on his three decades of systematic R&D work. The Probe has been successfully utilized as the basic hardware of Serata Stress Technology (SST) to achieve in-situ optimization of earthwork with great technological and economic gain. In the past, such a computer optimization of ground behavior (deformation and deterioration; D) has been considered virtually impossible because of formidable difficulties inherent in conventional methods for obtaining the basic computer modeling inputs, i.e., stress state (S) and material properties (P). With the development of SST, the optimization of earthwork (D) is readily achieved as illustrated by the schematic diagram in Fig. 1-1.

With this highly effective means of automatically obtaining the critical ground information by a non-destructive method by Serata Probe, a sufficient amount of data is quickly obtained for accurate mathematical optimization of engineering earthwork in-situ. This is SST, which is now applicable for survey, design, construction and safety assurance of all major earthwork effectively and economically. Such a comprehensive technology has not been previously available, it is proprietary to Serata Geomechanics Corporation and is protected by global patents. Overview of the Technology is briefly summarized below as an introduction to the new era of automated earthwork optimization.

1. Overcoming Deadlock of Conventional Methods

Over the past half-century, the conventional overcoring and hydrofracturing stress measurement methods have had minimal success because they are based on complex and time consuming operational procedures as illustrated in Figs. 1-2 and 1-3, respectively. The complicated methods indicate an urgent need for automation of stress/property measurement to overcoming deadlock of the elasticity assumptions, on which they are based.

2. Double-Fracture Method

To meet the urgent need for a more efficient means of in-situ stress and property measurement, Serata Probe was first developed by the invention of a double-fracture method for automatic measurement on-site in real-time. The Probe was a drastic improvement from the conventional methods and it was successfully applied to many failing mines to save them from their anticipated abandonment in U.S., Canada and EU in 1970s and 1980s (see Category 4). In spite of the major success with Serata Probe, it did not get an immediate global attention and utilization as expected. This is due to the fact that the earlier Serata Probe utilizing the double-fracture method had an inherent defect of certain irregularity in spite of its major improvement by the automation.

The defect was identified as the fallacy of elasticity assumption on which double-fracture method of stress measurement is based. The fallacy is demonstrated by application of the double-fracture loading to borehole made in biaxialy loaded rock specimens as shown in Fig. 1-4. Here, a set of eight rock specimens, are expected to develop double-fractures around each borehole as indicated by the red dotted lines. The reality of double-fracturing in every specimen is found by a considerable deviation from the theoretical value, clearly pin-pointing not only the basic fallacy of elasticity assumption of the method but also an urgent need for improvement.

3. Single-Fracture Method of Stress Measurement

In order to achieve the needed improvement, “single-fracture method” based on “principle of force balance”, was invented. The new method was made effective by adding a pair of steel friction shells to the pressure loading tube to mechanically “freeze” the borehole boundary as illustrated (in comparison with a double-fracture loading section) in Fig. 1-5. The friction effect created by the shells is capable of “freezing” complexity of material properties including preexisting fractures and complexities to produce a well-defined single-fracture as demonstrated by the laboratory experiments shown in Fig. 1-6. The automatic application method of single-fracture method is very simple and fast as explained in Fig. 1-7. Decisive advancements achieved by the method over the conventional methods of overcoring and hydrofracturing are categorically identified in Table 1-1. While the distinction between single-fracture method and double-fracture method is made also categorically in Table 1-2. Details of the development of the method are explained with laboratory and field data in Category 2.

4. Next-Generation Technology

Serata Probe has successfully overcome all of the difficulties of conventional stress/property measurement systems to become a next generation technology that achieves the computer optimization of earthwork with great technical and economic gains.

This is made possible by utilizing the latest Serata Probe, which is equipped with two quickly interchangeable loading sections (one for single-fracture to measure stress and the other for double-fracture to measure properties). It has taken the decades since its initial success to perfect the Technology to the current level of maturity. The whole Technology development is presented with a wealth of field verification in the following categories in this site.

Category 2: INNOVATION OF SERATA PROBE
Category 3: FIELD VERIFICATYION OF SERATA STRESS TECHNOLOGY
Category 4: EARTHWORK APPLICATION EXAMPLES
Category 5: ACCURATE TIME-PREDICTION OF EARTHQUAKES
Category 6: GLOBAL PROJECT RECORDS AND REFERENCES

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TABLE 1-1

Serata Method Compared with Conventional Methods in Stress & Property Measurements

Category \ Method	Hydrofracturing Method	Overcoring Method	**Serata's Method**
Simultaneous Measurement of Stress State & Material Properties	not possible	not possible	yes. done automatically
Application Depth	not applicable at shallow depth	not applicable at great depth	highly effective in all depth
Automation of Measurement, Analysis & Graphic Display on Site	not possible	not possible	yes. all done on-site in real-time
Requirement of Separate Supporting Tasks	high-pressure packer work, water injection & fracture indentation	probe cementation, overcoring & specimen recovery	none
Core Specimen Recovery and Laboratory Testing	required	required	not required at all
Application to Inhomogeneous Ground	no	no	yes with very high-accuracy
Applicability to Complex & Inhomogeneous Ground	no	no	yes
Accuracy in Stress Measurement	no better than ± 20%	no better than ± 20%	± 2% or better as needed by repeating
Relative Measurement Accuracy	1	1	more than 10
Time Requirement per Single Measurement	more than 4hrs. to 4 days	more than 4 hrs. to 4 days	less than 1/4 hrs.
Relative Measurement Speed	1	1	more than 10
No. of Possible Repeated Measurement at Same Position	1	1	far more than 1000
Economic Efficiency (EE)* of Measurement Method	1	1	1000

* EE = Economic Efficiency of Stress /Property Measurement
= (Relative Measurement Accuracy) x (Relative Measurement Speed) x (No. of repeating)

TABLE 1-2

Distinction between Single-Fracture and Double-Fracture Method

Method / Subject	Double-Fracture Method	Single-Fracture Method
Relationship	basic system	extended system
Principle of Measurement	elasticity	balance of force
Pressure Loading Mechanism	uniform application of oil pressure around borehole	loading by a pair of friction shells
Alternative Loading Section	P-800	S-800-A
Stress Measurement Accuracy	± 3~5%	± 0.1%
Application	in-situ material property measurement	high accuracy in-situ stress measurement
Earthquake Prediction Use	not enough accuracy	highly suitable

In-Situ Computer Modeling of Earthwork

SERATA STRESS TECHNOLOGY (SST)

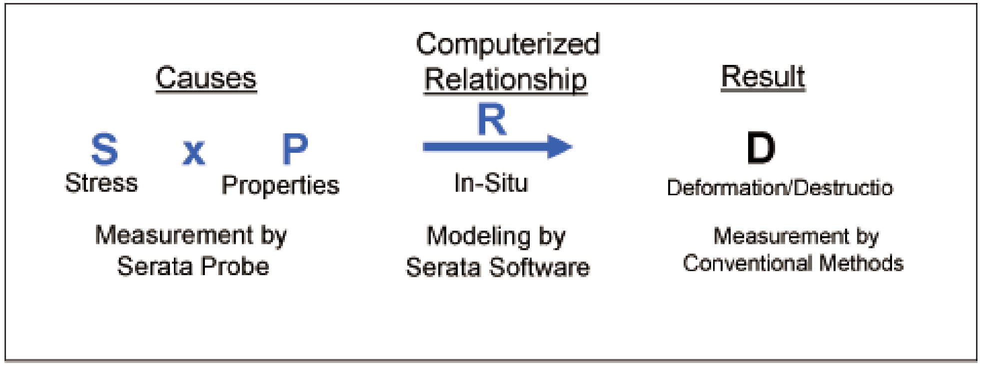


Fig. 1-1 Principle of SST for in-situ computer optimization of earthwork by S & P measurements with field modeling analysis using proprietary software

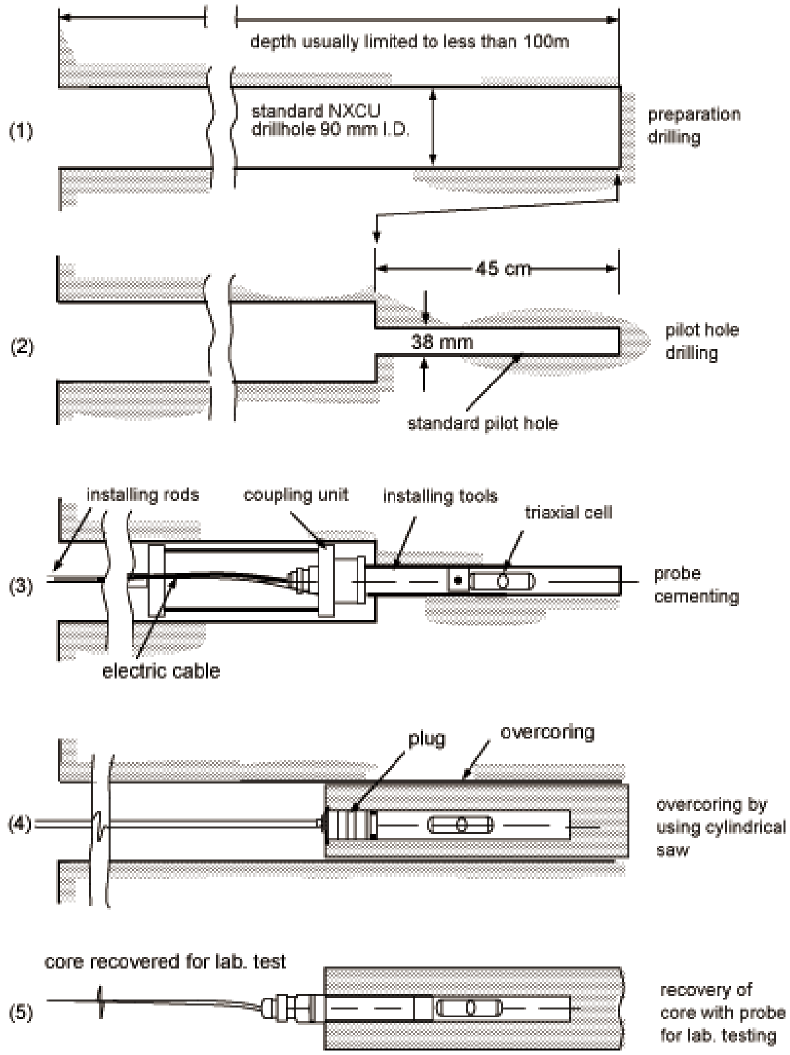


Fig. 1-2 Five-step overcoring method for obtaining single stress measurement. Test position cannot be used again for repeat measurement and method cannot be applied in complex or inelastic ground. The core with the sensor must be sent laboratory testing for material properties

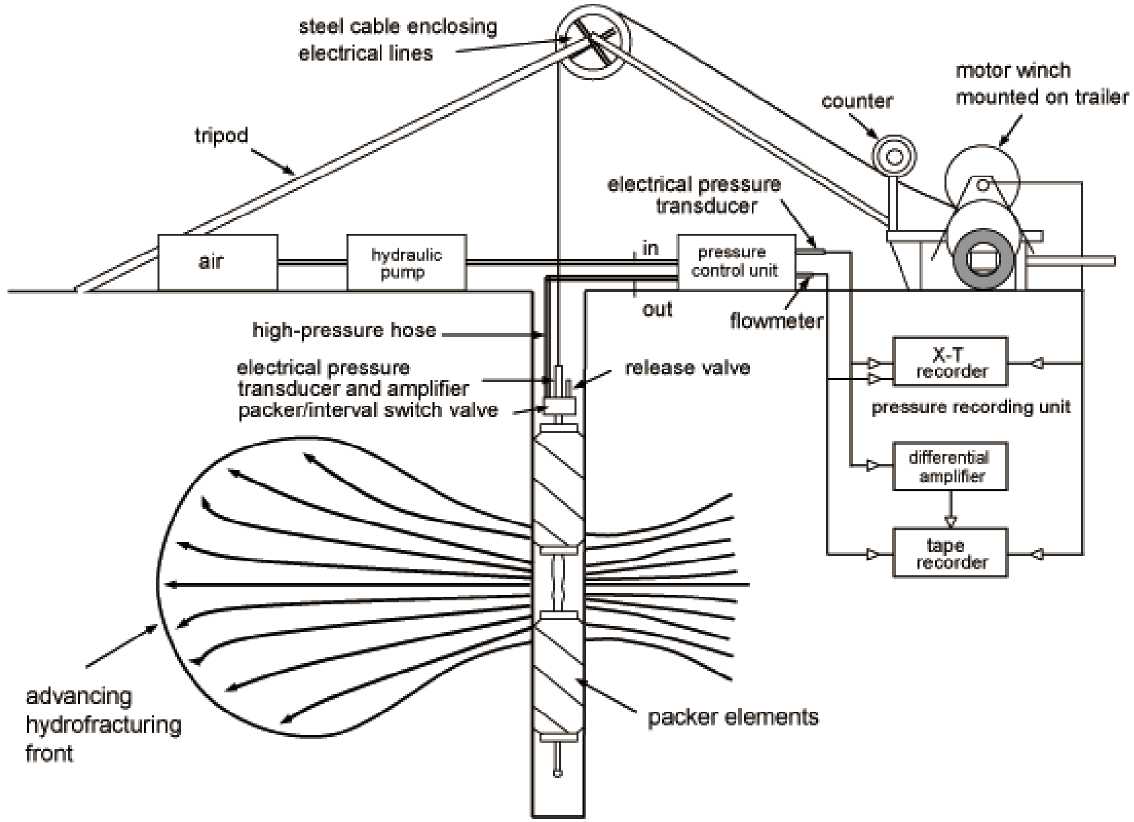


Fig. 1-3 Scheme of typical hydrofracturing operation consisting of packer installation, hydrofracturing, fracture indentation, packer recovery, core recovery and laboratory testing of core specimen, all required for completing single stress measurement taking days, weeks and sometime months depending upon depth of the measurement. A measurement position is used only once with no repeat measurement.

LABORATORY DEMONSTRATION ON NON-ELASTIC NATURE OF ROCK BEHAVIOR

Deviation from Elastic Behavior Utilized for In-Situ Property Measurement by Double-Fracture Method of Serata Probe

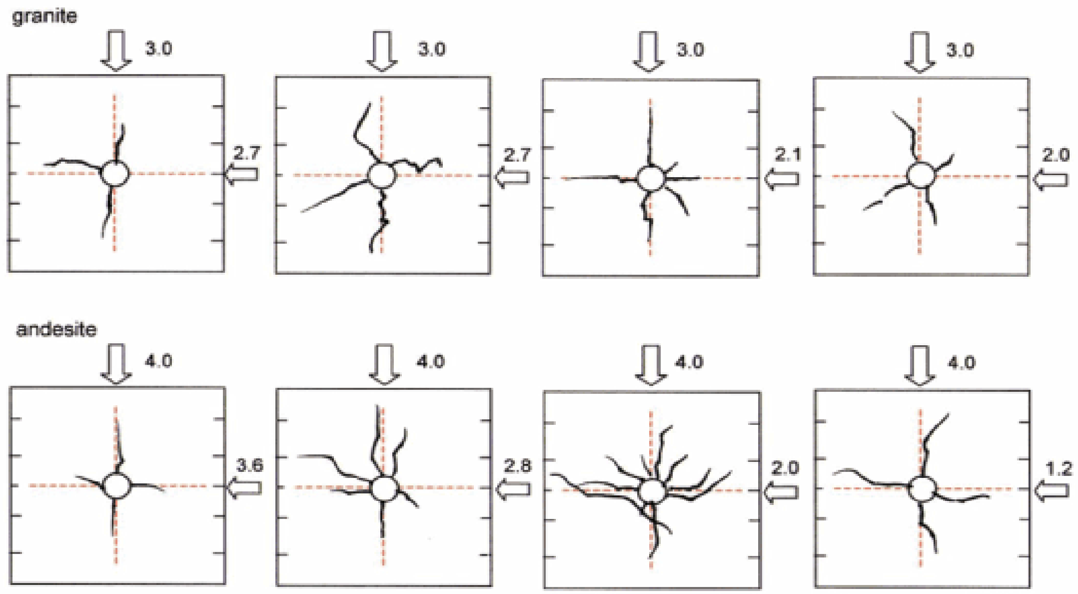


Fig. 1-4 Theoretical double-fracture pattern indicated by dashed cross lines compared with reality of rock fracturing tested in the laboratory, disclosing complexity of actual rock properties deviating significantly from the theoretical state of elasticity. This complexity of double-fracture deviation from ideal elasticity is utilized to determine real material properties in-situ without recovery of core specimen for laboratory testing

TWO RESPECTIVE METHODS FOR S & P MEASUREMENTS BY SERATA PROBE

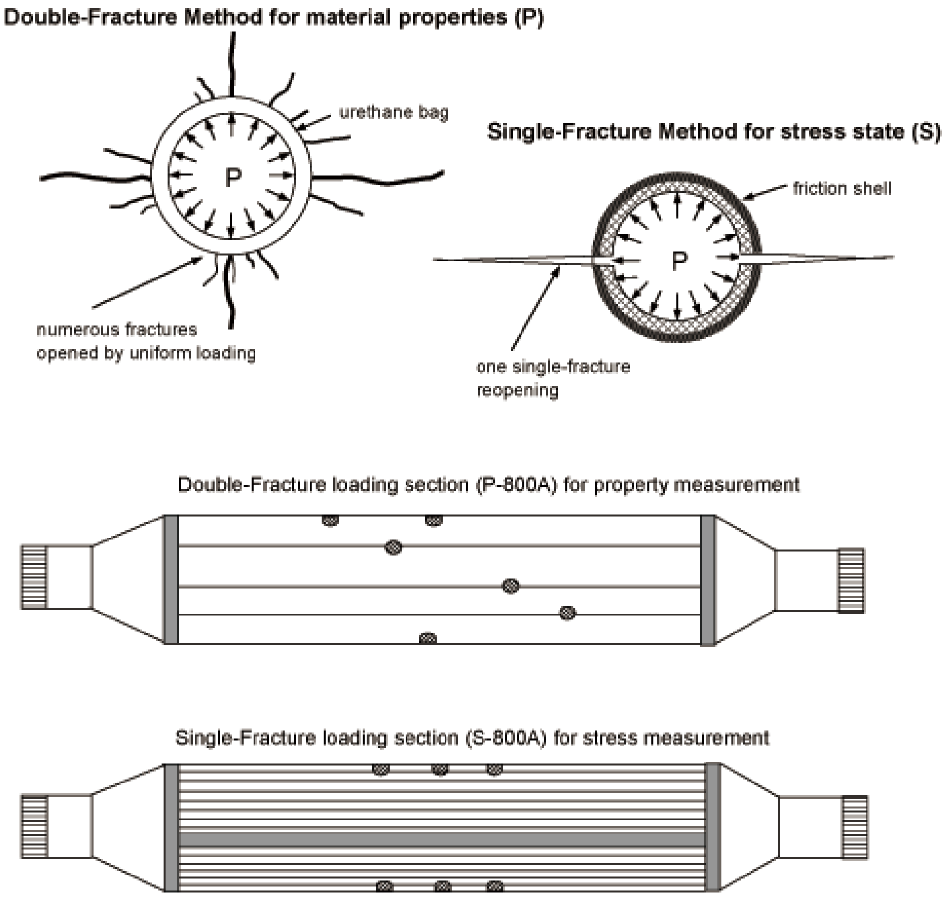


Fig. 1-5 Comparison of interchangeable loading sections of Serata Probe for choice of high-accuracy stress measurement by single-fracture method or faster property measurement by double-fracture method

FORCE BALANCE PRINCIPLE OF SINGLE-FRACTURE METHOD

Demonstration of Force-Balance Principle by Formation of
Single-Fracture with No. Interference with Preexisting Fracture

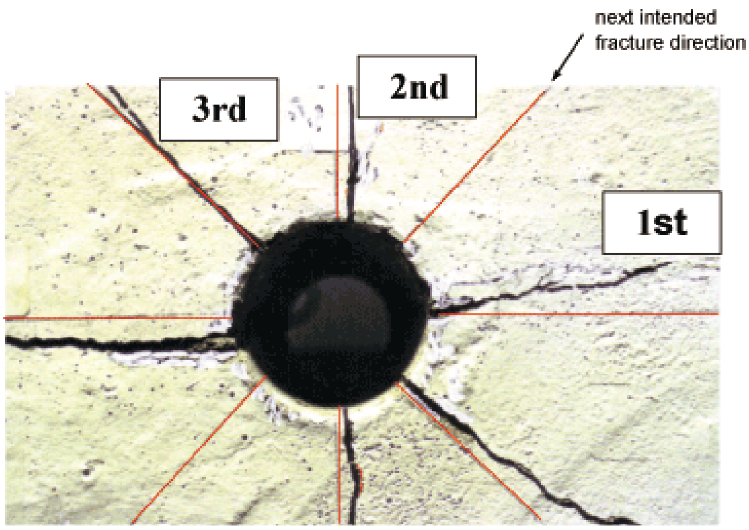
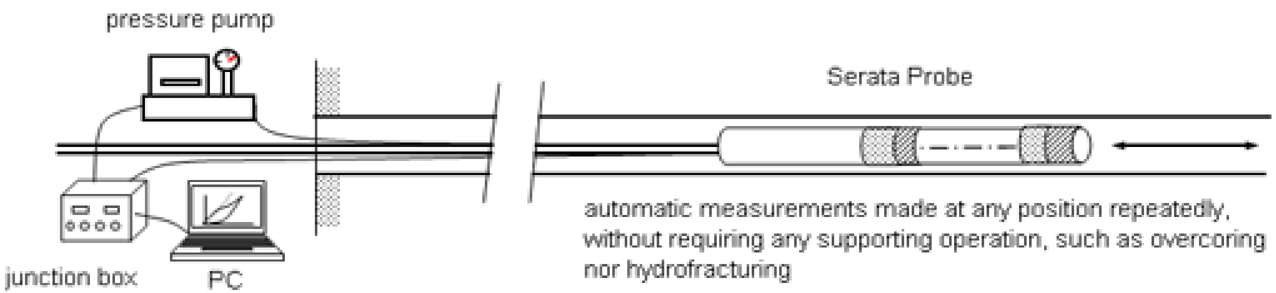


Fig. 1-6 Three single-fracture planes created individually by three different single-fracture loadings, demonstrating power of friction loading, which eliminates any effect from ground complexity including preexisting fractures



1. <u>Stress Measurement Principle</u>
   Quick, accurate and repeatable measurements of in-situ stress state are made possible in elastic as well as complex grounds by the innovation of force balance principle of stress measurement.
2. <u>Property Measurement</u>
   In-situ material properties of the ground are obtained simultaneously and automatically with the stress measurement from the boundary behavior of the test hole, totally eliminating the need for the conventional methods to recover core specimens for laboratory testing.
3. <u>Automatic Operation</u>
   A complete data analysis of the stress/property measurements is carried out by the field computer to obtain stress/property values in the final form of report presentation on site in real-time.
4. <u>Simplicity and Mobility</u>
   The measurement operation is made simple without requiring time consuming supporting works such as overcoring, hydrofracturing, fracture indentation, core recovery and laboratory testing, resulting in a large amount of time and cost saving.
5. <u>Overall Efficiency</u>
   The overall efficiency of Serata Probe is a few orders of magnitude greater than any of the conventional methods with a greater advantages as depth increases.
6. <u>Future Global Potential</u>
   Technical and economic contributions of the Serata Probe are expected by making computer optimization of general earthwork simple, accurate and economical.

Fig. 1-7 Drastic advantages of Serata Probe for in-situ stress/property measurement made possible by innovation of "force balance principle" successfully eliminating the dependence upon fallacious elasticity assumption