REPORT FOR 1977 -
U.S. NATIONAL COMMITTEE FOR ROCK MECHANICS

A Summary of the Work
Conducted during Calendar Year 1977
By the U.S. National Committee for Rock Mechanics and Its Panels

Assembly of Mathematical and Physical Sciences
National Research Council

National Academy of Sciences
Washington, D.C. 1978

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee and Subcommittees were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by the Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

SPONSORS: This project was sponsored in 1977 through Bureau of Mines contract J0177031 by the following government agencies: U.S. Bureau of Mines, U.S. Geological Survey, Urban Mass Transportation Administration, Federal Highway Administration, Defense Nuclear Agency, Department of the Air Force, Department of the Army, Department of the Navy, National Science Foundation, and Energy Research and Development Administration (now Department of Energy). The Panel studies reported herein were a continuation under contract J0177031 of projects begun in 1976 under contracts National Science Foundation C310, T.O. 159, Bureau of Mines J0166131, Bureau of Reclamation PO 6-01-ER-01793, Federal Highway Administration 6-3-0070, U.S. Geological Survey 36392, and Energy Research and Development Administration EG-77-C-10-0022.

A limited number of copies are available from
U.S. National Committee for Rock Mechanics
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. NSF/RA-780334	2.	3. Recipient's Accession No. PB291017

4. Title and Subtitle
U.S. National Committee for Rock Mechanics, Report for 1977, Summary

5. Report Date
1978

6.

7. Author(s)

8. Performing Organization Rept. No.
4

9. Performing Organization Name and Address
National Academy of Sciences
National Research Council
Assembly of Mathematical and Physical Sciences
Washington, D.C. 20418

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G) 7713297

12. Sponsoring Organization Name and Address
Applied Science and Research Applications (ASRA)
National Science Foundation
1800 G Street, N.W.
Washington, DC 20550

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)
The U.S. National Committee for Rock Mechanics, in the Assembly of Mathematical and Physical Sciences of the National Research Council, has served United States scientists and engineers concerned with rock-mechanics problems since 1967. This fourth periodic report for 1977 describes the work of the Committee and its Panels for calendar year 1977. The activities of the two Panels concerned with educational requirements and domestic/international activities are summarized. The last section of this report presents the findings and recommendations of the following three technical-study Panels, which were organized early in 1976 and completed their studies and reports in 1977: the Panel on Rock Mechanics Problems That Limit Energy Resources Recovery and Development; the Panel on Rock Mechanics Problems Related to Underground Construction and Tunneling; and the Panel on Rock Mechanics Problems Related to Seismology and Earthquake Engineering.

17. Document Analysis a. Descriptors

Rock mechanics
Tunneling (excavation)
Underground supporting
Earthquakes
Seismology
Energy resources
Civil engineering

b. Identifiers/Open-Ended Terms

Earthquake engineering

c. COSATI Field/Group

18. Availability Statement
NTIS

19. Security Class (This Report)

20. Security Class (This Page)

21. No. of Pages

22. Price
A03 - A01

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

CONTENTS

INTRODUCTION

The U.S. National Committee for Rock Mechanics, in the Assembly of Mathematical and Physical Sciences of the National Research Council, has served United States scientists and engineers concerned with rock-mechanics problems since 1967. The Committee conducts advisory studies, distributes reports of findings and recommendations, assists host universities in organizing annual national rock-mechanics symposia, and participates with similar committees from 33 other countries in activities of the International Society for Rock Mechanics (ISRM). These activities include international congresses at four- to five-year intervals, commission studies of rock-mechanics problems international in scope, and regional symposia on timely rock-mechanics problem themes.

This fourth periodic report for 1977 describes the work of the Committee and its Panels for calendar year 1977. The last section of the report presents the findings and recommendations of the following three technical-study Panels, which were organized early in 1976 and completed their studies and reports in 1977:

No. 1 Panel on Rock Mechanics Problems That Limit Energy Resources Recovery and Development

No. 2 Panel on Rock Mechanics Problems Related to Underground Construction and Tunneling

No. 3 Panel on Rock Mechanics Problems Related to Seismology and Earthquake Engineering

ACTIVITIES OF THE COMMITTEE — 1977

NOMINATION AND APPOINTMENT OF MEMBERS AND OFFICERS

Five members completed terms on the Parent Committee on June 30. They were succeeded by new members appointed for three-year terms (with one exception — a two-year term as noted below) beginning July 1. The new members, the retiring members, and the sources from which they were nominated are as follows:

	NEW MEMBERS	*ROTATING MEMBERS*
Geological Society of America	Fitzhugh T. Lee U.S. Geological Survey	Bruce R. Clark University of Michigan
Society of Exploration Geophysicists	M. Nafi Toksoz Massachusetts Institute of Technology	Gerald B. Rupert University of Missouri, Rolla
Society of Petroleum Engineers, AIME	Kenneth E. Gray University of Texas	William C. Maurer Maurer Engineering, Inc.
Transportation Research Board	William F. Brumund Golder Associates	George B. Clark Colorado School of Mines
At-Large	Madan M. Singh Engineers International, Inc.	Andrew H. Merritt D.U. Deere and A.H. Merritt, Inc.
At-Large	Melvin Friedman* Texas A&M University	Howard J. Pincus University of Wisconsin, Milwaukee

*For a two-year term to June 30, 1979.

Dr. Egons R. Podnieks, U.S. Bureau of Mines and representative of the American Society for Testing and Materials, was nominated and reappointed for a second term on the Committee.

Mr. George B. Wallace completed his term as Committee Chairman on June 30 and was succeeded by Thomas C. Atchison as Committee Chairman for the year July 1, 1977, to June 30, 1978. Mr. Sidney J. Green, President, Terra Tek, Inc., was nominated by the Committee members and appointed by the National Research Council to serve as Chairman-Elect for this same period — to become Chairman on July 1, 1978.

Dr. Eugene C. Robertson, U.S. Geological Survey, was appointed on July 24, 1977, by the National Research Council to serve an indefinite term as liaison representative of the Interagency Committee on Excavation Technology.

ANNUAL MEETING OF THE COMMITTEE

The Parent Committee and the Panel on Domestic and International Activities met at Keystone, Colorado, on June 20-22, just prior to the 18th Annual United States Symposium on Rock Mechanics. The Committee reviewed the current and planned programs of each of the five Panels and concluded that Panels 1, 2, and 3 would be dissolved on publication of their reports as planned for the end of calendar year 1977 — the report of Panel No. 1 to be published as an NRC study report and the reports of Panel No. 2 and Panel No. 3 to be included as part of the Parent Committee's *Report for 1977*.

The Parent Committee also approved the recommendations and preliminary plans proposed by the Chairman of these three technical Panels for establishing a new panel: *Rock Mechanics Research Requirements for Energy Resource Recovery and Development, Civil — Works Construction, Defense Requirements, and Earthquake Hazards Reduction*. The objective of the proposed new Panel will be to make an intensive study of specific research needs and opportunities to meet the urgent national requirements identified in the studies of Panels 1, 2, and 3, which were completed in 1977.

ACTIVITIES OF THE PANELS

The 1977 activities of the three technical study Panels and the two Panels concerned with educational requirements and domestic/international activities are summarized below.

Panel on Rock Mechanics Problems That Limit Energy Resource Recovery and Development — Sidney J. Green, *Chairman*.

Following preparations made in 1976, including appointment of 35 specialists to 6 Subpanels, a 3-day workshop was held January 13-15, 1977, at Dulles Airport near Washington, D.C. A total of 57 scientists and engineers participated in the workshop: 40 Panel and Subpanel members plus 17 observers. In workshop sessions the Subpanels prepared consensus papers discussing serious limitations to energy-resource recovery in the six Subpanel subject areas. After the workshop, a report was prepared by the Panel, presented to the Parent Committee for approval at its annual meeting, and subsequently completed and submitted in the fall of 1977 for NRC publication. A summary of the Panel's findings and recommendations is included in the final section of this *Report for 1977*.

Panel on Rock Mechanics Problems Related to Underground Construction and Tunneling — Ronald E. Heuer, *Chairman.*

The Panel continued its study begun in mid-1976 when the seven-member Panel held its only meeting. The study was accomplished through individual preparation by each member of critical rock-mechanics problems having impacts on underground construction. The Chairman prepared the report based on Panel-member contributions and circulated it to the members. The Panel report is included in the last section of this *Report for 1977.*

Panel on Rock Mechanics Problems Related to Seismology and Earthquake Engineering — Christopher H. Scholz, *Chairman.*

The Panel was formed early in 1976 and held its only meeting at the Spring Meeting of the American Geophysical Union that year. Following the meeting, the seven Panel members prepared, by exchanging draft papers and correspondence, a Panel report identifying key rock-mechanics problems in earthquake engineering and recommending several research approaches for solving these problems. The Panel's preliminary report was accepted by the Parent Committee at its annual meeting, and the report was completed by the Panel in September 1977. The Panel report is included, in full, in the last section of this *Report for 1977.*

Panel on Fundamental Problems in Rock Mechanics and Educational Requirements — William A. Hustrulid, *Chairman.*

The Panel continued its work on evaluation of educational requirements and how they are being met. The work of this Panel has been an ongoing activity of the USNC/Rock Mechanics since it was formed in 1967. The current work of the Panel is concentrated on development of a survey of rock-mechanics skills throughout the United States. A questionnaire for use in this survey was formulated by the Panel in 1977 and approved by the Parent Committee. The Panel plans to initiate the data-collection phase of the survey in 1978.

Panel on Domestic and International Activities
— Thomas C. Atchison, *Chairman*

The Panel assisted the Colorado School of Mines in organizing and conducting the 18th United States Symposium on Rock Mechanics held at Keystone, Colorado, June 22-24. The theme was "Energy Resources and Excavation Technology." The Subpanel on Awards selected recipients for the 1977 USNC/Rock Mechanics awards, which were presented at the 18th Symposium to individuals for outstanding papers as follows:

- Student Award
  Gregory E. Korbin
  "A Model Study of Spiling Reinforcement in Underground Openings"

- Research Award
  John W. Rudnicki and James R. Rice
  "Conditions for the Localization of Deformation in Pressure-Sensitive Dilatant Materials"

- Special Award
  George B. Clark
  "For continuing, outstanding dedication to rock mechanics research"

This Panel has also been assisting the University of Nevada, Reno, in its preparations for the 19th U.S. Symposium on Rock Mechanics scheduled for May 1-3, 1978, at Stateline (Lake Tahoe), Nevada.

International activities of the Committee in 1977 were participation in the International Society for Rock Mechanics (ISRM) Council meeting held in Stockholm in September, arranging for affiliate membership in the ISRM for 158 U.S. scientists and engineers, and participation of individuals from the United States in ISRM Commission studies. Also, one member of the Committee, John W. Handin, serves as ISRM Vice President for North America.

A seven-member delegation from the United States attended the 1977 ISRM Council meeting in Stockholm. Commission studies were reviewed, and the Council approved forming of a new *Commission on Volumetric Changes in Rock* (tentative title). Plans were reviewed for the 4th International Congress on Rock Mechanics to be held September 1979 in Montreux, Switzerland.

FINDINGS AND RECOMMENDATIONS OF TECHNICAL PANELS

LIMITATIONS OF ROCK MECHANICS IN ENERGY-RESOURCE RECOVERY AND DEVELOPMENT

The Panel on Rock Mechanics Problems That Limit Energy Resource Recovery and Development* prepared a report, title as above, for publication by the National Research Council early in 1978.[+] In a 5-page "Summary and Conclusions" the report outlined the rock-mechanics problems that critically limit resource recovery and development in geothermal energy exploration and production, mining and *in situ* recovery, nuclear-waste disposal, oil and gas recovery, underground storage — fuel oil, gas, water, or compressed air — and underocean tunneling for petroleum recovery.

The Panel report concludes that the following research is needed to reduce the limitations discussed in detail in the 83-page report:

- Research to determine and predict porosity, permeability, and fluid flow *in situ*

- Research to develop better methods for determining and obtaining shallow and deep *in situ* stresses

- Research to improve the ability to map fracture patterns, particularly major fractures and faults, at depth

- Research to improve the understanding of rock-fragmentation processes for increasing the effectiveness of drilling and excavation systems

- Research to increase understanding of the relation of laboratory-measured quantities to *in situ* conditions

- Research to provide the thermophysical and thermomechanical properties of rock, including fractured rock

---

*See Appendix for list of Panel Members.

[+]*Limitations of Rock Mechanics in Energy-Resource Recovery and Development*, available (cite NRC/AMPS/RM-78-1) for $6.00 per copy from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. A limited supply is available from the USNC/RM Secretariat.

ROCK-MECHANICS PROBLEMS RELATED TO UNDERGROUND CONSTRUCTION*

To identify research needs for solving rock-mechanics problems related to underground construction, the seven Panel members and one other contributor individually prepared lists of problems that they, based on their personal experience, believed had a significant impact on underground construction. The members were asked to devote attention to problems that had practical, day-to-day importance as opposed to unanswered, fundamental research questions of uncertain immediate impact. The eight individual lists were then combined into the master list shown in Table 1.

The individual Panel members were then asked to assign an order of importance to each topic and to indicate what they believed to be the chance of success in developing solutions to the problems in the near future. For any topics that Panel members felt unqualified to judge, they left a blank, which was not counted in subsequent analysis. The scale used in this evaluation system was as follows:

Importance	Chance of Success
1 = very important	1 = yes, good chance
2 = significant	2 = intermediate
3 = not very important	3 = little chance of success

The individual evaluations of this master list were then combined, and the average rating was calculated for each topic. The numerical results are also given in Table 1. To indicate the degree of concurrence among the Panel, the standard deviation (Std. Dev.) was also calculated for the "Importance" of the problem. A Std. Dev. of zero means all Panel members assigned the same order of importance. A Std. Dev. in the range of 0.3 means all members assigned the same order of importance, except one who assigned a value one number higher or lower; a range of 0.5 means at least two members assigned values different than the rest; and a range of 0.7 or more indicates considerable difference of opinion, with evaluation ranging from 1 to 3, and several at each extreme.

From the overall evaluation shown in Table 1, the problems considered most significant (rated 1.0 to <1.25) have been abstracted as follows:

- Identification and Determination/Quantification of Significant Rock Properties
  - Rock mass discontinuities on the scale of faults, shear zones, and folds

*Report to the Parent Committee of the Panel on Rock Mechanics Problems Related to Underground Construction and Tunneling. See Appendix for list of Panel members.

- Support Methods and Requirements

  - Support requirements for different types of behavior such as overstress, loosening, and swell
  - Prediction of requirements before construction
  - Rational design of different support elements
  - Range of applicability of different support systems
  - Mechanism and behavior of reinforced rock mass

- Moleability

  - Support of difficult ground and sudden ground changes

- Implementation, Education, and Interaction

  - Summary and general description of methodology used by practitioners — useful as guide to practice

- Documentation of Field Behavior

  - Quantify and correlate with geologic setting
  - Document actual problems and solutions
  - Summarize and correlate behavior in case histories
  - Make case history reports of tunnels accessible to interested public

The problems that were rated as next most significant (1.25 to 1.50 inclusive) are listed in Table 2.

As is evident from the list, solution of some of these problems will require research into the fundamental mechanics of support systems and rock masses, and the interaction of the two. Other solutions will require improved exploration methods and utilization of these methods. The need for improved documentation and explanation of actual rock behavior in the field, as a means for improving our understanding of rock behavior, was given a high rating.

The Panel recommends that the U.S. National Committee for Rock Mechanics make specific recommendations on how solutions may be developed for the high-priority problems identified here.

TABLE 1 Identification and Evaluation of Rock-Mechanics Research Needs in Underground Construction

Suggested Topics for Research	Importance Average (Std. Dev.*)	Chance of Success Average
A. Site Exploration		
1. Better coring and sampling devices	2.14 (.69)	1.83
2. Better and standardized methods of mapping geology encountered in tunnels	1.71 (.49)	1.57
3. Better and standardized methods of core logging	1.57 (.53)	1.64
4. Remote-sensing borehole devices for obtaining 3-D pictures of geologic features in a cylinder around the tunnel; both prebid and ahead of face during construction, both horizontal and vertical, identify smaller scale features close in, larger features farther out	1.25 (.46)	2.25
5. Recommend guidelines for minimum exploration needed for a tunnel project	1.38 (.52)	1.50
B. Identification and Determination/Quantification of Significant Rock Properties		
1. Rock Material		
a. Mineralogy, strength, hardness, anisotropy	2.25 (.89)	1.40
b. Permeability	2.25 (1.04)	1.60
c. Weathering and decomposition	1.88 (.99)	1.80
d. Distinction between rock and soil significant to engineering work	2.00 (.93)	1.60
2. Rock Mass		
a. Boundaries between homogeneous zones	1.83 (.98)	1.75
b. Permeability, location of water table	1.33 (.52)	2.00
c. Discontinuities on scale of jointing and bedding: location, orientation, tightness, filling, strength, compressibility	1.33 (.82)	1.80
d. Discontinuities on scale of faults, shear zones, and folds: location, orientation, extent, character	1.00 (0)	1.40
e. General mass quality	1.50 (.83)	1.80
3. Index properties — simple, inexpensive, meaningful index properties to quantify significant properties	1.62 (.92)	2.14

*Standard Deviation

Suggested Topics for Research	Importance Average (Std. Dev.*)	Chance of Success Average
4. Typical values and variability of properties	1.71 (.76)	1.17
C. Mechanics of Rock Behavior		
1. Basic failure mechanisms, strength envelopes, behavior of both intact rock and rock masses: understanding, quantification, ability to predict from measured properties of Topic B, stress-strain-time	1.71 (.49)	1.71
2. Basic mechanisms (stress-strain-time) of behavior of rock mass around a tunnel or chamber excavation for various conditions of loosening behavior, overstress, and swell; ability to predict behavior from measured properties of Topic B; analytical methods:		
a. Stand-up time in all conditions	1.50 (.76)	2.14
b. Size effects of different size openings	1.25 (.46)	1.75
c. Loosening of jointed mass: time dependent progression, effect of support restraint (and bald headed), loads at different times and degrees of restraint, deformations as a function of time, loosening, tolerable deformations before collapse	1.25 (.71)	2.00
d. Overstress behavior (brittle fracture, plastic yield): rate of failure development, nature and progression of failure, gravity-load effects super-imposed on free-field stress effects, effect of varying ratio of σ_h/σ_v free field, progression from overstress to loosening behavior, creep, relaxation, movement associated with overstress failure, rate and magnitude, effect of support restraint	1.38 (.52)	2.00
e. Swell behavior: susceptible material, rate and magnitude of movement, swell pressure if restrained	1.50 (.53)	1.86
f. Surface deterioration: air slaking, water reaction, stress relief, basic mechanisms, susceptible materials, necessary environment, index properties and tests, progression from surface deterioration into general instability, improved protective coating	1.38 (.52)	1.86
g. Effect of different excavation and support methods upon basic behavior: destressing associated with blast-induced fractures, "gentle" excavation of mole	1.25 (.46)	1.75
h. Dynamic behavior and effects: earthquakes, blasting	1.86 (.90)	2.00
i. Shafts — all the same problems and considerations as given above for tunnels and chambers	1.75 (.71)	2.00

Suggested Topics for Research	Importance Average (Std. Dev.*)	Chance of Success Average
j. Effects of sequence of incremental excavation on behavior of large openings	1.50 (.53)	1.88
k. Pressure tunnel behavior	2.14 (.38)	2.00
D. Support Methods and Requirements		
1. Support requirements for different behavior discussed in Topic C	1.00 (0)	1.80
2. Prediction of support requirements before construction	1.14 (.38)	2.00
3. Effects of different excavation methods and incremental excavations sequence on support requirements	1.29 (.49)	1.86
4. Rational design of different support elements	1.14 (.38)	1.71
5. Range of applicability of different support systems	1.14 (.38)	1.50
6. Mechanism and behavior of reinforced rock mass, effects of reinforcement variables	1.12 (.35)	2.00
7. Rock-bolt anchorage capabilities, capacity, creep, and long-term stability	1.88 (.83)	1.17
8. Fully encapsulated, nontensioned rock reinforcement: behavior and mechanisms, long-term stability, corrosion effects over long term	1.71 (.49)	1.71
9. Behavior of steel ribs: deformations, load-carrying mechanism	2.14 (1.07)	2.00
10. Rational analysis of concrete lining/rock interaction and behavior, rational design of continuous linings	1.28 (.49)	1.43
11. Grout applicability, behavior, and use	1.71 (.49)	2.00
E. *In situ* stress state		
1. Variability	1.71 (.49)	2.00
2. Measurement devices	1.71 (.49)	1.71
3. Stress history effects	2.29 (.95)	2.50
F. Moleability		
1. Prediction of penetration rates: important variables, quantification, index properties	1.25 (.46)	2.09
2. Gripper effects on wall stability	2.33 (.52)	2.00
3. Gripper reaction capacity of rock	2.40 (.55)	2.00
4. Stand-up time, size effects of mole excavation	1.29 (.49)	1.86
5. Support of difficult ground, sudden ground changes	1.14 (.38)	1.86

Suggested Topics for Research	Importance Average (Std. Dev.*)	Chance of Success Average
6. Continuous exploration ahead of face	1.29 (.49)	2.36
G. Fluids		
1. Measure of mass permeability, storage coefficient	2.00 (.82)	2.00
2. Prediction of fluid flow through rock masses, water flow into underground excavations	1.71 (.95)	1.92
3. Pore-pressure effects on mass stability and behavior	1.62 (.74)	2.00
4. Effects of dissolved and suspended matter in fluids upon rock properties and behavior	2.19 (.84)	2.00
H. Fragmentation		
1. Mechanical cutters: basic fragmentation mechanisms, muck size, penetration rates, energy requirements	1.50 (.76)	1.64
2. Relative energy expenditures for different fragmentation methods	1.86 (.69)	1.50
3. Drillability as a function of mineral content or grain size, for example; for different drilling methods	2.14 (.69)	1.58
4. Effect of rock defects on fragmentation process	1.86 (.90)	1.75
5. Basic mechanisms of different fragmentation processes	1.71 (.76)	1.67
6. Improvement of excavation and drilling devices: faster, less energy, more dependable	1.50 (.53)	1.62
I. Classification Systems		
1. Meaningful index properties	1.81 (.92)	2.50
2. Typical values and variability of different properties	2.50 (.53)	2.14
3. Meaningful classification system over wide range of ground conditions	2.25 (.71)	2.38
J. Environment and Safety		
Significance and necessity of various MESA, OSHA, and EPA regulations	1.71 (.95)	1.86
K. Implementation, Education, Interaction		
1. Summary and general description of methodology used by practitioners — useful as guide to practice:	1.12 (.25)	1.38
a. Exploration programs: planning, requirements, interpretation, and evaluation		
b. Design of structures and support systems		

Suggested Topics for Research	Importance Average (Std. Dev.*)	Chance of Success Average
c. Contract documents		
2. Education of practitioners to raise "average practice" closer to current "best practice"	1.50 (.76)	1.88
3. Improved communication and sharing of experience: civil engineers, geologists, and mining engineers, both within the U.S. and between the U.S. and other countries	1.38 (.52)	1.94
4. Training and education for controlled-blasting techniques	1.62 (.52)	1.88
L. Documentation of Field Behavior		
1. Quantify and correlate with geologic setting: stand-up time, size effects, loads on tunnel supports, deformations before failure, surface deterioration	1.00 (0)	1.44
2. Document actual problems experienced in real tunnels and procedures used for solution	1.12 (.35)	1.44
3. Summarize and correlate behavior in case histories	1.12 (.35)	1.02
4. Make history reports of tunnels accessible to interested public	1.14 (.38)	1.71
5. Summarize and accumulate data in given geographic areas	1.64 (.75)	1.50

TABLE 2 Problems With Importance Ratings of 1.25 to 1.50 Inclusive, Abstracted from Table 1

	Topic Key (Table 1)
Site Exploration	
— Remote-sensing borehole devices	A.4.
— Recommended guidelines for minimum exploration	A.5.
Identification and Determination/Quantification of Significant Rock Properties	
— Permeability, location of water table	B.2.b.
— Discontinuities on scale of jointing and bedding	B.2.c.
— General mass quality	B.2.e.
Mechanics of Rock Behavior: Basic mechanisms of behavior around underground openings	
— Stand-up time	C.2.a.
— Size effects	C.2.b.
— Loosening of jointed mass	C.2.c.
— Overstress behavior	C.2.d.
— Swell behavior	C.2.e.
— Surface deterioration	C.2.f.
— Effects of different excavation and support methods	C.2.g.
— Effects of sequence of incremental excavation on behavior of large openings	C.2.j.
Support Methods and Requirements	
— Effects of different excavation methods and incremental excavation sequence on support requirements	D.3.
— Rational analysis of concrete lining	D.10.
Moleability	
— Prediction of penetration rates	F.1.
— Stand-up times and size effects	F.4.
— Continuous exploration ahead of face	F.6.
Fragmentation	
— Mechanical cutters	H.1.
— Excavation and drilling devices	H.6.
Implementation, Education, Interaction	
— Education of practioners to raise "average practice" closer to current "best practice"	K.2.
— Improved communication and sharing of experience between different disciplines and different countries	K.3.

ROCK-MECHANICS RESEARCH RELATED TO EARTHQUAKE PROBLEMS: FUTURE GOALS*

Introduction

Rock mechanics has had a profound impact on seismology within the last decade. This has resulted from the application of the physical understanding of rock fracture and friction, gained from laboratory rock-mechanics studies, to studies of the earthquake-source mechanism.

The U.S. National Committee for Rock Mechanics, recognizing the seriousness of rock-mechanics limitations to future progress in the understanding of earthquake mechanics, created the *ad hoc* Panel whose report is presented here. During the course of the Panel's deliberations, a greatly expanded effort was undertaken by the federal government to solve the problems of both earthquake prediction and earthquake-hazard mitigation. Rock mechanics plays a prominent role in both areas, and it is gratifying to see some of the areas recommended below being funded at an appropriate level for the first time.

Despite the rapid gains in knowledge of basic science applicable to the earthquake mechanism in the past ten years, progress in understanding rock-mechanics fundamentals remains the critical factor for future progress in earthquake seismology. There are three main areas that require concentrated effort. The first is to study the physical processes in rock deformation that are related to earthquakes but that are as yet poorly understood. The second is to attempt to solve the scaling problem so that laboratory-derived observations can be scaled quantitatively to the much greater length and time scales of natural seismic processes. The third is to expand the field measurements of rock-mechanics parameters to improve our understanding of the fault zones and large-scale properties of the crust.

In this report we have outlined what currently appear to be the key problems needing further study in each area and have recommended several approaches that we believe will be most effective in bringing about meaningful progress.

Physical Processes

There are many mechanical processes relevant to earthquake physics that remain poorly understood. Progress in basic earthquake mechanics has been extremely heartening in the past decade and plays a major role in the confidence expressed by seismologists in our ability to develop earthquake-prediction capabilities in the next decade. These problems are best approached through basic laboratory and theoretical studies, some of which are now under way. We focused on the following areas as particularly important: friction, attenuation, dilatancy-diffusion, mechanical properties of fault rocks, slow rate effects, and mixed brittle-plastic processes.

---

*Report to the Panel Committee of the Panel on Rock Mechanics Problems Related to Seismology and Earthquake Engineering. See Appendix for list of Panel members.

Friction

It is now recognized that rock friction is a very complex phenomenon. Much more laboratory work is required, with an emphasis on careful separation of the many variables that affect rock friction, in order to understand the microscopic processes that occur in friction and to be able to deduce the macroscopic processes from them. Important variables include temperature, porosity and pore pressure, strain and loading rate, sliding surface topography, and surface particle configuration, as well as material composition. Since most earthquake hypocenters lie in the depth range of 8-16 km, the range of values that these factors could possess is extremely broad.

Attenuation

Attenuation of seismic waves remains a real candidate for use as a remote-sensing tool for detecting physical conditions near the earthquake source from the ground surface. Yet, the physical mechanism for the attenuation of seismic waves within the crust is poorly understood. Again, rock-mechanics research on attenuation should evaluate the role of environmental parameters over a wide range of seismic frequencies and at high temperatures and pressures. Because of potential scaling effects, attenuation studies might well be able to take advantage of the large-scale controlled experiments recommended below.

Dilatancy-Diffusion

The dilatancy-diffusion and dry dilatancy theories of earthquake precursors are based on relatively simple laboratory experiments that simulate only crudely the actual conditions leading to an earthquake. The theories must still be quantified, and effects such as loading conditions on dilatancy and associated phenomena (e.g., velocity changes) must be investigated.

Mechanical Properties of Fault Rocks

Fault zones contain various thicknesses of wear material that range in properties from clay fault gouge at the surface to flinty mylonites at depth. The properties of these materials strongly influence the frictional properties of faults. Research is just beginning into the detailed character and mechanical behavior of fault rocks. Since virtually all models of the faulting process must assign some properties to the material that is actually taking up the movement, a high-priority program of laboratory investigation is clearly required. As a further complication, the behavior and even the character of the gouge *in situ* near the earthquake source may be vastly different from that of gouge that is accessible to sampling at or near the ground surface. A wide range of conditions must be investigated in the laboratory.

Slow Rate Effects

Geologic strain rates are many orders of magnitude slower than those encountered in the laboratory. Slow rate processes, such as stress corrosion cracking, that may appear secondary in laboratory experiments, may predominate in nature. Greater attention should be placed on rate-dependent rock properties.

Mixed Brittle-Plastic Processes

Most rock-mechanics research in the past has been concentrated either on purely plastic behavior at high temperatures or on purely brittle behavior at low temperatures. Most earthquakes, however, occur under temperature conditions of 100-500°C and pressures of 1-5 kb. In this range, combined brittle-plastic phenomena are likely to occur. Very little is known about such mixed processes in rock or their interactions. Research in the future should be redirected to experimental programs under these pressure and temperature conditions.

The Scaling Problem

Although the physics of earthquakes is best studied in theoretical and experimental laboratory work, the problem of scaling these results to nature requires a combined approach using large-scale *in situ* measurements and numerical modeling. The following recommended approaches to this problem hold considerable promise for exciting results.

Medium-Scale, Controlled, In Situ *Experiments*

The Panel envisages a series of experiments similar to existing laboratory experiments in that all parameters such as stress, pore pressure, and strain rate are controlled and manipulated, but with the scale in the range of meters to tens of meters rather than the centimeter scale of the laboratory. The difficulty with the latter is that the parameters are largely one dimensional from the standpoint of the rupture process and that the effect of size on friction, for example, cannot be ascertained.

The cost of experiments rises as rapidly as the dimensions, and it is important that the experiments be much more thoroughly planned at this enlarged scale if the scientific community is to take full advantage of funds made available. The most effective way to maximize scientific benefit is for the appropriate organization to publicize proposed experiments or facilities and seek proposals for complementary experiments to be run simultaneously.

Three types of medium-scale, loading/sliding experiments are recommended: on large blocks cut in quarries; on natural joints and faults cut out *in situ;* and on large, prepared samples in the laboratory.

Large-Scale, Quasi-controlled Experiments

These experiments encompass the size range from 10 m to 10 km. At this scale, complete control of the conditions is seldom feasible, but there are many "natural" experiments of this size that could be much more effectively utilized from a scientific standpoint.

A second important experiment might make use of the programmed collapse of mine roofs during mining operations. While the fracture mechanism is probably tensile rather than shear, the magnitude of loading and movement is appropriate for testing scale effects. Under proper controls, a shear mechanism could probably be induced.

Development of rock-mechanics instrumentation that is adequate for measuring very large-scale effects will need additional financial support. Some techniques can be borrowed directly from mining and tunneling technology. But increased emphasis will undoubtedly be placed on measurement techniques that can be used from the surface or from standard-diameter boreholes.

Numerical Modeling Techniques

As our knowledge of how to scale laboratory-derived data grows, the bridge by which such data can be applied to earthquakes will be numerical modeling. It is therefore important that this field receive substantial support, and that close working ties with the scaling experiments be maintained.

Field Observations

The program for collecting field observations relevant to the earthquake mechanism is lagging, in part because of high costs and in part because appropriate measurements may not be possible at the present state of the technology. Field-measurement techniques are a part of the current U.S. Geological Survey Earthquake Hazards Reduction program. But a basic research and development program seeking new ways to measure earth properties either from the ground surface or from boreholes should be a high-priority objective. Several of the most important rock-mechanics observation problems are described below.

In Situ *Stress Measurements*

At present there is no consistently reliable, precise method of measuring the total stress field *in situ*. The two methods now most commonly used, hydrofracturing and overcoring, are expensive and limited in the settings in which they can be used. Furthermore, they have not been adequately tested against one another. Yet stress levels may be the most important single bit of information needed to understand the earthquake-source mechanism. More research should be directed toward novel methods of measuring stress, and newly evolving methods should be systematically tested against one another.

Fault-Zone Parameters

Detailed geological and geophysical investigations of fault zones that are exposed for study have only recently yielded information useful to rock mechanics. The system is extremely complex and difficult to model, but intensified efforts to collect values of the important parameters — including types and distribution of movements; amount of gouge; brecciated fragment size, shape, and distribution; size of deformed zone and relative amounts of deformation; and porosity and residual pore pressures — would greatly improve the quality of fault-zone models.

Remote Property Measurements

The ultimate understanding of earthquake sources will come from actual measurements of conditions in the source area, either using ground-based remote techniques or borehole measurements from great depths. While the drilling technology has improved rapidly for both scientific and economic reasons, only a relatively few properties can be measured at depth using existing equipment. With the prospect of an increasing number of deep boreholes becoming available, a research and development effort in borehole measuring techniques should be highly productive.

Continental Drilling Project

The Continental Drilling Project recommended recently by the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) appears to be an ideal vehicle for improving the field measurement expertise of the rock-mechanics community. Strong arguments for supporting the program would include: first, the opportunity for scientists and engineers to test imaginative new techniques for measuring deep-crustal-rock properties; second, the opportunity to drill fault zones directly and obtain actual material from the neighborhood of potential earthquake-source regions for futher laboratory studies; and third, the opportunity to measure *in situ* stress and pore pressure at greater depths.

Coordination and Future Growth of Rock-Mechanics Programs

The U.S. National Committee for Rock Mechanics has charged the Panel with preparing an overview statement on potentially profitable directions that rock-mechanics research could take to help solve the most pressing problems related to our understanding of earthquakes and their causes. The Panel recognizes a clear need for an increased level of communication and coordination among government agencies responsible for large earth-related projects, among public and private agencies responsible for funding rock-mechanics-related research, and among industrial and academic rock-mechanics researchers. The direction that rock mechanics is expected to take in earthquake studies will require some substantial outlay of funds for a smaller number of larger projects. The success of rock mechanics in a large-scale, coordinated research project depends on maximizing the information that can be obtained during the life of the project. Where responsibilities and needs cross agency lines, the U.S. National Committee for Rock Mechanics, acting with the Committee on Seismology, will play a pivotal role in bringing together all the parties in an effort to assure the maximum benefit for each research dollar spent.

The Panel recognizes that progress in rock-mechanics research related to earthquakes is limited by the small number of trained researchers and laboratories, rather than by the availability of adequate funds to support them.

Conclusions and Recommendations

Rock-mechanics research can be expected to have a major role in continued progress in our understanding of earthquakes. The goal of the rock-mechanics community is to maximize the information gained, through the wisest, most efficient use of available research funds. The Panel suggests three major directions for future research that promise to be rewarding:

1. A continued research program aimed at understanding the physics of basic processes in earthquake movements, including friction, seismic-wave attenuation, dilatancy, diffusion, mechanical properties of fault gouge, slow rate effects, and mixed brittle-plastic processes.

2. An expanded effect to solve the scaling problem by conducting carefully designed, medium- and large-scale experiments and a continued effort to improve numerical-modeling techniques and computer codes.

3. An enlarged field-observation and instrumentation program designed to improve the ability of the rock-mechanics community to collect meaningful data from the growing number of deep boreholes expected to be available in the near future.

The Panel specifically recommends

- That federal government agencies support, on a continuing basis, laboratory and field research on the physical processes associated with the earthquake mechanism at a level equivalent to that established recently by the expanded earthquake-prediction program.

- That funds be made available for a limited number of thoroughly planned, multiple-use, medium-scale (1-10 m) loading/sliding experiments.

- That the appropriate agencies with jurisdiction over large construction projects provide cooperation and logistics support for research mission-agencies and organizations to carry out large-scale, quasi-controlled, rock-mechanics experiments whenever appropriate facilities or sites become available.

- That both surface and borehole techniques for field measurements of rock properties be given a high priority in future research and development efforts, in order to take advantage of upcoming and unique field and borehole settings.

- That the Continental Drilling Project receive high priority for available funds, and that a specific target of the drilling be one or more active fault zones.

- That the U.S. National Committee for Rock Mechanics take the leadership role in coordinating rock-mechanics research appropriate to earthquake studies by working actively to bring together researchers and project directors, providing expert advice, and keeping the rock-mechanics community informed of progress and results on specific projects.

- That the U.S. National Committee for Rock Mechanics and federal government agencies encourage graduate training in rock mechanics and the growth of new laboratories, together with an increase in funding necessary to support them.

MEMBERSHIP 1977, U.S. NATIONAL COMMITTEE FOR ROCK MECHANICS

OFFICERS

Thomas C. Atchison, *Chairman*
Department of Civil and Mineral Engineering
University of Minnesota

Signey J. Green, *Chairman-Elect and Representative of American Society of Mechanical Engineers*
President
Terra Tek
Salt Lake City, Utah

*George B. Wallace, *Immediate Past Chairman*
Principal Engineer
Bovay Engineers
Spokane, Washington

MEMBERS AT-LARGE

Norman A. Dixon
Office of the Chief of Engineers
U.S. Army Corps of Engineers
Washington, D.C.

Melvin Friedman
Center for Tectonophysics
Texas A&M University

Ronald E. Heuer
Department of Civil Engineering
University of Illinois

William A. Hustrulid
Department of Mining Engineering
Colorado School of Mines

*Served as Chairman July 1, 1975 to June 30, 1977

**Andrew H. Merritt
D.U. Deere and A.H. Merritt, Inc.
Gainesville, Florida

**Howard J. Pincus
Departments of Geological Sciences and Engineering Mechanics
University of Wisconsin, Milwaukee

Madan M. Singh
President
Engineers International, Inc.
Downers Grove, Illinois

SOCIETY REPRESENTATIVES

Society of Mining Engineers
Jose F. T. Agapito
Consultant
Grand Junction, Colorado

American Society of Civil Engineers
Don C. Banks
Chief
Engineering Geology and Rock Mechanics Division
U.S. Army Corps of Engineers
Vicksburg, Mississippi

Transportation Research Board
William F. Brumund
Principal
Golder Associates
Atlanta, Georgia

**George B. Clark
Excavation Engineering and Earth Mechanics Institute
Colorado School of Mines

Geological Society of America
Fitzhugh T. Lee
U.S. Geological Survey
Denver, Colorado

**Bruce R. Clark
Department of Geology and Mineralogy
University of Michigan

**Term ended June 30, 1977

Society of Petroleum Engineers
Kenneth E. Gray
Department of Petroleum Engineering
University of Texas, Austin

**William C. Maurer
President
Maurer Engineering, Inc.
Houston, Texas

American Society for Testing and Materials
Egons R. Podnieks
Research Supervisor, Surface Mining
Twin Cities Mining Research Center
U.S. Bureau of Mines
Twin Cities, Minnesota

American Geophysical Union
Christopher H. Scholz
Senior Research Associate
Lamont-Doherty Geological Observatory
Palisades, New York

Association of Engineering Geologists
David T. Snow
Department of Geology
Colorado School of Mines

Society of Exploration Geophysicists
M. Nafi Toksoz
Department of Earth and Planetary Sciences
Massachusetts Institute of Technology

**Gerald B. Rupert
Senior Research Investigator
Rock Mechanics and Explosives Research Center
University of Missouri, Rolla

LIAISON REPRESENTATIVES

Building Research Advisory Board
Mr. John P. Gnaedinger
President
Soil Testing Services, Inc.
Northbrook, Illinois

**Term ended June 30, 1977

Transportation Research Board
John W. Guinnee
Transportation Research Board
National Research Council
Washington, D.C.

Interagency Committee on Excavation Technology
Eugene C. Robertson
U.S. Geological Survey
Reston, Virginia

EX OFFICIO MEMBER

John W. Handin, *ISRM Vice President for North America*
Director
Center for Tectonophysics
Texas A&M University

SECRETARIAT STAFF

Robert L. Bangert, *Executive Secretary (Part Time)*
U.S. National Committee for Rock Mechanics
National Research Council
Washington, D.C.

***O. Allen Israelsen, *Executive Secretary (Part Time)*

Susan V. Heisler, *Assistant Executive Secretary (Part Time)*

Barbara S. Adams, *Administrative Assistant*

Iris F. Spriggs, *Secretary (Part Time)*

***Served from June 1, 1976 to February 1, 1978

PANEL ON ROCK MECHANICS PROBLEMS THAT LIMIT ENERGY RESOURCE RECOVERY AND DEVELOPMENT

Sidney J. Green, *Chairman*
President
Terra Tek
Salt Lake City, Utah

Ellis L. Armstrong
Consultant
Salt Lake City, Utah

John W. Handin
Director
Center for Tectonophysics
Texas A&M University

William C. McClain
Nuclear Division
Union Carbide Corporation
Oak Ridge, Tennessee

George B. Wallace
Principal Engineer
Bovay Engineers
Spokane, Washington

SUBPANEL ON GEOTHERMAL ENERGY EXPLORATION AND PRODUCTION

T. William Thompson, *Chairman*
Department of Petroleum Engineering
University of Texas, Austin

Donald W. Brown
Group Q-11
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Sheldon E. Elliott
Branch Manager
Phillips Petroleum
Bartlesville, Oklahoma

Gregory L. Nesbitt
Manager, Fuel Resources
San Diego Gas and Electric
San Diego, California

SUBPANEL ON MINING AND IN SITU RECOVERY

Hilmar A. Von Schonfeldt, *Chairman*
Occidental Research Corporation
La Verne, California

Wilson Blake
Consultant
Hayden Lake, Idaho

Carl G. Broadbent
Metal Mining Division
Kennecott Copper Corporation
Salt Lake City, Utah

James N. Johnson
Group T-4
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

William G. Pariseau
Department of Mineral Engineering
University of Utah

David T. Snow
Department of Geology
Colorado School of Mines

SUBPANEL ON NUCLEAR-WASTE DISPOSAL

Wolfgang R. Wawersik, *Chairman*
Geomechanics Research Division
Sandia Laboratories
Albuquerque, New Mexico

Bruce R. Clark
Department of Geology and Mineralogy
University of Michigan

John W. Handin
Director
Center for Tectonophysics
Texas A&M University

M. Ashraf Mahtab
Senior Rock Mechanics Engineer
Acres Consulting Services, Ltd.
Niagara Falls, Ontario, Canada

James E. Russell
Nuclear Division
Union Carbide Corporation
Oak Ridge, Tennessee

Paul A. Witherspoon, Jr.
Lawrence Berkeley Laboratory
University of California, Berkeley

SUBPANEL ON OIL AND GAS RECOVERY

Henry J. Ramey, *Chairman*
Department of Petroleum Engineering
Stanford University

Rodney J. Clifton
Division of Engineering
Brown University

Robert M. Forrest
Manager, Supply Research
Columbia Gas Systems Service Corporation
Columbus, Ohio

Kate H. Hadley
Senior Research Geologist
Exxon Production Research Company
Houston, Texas

Henry B. Woods
Consultant
Houston, Texas

SUBPANEL ON UNDERGROUND STORAGE — FUEL OIL, GAS, WATER, OR COMPRESSED AIR

Dougal R. McCreath, *Chairman*
Head, Geotechnical Department
Acres American, Inc.
Buffalo, New York

Ellis L. Armstrong
Consultant
Salt Lake City, Utah

Richard E. Goodman
Department of Civil Engineering
University of California, Berkeley

Norman L. Hawes
Manager, Special Projects
Southern California Gas Company
Los Angeles, California

Charles H. Jacoby
Manager, Mining and Mineral Engineering
International Salt Company
Clarks Summit, Pennsylvania

John G. Lewis
Division Manager, Energy and Energy Related Projects
R & D Associates
Marina Del Ray, California

Jeffrey H. Rumbaugh
Senior Staff Engineer, System Engineering and Operations
Potomac Electric Power Company
Washington, D.C.

SUBPANEL ON UNDER-OCEAN TUNNELING FOR PETROLEUM RECOVERY

H. Donald Outmans, *Chairman*
Research Associate
Union Oil — Union Research Center
Brea, California

J. Donovan Jacobs
Chairman
Jacobs Associates
San Francisco, California

Hans O. Jahns
Exxon Production Research Company
Houston, Texas

William C. Maurer
President
Maurer Engineering, Inc.
Houston, Texas

Terence G. McCusker
Manager, Tunnel Division
Perini Corporation
Fort Lee, New Jersey

Malcolm Mellor
Experimental Engineering Division
U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire

William M. Sackinger
Geophysical Institute
University of Alaska, College/Fairbanks

PANEL ON ROCK MECHANICS PROBLEMS RELATED TO UNDERGROUND CONSTRUCTION AND TUNNELING

Ronald E. Heuer, *Chairman*
Department of Civil Engineering
University of Illinois

George B. Clark
Senior Research Associate
Excavation Engineering and Earth Mechanics Institute
Colorado School of Mines

Andrew H. Merritt
Don U. Deere and A. H. Merritt, Inc.
Gainesville, Florida

Dewayne L. Misterek
Head
Rock Mechanics Section
U.S. Bureau of Reclamation
Denver, Colorado

Howard J. Pincus
Departments of Geological Sciences and Engineering Mechanics
University of Wisconsin, Milwaukee

John D. Smart
Stone and Webster Engineering Corporation
Denver, Colorado

P. E. Sperry
Consultant
Woodland Hills, California

PANEL ON ROCK MECHANICS PROBLEMS
RELATED TO SEISMOLOGY AND EARTHQUAKE ENGINEERING

Christopher H. Scholz, *Chairman*
Senior Research Associate
Lamont-Doherty Geological Observatory
Palisades, New York

John W. Handin
Director
Center for Tectonophysics
Texas A&M University

David T. Snow
Department of Geology
Colorado School of Mines

*Bruce R. Clark
Chief, Rock Mechanics Section
Leighton and Associates
Irvine, California

Earl R. Hoskins
Department of Geophysics
Texas A&M University

Amos Nur
School of Earth Sciences
Stanford University

Lane R. Johnson
Department of Geology and Geophysics
University of California, Berkeley

*Formerly at Department of Geology and Mineralogy, University of Michigan

PANEL ON FUNDAMENTAL PROBLEMS IN ROCK MECHANICS AND EDUCATIONAL REQUIREMENTS

William A. Hustrulid, *Chairman*
Department of Mining Engineering
Colorado School of Mines

Thomas C. Atchison
Department of Civil and Mineral Engineering
University of Minnesota

Edward J. Cording
Department of Civil Engineering
University of Illinois

Gerald B. Rupert
Senior Research Investigator
Rock Mechanics and Explosives Research Center
University of Missouri, Rolla

Charles A. Babendreier, *Observer*
Engineering Mechanics Section
National Science Foundation
Washington, D.C.

John W. Corwine, *Observer*
Mining Research Resources
U.S. Bureau of Mines
Washington, D.C.

PANEL ON DOMESTIC AND INTERNATIONAL ACTIVITIES

Don C. Banks, *Chairman*
Chief, Engineering Geology and Rock Mechanics Division
U.S. Army Corps of Engineers
Vicksburg, Mississippi

*Thomas C. Atchison, *Chairman*
Department of Civil and Mineral Engineering
University of Minnesota

George B. Clark
Senior Research Associate
Excavation Engineering and Earth Mechanics Institute
Colorado School of Mines

Herbert H. Einstein
Department of Civil Engineering
Massachusetts Institute of Technology

William A. Hustrulid
Department of Mining Engineering
Colorado School of Mines

William R. Judd
School of Civil Engineering
Purdue University

Yung Sam Kim
Department of Mining Engineering
Mackay School of Mines
University of Nevada, Reno

Fun-Den Wang
Director
Excavation Engineering and Earth Mechanics Institute
Colorado School of Mines

*Term ended June 30, 1977