HIGHWAY RESEARCH
CIRCULAR

Number 20 Subject Classification: Exploration-Classification, Foundations, Mechanics (Earth Mass), Construction General Materials, Highway Design April 1966

COMMITTEE ACTIVITY
Committee on Engineering Geology
Department of Soils, Geology and Foundations
Highway Research Board

APPLICATION OF THE PLOWSHARE PROGRAM OF NUCLEAR EXCAVATION EXPERIMENTATION TO HIGHWAY CONSTRUCTION

Report to the San Francisco Operations Office
United States Atomic Energy Commission

Under a 23 September 1965 Letter Contract Between
The Atomic Energy Commission *

And

The National Academy of Sciences

*In developing the application of nuclear explosives to industry and science, it is the policy of the Atomic Energy Commission to cooperate with other interested organizations, public and private. This cooperation encompasses a spectrum of activities ranging from informal discussions to planning and execution of nuclear explosive application experiments of mutual interest to the AEC's Plowshare Program and other industrial or public groups. Inquiries may be directed to John F. Philip, Director, Special Projects Division, San Francisco Operations Office, U. S. Atomic Energy Commission, 2111 Bancroft Way, Berkeley, California (94704).

HIGHWAY RESEARCH BOARD • NATIONAL ACADEMY OF SCIENCES - NATIONAL RESEARCH COUNCIL
2101 CONSTITUTION AVENUE, N.W. WASHINGTON, D.C. 20418

Contents

Summary

The Committee on Engineering Geology endorses the Plowshare program and recommends that additional tests be carried out, some of them aimed specifically at highway applications. Additional tests should be conducted on the Nevada Test Site and off the site. The experiments should be conducted in rock media and in geologic environments not previously tested. Seismic and radiation hazards can be controlled within economic limits.

Introduction

The Committee on Engineering Geology, HRB, visited the AEC Nevada Test Site on October 11, 1965 to observe selected excavation experimental areas. The purpose was to study the results obtained from these experiments with the view of applying the methods to highway construction. The tour included the following: chemical high explosive cratering and trenching experiments in alluvium; the Sedan nuclear explosion crater in alluvium as shown in Figure 1; nuclear explosion cratering experiments in basalt shown in Figure 2; and chemical high explosive cratering and row charge experiments in basalt.

Reports dealing with these and other selected experiments provided background information. This report is based on the discussions held October 11 and 12 by members of the Committee, guests and representatives of AEC.

Plowshare is a research and development program to investigate the peaceful uses of nuclear explosives. The program is conducted by the U. S. Atomic Energy Commission under the technical direction of its contractor, the University of California Lawrence Radiation Laboratory. Plowshare is a venture that has many facets and ramifications. For the most part, comments are confined to excavation as applied to highway construction. While concerned mainly with testing physical response, this report also mentions psychological factors as these appear to be a real stumbling block in the implementation of experiments necessary to define more clearly the limits of applicability of the method. At the same time, it is recognized that this committee does not have the competence to render professional judgment on radiation hazards.

Objectives of Blasting for Highway Construction

Some of the primary objectives of blasting for highway construction are complete removal of material, fragmentation of rock preparatory to removal, fragmentation of rock for aggregate production and fragmentation for vertical drainage of water.

Complete removal of material consists of "lift out" and lateral translocation

of material simulating the results obtained in the Pre-Buggy cratering experiments that produced a trench with high side "lips." This method of excavation would leave certain favorable features and some unfavorable features. By controlling size and location of shots, it could produce the necessary excavation in entering and leaving dissected tablelands, crossing benches, and could also produce cuts of extended lengths through hills where only shallow cuts in rock are necessary. An unfavorable feature of the lateral throwout of the ejecta is that it leaves unsightly back slopes that are not in keeping with current requirements for highways. Shaping of the ejecta prior to seeding for erosion control could be accomplished easily with present-day equipment where the material is alluvium. Where the material is hard rock, shaping would be a more expensive operation.

In some operations the objective of blasting is fragmentation of hard rock into sizes that can be excavated by currently used equipment and moved without difficulty to areas of deposition. The experimental shots observed at the Nevada Test Site generally produced sufficient fragmentation for excavation by means of power shovels. A related objective that might be obtained by nuclear blasting or by combining nuclear blasting with currently used methods is that of lift-off and lateral displacement of material on a mountainside location. The purpose here would be to make the excavation in sound rock with adequate stability to insure against future landslides by excavating so that the roadbed is in stable rock. Although complete lift-off and translocation of material for side hill locations has been accomplished to date by present methods, it has been employed primarily to produce the desired fragmentation of rock so that the broken material could be excavated by power equipment and the position of the roadbed placed on bedrock.

Blasting is employed to fragment hard rock for the purpose of producing material to be crushed to provide aggregate for construction. Gradation of sizes of rock ejected in experiments in basalt have been classified and so well documented that anyone familiar with maximum permissible sizes of fragments that can be crushed economically may readily determine the suitability of nuclear blasts for this purpose.

Explosives have been employed in producing fissures or otherwise fragmenting rock to permit vertical drainage of water contributed by local aquifers. This use of blasting is somewhat specialized. However, in some situations, high energy shots might serve the dual purpose of translocating material and providing vertical drainage for water.

Current Status of Nuclear Excavation Research

It appears that the first objective of the Plowshare program in its initial phase was to acquire fundamental cratering data. There was no specific project or application toward which the testing was directed. The program has indeed assembled a considerable amount of useful data on nuclear excavation. Experimentation has gone through a necessary and fundamental part of the basic research required to demonstrate the potential value of the method. Research has been directed towards

the defining and measurement of variables. This is certainly the proper approach. Some members of the Committee thought so much progress had already been made that the word development might properly replace the word research for the additional testing that is necessary for application of the method. The method is now well enough understood so that research should be directed to answering problems that would come up in actual application.

Factors considered critical to application of the method are topography, rock media, water table and climate. Excavation experiments to date have been conducted on flat topography in three types of rock units--alluvial fill, basalt and volcanic tuff. By design the tests were located in dry material above the water table. By geographic location of the Nevada Test Site, the experiments were of necessity located in an area of low rainfall.

It is understood that considerable progress has been made in developing nuclear explosives suitable for excavation use and that this work, of equal importance to the work described above, is, of course, continuing.

Research Related to Highway Excavations

Highway construction problems involving extensive excavation do not exist on flat surfaces with the exception of locations that traverse dissected tablelands. Excavation problems are associated with long sidehill cuts and in mountain passes. It is in rugged terrane where large quantities of rock are excavated and where high fills are necessary. This is also the locale where construction costs are high.

Rock media in which excavation tests have been conducted are limited in geographic distribution, or are not typical of the kind that generally pose problems in highway excavations. Among the most serious problems are those associated with deep cuts located in thick sequences of shale and shale interbedded with limestone or sandstone. Where the beds are inclined the problems are accentuated. Excavation in moist clay shales is difficult because of the tendency of this medium to push out a hole in the form of a bottle when shot with high explosives. Maintenance of deep cuts in these rocks is expensive because raveling and small-scale slumping is an everyday occurrence and landslides are frequently developed. Shales and shales interbedded with other lithologies are widely distributed throughout the United States. Benching is one of the designs used to increase slope stability in these rock sequences. Mentioned as a more localized problem was excavation of till during construction of the St. Lawrence Seaway; in the summertime the till is a spongy mass and therefore hard to move; in the wintertime it is frozen, therefore brittle and hard to move.

Many highway cuts intercept perched water tables and some extend below the water table. Nuclear excavation testing, however, has not been conducted in wet media. Test information in this environment will be necessary before the method can be reliably recommended for excavating highway cuts.

All excavation experiments have been conducted in the semiarid climate of the Nevada Test Site. Most highways, however, are located in areas of appreciably higher rainfall. Crater slopes that were observed appear to be stable under existing arid conditions. Serious doubt was expressed that the slopes, even in the basalt experiments, would remain stable in the event of prolonged rainfall. A requirement of highway cuts is that the slopes must be stable where the base of the cut is adjacent to the roadway. Repeatedly the same question was posed: Can an economically stable slope be provided by this method? There are several aspects to the question.

The connected series of craters that provide the excavation is only the beginning of the construction. A road must still be constructed at the bottom of the cut. Two problems are paramount, slope stability and foundation stability. Can the explosion be designed in conformity with the structural configuration of the rock so that a stable slope will result from one event? Or, with a reasonable expenditure of money by using conventional methods of earth removal, can the slope be rendered stable?

Reworking a blast-shattered slope is highly expensive and dangerous. The base of the excavation, which is also the road foundation, is flexible and probably will require reworking. The road itself may need to be located on a fill section placed on the bottom of the excavation surface. The height of the fill will depend in part on the stability of the slope. Tests designed to answer such questions need to be conducted.

Recommended Testing

Additional excavation tests with high explosives and nuclear devices are recommended. They should be designed to provide answers to questions that are asked by highway engineers. Some of the questions are mentioned above. Experiments should be conducted in rock media not previously tested and in other geographic, climatic and geologic environments. Some of the testing can be conducted on the Nevada Test Site. Other tests will need to be located off-site to meet the recommended environmental conditions.

Two or more on-site experiments are recommended. One of the experiments suggested is construction of a hillside road in flat lying tuffaceous rocks. The other experiment should also be a road construction project, but located in folded and inclined alternating sequence of limestone and shale. The objectives of the experiments would be: (1) evaluation of slope stability in a side hill cut where topography is irregular, and (2) testing of the response of other media. Presplitting, by developing a plane of preferred weakness, might be tried in one of the experiments to determine what effect this preshot preparation may have on developing a designed slope of greater stability.

Off-site experiments should be conducted in other media such as highly weathered igneous and metamorphic rocks and particularly in horizontal and inclined

shale and interbedded shale and limestone sequences in areas of moderate to high rainfall where control of perched or ground water is a problem. The objective would be to evaluate slope stability under these environmental conditions. Because there is reliable correlation between nuclear and high explosive tests, some of the smaller experiments in sensitive locations could be conducted with high explosives.

Identification and Initiation of Off-Site Tests

The need for off-site testing is clearly evident. Identification of the locations for off-site test areas that meet the experiment requirements is the next procedure. The procedure involves application of marketing research techniques and should include economic considerations as well as acquisition of experimental data. Economic considerations require a better understanding of the following: size of the project, guideline for project analysis, engineering requirements, nuclear or high explosive experiments and financial arrangements between a highway department and Plowshare.

Off-site experimental areas should be selected to test the method in specific rock media not found on the Nevada Test Site and in other environments. Topography, climate and ground water are fundamental considerations in establishing a priority listing of preferred experimental sites. The next step in site selection would be to determine from highway departments the presence of potential projects in the preferred test areas. Certainly some potential projects would be identified. Arrangements could then be made between the highway department and Plowshare to carry out the experiment cooperatively.

The size of a project is significant. If the project must be comparable to Carryall, then there are few projects in the continental United States with which highway departments are associated. However, if the size of the projects can be scaled down from the magnitude of Carryall to sidehill cuts about 1,000 feet long that have about a million-dollar price tag for excavation by conventional methods, then many projects are available. Testing on a small scale will provide data necessary for the design of large highway excavations that have not yet been conceived because thinking, by and large, is geared to proven conventional methods.

Plowshare should establish broad guidelines that define the general kinds of engineering and other requirements that are needed to serve as a basis for project analysis and proposals. The guidelines should include definition of the limitations of the method so far as this is known, such as safety restrictions (seismic and radioactivity), description of possible funding arrangements, technical limitations, including crater perimeters and crater stability. Guidelines are needed by highway engineers to determine whether or not a proposed highway cut can be excavated by nuclear methods. It is highly probable that some projects not amenable to excavation by nuclear methods would be ideally suited for complementary experimental testing with chemical explosives.

The nuclear method of excavation is not yet at the stage of development where it can be presented to a highway department as a technique proven in all its aspects. However, the method can be presented as having a high success potential. It is believed that many highway departments would support an experimental test excavation, provided that Plowshare would defray most of the cost. In this context, two points of view were expressed with respect to continuing experimentation. One was that certain testing be conducted at the Nevada Test Site, where the results would be primarily of developmental value. The other was that testing be conducted off-site on actual projects where, if the experiment is successful, the excavation will be of direct benefit to a highway undertaking. Implied is the element of a small risk of failure, such as is associated with any experiment. Since the excavation would have as its primary objective the accumulation of additional experimental data, it seems reasonable that Plowshare funds should defray most of the incurred expenses.

Hazards

Three potential hazards are associated with the use of the nuclear excavation method: radiation, seismic effects, and air blasts. These special problems are viewed as being similar to earlier problems associated with the use and development of chemical explosives. To be sure, they are different in detail, yet they fall into a similar family of problems that can be solved.

The radiation hazard can be controlled, but it has a great emotional impact on the lay public. Highway planners and engineers are included with the lay public in having irrational fears. Several members of the Committee stated that they had misconceptions about the radiation hazard prior to their visit to the Nevada Test Site. This hazard is now viewed by them as a problem that exists, but one that can be controlled. As continuing research on nuclear devices develops cleaner reactions, the problem becomes less significant. Also, most of the radioactive fission products developed by detonation remain below the surface.

Radioactive contamination of ground water is monitored and studied by several groups. In terms of radioactivity released by a detonation, the contamination of ground water is small because about 90 percent of the fission products are trapped in insoluble slag. As a result of ion exchange, much of the reactive material moves considerably slower even than the ground water. Along with this, there is also decay of the radioactive products themselves. In most cases, ground water does not appear to be a major problem.

It is believed that much of the irrational fear associated with radiation can be overcome by education. Before off-site experiments can be conducted, the local people must be reached by an educational program that explains the problem. Irrational fear will be the single greatest stumbling block to initiating off-site use of the nuclear method of excavation. It appears that public education in this area has not been highly successful to date.

The seismic and air blast effects from high energy cratering detonations are probably a greater economic problem than radiation. Damage to manmade structures from shock waves is a distinct possibility, and one that must be taken into consideration for every experiment using a large explosion. The problems, however, are solvable. Each experimental site area will require geologic investigations to evaluate the potential seismic response. In some environments it may be desirable to detonate small charges and instrument the effects to assess the potential response of a large detonation. Such information may indicate that the site is not a suitable location for the experiment.

Air blast magnitude can be predicted and shot time atmospheric conditions selected to preclude atmospheric ducting in undesired directions.

Considerable work is being done in these areas and studies of these potential hazards must be a part of any individual excavation undertaken.

Test Ban Treaty

Plowshare program experimentation is somewhat limited by the Test Ban Treaty. The treaty prohibits atmospheric detonations and stipulates that radioactivity contributed to the atmosphere from underground nuclear events must not leave the territory of the country conducting the test. Though this requirement may deter the location of off-site excavation experiments in states adjacent to national boundaries, the restriction should not prohibit such experimentation located inland. Further, continuing research is developing progressively cleaner explosives of smaller yield, and has the objective of reducing production costs of these nuclear explosives.

Cleaner explosions yield less radioactivity to the atmosphere than was produced by devices used in earlier experiments thereby allowing a progressively greater degree of freedom of operation within the framework of the Test Ban Treaty. Compared with above ground detonations, atmospheric contamination from excavation shots is greatly reduced in that all but a small fraction of the radioactive material is trapped in the ground.

Small excavations can be produced more economically by conventional methods than by nuclear methods. Theoretically, large excavations can be produced more economically by nuclear methods. This concept has conditioned nuclear project thinking to consider only the largest of excavation undertakings. However, if significant cost reduction for nuclear devices of lower yield is possible, the wide range of economical application between the two methods would be substantially narrowed thereby making many smaller projects feasible. Many smaller projects, though they are large by current road building standards, are within the field of highway construction. Demonstration of safe construction practices along with the increasingly greater competitive range may be expected to extend use of the method within the present Test Ban Treaty stipulations.

High explosive and nuclear testing should be continued on a successively broader scale. The purpose is to develop the method for use on smaller projects as well as to refine the technology so that if the Test Ban Treaty is relaxed or modified to meet a specific requirement the method will have been reliably proven for use on large excavation projects such as a Trans-Isthmian Canal.

Conclusions

Developing excavations by nuclear devices is essentially no different from other methods using explosives; only the energy source is different. It has the distinct advantage over other methods in the capability of releasing a tremendous amount of energy from a point source and thereby accomplishing a great deal of useful work cheaply. Radiation, seismic hazards, and air blast are disadvantages that can be controlled. Though still in the experimental stage, the method has a high success potential. Additional testing will provide limits of applicability of the method. As testing continues and bounds are determined by experimentation the nuclear method of developing excavations will take its proper place as one of several tools available to engineering undertakings on a competitive basis. In some cases this method may make a specific project feasible that could not be accomplished within economic limits by any other known method of developing large excavations. Expansion of the Atomic Energy Commission's efforts to inform highway engineers of this work is in order.

Future research planning should include the items listed below:

(1) Additional testing in rock types and geologic situations with emphasis on:

- (a) Shale
- (b) Inclined beds
- (c) Sidehill slope cuts
- (d) Water-saturated environment
- (e) Areas of moderate to high rainfall

(2) Continuing evaluation of slope and fallback stability characteristics with emphasis on:

- (a) The establishment of an economically stable slope
- (b) Foundation stability of the fallback

(3) Continuing radioactivity, seismic and air blast safety studies

Problems that need solution before practical application will be possible in the highway industry include:

(1) Public acceptance based on safe off-site excavation experiments

(2) Providing state highway officials with an understanding of how nuclear excavation projects can be considered and undertaken

(3) Research should be directed specifically toward problems that will be encountered in actual applications.

List of Participants and Their Affiliation

The Academy and its Research Council perform study, evaluation or advisory functions through groups composed of individuals selected from academic, governmental, and industrial sources for their competence or interest in the subject under consideration. The members serve as individuals contributing their personal knowledge and judgments and not as representatives of any organization in which they are employed or with which they may be associated.

Name, Address and Affiliation of Members of the Committee on Engineering Geology, HRB. All members participated in field review and the discussion leading to the report.

Dobrovolny, Ernest (Chairman)
Research Geologist
Engineering Geology Branch
U. S. Geological Survey
Federal Center, Denver, Colorado

Dodson, A. C.
Chief Geologist
North Carolina State Highway Comm.
Highway Building
Raleigh, North Carolina

Hansen, Dr. Spenst M., Geol. Eng.
Plowshare Division
Lawrence Radiation Laboratory
P. O. Box 808 (L-43)
Livermore, Calif. 94551

McGregor, Dr. Duncan J.
State Geologist
Science Center
University of South Dakota
Vermillion, South Dakota

McNeal, John D., Research Eng.
State Highway Commission of Kansas
State Office Bldg.
Topeka, Kansas

Philbrick, Dr. Shailer S.
Geologist, Chief, Foundation & Materials Branch
U. S. Army District of Pittsburgh
Federal Building, 1000 Liberty Ave.
Pittsburgh, Pennsylvania 15222

Robinson, Dr. Charles S.
Consulting Geologist
Room 3
7590 W. 16th Avenue
Denver, Colorado 80215

Royster, David L., Chief
Soils & Geological Section
Tennessee Department of Highways
2200 Charlotte Ave.
Nashville, Tenn.

Smith, Rockwell, Research Eng./ Roadway
Association of American Railroads
3140 South Federal St.
Chicago 16, Illinois

Smith, Travis W., Asst. Mat'ls. & Research Engineer-Foundation
California Div. of Highways
5900 Folsom Blvd.
Sacramento 19, Calif.

Name, Address and Affiliation of Other Participants Having Responsibilities with the Highway Research Board

Humphres, Herbert W.
Assistant Director of Highways
for Construction
Washington Highway Commission
Highways-Licenses Bldg.
Olympia, Wash. 98501
(Chairman, Constr. Div., HRB Dept. of
Maint. and Constr.)

Johnson, A. W., Engineer of Soils,
Geology and Foundations
Highway Research Board
Nat'l. Academy of Sciences
2101 Constitution Ave.
Washington, D. C. 20418

Lacey, Delbert L.
Assistant Engineer of Mat'ls.
Kansas State Highway Commission
State Office Building
Topeka, Kansas

Lund, Orville L.
Assistant Engineer of Materials & Tests
Highway Testing Laboratory
Nebraska Department of Roads
P. O. Box 1991
Lincoln, Nebraska 68501

McDowell, Chester
Supervising Soils Engineer
Texas Highway Department
703 East 43rd St.
Austin, Texas 78751

Yoder, E. J. (Prof.)
School of Civil Engineering
Purdue University
Lafayette, Indiana
(Chairman, HRB Dept. of Soils,
Geology and Foundations)

The Atomic Energy Commission was represented in the discussion by:

Mr. Harold B. Curtis
San Francisco Operations Office
U. S. Atomic Energy Commission
2111 Bancroft Way
Berkeley, California 94704

The tour of the Nevada Test Site on October 11 and discussions concerning the experimental sites visited were conducted by:

Mr. David F. Miller
Nevada Operations Office
U. S. Atomic Energy Commission
Las Vegas, Nevada 89101

Mr. Paul R. Fisher
U. S. Army Corps of Engineers
Nuclear Cratering Group
c/o Lawrence Radiation Laboratory
Livermore, California 94551

Mr. David D. Rabb
Plowshare Division
Lawrence Radiation Laboratory
Livermore, California 94551

Figure 1. Sedan Crater, Yucca Flat, Nevada Test Site—100 Kt shot detonated 6 July 1962. Material: layered alluvial silty, gravely sands and sandy gravels. Radius at preshot ground surface, 600 to 625 ft; maximum depth of apparent crater, 320 ft; depth of burial, 635 ft below preshot ground surface.

Figure 2. Danny Boy Crater, Buckboard Mesa, Nevada Test Site—0.42 Kt shot detonated, March 1962. Material: basalt, vesicular, occurring in horizontal beds 2 to 10 ft thick, with joint spacing 2 to 5 ft. Radius at preshot ground surface, 102 to 115 ft; maximum depth of apparent crater, 62 ft; depth of burial, 110 ft below preshot ground surface.