PRNC - 110 PUERTO RICO NUCLEAR CENTER PLOWSHARE WORKSHOP July 1 through August 15, 1967 Conducted by A.S. Cheney and K. Talley University of California, Davis offered by the Division of Nuclear Engineering Donald G. Sasscer, Stead Kmid B. Pedersen, Bittor OPERATED BY UNIVERSITY OF PUERTO RICO UNDER CONTRACT NO. AT (40-0183 FOR U.S. ATOMIC ENERGY Commission ---Page Break--- TABLE OF CONTENTS REPORT. Ceed Dbit 1 ~ Reference Material for Nuclear Civil Engineering. 2 Mile 2 - Topics covered in Summer Plowshare Workshop... Page 3~ Sequence of Lectures in Plowshare Workshop = Puerto Rico = 1967.,.. Plowshare APPENDIX B ---Page Break--- PUERTO SECO NUCLEAR CENTER PLOWSHARE WORKSHOP, 1967 INTRODUCTION In 1964, the third Plowshare® symposium was held on the Davis Campus of the University of California under the sponsorship of the Lawrence Radiation Laboratory at Livermore (LRL), the Atomic Energy Commission, the American Nuclear Society, the American Society for Engineering Education (ASEE), and the Department of Applied Science, U.C. Davis. An ASEE committee used the papers presented at the symposium to assess the suitability of introducing Plowshare technology into academic curricula. The committee felt that such action was premature. Their contention was that the field was still in the research and development stage. Further, they felt that the science and technology of nuclear explosives was not sufficiently codified for instruction, and that the expertise to do so was available only in a few laboratories, such as LRL and Sandia. Publication of the symposium papers and improving awareness of the potentials of nuclear explosive engineering could have modified the situation. Since 1964, several schools have added descriptions of the effects and uses of underground nuclear explosives to regular engineering courses or have started formal instruction in Nuclear Civil Engineering. Many of these innovations are within 150 miles of FRE PFOA to make constructive use of nuclear explosives known as ‘the’.

Plowshare Project. (Dg, 5. Cotaberg, “The Third Plowshare Symposium," J. Eng. Educ., 355 4, 100 (1964). (p) K. Kruger, “A Graduate Level Course in Nuclear Civil Engineering,” Trans. Am. Soc. Civ. Eng., 9, 1, 208 (1966). (c) K. Talley, "Plowshare in University Programs," 9, 1, 312 (1966). Trans. Am. Soc. Civ. Eng., (p) K. Kruger, “Nuclear Explosives as an Engineering Subject,” Nuclear News, 10, 4, 18-20 (1967). ---Page Break--- each other: at Stanford University and at the University of California at Davis. The Stanford course is a 30 quarter hour lecture series taught by Prof. Paul Kruger of the Civil Engineering Department. (The content of this course is briefly described in reference 2 and is available in the form of a syllabus -- see Table 1.) At Davis, the phenomenology and physics of nuclear explosions is given in 30 quarter hours in the Department of Applied Science. The use of these compact energy sources is given in a subsequent course (also 20 quarter hours) taught in the Civil Engineering Department. (The content of these courses includes a good deal of the topics presented in Table 2. The main text for both courses is The Constructive Uses of Nuclear Explosives -- see Table 1.) Both Stanford and Davis restrict their courses to graduate students. It has been slightly more than a year since the Plowshare program started at URL. Large-scale excavations, such as new sea-level transisthmian canals, have been studied carefully as to their practicality. The personnel at LRL, in cooperation with other researchers, have performed many of the experiments needed to provide data for engineering design. A Presidential Commission is currently studying possible routes and construction methods for a sea-level transisthmian canal. No routes proposed would use nuclear explosives. While such spectacular excavating projects tend to attract public attention, there may be more potential in the development of the technology of completely contained underground explosives. Such an explosion must be designed to reduce structural damage due to ground.

motion, but the hazard of radioactivity release can be eliminated. Project Casbuggy, scheduled for fall 1967, will test the ability of nuclear explosives to stifle production. Other experiments, planned or proposed, will add to the exploitable resources of the world: oil, shale, minerals, water. SOBER WORKSHOP PROGRAM AT UPR/FRNC In addition to acting as a center for Latin American research in nuclear science and engineering, the Puerto Rico Nuclear Center (PRC) is charged by the United States Atomic Energy Commission with the dissemination of nuclear technology throughout Latin America. This includes instruction in the nuclear sciences and engineering. The dual purpose of the PRNC joins naturally in the transisthmian canal: when the canal is built, Latin American engineers will play a large role and, if nuclear explosives are used, there must be available a local training center well versed in Plowshare technology. The Nuclear Center and the Engineering Faculty of the University of Puerto Rico wished to broaden their role in nuclear engineering and science and at the same time prepare the University of Puerto Rico to be a Plowshare training center. Dr. Henry J. Gouberg, Director of the FRNC, invited Profs. J. A. Cheney and W. K. Talley to lead a three-month workshop at the Mayaguez branch of FANC. These two people were responsible for the development of the program in Nuclear Civil Engineering at the University of California at Davis. The purpose of the workshop was to provide a complete background for members of the scientific staff of the PRNC and for the faculty members of the UFR: the scientific basis, the phenomenology, the engineering principles, and the constructive uses of nuclear explosives -- and to then let the UPR design a course for its own students. The effort was interdisciplinary; there were representatives from the departments of chemical, civil, mechanical, and nuclear engineering, physics, and staff members from FRNC. Despite the fact that most of the projected uses

Break--- fall into the traditional province of the civil engineer (excavation, mining, petroleum reservoir stimulation, aggregate production, water resource development and conservation, etc.), all other engineering fields are touched by the technology of nuclear explosives. This is because the nuclear explosive is not simply a scaled-up conventional high explosive, but introduces its own peculiarities, e.g., energy density in the megabar range, shocks strong enough to vaporize rock, large earth motion due to spalling, neutron-induced radioactivity, fission product radioactivity, etc. LECTURES IN NUCLEAR CIVIL ENGINEERING The choice of material covered during the workshop was governed by the familiarity of J. A. Cheney and W. K. Talley with their courses at Davis. It was recognized that the participants were well grounded in one or more of the topics presented (e.g., basic nuclear science, or hydrodynamics, or construction practice or structural engineering), but no one person was familiar with them all. Table 3 presents the hour by hour lecture topics given to provide an introduction into all the areas covered by nuclear civil engineering; perhaps more importantly, the program provided the faculty group with a common vocabulary. The source material was either from the text by Teller, Talley, Johnson and Higging (Vol. 1 Table 1) or from notes included in Appendix A of this report. The notes comprise an introduction into civil engineering to persons working in the Plowshare technology, who have little or no civil engineering background. They serve only as a brushing of the surface in order that all the participants will have a better understanding of the approach taken in civil engineering to certain basic problems associated with the constructive use of nuclear devices. ---Page Break--- The first two lectures were concerned with the problems of organization and management of a large construction project. This was followed by twelve lectures on engineering mechanics and soil mechanics as applied to problems.

associated with the design of nuclear civil engineering projects. The topics include the theory of elasticity, elastic waves, failure theories and mechanics, the stability of slopes, groundwater flow, the transient response of saturated soil, the dynamic analysis of structures subject to ground motion or air blast. The last two lectures included in this set of notes deal with the drilling code for large diameter holes in soil or rock and the problems of numerical instability associated with computer solutions. As each topic was presented, it was contrasted and compared with the need in a similar topic as it would have been in a traditional engineering discipline. Two examples make this clear: In developing the Rankine-Hugoniot equations for shocks, a compressible fluid was used for an analogy. When use was made of the resultant equations to discuss phenomenology, it became clear that a hydrodynamic shock traveling through rock is not entirely analogous to one in a fluid. In granite, as the pressure level of the shock declines, there is formed a sonic, elastic 40 kilobar wave that precedes a slower, several hundred kilobar plastic wave. At pressure levels above 300 kb and at those below the elastic limit, there is but one compression wave. In the discussion of engineering practice, it was pointed out that on construction projects contractors would be likely to submit fixed price bids if conventional methods are to be used; on the other hand, if nuclear explosives are specified, the bid is likely to be cost plus fee. Hence, two bids for doing the same job should not be compared directly when one is based on using nuclear explosives and the other is based on the use of ---Page Break--- outline for the content of a graduate course in nuclear civil engineering to be taught at UPR in the Spring of 1968. The notes in Appendix A and the text "Constructive Uses of Nuclear Explosives" by Teller, Talley, Higgins and Johnson comprise the material in satisfaction of the first item above, presenting a one semester (40 contact hours) course.

Course is scheduled for the spring semester 1968 to be offered in cooperation between the Departments of Nuclear and Civil Engineering. It should be a graduate level course (600 series), carrying three unit credits, and consist of the topics listed in Table 2. In order to fit in the time limit of one semester, the topics of Thomas-Fermi Model, Hydro Codes, Equations of Hydro Dynamics, Planning and Organization of Construction Projects, and certain scientific applications had to be omitted. However, it was the consensus of the discussion near the end of the workshop that a treatment of similitude and modeling should be added. The expanded outline of this course as suggested by Messrs. N. Beylerian, J. As Cheney, K. Pedersen, and W. K. Talley is given in Table 4. Also, in order to facilitate the instruction of the course, a set of typical homework problems have been compiled and listed in Appendix C. To accompany this instructional program and to provide the topics for their graduate students, the faculty are widening their research interests to include problems in nuclear civil engineering. For example, they have been conducting research on the solubility of certain copper ores to determine the feasibility of mining large, low-grade ore bodies in situ leaching. They are now planning to subject ore samples to transient shocks in the 10 to 100 kB range and will determine what effect, if any, this will have on solubility. These stress levels can easily be produced in an ore body by the use of nuclear explosives. ---Page Break--- The crossing of traditional departmental boundaries often required perhaps an additional advantage to the research such as this, University of programs in nuclear civil engineering. Beylerian Figure 1 ---Page Break--- Sources: Theoretical Shock Wave Brine, with Explosive Generation Ste ————+@) Crater Suatsriog [>] Sheets, Sand-tox, Colliding plates, black powder, focused. Shocks, High-altitude ARRAYs. Theoretical Sequential arrays of timed detonation explosives in 2 and 1 of black powder.

S"ainenstovs, | | charges in arrays tand-bon sanitbex peiner yield =r Tecsite HO Tabaie content Anglytic work fon 2 and 3edim Beouetries Review of sethods, Analytic work on i-dim (2,2) eechntques Tay eds Tee Ge] [Est] [ie Constant sedivm Tesowfer tunction,| | extension] | rieid ceata] | of know, vartable,Ly | albedo for (jn) | 9] of teats || of bese fonog. &'heterog..'| | ané other w0'"” || to 2 ane || wethode Hp content deterainations, 3 di Ghote) || one-dimensional tuations Pigure 2. Project Network ---Page Break--- 10 ‘Goloaie Garvey Mock Survey. Survey for ore ieroscopic study body suitable Jot ehe known PR. for NB. aining ore bodies + ‘Other Oren Methods developed to be applied to ore bodies in other places, Waclear eat Add-on Shocking of substantial quantities of aineraloar Preparation| of hock stressing Snall_ samples Steady State Fracture 1 | [aera Cracking woe t Plexiglass. conparison} | Extension of wethod I ' I UI with IRL experinents to rock media Taachiog Studies Rati Chianey 7 ~ of ME-Simulation ab; 12504; Tine dependence teaching of [--————+ | reaching tneateu Selected ore of shocked ores apes comparisons ges 2 atftunton Ton-Bachange fpemearirg Characteristics ‘changes due of rocks to shocking ‘ ' Distribution Dyamale bier] : Goettictent Geet fictente -— Fission products Organic - : in CuS0, separation %» | pa ---Page Break--- ‘Analysis of construc- ‘tion practi visual inepection; earthquake public “complaint” spectr: Stattectes [>| correr. wien Danage fron earthquakes Semple Geeactares [—— 9} tarse detonations l Wrediction of ‘Thcesbold Deane mm ("LAL") struct ~ 9 Dunsaie Slope Stabiliey | [Slope Stability Slope Seabee Laboratory |} rieia exp. ith cxperinente with Erenetene shocks Eraneient shocks; Liquefaction ---Page Break--- /d-)4f * A sonora ereatwent of the Floushare Project, including # lucid developoent of the politieal-social implications of successful nt of nuclear explosives, ie avatlable in: 7. "Project Plowshare, the Development of the Peaceful Uses of Nuclear Explosives," R. Sanders,

Public Affairs Press, Washington, D.C., (1962) the following basic texts have served as useful references for the non-civil engineer studying Nuclear Civil Engineering: 8, "Basic Soil Engineering,” B. K. Hough, Ronald Press, New York, 1965. 9, "Project Management with CPM and PERT," J. J. Moder and C. R. Phillips, Reinhold, New York, 1964. 10, "Construction Planning, Equipment, and Methods," R. L. Peurifoy, McGraw-Hill Book Co., New York, 1956. 11, "Handbook of Engineering Mechanics," W. Flugge, McGraw-Hill Book Co., New York, 1952. ---Page Break--- TABLE 2 (Cont'd) Scene Applications ‘ Earthmoving Applications: Neutron physics: Canals and mountain cuts clear structure arbors Sedimentation Water resource development. Meteorology Contained Applications Chemistry Aggregate production Materials science Petroleum reservoir stimulation Underground storage ‘and oil shale Mining ---Page Break--- TABLE 3. SEQUENCE OF LECTURES IN PLOWSHARE WORKSHOP - PUERTO RICO - 1967 Notes Participant's lectures Source Topic Brief History of Plowshare Project and Comparison of Energy Sources Organization of Civil Engineering Construction Project Nuclear Radiation and Radiation Hazards Basic Equations of Hydrodynamics The Critical Path Method of Scheduling and Project Control Foundations of Statistical Mechanics Thermodynamics, Compressibility and the Virial Theorem Basic Equations of the Theory of Elasticity Rankine-Hugoniot Equations Equations of Shock Waves in Elastic Media (Basic Equations Solutions to the Elastic Wave Equations Reflection and Interaction of Shocks Radiant Energy Content and Transport Failure Theories in Mechanics Failure Theory in Soil Mechanics Rudimentary Analysis of Slope Stability Drilling of Large Diameter Holes in Soil and Rock Nuclear Explosives: Size, Shape, Weight, Cost and Yield Production of Radioactivity - Fission and Fusion Flow in Porous Media Seepage Forces ---Page Break--- Lect. No. 23 2 28 23 30 32 2 35 36 38 40 Source ---Page Break--- TABLE 3 (Cont'd) Topic Nuclear Excavation - Fallout

‘Transport of Radioactivity in Groundwater Settlement in Saturated Soils Phenomenology: Contained Explosion Phenomenology: Cavity, Chimney, Crater Movie: Project SEDAN Structural Dynamics Structural Response; Spectral Analysis Geological Description of the Island of Puerto Rico Structural Response: Sediment 1 Phenomenology: Craters Measurement of Explosions: Instrumentation Prediction of Explosions: Hydrocode Shock Wave Characteristics and Predictions Mathematical and Physical Instabilities Hazards Evaluation - Groundshock and Neutron Physics Other Engineering Parameters Isotope Production, Seismology | Barcooving Applications; Water Resource Conservation | and Development Meteorology; Upper Atmosphere, Fracturing, Rubble

Size Distribution, Chimney Tonnage, Aggregate Production Tar Sands and Oil State ‘Transisthmian Canal ---Page Break--- etc. No. a 48 4 so st 3 ‘TABLE 3. (Cont.) Complete Carryall (trench cut) Chariot (barrows) Gas boggy (cavern attenuation) Mining Geothermal Heat/Simulation Neutron Diffusion and Isotope Production ---Page Break--- TABLE 4. etc. No. 1 2 10 n 2 3 15 6 v 8 ws 20 2 2 23 2 » COURSE SCHEDULE IN NUCLEAR CIVIL ENGINEERING AT UPR Total The Plowshare Project Nuclear structure and energy sources Nuclear radiation and hazards Cost, size, shape, and placement Determination of yield and production of radioactivity Distribution of radioactivity: fallout and groundwater Thermodynamics and compressibilities Theory of elasticity 1 Waves in elastic media Rankine-Hugoniot relations Shocks and shock adaptability Spallation due to shocks Interaction and reflection of shocks Contained explosions: cavity, chimney, scaling cratering experiments: apparent crater, sealing Stabilities and modeling Medium properties and instrumentation Structural dynamics Hazards due to groundshock and airblast Failure theories in mechanics (couplings) Slope stability ---Page Break--- 20 TABLE 4 (Cont.) Topics Flow in porous media, seepage forces Settlement of saturated soils in Canals, mountain cuts, and harbors Water resource

development Aggregate production Petroleum reservoir stimulation; underground storage Tar sands and oil shale Mining Nuclear physics Seterology ---Page Break--- APPENDIX A ‘ LECTURES IN NUCLEAR CIVIL ENGINEERING Delivered by James A. Cheney at PUERTO RICO NUCLEAR CENTER University of Puerto Rico Mayaguez, P. R. ‘CONSTRUCTION MECHANICS Introduction Construction is the ultimate object of design. In many cases, as in the peaceful uses of atomic explosions, the construction technique is the subject of research and development. Design must take into account these new construction methods and techniques. The techniques proposed by the Plowshare project at Livermore Radiation Laboratory require projects of incredible magnitude in order to be economically feasible. Building an Isthmus Canal by a single row of charges, building a harbor basin in one explosion, and others, require immense energy release and are only feasible because such an explosive, namely the nuclear explosive, is available. ‘The purpose of the Plowshare Summer Workshop is to see how this new technique fits into the construction industry as a new method in competition with existing methods of construction. ‘The Engineer and Construction The engineer is that person who prepares the plans and specifications and supervises the construction of a project. In the case of the usual design project, the engineer is constantly concerned with reduction in costs if he is performing his service conscientiously. However, he is faced with the problem ---Page Break--- 2 that cheaper, more efficient techniques of construction are sometimes not effected because the construction contractor does not recognize the economies of the new construction technique or unusual design. Contractors will bid high on those unusual or uncommon because they fear the unknown. Usually when a project involves many uncertainties, the contract may be awarded on the basis of cost plus a fixed fee. Undoubtedly this would be the case in the Plowshare applications. But this leads to an unfair comparison.

In that the project by conventional methods would be by free competitive bidding. The former method has the disadvantage that the contractor is not concerned with keeping the costs down. Costs may be considered divided into five items: materials, labor, equipment, overhead, supervision, and profit. The last is not controlled by the engineer, but the others are influenced by the engineer and require that he be knowledgeable of construction methods. The project engineer is faced with the problem of comparing a new technique with current techniques. Some knowledge of current techniques is needed. A basic knowledge of construction principles, soil dynamics, soil mechanics, and nuclear explosion phenomenology is required for the simplest of cost and feasibility evaluations.

Construction Organization
The organization of a construction company in the United States of North America consists in most cases of a single contractor who employs a small group of trusted people who may include a bidder, a foreman, and a timekeeper and accountant. Larger organizations, which would be more likely to embark on a project involving nuclear power in construction, have administrative groups in the main office that carry out the same work.

---Page Break---

A typical organization may be shown in an organization chart, done in industry.

Contracting Company
Accounting
Bidder
Public Relations
Construction Engineer
Superintendent
Project Purchasing
Chief Clerk
Engineer
Agent
Timekeeper
Carpenter
Contractors
Foreman
Concrete Foreman
Electrical Foreman
Etc.

(CONTRACTOR ORGANIZATION CHART)
There are problems that merit discussion in each of the areas in the block diagram above. The features which bear discussion involve:
- Public Relations
- Labor Law
- Labor relations
- Performance Bonds (Insurance)
- Public Liability Insurance
- Hidden Costs
- Lost Time
- Cost of bidding
- Miscellaneous
- Losses
- Depreciation
- Increase of capital investment
- Accounting methods and cost control
- Safety

The discussion as applied to Nuclear Civil Engineering will be centered on that of bidding. This involves knowledge of all the other aspects of management as they affect contracts and also requires knowledge of construction scheduling. A good bid will include a project schedule which should be used to determine the relative progress during construction. In preparing a bid for a construction project, pre-bidding studies are required to determine the influence of topography, geology, sources of materials, access to the project, housing facilities, storage facilities for materials and equipment, labor supply, and local services. In the case of a Plowshare project, many, if not all, living accommodations may have to be supplied by the contractor. ---Page Break--- The use of substitute construction equipment having higher capacity, efficiencies, higher speeds, more maneuverability, and lower operating costs should be considered. Bonuses to key personnel for beating deadlines, use of radios for quick communication, and periodic conferences with key personnel to discuss plans, procedures, and results should aid morale and lead to better coordination among various operations. The Project Schedule Just a few years ago, there was no generally accepted formal procedure to aid in the management of projects. Each contractor had his own scheme, which often involved limited use of bar charts. The first formal procedure for determining a project schedule was PERT (Program Evaluation and Review Technique) (1956) and quickly followed by CPM (Critical Path Method) (1959). The first was developed at Lockheed Missile and Space Co., in connection with the development of the Polaris weapon system, and the latter was developed by the DuPont Company. Since that time, the methods have been applied largely throughout the construction industry. The principal feature of PERT is a statistical treatment of the uncertainty in activity performance time and includes an estimate of the probability of meeting specified scheduled dates at various points.

stages in the project. ‘The object of CPM is to determine how best to reduce the time required to perform routine construction work. ‘The nuclear civil engineering project is more likely to involve the CPM approach, although certain development aspects of the devices themselves and the determination of the scaling laws or computer codes might be appropriate ground for PERT procedures. ‘The Project Network ‘The project network is the heart of the CPM and PERT procedures. It is best explained by an example. We first state which statements describe the sequence of operations in a project. This may be given in the form of a chart. Activity Depends on Activity. The node or circle notation is the activity network junctions. The first attempt at making a network is best done by connecting the operations, denoted by circles, with directed arrows indicating the sequence. Thus for the above, later this may be cleaned up to give a neater appearance and the arrow head may be dropped since the sequence may be associated with position. ---Page Break--- Determination of the Critical Path To determine the critical path the activities must be given times of completion. Usually the times given by a contractor would be those for the most economical production and, therefore, represent the minimum cost. The following table will be made and Normal Time. The Earliest Start and Earliest Finish refer to the Earliest Start time and the Earliest Finish time for each operation. These times are determined by considering the normal time for the operation and the project network. A and B depend on nothing, therefore, start at zero; C, however, may not start until A is finished (the network) therefore, the E.S. for C is the E.F. of A. If the start time for an operation depends upon more than one operation being finished, the later finish time of all preceding operations must be used. Thus, the E.S. for D is the E.F.

P. for C rather than B. The procedure leads to the minimum number of days to complete the project, 57. L, 8, and L. F. refer to the Latest Start time and Latest Finish time that an operation may have and still complete the project in the earliest possible time, i.e., 57 in the example. These numbers are obtained by starting at the last operation and determining how late they may be started and moving backward to determine this for each operation. Operation Normal Time L is 5 5 0 1,000 5 10 15 5 3,000 150 5,000 c 20 5 3 0S 20,000 > 15 530 S80 30,000 r 20 yo 5030 80-0, 000 r 10 so a7 000 4 7 so? 8087000 $72,000 For example, F may finish at 57 along with W and therefore have a start at 47, E just finishes before so E has Latest Finish that is Latest Start for H. Where there is a choice between the start of two or more operations, the earlier of them must be used for the latest Finish of the preceding operation. The lag time is defined as either the difference between L.S. and E.F. or L.P. and E.F. Those with zero lag time are said to be critical and the network path connecting critical operations is a critical path. Thus, operations AGDEH form the critical path. The significance of the critical path is that in order to shorten the total time for a project, some segment of the critical path must be shortened. The above analysis has used the circle notation in the project network. It should be pointed out that another notation is commonly used for application with the high-speed digital computer. The operations are represented by arrows with each arrow represented by a number at its tail and a larger number at the head. Operations that have the entering operation carry the start number corresponding to the finish number of the preceding arrow. Thus, the example above may be depicted as L Dummy: x " 7 a An anomaly occurs where operation E follows C and D, but P follows just D. If E and F both had the same start numbers there would be no way of showing the proper sequence. The

anomaly is solved by inventing an operation called Dummy which takes zero time, but separates the start of © from the end of D. Shortening the Project Since the normal time schedule was defined as giving certain cost, shortening the project (or for that matter, lengthening the project) will increase the cost of production. Presumably there will be maximum cost associated with every operation being performed as fast as possible. The operation times for that are called crash time and the associated cost the crash cost. A critical path analysis may be made for the crash program and is given below: Critical Path for crash Program Operation Normal Time LS. Le. ag a 5 o 5 0 5 9 4,000 2 8 o 8 2 10 2 4,000 © 5 5 1 5 1 0 2,500 ¢ 8 513 7,000 > 10 10 20) 102) —30,000 z 10 2 30 «203040, 000 ' 15 2 38205 8,000 x 5 30035088 _ a 200 $100,700, ---Page Break--- 20 We may note immediately that those operations in the crash program which have lag time would be done foolishly since their time could be extended thus reducing the short for project Shortening ‘Three points on a cost-time plot are available to allow us to interpolate linearly between eras fast without changing the duration of the project. The procedure from the above layers, Namely, the normal time, crash time and the optimum crash time, land normal time for ‘The optimum crash time cost is obtained by lengthening those operations which are not on a critical path to eliminate the lag times. too 70 Time First we list the cost/day of shortening in order of increasing cost. 07 Cost/pay 100 100 500 1,000 1,000 1,000 2,000 ---Page Break--- a ‘To shorten the project in the least expensive way, we shorten the first operation on the list that is also on the critical path. It happens to be Gor H. There are two restrictions on the amount of shortening. Either the operation is shortened to crash time or the lag time is used up in a parallel path whichever is smaller. This later limitation is determined by noting those operations whose lag time could be reduced by a reduction in

operation time of G. Thus, operation lag times on C and B would be reduced by one day for every one day shortening of G. Since the maximum shortening of G (crash) is 6 days, but B has a lag equal to only 5, G may be shortened by 5 days and increased in cost by $500. This gives another point on the cost/time curve. The next one to shorten is H, having a crash limit of 2 days, but it affects only F which has a lag of 2, so the project is shortened by 2 days for an increase in cost of $200. The next cheapest reduction is either B and C, or D. (B is on the critical path now, but it can only be shortened if A or G is shortened too, but A cannot be shortened.) Operation Cost/Day B

$500 C $600 D $1,000 The combination B and G has a steeper cost slope but can only be shortened to crash time for G, which is 1 day at an increase in cost of $600. D may now be shortened to crash time leaving a lag of 4 in operation C, reducing the time by 10 days at a cost of $10,000. We thus arrive at the optimum crash program from the normal time point of the cost time curve, ---Page Break--- 2 FUNDAMENTALS OF ELASTIC THEORY Concept of the Continuum The continuum is an assumption that macroscopic properties of materials are correct for microscopic elements of the object. This assumption permits the elimination of ambiguities concerning the interaction of repulsive and attractive forces between atoms which when viewed from the gross scale may be treated as average properties. The equations that we write depend upon the coordinate Cartesian coordinates the element is rectangular. Let a be a variable for 2a and let Fr be a variable for O. The letter σ shall be used to denote stress. A stress is positive on a back face if it is directed opposite to the coordinate direction and positive on a front face if it is directed in the coordinate direction. The first subscript defines the face upon which the stress is acting and the second subscript the direction of the stress component. In order to not clutter the line we have shown the stresses on two parallel planes.

There are similar forms of stresses on the other planes. For each of the coordinate directions we may write the summation of forces. For example: ---Page Break--- 3 d, s + Sivay)aae— oyyanae + (ys Bs aadonay = My anny ® ‘ + Gays ee Apayan ery oyon = anager dts _ te 8 oe where ys the displacement in the y direction. The body force. In addition to the sum of the forces we may also set the sum of the moments about any axis equal to zero. For example: (yn + 2euy ay) axe 3) HOR Oy Cyy + Mey az) axey oz sey 9 @ryt Sts + es axon SB, 2 peaxaySh=0 3 OY 2 On 32 | Neglecting terms of higher order we obtain Tyee % Similarly Cay Oye Ours Cay The above relations may be combined with the other equilibrium equations to give ---Page Break--- 4 mese axe the equations of motion in terms of stress. If acceleration is zero they become the static equations of equilibrium. ‘Stress-Strain Relations ‘The constitutive relations (Equations of State) relate the stresses to appropriate strains. We shall use Hooke's law for these separate relations: E€ sat Gea F(t Fax) Eby Oy > Tax ad Eaes tae e(eus toon) Gry: ry Goya t Oye Geuw Oy were gs 20st) Definition of Strain ‘To complete the set we must know the relations between strain and displacement: we can 2 eer Eby GE) Cae Se ~ oe yee. Oey Qu, ,aw Gays Set Sz) Gero Se 5 bo BEE these equations are sometimes called the kinematic relations. Compatibility Relations, It may be noted that not all the strains can be independent since they are related to only three independent displacements. For example * Oreny | Dew , dthyy dxdy Dy 33" ---Page Break--- 3» ‘There are six such relations possible. Gyelse-Suhses tution Lt {2 often helpful to note that any equation in elasticity theory may be changed by a cyclic exchange of the scripts and displacements to yield another equally valid equation. « x wD i. I; management of Bqusto For the purpose of investigating the existence of elastic waves, we will rearrange the above three sets of equations (Equations of Motion, Equations of State, Kinematic Relations). The

Equations of State (stress-strain law) may be solved for stresses g, Toe [from eee + Egy seas] and € Cry [not OP has eee been] 7 fe aa Gazanas Thayer és) fy GE ny 4 ee Gey ye 2 Gbxe of Gan tye baa) org Fee Gann (from sar heal or TEs 5 48 + fee)? 7 38 kaye gy? Cee Goren’ * € SE _ (Eas O yy ae? ie ene ---Page Break--- For convenience in writing some new symbols may be defined: te e+ Cyt eggs See nt alee) . a . ta her BOE ae ye her 2Ge sy a es dak, ty Ea Pye GE ae Mabey These equations for stress may be substituted into the equations of motion, resulting in (ava) 22. G Sage +33)- tt o grade +aGR+ He SE)- Eo Car oge (GE + BF SS)- CHrro These are in the absence of body forces, Ky Yor 2. These equations may be further simplified by use of the (7 ? operator. Beat i vii 357 Sp ‘ O46) 38 4 Gutu-e3ts0 Qr@) ® 4 GUY» gw, 9 Ore) route ee ° ---Page Break--- ” Waves of Dilatation Differentiate the three equations respectively with respect to x, y and z and then add them together. We obtain Q-+eaa)vte - pre ro This defines the preparation of a disturbance of volume. The above relation may also be derived on the basis of considering the type of motion which is free of rotation. Hence, the waves resulting are considered irrotational, dilatational or simply P (waves) Shear Wave If we place the restriction of no change in volume on the differential equations, € = constant and Gotu - eFrr0 Goto. zero av? o- eRe, 'The above expressions permit shear distortion; hence, these disturbances are called voluminal, shear, or $ wav reity of Pr 8 The wave equation has the form aro Sie ws wherein ¢ 10 tbe velocity of propagation. Hence, the dilatational wave has velocity 2226 ---Page Break--- 8 and the shear wave has velocity 6,2 T= e he dilatational waves travel faster than the shear waves, hence the wave fronts of these two waves move farther and farther apart as they solve from a source, Given a expected distance from the source R Retalartils : Ate ty-ta shen bt: BR R Sar SsQ ta * te tne eine difference between the SETA of the dilatational.

wave and the shear wave {# measured cal Canes Rez ot This relationship is used to determine the distance of an earthquake from an observer. Several ratios are required to pinpoint the actual location. The determination depends upon the accurate knowledge of Cg and Cy for the earth. The dilatational wave arrives first, hence it's called primary (P), and the shear wave arrives second, hence secondary (S). For example, in steel cq = 18,000 fps, Cy = 10,500 fps, whereas in granite Cy = 16,000 fps and Gy = 10,000 fps. Surface waves are reflected from a surface of discontinuity in the medium. In general, the incident wave produces four waves: a reflected dilatational wave and shear wave, and a refracted pair. Of course, amplitudes and angles with respect to the surface of the subsequent waves must be such that the stress components across the surface be continuous. ---Page Break--- From the requirement of continuity of displacement swa = 2 sid, aa fa dz +9 84 wherein 4 and @, are angles of reflection and @y and ©, are angles of refraction to the angle of incidence 94 de & Ae % When waves from the interior strike a free surface a special type of wave occurs which has been called the Rayleigh wave. If the x-y plane is assumed to coincide with the free surface and propagation is assumed to be in the x direction, WO is implied. Since neither dilatational or shear waves satisfy these conditions, a new type of wave must be developed. Actually, the surface wave developed by Lord Rayleigh is a combination of the two waves previously described. The derivation made by Lord Rayleigh will be outlined briefly and the results discussed. The following expressions for dilatational waves were assumed: Mat se TF sw (pt- se), Uys 2 cos Cpt ax) were and the following for shear waves: Us. be" sivlgt-se)s Bs > se? ere (pt -sx) w, ---Page Break--- It can be shown that the expressions satisfy the conditions for the two respective A more general type of plane wave is obtained by linear combination of the above two waves, Le mw 5eF syalet sade Abe

M siu(pl- 92). VnPETS cos(pt-5x) - Rb ey Cos(pt-sy). We have the constants A, b, py, Fy that have to be evaluated to satisfy the boundary conditions. These are to express mathematically that on the surface y ~ 0, the normal stress fs and shearing stress fy are zero. Using the expressions developed for stress, we obtain the equation in terms of arrangement, which we have to satisfy. If the two sets of solutions are substituted into the statational wave equation and the shear wave equations, the following relationship must hold: where Pp is the velocity of propagation in the x direction. Substituting our proposed combined solution into the boundary conditions, eliminating the constant A, and introducing previously determined values of 4 and Ca, we obtain: since Cl is less than Ca, and taking Cr equal to cS, we obtain: The roots of this equation define the velocities of propagation. The results may be compared in the following figure. Thus, we see that Rayleigh waves are always slower in velocity of propagation than the other two types.

ALLURE THEORIES. We have already dealt with the stresses acting on an elemental cube. The entity of all stresses associated with one point, regardless of the orientation of the element, is called the stress field. It may be expressed as a matrix or as the tensor form. The matrix form is simply an entity in a tensor if it transforms according to a certain transformation law. Namely, if we rotate the coordinate system by an angle, the stress components transform as follows: where x', y' are the new coordinate directions. Note that a vector transforms as: or in matrix notation.

For the stress vectors on the...

principal planes x and y, Py "Oxy A, ake Bye * Sym Aye Fay = Ty Aye Bay O ny Ay Fea Fey tos ese ‘ |": Fay . S eyy bse cose] | Fys &, Fae Fey swe at ay ‘he reciprocal of the areas associated with stress vectors P also transform vectorially. ue, UGE EI te: (1 Le] + Le] Lx] , @] GAIL] wherein [6] = (em = the sector transform and aF ke the transpose of a. ‘Tite may then be written simply. (oJ. [ayforte') above is called « tensor. Essentially a tensor i# an entity that ts the product of two vectors. $e —EB ---Page Break--- 44 train te a tensor quantity. ‘The displacements Lf kept small are vector quantities transforming « vector for rotations of the coordinate system, The lengths (sides of the element) are also vector quantities and the inverses of the lengths are also vector quantities leading to fe]+ (s] Celle] Stress Invariants Yield criteria certain quantities may be found which remain constant when « transformation is made. One of these is called the trace Gee + Cys Tea t 9F ys matrix may be written as Cie Sey See wherein Ugg = Cacdete: Fas Another invariant is hydrostatic stress. (& oss)" a Gy this can be interpreted as the equation of circle (Mohr's circle) in coordinate system Oge gy 80 ay Mohr's Circle ---Page Break--- oy vents the orientation with respect to the principle wherein the angle © repr: those planes having zero shear stress. In general, 3 Mohr circles can be drawn for rotations about the three coordinate directions: the Mohr Circle in Three Dimensional Stress material parts of slips. Thus, two limits my Failure may occur because be drawn, one limiting the maximum shear, the other limiting the maximum tension. The maximum shear criterion for yielding is due to Tresca and is called the ‘Tresca Yield criterion, The tensile limit {4 really « rupture criterion. ‘Another type of rupture, that {e slip is predicted by the Mohr envelope. This Ca Shear Ultimate Criterion) Teosue Untiuare (Fanewne) ---Page Break--- 46 forms the strength criterion for most soils. In general, the strength criterion to the stress

invariants If the material is for a material must be relat Aetropic. A stress invariant is a relation involving the stress components that remains constant during a rotation of the coordinate system. In general, for isotropic materials there are three independent stress invariants. which may be related to the radius of the Mohr circle being constant. The principal stresses are related to the mean normal stress, which is important. This may also be true in materials at extremely high pressure. Thus, general yield theory involves all three stress invariants. The most commonly used yield criteria are: Tresca (Maximum Shear Stress) where $T = (\sigma 1 - \sigma 2)/2$, and the von Mises criterion. The latter being a generalization of the Mohr envelope or Coulomb's Law for soil. The latter was obtained empirically from the formulas using tubes. The von Mises criterion was originally proposed as a mathematically smooth approximation of the Tresca criterion. In three dimensions using the principal stresses $\sigma 1$, $\sigma 2$, $\sigma 3$, we can plot the von Mises yield condition as a circular cylinder of radius JF whose axis is equally inclined to the three principal stresses. The Tresca yield criteria matches the von Mises criteria at six points, but is formed of straight interaction lines rather than curved. The phenomenology of Stress-Strain The foregoing criteria for yielding attempt to predict at what value of stress the stress-strain curve for the material subjected to biaxial and triaxial loading will become non-linear. For many years work has been carried out to explain why after the yield point is reached and plastic action is occurring the stress continues to rise. This behavior has been called work hardening. The reverse question, "Why is it non-linear at all?" was not asked. It is the answer to this question that gives the most light to the subject. If one

asks what should the breaking strength of metals be, based upon the forces of attraction between particles, the answer from the physicist is that the breaking strength is in the order of Young's modulus, i.e., 10^7 Pa. To understand this strength is not achieved, a new theory was proposed called Dislocation Theory. The basis of dislocation theory is that, if an element in an array of elements is moving then as the array is distorted by shear, a certain strain is reached (elastically) where a neighboring element is likely to jump laterally to fill the void. Essentially the void or dislocation moves across the field until it reaches a boundary leaving behind a permanent set in the strain. A metal is visualized as being strewn with such dislocations that permit plastic flow. This plastic flow takes time to occur, however, and also probability enters into the occurrence of each dislocation jump. From an engineering macroscopic view there are two types of behavior occurring with each addition of load: an elastic stretching which takes place instantaneously and a plastic or creep stretching which takes time. Creep tests can be run where the load is applied suddenly and the material then allowed to creep for long periods of time. A cross plot of these curves for a given time since loading yields isochronous stress-strain curves. The usual stress-strain diagram may be generated from these curves. The test machine generally operates at a constant strain rate. Once the stress level is above a plastic threshold, a certain amount of error occurs depending upon time at the stress level for each loading. We can approximate the behavior by connecting points on the isochronous stress-strain diagrams corresponding to creep time and total strain. The important point here is that the stress-strain diagram depends upon the rate of loading. The more rapid the loading the more elastic it behaves and may under extremely rapid loading behave as a brittle material and shatter. Strength is the

discussion of failure theories it was mentioned that the Mohr envelope or Coulomb law is used in Soil Mechanics. There are two types of soil tests used to determine the basic strength parameters in the Coulomb law: the direct shear and triaxial compression test. The direct shear test takes a block of the soil, places a normal load on the block and then determines the force necessary to shear the block in two. The triaxial test takes a cylinder of the soil, usually sealed by a thin rubber membrane, places it in hydrostatic pressure and then applies an axial load to failure. Mohr's circle can be drawn for either loading situation and enough variation made in the normal force or the hydrostatic pressure to define the Mohr envelope. The Mohr envelope may be curved. However, for purposes of simplicity, it is assumed to be linear in the range of interest, namely in the form wherein the shear strength on the failure surface is represented as $\tau = c + \sigma \tan(\phi)$, where τ is the shear strength, c is the cohesion, σ is the normal stress on the failure surface, and ϕ is the coefficient of internal friction (the effective friction angle). Rankine and Coulomb The earliest work done on slope stability and the stability of retaining walls was by Rankine and Coulomb. Essentially they used the above equation and assumed a straight sliding surface. The surface that gave the lowest factor of safety is considered critical. The factor of safety is defined as FS = Resisting Moments / Driving Moments. The slope is divided into vertical slices (hence the common name: Method of Slices) as the forces on the trial sliding surface are determined, ignoring the possibility of interaction between the slices themselves. The weight is determined as the volume of the slice times the unit moist weight. The local angle.

must be measured for each slice and the resisting moments summed ---Page Break --- % -e (Se + Aweose tan d)® ‘The driving moment may be determined by summation my EWR IO ‘to other types of safety factor can be calculated. Safety factor with respect to height: as fe -& ise — € [ow sive-awees tang] Safety factor with respect to friction 2 Aw cos 6 tan g = Z4w cose tone eowsve-¢ * cose he Felliniue method in principle can be applied for any loading conditions eon. Including seepage and ground acceleration. Example: Consider the case of saturated soil immediately after the formation. The normal effective stress of a slope by an explored trial sliding surface will not have had time to change while the full saturated weight of soil acts in the driving moment. sarvaare A physical wave ---Page Break --- sa Flow Tarovan POROUS MEDIA ‘Darcy's law anion wearein 4 flow rate k= coefficient of permeability j 4 = hydraulic gradient A = cross-sectional area The pressure gradient for ‘nearest Ian 8 even by sce he eb tonne wm dsb nr a fo barom, The pressure is given by po hye, i Manca in terms of p 2 ne tiye % ‘Sonbimutty Stutf ta = stutt ---Page Break --- se ‘Assume incompressible flow: Proper errors Se ttre t avs 4 8 OD ax)oyoas (%y Bers) oxox y+ $m arora which reduces to 08. | 3% de We Ty TO sunereticins Vy 2(A/q), into the continuity equation din, wy, IN, a a te o * 7 vtheo Leplacie If we define our system in two dimensions the following argument can be ase: consider the flow past' two points in a two-dimensional flow. The flow across s ‘THF 10 is the same as the flow across AGF by continuity. Let the function denote the flow rate from left to right across any path connecting A and P. If we take another point p' the added flow rate would be Yat P' minus Sy at P ---Page Break --- 35 or YY. Let PP! be dy, then Viody. Oy fy Similarly, for an element PP" = dx. dy But continuity requires that WM ayy ax Oy Me see that Y maintains continuity identically. Thus the velocity components sty be given by Vays ad, av ae oS Vy koh. _aw ay) oa Prove this relat and from

previous logic the stream lines (lines of constant Y) are at right angles (orthogonal) to the equipotential lines (h = const.) ‘SKETCHING EQUIPOTENTIAL LINES Consider the flow to be in the X direction in a sea having a total head drop of H. The equipotential lines can be drawn so that each represents a equal drop Ah where: She © ‘The hydraulic gradient is then the vertical gradient aT ax aw a | ---Page Break --- ‘The velocity across the element is ow Bee ke Or The flow is p BQs ¥ ore kak > Make 2 P/ax = Od 4 ten &@. in one flow path » ROK = 5 "%y Count the number of flow tubes, m oral lov Qs me Qe Relation Between Particle Velocity and Macroscopic Velocity: If we wish to know where a particular particle of water is after a length of time t, we must know the true velocity at all times. But this varies from j point to point depending upon the constrictions through which the water flows. i ---Page Break --- 3 One approach is to take an effective tube size that is equal to the gross area (A) times the porosity (n) of the permeable material. Porosity being Ve . Vets : where in Vo = volume of water Vy = volume of solids In this way the average particle velocity is given by Fle Gost tietent of m The coefficient k may be written coefficient K divided by the viscosity su wherein E is a property of the porous material, having units of length squared and je is a property of the fluid, having units of lb- Forces Due to Seepage mm fe are two types of forces: forces in the water phase, and forces between the particles (or effective stn 3 er 38 ‘Vv BPrasvogerrioreyor -¥ 4 ‘4 . The body force Yo+O, normally. In fact KeLs0 2! Gays dbay or eft ---Page Break --- 38 Statlarly ae ‘uy Rovever, for the vertical direction Kin oe BE Wig Hanneged Note that for a vertical flow we may reach a quick condition wherein Oy*O 2 Ved /a, everywhere, Then Yaigray and or Ho, ce, he ve, Anisotropic Permeability yes ah My? ky Po were shown fe Thy kik oA BAO ranatorm che Giewaston so hat then ---Page Break --- 59 hy { ay %, Jee Susus Law eos contours in Ky region must be

closer together all other things remaining the same. Smaller K means greater resistance to flow. But the potential line should match at the contact. Beneath the refraction of flow is required, Consolidation Theory - Incompressible Fluid, Compressible Media. Consider the soil to be a composite material. The relationship between the container being filled with water, with the drainage cock turned off, the water behaves as follows: it will carry a portion of the load until it reaches equilibrium with the load; then it carries all the load, the water carrying none. We need three things: the constitutive equation for the solid phase as a function of pressure (Darcy's Law relating volumes to pressure), the rate of flow, and the continuity equation.

The consolidation of a block of soil is caused by applying a sudden load and recording the settlement until it virtually stopped. Two things set the settlement to be determined from such a test. The σ vs p curves for final settlement are determined from the endpoints of the settlement for each application of load, but also the time delay in deflection gives data from which the effective permeability or consolidation coefficient may be determined experimentally. This latter is important since permeability in clay is so small as to make other methods for determination impractical. For clay, it appears that after reaching the original state of stress, the deflection (or volume change) is an exponential function of p, namely e^(c+p) (on semi-log paper this plots as a straight line over a scale range of pressure change).

The rate of flow is given by Darcy's Law: Q = k_i (head in excess of steady state). So flow or equilibrium progresses with the water in the space between the solids being pushed out, governed by Darcy's Law:

Q = -k * (dp/dz).

the de | Ff ester ee ---Page Break--- 2 ‘This can be generalized to three dimensions Ohas k ty — VF has de OH STRUCTURAL DYNAMICS Introduction the use of orthogonal functions in solving dynamic problems in structures and books giving detailed discussions and examples of the method. However, as yet, civil the procedure in the analysis of buildings under engineers have not adopted earthquake and blast loading. In the case of earthquake loading, the most assumed horizontally applied load equal common procedure to design for to some percentage of the weight of the structure. This percentage of the gravity force has been chosen on the basis of experience and judgment of blast design, being of general interest only recently to practicing engineers. Due to the application in civil defense, it has been treated more fully from the theoretical standpoint than has seismic design. However, as will be pointed out in this section, the theory and solutions obtained from blast problems are equally applicable to earthquake problems. Conversely, methods used in the analysis of the response of structures to ground motion may readily be used to analyze the response of structures to blast. A great deal may be gained by comparing progress made in both fields. The purpose of this analysis is to present the normal mode method in a simplified form. It is hoped that the simplified equations involving parameters having some physical significance will clarify the approach and make it more amenable to use in general design. ---Page Break--- ‘Nomenclature Certain basic quantities used in the derivation to follow are shown in Figure 1. Other symbols will be defined as they are first introduced. Fee Modulus of Elasticity Flexural Rigidity Base of Natural Logarithm (2.73) Acceleration Due to Gravity Moment of Inertia Length of the Beam Mass Per Unit Length Bending Moment Force Generalized Force Generalized Coordinate Time Relative Energy Potential Energy Shear Distance Along the Beam Displacement, Velocity, Acceleration ——— —=“#R

---Page Break--- For the purpose of presentation, examples will be limited to involving structures which may be approximated by uniform beams. The differential equation of motion of a beam neglecting shear deformation and rotary inertia has been derived many times. Two of the more convenient references are Timoshenko and Karman and Bato. This differential equation may be solved by any one of the classical methods. It is known that these series of characteristic methods lead to a unique solution in terms of an infinite number of characteristic functions (normal modes) which are orthogonal. Much labor can hence be saved by adopting the common procedure of assuming the form of the solution and evaluating the coefficients of each term (method of normal coordinates). The case of a beam subject to motion at the supports will be treated here, and similarities between this and other types of loading will be pointed out. To end conditions for the beam, however, there will be restrictions: it will be postulated that all supports will undergo the same displacements. Expanding the deflection of the beam relative to its supports in terms of generalized or normal coordinates, we obtain,

Y = Y■ + Σ by ϕ■(Y)

where Y■ is the notion of the supports, ϕ■ is the characteristic function, and q is the generalized coordinate. The equations of motion of a beam in terms of its generalized coordinates are Lagrange's equations. Superscripts refer to references given at the end of the section.

---Page Break---

Potential Energy (3) Kinetic Energy (4) Generalized force (5)

Substituting Equation (1) into Equations (3) and (4) results in

F = C■Y + C■Y''

In the case being considered, the only force applied to the beam is applied at the supports. However, the motion of the supports is not a function of the beam. Therefore, substituting Equations (6), (7), and (8) into the Lagrangian equations yields:

L = ∫(T - V)dx

---Page Break---

characteristic function represents the shape of the harmonically vibrating beam in the absence of external excitation. This function has been established as $: (x) + H e w B e B \cos f e + C a h B u r d e o s s a Y o m where! $+. ‘This may be verified by study of reference number 1. The auxiliary constants are determined by the boundary conditions imposed on the beam and the condition of orthogonality, namely 4 oe hero Sor bay w= 1 6. (1) he » so aD Jf, #1 6:9) Arbitrary reas © For the case inj, 1¢ it is convenient to normalize the equation by letting the arbitrary value of the integral be equal to m. It follows then that 4 Lm O28) ml ” f FAY se tort tron functions (0) and 1) at vetining Bae Equation (9) becomes mh [9 wy he om per ELM." an nearesog tn ets EE 9.90 oy, forte rpca G4 [Occ te oo Te can be shown! that w, are natural undamped frequencies of free vibration and that for conditions of zero velocity and acceleration at time equal zero, Equation (14) has the following general solution: t sed aft as) Bee B L Kept [Ose dete, ---Page Break--- 7 ae & e (ae) Gee: a2 Peon he Ghegy ie Cb addy ; The above equations solve for the unknown function gc, and theoretically, the problem is solved. Let the same procedure be followed for the case of an arbitrary impulsive load on the beam, the following solution for q would be derived: > f t FOE [tien Do) dew: fh) fewclegid, 0 where the applied load wr (e, &) 2 WWF) may £ Py s+ Maximum total blast force: Gi(qy --+ Seace dtvcetbation of force. F(¢) + Toe variation in the force. In the above solution for bi t loading it has been assumed that the load may be broken down in the manner indicated. If for any reason the space distribution of force is a function of time or the time variation of force is a function of distance, the above solution is invalid. However, many times blast loadings may be approximated closely by the above assumption. Simplified equation In fairly recent years studies have been made which simplify the numerical work involved in using the normal mode approach. One of the most

important. Publications has been the tabulation of characteristic numbers, characteristic functions, and the successive derivatives of the characteristic functions. These tables are due to Young and Felger and have been published by the University of Texas. Other investigators, such as G. W. Housner and W. T. Tsonot, have applied electronic computers in solving the time-varying part of the solution. In order to see how these various investigations fit together, it is convenient to express Equations (10) and (17) in the following form: Lk os ow fe (aye weere, per aia ror nartnguabe Poa? eomad! ez ar ki foc 4 Ef 0 WB aide her EG euide Dew ff LF tq) siole-grde ora f fF se wy, Conde, (BL) %2 etm fF, 2 f Bayt: wit et €! er With the calculation of the vector at the above constants are non-dimensional. By comparison between the two columns, it is possible to see the similarities as well as the essential differences between earthquake and blast response. Participation Factor The coefficient ky determines to what extent various modes participate in the static deflection for the blast case. It is, therefore, called the participation factor. The value of this factor takes a weighted average of the characteristic function #r(y - When the exciting force is uniformly distributed over the length of the beam, Wg) + /, and the participation factor for blast becomes a straight average of Dy/y. As may be seen from the coefficient C, the weight of the structure is analogous to an exciting force in the earthquake case, inasmuch as a bottom beam is under consideration. It is constant that by for the earthquake case (6 shown as a cascading average of (a): If the beam had a distribution of weight Wea, the ky for earthquake would be the same as for the dynamic load factor. A dynamic load factor is considered because it tells how much the state.

Fesponse {a cagnified to obtain the dynamite response + This is precisely what the factor D does. For the blast case, the integral involved the time variation percentage of gravity to be substituted. It should be noted that the dynamic load factor must be applied to the response of each node separately, since in general Dy will be different for different nodes. For design purposes, let D be the maximum value of Dy that is of interest. Although there is certainty that the maximum values of Dy will occur at the same time for various modes, the times are not greatly different and one must always consider the worst probable condition in design. The determination of the dynamic load factor for all but the most simple load histories becomes a very difficult numerical task. It is here that analog computers have come to the aid of the engineer. GW Housner noted that the quantity Dy represented the acceleration in percent of gravity of a one degree of freedom structure of frequency Wy. Substituting real earthquake accelerograms for the term Ys and determining the maximum value of the integral for all reasonable values of frequency, a distribution of acceleration versus period could be drawn, which is similar to a distribution of light intensity versus wavelength. For this reason, the curves of maximum Dy versus period, which have been obtained by means of electronic computers, have been referred to as earthquake spectra. Damping can be included in the differential equation of motion of a beam by including a force term which is proportional to velocity and in phase with the deflection. This results in the addition of an exponential term in the dynamic load factor, namely e - 2.2 Fay. where n is the per unit of critical damping. Housner has shown the effect of the inclusion of damping on the earthquake spectra. Most of the published work giving actual values of maximum dynamic load factors has been for earthquake excitation. However, the analog computer and techniques are equally applicable.

exettation, W. T. Thomson has been carrying on research at the University of California along these lines. Characteristic Values There are two characteristic values that enter into the solution which are properties of the freely vibrating beam. One of these values is the characteristic function (a) which describes the shape of the 18 mode. The other value is the characteristic number g, £. For uniform beams, the characteristic values are determined by end conditions and Equations (11) and (12). Young and Pelgar have tabulated values of Oy (uv), O “oon e a tal PEO), 8 cus Prtey OW) and AB! for all combinations of clamped, planned, and free end conditions with the exception of the pinned-pinned case which results in a simple sine function. The primed values are the successive derivatives of #. (q divided by successive powers of (js to order to retain non-dimensionality. ---Page Break--- n nt and Shear Substituting the factors described above into Equation (1): e . eat) * Soles ort % MEE pL, a iT ay! ' For the blast solution 2) 22S Yu,d) = 24 Poe kee er = Gar Ove) ‘The designing engineer is usually more interested in moments and shear than in deflection. Since Qy (y is the only variable quantity in the equation above that {9 4 function of % , tt {e the only value that changes. For earthquake: Mexey mg L* = Pity hele @) oe @eep CHC) Yor bia 29° ay Ma) : ALE Pos £ele 0, ¢4) nr For earthquake: Yee) : eget “ . or blast - . y, 25 % ; a) Cran Te should be noted that these solutions have neglected shear deformation and rotatory inertia. However, for cost engineering purposes these effects are negligible. Application Earthquake The Southern California earthquake of July 21, 1952 resulted in widespread damage in the region of Arvin, Tehachapi and Bakersfield, California. Much of this damage was due to the lack of resistance to lateral forces. Some structures, however, had been designed under the earthquake provisions of modern building codes, the performance of this latter group of structures Ae a

true test of the validity of design techniques. As an example of the normal node method of analysis, the Arvin High School Administration Building will be studied. The Arvin High School Administration Building is a two-story reinforced concrete building with brick veneer, except that the second-story wall at the west end was 8 1/2 inch reinforced grouted brick masonry without openings. Following is a description of the damage: The west end second-story wall was fractured. Subsequent shocks increased the damage and the wall became badly cracked. The adjoining concrete wall on the north wall (faced with brick veneer) cracked along a horizontal construction joint. After the west wall cracked, later shocks caused plaster damage and spalling to metal lath and plaster reinforcements which attempted to resist forces for which they were not designed, dependence in design having been placed on the exterior west wall. There was also evidence that the second-story wall at the south rocked somewhat because there were minor brick spalls at their base. There was no collapse. Investigators studying the cause of the damage stated that the wall was of faulty construction although there was reason to believe that the flexibility of the 200-foot-long roof diaphragm contributed to the failure. ---Page Break--- The plot plan and section of the Administration Building are shown in Figure 2. The loads entering the end wall during an earthquake may be approximated roughly by analyzing a uniform beam of similar dimensions to the roof slab. The moment of inertia is approximately 90x10 inches. The force entering the end wall may be computed using Equation 25. We assume that the interior columns and partitions give vertical support to the diaphragm, but do not offer resistance to lateral motion. The diaphragm may be considered to be a beam with end conditions lying somewhere between full fixity and simple support. The condition of simple support will be found first. The characteristic

function for a simply supported beam is given in Git © VE an FF e@n the characteristic number ta 2. Behece co The following is a tabulation of the computed dynamic parameters: 1 1 2 3 “ ° $e cx20) ° ° ° . en aw ve ME . i ar so vr avr avr Yr ° jr ° YET 2 a fomte r ~ Pm Py ---Page Break--- %

‘the fundamental period of vibration is 0.34 seconds wherein the following values were assumed: E+ 2asxwt ZL 90 vio inches* me ny Bnsee ae 4 Since there is no spectrum available for Arvin in the shock of 2900 were ‘oly 21, 1952, the spectrum for El Centro in the shock of May 18, 1940, component N-S will be used, See Figure 3A. Therefore, assuming a damping factor of 0.10 we may pick the dynamic load factor off the spectrum. This yields a value of approximately 0.08 Since the fundamental period of vibration is by definition the longest period excitable Substituting into Equation (25) gives the following result: song {epee . ono + tt . } smn seay coof TQM ., EC oa} i 7 or 2 265,000 * | ‘The area of the wall cross section is approximately 3000 square . ‘on the end wall is 89 pat, inches, ‘Therefore, the average shearing stress which could cause failure. However, the partitions should help to reduce this stress and the dynamic load factor at Arvin may have been less than at EL Centro in 1940. ---Page Break--- 1s If in the above analysis end conditions of full fixity were assumed the same answer would result since increased restraint tends to decrease the period of vibration. ‘A very important point has been demonstrated here. In the above example the solution could just as readily have been obtained by multiplying the static shear at the wall under an mg loading by the dynamic load factor Dy. This follows from the definition of Dy i.e., the factor by which the static response is multiplied to obtain the dynamic response, Structures having long periods of vibration take advantage of the reduction in the value of Dy as shown on the spectrum. Blase ‘A somewhat more hypothetical example for

Blast type loading could be obtained by analyzing the above structural element under an impulsive loading. If we assume a pulse type load of 0.3 seconds duration time, the maximum Dy plotted against period takes the appearance shown in Figure 38. This curve might reasonably be called the blast spectrum. Since the period of the roof slab is 0.36 seconds, the dynamic load factor for all nodes is roughly 2.0. In other words, the dynamic response is twice the static response under the maximum blast load.

In the foregoing discussion, it has been shown how the response under dynamic loads may be expressed as a series expansion involving four non-dimensional parameters and one dimensional constant. The equation takes the following form:

This form of solution is not limited to beams. In fact, all structures subject to dynamic excitation, where the principle of superposition is valid and loads may be broken up into a time variation times a space distribution, may be analyzed using the above form of solution. Prototype structures must be approximated by simplified models in order to satisfy the above conditions. Structures having uniform distributions such as stacks, silos, or individual structural elements may be approximated by beam theory. Buildings where weight is concentrated at floor levels may be approximated by the so-called shear building. Structures having large shearing deflections in comparison with their bending deflections may be approximated by the so-called shear beam.

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1953. 5. Tomson, W. T., Impulsive Response of Beans in the Elastic and Plastic Range, Journal of Applied Mechanics, Sept. 1954. 6. Stetnbrugge and Moran, An Engineering Study of the Southern

California Earthquake of July 21, 1952, Bull. of Seis. Soc. of Am. Vol. 44, No. 21, April 1956. ---Page Break--- n SECTION A-Aw Figure 2 - Arvin High School, : ---Page Break--- 78 20 UNDAMPED NATURAL PERIOD ~ 3 SECONDS Figure 3A = Acceleration spectrum for El Centro, California Earthquake of 18 May 1940, Component W-5 ve bumsr remeron Where te + 0.3 sec I | ° Os 70 1s 20 2s 30 UNDAMPED NATURAL PERIOD -T IN SECONDS Figure 32 - Maximum dynamic load factor for step function shock duration 0.3 seconds versus undamped natural period ~ 2, ---Page Break--- LARGE-DIAMETER DRILLING FOR EMPLACEMENT OF NUCLEAR DEVICES Ref: Proc. of Third Plowshare Symposium p. 239-268 Drilling Methods Diameter Depth . 1. Churn Drilling “ 600-500" 30" requires one pass 30° 11 more than one pass Penetration rate 28" 12'/min to 36 "syne ‘A percussion type drill consisting of a long si 1 bie hat is mechanically lifted and dropped to create the rock. 2. Auger Drilling 1s" 65° » Useful in soft material that can stand open during drilling. However, drillers mud or casing can be used in softer materials 36" hole 100° 3+ Core Drilling 200" Chilled steel shot is used as cutting material, See p. 252 Peurifoy, Construction Planning, Equipment and Methods Rotary Drilling 130" 570" 30" 1400" 25" 1700" Like of well drilling. Some 1 8 Det sro/ee = = saoyee. 2. Auger § Use for 36° soft $20/ft for 72° hard 3. Core Drilling $12/Ee - $120/€ soft to hard for 36" hole . 4. Rotary Drilling 26 hours, ---Page Break--- 80 depth/fore Diameter casing 10 160-500 $00+1000 100061500 150%2000 ——_2sHIN-2500 36 a a so 32 3a au 0 6 6 » 0 2 ™ 8 ®0 ao 66 %0 8 a %0 Prof. Talley will talk on device size Monday hence for now we will consider the following dimensions Base Depth 21D 100" 38 750 65" 2500" sample 33) @ 750" se Third Plowshare Conf. Proceedings p. 239-250 Actual sorting will be 48* tn

diameter and will be drilled by a drill rig with 700 input horsepower. The drill rig cost will be $1200 per day operating and $800 per day non-operating. 1. Rig Mobs Location a. hauling 1000 miles @ $10/mile 10,000 b. Rig cost = 250 miles/day, 8 days @ 800.00 __3,200 Total 913,200 Site Preparation 32 dozer hours @ $15.00 480 Rig time 3.5 days @ $1200- $4,200 ancillary support 200 Sub Total $5,400 Surface Hole - 56" deep 8, Drilling 54” hole ---Page Break--- 6B. (1) Rig time = 15 hours @ $50.00 (2) cutter costs = 50' @ $21.00 (3) material costs b. surface Pipe (1) Pipe - 6596 lb @ $0.20 (2) cement = 115 lbs @ $1.50 (3) Rig time - 2 days @ $1200 Sub Total Drill 48" hole 50° - 750 4. Rig time 200 hours @ $50.00 (5) cutter costs - 700 @ $15.00 (6) Fluid Costs - 2500 Bbls @ $2.00 + Condition hole and run heavy casing 4. Casing Cost ~ 750" of 3/4” wall 226,500 lb @ $0.20 b. Casing welding cost $36 Joint for 19 joints Cement cost 3700 lbs @ $1.50 4. Cement pumping Rig time - 8 days @ $1,200 Sub Total, Run light perforated casing 4. Casing cost 750’ @ $10.50 (5) Rig time 2 days @ $1,200 Sub Total $730 1,030 1,339 in 2,600 $5,711 $10,000 11,200 5,000 $26,200 $45,000 63 5,050 600 2,800 960,834 97,875 2,400 $10,275 a ---Page Break--- 82 Tear Down 4. Rig time, 3 days @ $1,200 3,800 b. ancillary support 1,000 Sub Total $4,600 8. Rig demobilization 13,200 9. Total Costs a. heavy Casing 129,565 or $/ton b. Light Casing 79,006 or $/ton MATHEMATICAL INSTABILITIES Because practical problems in hydrodynamics are usually terms of non-linear models and because the physical situations are two or three dimensional, analytic solutions are not to be found. Numerical analysis can produce some answers, but even this technique fails at times. For instance, the two-dimensional pressure profile of a circulation about an infinitely long wing can be obtained to any required accuracy by use of a digital computer. But when the wing is finite, the problems become three-dimensional and are beyond the capabilities of present-day high-speed digital.

computers. Even the relatively simple problem of one-dimensional time-dependent flow, which actually can be handled by computer, requires some special care. Thus numerical analysis can introduce instabilities which have nothing to do with the physics of the situation. We can best illustrate the point by outlining the numerical solution of a particular partial differential equation, the hyperbolic equation: which is the simplest general equation describing hydrodynamic flow. In the general case, c itself depends on the derivatives of the displacement u and thus (1) becomes non-linear. Let us suppose that we try a solution to (1) of the form u + ε, where u satisfies (1) exactly and ε is a small additional term, introduced, say, by rounding-off error. Substitution of the trial solution u + ε into (1) produces where it is known from the solution of (1). Since ε is small, the dependence of c on ε may be neglected and (2) can be treated as a linear equation. We are concerned with the behavior of this error, ε, as x and t change. The numerical differencing technique used to deal with (2) is pictured in the figure: a lattice is constructed such that as we move upward we are solving forward in time in increments of Δt, and if we move to the right or left we move in the positive or negative x direction in increments of Δx. Note the notation ε(y, t) means the value of ε at x = x_max and t = t_naturally, ε(5) is. The lattice used for finding the behavior of ε by means of a difference equation. Assume that ε is known at every point in space for all times up to t = 0. We can then move forward in time and calculate ε at any point. Actually, our assumption is unnecessarily strong: (2) is a second-order equation in time, so it will suffice to know ε and ε_t for all m, that is, for all x at k = 0 and t = -Δt. Let us study a general Fourier component of the error. Since (2) is linear, the solutions can be obtained by the superposition of Fourier components, thus we

shall be able to predict the behavior of all possible error. We consider Emo * Cote) etemet @) and Ca EG OOH where j= 71, k is a wave number, and € are coefficients independent of space and time. A difference equation can be formed from (2) by returning to the definition of the derivative l); + €or ~*ee to,. Cae © = Bch € \Goskax-1) (7) equations for x = 0 will be similar except for a common factor elkmOx. Dividing by this factor, one is led back to (9). ---Page Break--- which La follows from direct substitution of (3) into (6). Equating (5) and (7) produces the difference equation corresponding to the differential equation (2): act Lor 2oetbon* aoe ey [ees kan] © (ae. oF using (3) and (4), €,- 2046, 22 ©, [cos kan 7 o (ay from which {¢ follow that 6-22. [eos Kon-] + 2e,- €, ao) at insertion of a word or two concerning the validity of (10) was appropriate. As_ox and at approach dx and de, the difference equation approaches a differential equation and becomes ict. For finite & x and At, (10) is an approximation in which terms of second order in Ax and Ot have been neglected. Surprisingly, even for small & x and AC, we shall see that what matters in the behavior of the error term is the ratio of &x/at to c. rer et ce (22) (10) becomes 6.2 2e-6, + (nonlinear corrections). At each step forward in time (remember that the indices in (10) refer only to the time increments) the influence of the side points will be very weak. Each step represents a very small extrapolation into the future and the situation ---Page Break--- 85 is similar to that of a total differential equation depending on time alone. This result appeals to common sense: while &x and At must both be small, if Ax CQ eRe, a signal from the side points cannot arrive at the point of interest until long after the time increment step has been completed. For ct, (20) becomes € € [cos kax-i] + (small corrections) a2) ‘There will be no problem if there is not such spatial variation in the error. ‘This corresponds to a small wave number, k ~ 0, a very long wavelength.

vave. Then con kax = 1 - $(kax)^2/2$. (12) For this approximation ts Ey eg teu a3) a 2 vncte 27 (Q22)" tu tars, (onto? te amet and € gs the esar ere e ee begin to die out. On the other hand, there will be some value of k such that cos kax ≈ -1: the value of € changes sign as we move horizontally across the grid. (12) is then 65-4 @* ‘Thus €1 is greater than €g and the error grows exponentially as time increases. Physically, what has happened is that before the temporal step is finished, signals reach the new point from points far to the sides. The calculation, which is limited to neighboring points, ignores this fact. There are at least two ways to cure the problem. The first is that since the space and time increments are such that "sonic" signals from more than four neighboring points reach the new point of interest, simply include the additional terms in (10) needed to ---Page Break--- #7 account for the other signals. The drawback to this method is that the recursion relation becomes much more complicated. The second method is to alter the size of the lattice spacing so that Ot & Ax/e, which has the distinct advantage that it keeps the simple form of (10). The situation just described is the well-known Courant Instability. Other mathematical instabilities arise in the neighborhood of shocks and several others must be considered when two-dimensional flow problems are to be solved. The electronic computer will become an even more important tool in hydrodynamics. But it can be useful only when handled with caution and mathematical insight. The use of computing machines requires ingenuity which is most un-machine-like. ---Page Break--- as APPENDIX PARTICIPATING FACULTY LECTURES The notes to follow have been prepared by participating UPR Faculty Members: L. E. Mora-Farfa, Department of Civil Engineering; canals Rfow Carvajal, Department of Mechanical Engineering; Project Carryall (Highway and Railroad route); N. Beylerian, Department of Civil Engineering; Project Chariot (Harbors); D. Taylor, Department of Chemical Engineering.

Project Gasbuggy (Gaswell stimulation) F, Mutloz-Ribadeneira, Department of Chemical Engineering Mining Applications K. Pedersen, Department of Nuclear Engineering Geothermal Heat and Salt Water Conversion M. Saca, Department of Physics Isotope Production | ---Page Break --- 89 T, Interoceanic Sea Level canal. AL On-site surveys: to start January 1967 (U.S. Government) Acoustic Wave Program: Rockets 100,000-200,000 ft (U.S. Government): metal chaff - radar tracked Radiological Safety feasibility of using ‘nuclear explosives i 1. Marine phytochemistry and biology 2. Fish resources in estuaries and oceans on both sides of the Isthmus 3. Terrestrial, freshwater, agricultural, and marine ecologies Radiohydrology 5. Human ecology Radiation dose estimation D. Meteorology: Transportation and deposition of radioactivity Studies: wind patterns and rainfall two weather stations in research development A. Special Explosives and Replacement Techniques 3. Cratering Calculations C. Cratering Experiments TIT. The Transisthmian Canal Problems: National Political: All economic consequences are predicted; complete safety is assured. IV. Nuclear Explosives: Cheapest way of moving large quantities of earth. ---Page Break --- Chemical Nuclear size tare Seal Energy Density Salt Large Temperature low Very High Pressure High Very High: ‘The largest conventional explosive is larger than the smallest nuclear explosive. Prices: $350,000 - 10 kt Acaing and firing included $600,000 - 2 Me 20 Kt of Ter = 94x10^?! ergs = 7.961009 aru = ratol? ators: Immediate Danger from Explosions HW. E, — blast and fallout seven, plus thermal and nuclear radiation Thermal radiation is not emitted because the explosions are contained. The main immediate danger is from falling debris and, over a bigger distance, from shock transmitted through the air. Fifteen miles will eliminate any actual danger of these types, ££ 10 ME The upper Limit on Metal Excavation Technology - Technical Questions 1. How does crater size depend on geological properties? can data on

crater size, seismic effects, acoustic waves, and radioactivity distribution of low yield experiments be extended to megaton range? 3. How do nuclear charges in a row interact? ---Page Break--- 4. Can projects for nuclear excavation of channels through terrain varying in rock type and elevation be designed with confidence? VI. Interoceanic Sea Level Canal Atlantic-Pacific Interoceanic Canal Study Commission Investigation by AEC U.S. Army Corps of Engineers. Panama Canal Co Routes Route 17 - Sasaard - North - Darien - Panama Route 25 - Atrato, Truando - Choco - Colombia VEL. Crater Design - Parabolic Approximation ---Page Break--- 2 ‘PROJECT CARRYALL 3. Rfos-Carva jal ‘SOURCES OF INFORMATION 1. Fry, John G., Stone, Ray A., and Crutchfield, William H., "Preliminary Design Study in a Nuclear Excavation Project Carryall.” Presented at the “43rd Annual Meeting of the Highway Research Board, Washington, D. C., January 13-17, 1964, Abridgment to

UORLA7632, pp. 11-16. 2. Wruger, Paul, "Nuclear Civil Engineering," Technical Report No. 70, Department of Civil Engineering, Stanford University, Stanford, California, pp. 261-263. 3. Zodtner, Uarlan, "Operating and Safety Problems Associated with a Nuclear Excavation Project," Presented at the 43rd Annual Meeting of the Highway Research Board, Washington, D. C., January 13-17, 1964. Abridgment to VORL-7632, pp. 17-20. 4. Prentice, H. C., and Peterson, E. T. L., Jr., "Construction and Feasibility Associated with Nuclear Excavations." Presented at the 43rd Annual Meeting of the Highway Research Board, Washington, D. C., January 13-17, 1986. VORLA7632. 5. Talley, W. K., Railroad Engineering 1. Rerouting 14, Expansion of highways and railroads have been limited by tools and equipment available. >. Changes in routes pay through savings in fuel, wages, reduced time, reduced distances, etc. IZ. Project Carryall 4, On a portion of the transcontinental main line, 165 miles long, between Needles and Barstow, California, there is a 78 miles stretch of ---Page Break--- 9 Railroad that was to be

relocated, (Between the stations of Goffs and Ash MIL, Where the Line has a deviation southward to eliminate passage through the Brieco Mountains = a rather lush, narrow chain of mountains in the riddle of the Mojave Desert. D. Present Line deficiencies 1. train retarded by -Aes curves 2. ascending grades of 1.60 percent 3+ 2000 ft of elevation lost in dropping from an elevation of 2600 ft at Goffs to a low point of 200 ft at Cadiz and then rising to an elevation of 1900 ft at Ash RLLL, + Cutting through the mountains on a direct line would 1. shorten the distance 15 miles 2. maximum grade would only be 1 percent with a maximum curvature of only 1 deg. would save an hour in travel time. Phase would require 42-mile long tunnel (using conventional means for its construction), 1. Main disadvantage: expensive and costly to maintain. ©. California Division of Highways 1. was investigating possible shorter routes for U. S. Highway 66, which will become Interstate Highway 40, £. Joint feasibility study for the purpose of utilizing nuclear excavation technology was undertaken by the railroad company and the highway division with the technical assistance of the ABC and the Plowshare Division of UCRL. (Code name - Project Carryall.) ---Page Break--- mr. Details of Project Carryall The cut was to be about 2 miles long with a maximum depth of about 360 ft and a top width ranging from about 600 to 1300 ft. A total roadway width of about 330 ft was to be provided with the railroad (double track) located along the toe of the southerly slope, the eastbound highway (2 lanes) through the center, and the westbound (2 lanes) at the toe of the northerly slope. Ultimate expansion of the highway to a total of eight lanes was taken into consideration. Geology of the area 1. consists of soft volcanic rock underlain by meta-granite rock. The use of 22 nuclear devices nuclear excavation design contemplated ranging in yield from 20 to 200 ke (total yield: 1730 ke), and arranged in a row (would probably have been fired in two detonations. A

Drainage problem was to be solved by trapping the flow in a separate crater, made upstream from the channel with a 100 kt nuclear explosion. Radiological Safety 1. The cloud of dust resulting was low radiated to po activity levels, not sufficient to be hazardous. 2. Entry for an 8-hour work day should have been possible within 4 days. In the Blah 1, Town of Amboy - major problem but still no damage was expected 1. below the threshold of damage. Ground shock 1. Some minor damage, such as cracked plaster was expected at Amboy. 2. Another problem - 900-psi gas line located 2 1/2 miles south of the cue. ---Page Break--- 9s 4 Construction Costs (from Nuclear Civil Engineering by Paul Kruger, Technical Report No. 70, Dept. of Civil Engineering, Stanford, California) 4. Conventional methods: RR tunnel (12,800 ft) 4.36 mt $14,552,000 : Freeways 18.03 as 7,170,000 $21,722,000 P+ Nuclear Explosives Preliminary investigations 330,000 Pre-shot construction (holes) 2,289,000 Nuclear excavation costs 21,940,000 Post-shot construction of RR 2,874,000 | Post-shot construction of Highway —$4,232,009 916,765,000 23 devices @ $0.5" (eat')

—$11,300,000 j wnas. Cancellation 4. Project Carryall was cancelled, ---Page Break--- 9% Quantum PROJECT 1M, Beylertan ARBORS: In order for nuclear devices to be economical civil engineering tools, a project must be of extremely great magnitude. A large scale canal, a mountain pass, and harbor are at this time the most likely targets for harbor project - of application of nuclear energy. We shall concentrate on project 'CHARIOT'. Unfortunately, natural harbors do not occur where they are needed most, although man has led to this fact by settling where they do occur naturally. Nevertheless, new horizons open, and regions hitherto hostile have to be exploited for their wealth. Since sea transportation remains the least expensive means of transportation, harbor facilities are needed early in the development of an area. The choice of a site for a future harbor, and its method of construction will be

Decided after weighing several factors, such as cost, safety, urgency, and a host of intangibles (such as politics). From an engineering viewpoint, one consideration must be given to expanding already existing facilities: a. improving existing natural features, such as deepening and widening of a river mouth, lowering the ocean bottom, b. construction of wave breakers, c. carving a harbor from the land, d. maintenance projects, and other considerations.

As for the choice of the method of construction - that is, using nuclear devices or not - we may note that under only a few conditions are nuclear devices considered feasible at this time. However, sometimes those conditions do exist, and nuclear energy may yet prove to be the practical solution for harbor construction on the West Coasts of Alaska, South America, or Australia. Some of the reasons common to those areas that make this method of construction practicable are: 1. Freedom of choice of site, rather than dependence on natural features, 2. Sparse population; making relocation costs minimal, 3. Generally deep ocean approaches (or freedom from excessive sedimentation). We may note that cratering under the ocean floor is not an economical process, since craters will be shallow and wide. The idea was considered on the Eastern Coast of Australia and abandoned.

A need for a harbor. The Alaska site satisfied the first three considerations in general, but ice use and need were questionable. It would probably become an important area for the population in time, and fishing boats would find refuge in the harbor in times of need. But those were not considered to be enough, and no clear evidence was found that a harbor would in an appreciable measure boost the economy of the area. The area has no mining prospects or timber lands.

LOCATION IN ALASKA AND GEOPHYSICAL CHARACTERISTICS OF THE AREA: The particular site chosen on the Western Coast of Alaska has appealed to engineers for the following reasons: 1. It is centrally located, that is to say, it would serve

« coastline. to the north and to the south of the site, from the Bering Strait to Barrow. This site is relatively ice-free, and the Chukchi Sea is relatively calm in this area. The area is thinly populated. ---Page Break--- 98 4. The approaches are naturally deep enough for fishing boats sailing in the Chukchi Sea, the geophysical characteristics of the area can be summed up as follows: Ocean characteristics: The Chukchi Sea is, in general, rather shallow near the coast; it has a depth of about 50 feet at about 2 miles from the coast, and depths of more than 150 feet anywhere between Alaska and the northeastern coast of Siberia are rare. Near the Chariot site, ocean depth reaches 15-20 feet immediately, then gradually reaches 50 feet at a distance of 2-4 miles. Currents: Currents are northwesterly, about 0.5 knots/hr, paralleling the depth contours. In general, surface currents seem to have the direction of the winds when the latter are strong. Coastal Features:

Though the coast north of Point Hope is rapidly being eroded by strong winds and waves, the more protected shore near the Chariot Site doesn't seem to be subject to any important changes. However, during strong storms, depending on the angle with which the waves strike, beaches may be eroded rapidly affecting depths of up to 30 feet (hundreds of cubic yards per hour), to be deposited back when calm returns. Floating ice is found 6 months of the year; nevertheless, the area is noted for its relatively large amounts of open water. In January and February, ice can form very rapidly. Average thickness of ice may be taken to be about 5-5 feet. Exceptional cases occur when icebergs are brought to the Alaskan coast by high winds. Climate: This region of Alaska is in the Arctic Tundra belt that covers the northern coasts of Alaska, Canada, and Siberia. It has a rather severe climate with eight months of winter and four months of spring-type weather. In winter, low temperatures may be -40°F and high temperatures around freezing. In summer, freezing temperatures may occur any day.

high temperatures ---Page Break--- over 70°F are also possible. In winter, there are 26 days without sunrise, and in summer there are 54 days without sunset. During winter, northerly winds may reach gust velocities (over 80 mph); even in summer, 30 mph winds are not uncommon. Storms may be expected half the time even in summer. Surface winds seem to have a depth greater than 1500'. Of great importance to us, since any fallout will depend on it. Hydrology: Average annual precipitation is about 8” in the form of snow, that will melt in summer to form the many rivers and creeks of Alaska. In the Chariot site, the Ogotoruk Creek may discharge much as 1260 cu ft/sec at the height. The summer average is 250 cu ft/sec. From October to May, there is no flow. Although not in any large quantity, groundwater is found to be present in the permafrost and under it; some wells and springs are supplied by those waters. The creeks, rivers, and many lakes or ponds form part of the overall water situation. In summer, some rivers and wells are utilized to supply water for human consumption, but in winter, snow is the primary source, as well as during hunting and fishing trips. The soil is mudstone (permanently frozen starting at a depth of 1' or 2' to a depth of about 1100'), and sandstone around the Chariot site. Within 100 yards of the coast, the depth is nearer 950’. This means that all devices would have to be detonated in frozen soil. Tests near the surface show that frozen mudstone has about 12.5% moisture. This is thought to be somewhat less at burial depths. The specific weight of this soil ranges from 2.5 to 2.74. More exact data on porosity, water content, etc., should be available by now. ---Page Break--- 100 BIOENVIRONMENTAL FEATURES It was found that the Chariot site was almost continuously inhabited by the Eskimos from the middle of the 18th century until recently. Nowadays, the nearest communities are at Point Hope (32 miles, pop. 300), Kivalina (60 miles, pop. 140), and Noatak (75 miles, pop. 270). The Eskimos have

traditionally been hunters; they still depend on hunting for their food. Miebing in the Chukchi Sea seems to be a recent development. The many lake and pond areas are not reliable in providing fish in sufficient quantities. However, this area has surprised researchers by the number of species of all types of living creatures that exist here. Out of 60 known species of animals in Alaska, 31 were found in the area (polar bear, walrus, seals, whales, caribou). Fifty-five species of freshwater and marine fishes, 300 species of flowering plants, 120 species of inland birds, and more than 1400 species in other groups also exist here. Land animals are few in number (hundreds of caribou), but nine species of birds have a population of about 1/4 million. These birds nest in the sea cliffs within 8 miles of the Chariot site, the nearest one being within two miles of ground zero. At this time, it must be acknowledged that under the guidance of the ABC, more than 40 separate investigations were conducted to obtain information on such varied features as: climatic cycles in the atmosphere and in the soil, geological and hydrological features, mechanical properties of the soil, chemical composition of the soil and bodies of water (contents of calcium, magnesium, potassium, sodium, strontium, etc.), complete ecological surveys of the land, the bodies of water, and the air, ---Page Break--- radiological analyses of all types of living organisms, and terrestrial materials, such as determination of radioactivity and strontium-90 and cesium-137 levels in Alaskan soil and air. The harbor would be carved out of the land by detonating four 20 kiloton devices to make an entrance, and one 200 kiloton device inland was expected to provide a circular harbor of 1800 feet in diameter. However, recent times have indicated that the harbor would be closer to 1500 feet. The three 20 kiloton devices would be placed near the mouth of the Ogotoruke Creek, at about 200 feet from the coast, at a depth of 400 feet. The other three 20 kiloton devices would be placed.

in « northerly direction at distances of 500’. ‘The 200 RE device was to be placed at « distance of 900" from the 120 Ke device in the WW direction, at « depth of 800'. Taking the Depth of Burial as the base, and using Pige. 4-50 and 4-51 (Cum) with 400/20!/3 4 «50,6 mperl/3-4, + obtain, Apparent Crater Radius: 45x2,41x3.28 = 380 Apparent Crater Depth: 25x2 4123.28 = 200! Other Data: Lip Height: 50’ Depth of True crater: 520° Radius of True Crater: 450! For the 200 kT device all those values are doubled. Spacing of 500" between the 20 kT devices will ensure a continuous attach. >, No thermal effects are expected, ~ Sy AE Blase: Fig. 4-55 (CUMR) may be used to draw the maximum air blast distance curve for the total 280 kT charge. ; (CONE), the abscissa is divided by aol! and the ordinate is In Fig. 4-55 eee ---Page Break --- 102 Divided by 5, since air blast seems to be only 20% of what it would be if the blast were in the atmosphere. See accompanying graph. 4, Select Disturbances: In alluvium the surface velocity is given by Equation 4.3-2 as veo BR catee for the 8 30h at closer ranges (fr: the phone shot) 1.85 ve ae OP) in salt beds. qn. 4.3°6 thus, for the arbitrary velocity of 10 en/see R= 5 miles using Eqn. 4.3-6 R= 10 miles using Eqn. 4.3-2 (not applicable) IF the 10.en/aee velocity is accepted as the plaster cracking limit, then no damage would be expected in any of the settlements in the neighborhood, especially since no plaster exists there. €. Throwout (very speculative) Downwind 1/4 mile almost 120" Crosswind 1/4 mile 40” Downwind 3/49. almost 1/4" Crosswind 3/4 m. 04 out: Approximately .5% of total produced r: carried by winds (S knots), and 80% of this would fall within 20 miles downwind. The explorations were initially scheduled so that fallout would be over the land. However, those winds were not considered reliable, and finally it was agreed upon that northerly winds would be utilized despite inherent difficulties in collecting samples after the event. ---Page Break --- ---Page Break --- rate after

one hour - Point Hope Chariot Site > Estimated Dose Contours ---Page Break--- 105 PROJECT CHARIOT: if carried out as planned, the following would be a summary of effects, as anticipated: There would be no need to evacuate any of the settlements. No structural damage was expected due to seismic effects or air blast. Though based on statistical analysis, some windows might be broken as far away as Kotzebue. In the immediate vicinity of the site, all life might be assumed destroyed within a 1/2 mile radius. In case winds were seaward, destruction of marine life would be smaller, owing to the cushioning effect of the sea, and already sparse marine life. Plants would be buried under throwout material in this area. The greatest ecological change might be due to slides of the sea cliffs harboring the five colonies of birds. Particularly, if the tests were performed during the nesting season, damage to eggs might affect important changes in the bird population. Due to lack of experiments under similar circumstances, conditions at the entrance to the harbor can't be estimated yet. In extreme cases, the entrance may be blocked completely by throwout material, in which it could take several years for water to seep into the craters. On the other hand, the entrance might also be completely open. In that case, it would take the ocean a few hours to fill the harbor. The Ogotoruk Creek would be dammed about 2000' upstream, thus forming a lake. Another dam would be created at the present location of the Ogotoruk Creek mouth. Either a second lake would form, or the creek would erode some of the present coastal zone and form a lagoon, as is the case presently. ---Page Break--- 106 conclusion: The Chariot Project was shelved several years ago. Thus, engineers have been denied the chance to apply nuclear energy to a useful project at a very small ecological cost. Biologists were deprived of the opportunity to observe the changes induced by an instantaneous biological change, and also note the development of life in a region where new

Lakes and creeks would form, following the formation of the harbor. ---Page Break--- 107 PROJECT cAsnvCcY D. Taylor Coal and fuel oil are used to produce 60% of the electricity in the U.S. (1). The burning of this fuel contributes about 64% of the SO2 emitted to the atmosphere. In 1963, this amounted to over 10 million tons of SO2 (2). The Health, Education, and Welfare Department has already set tight sulfur content levels on fuels burned by federal installations in some major cities. It has been estimated that if the sulfur emission standards of fuel restrictions now recommended by HEW were to be made effective at this moment throughout the U.S., more than 90% of the 240 million tons of coal presently purchased by electric utilities could not be consumed (1). There are four possible ways to solve the problem of SO2 emission. 1. Nuclear Power. The use of nuclear power is expanding at a very rapid rate. About one half of the new power plants being ordered are nuclear. Some estimates foresee that nuclear energy will produce 20% of our electricity by 1980. Even then, there will be an increase in fossil fuel consumption due to demand for power. 2. Sulfur dioxide removal from stack gas. Much research has been done on this aspect of the problem, but a large-scale, economic solution has not been found. 3. Removal of sulfur from oil and coal before it is burned. This option is possible but expensive. The Caribbean refineries, which treat crude with a high sulfur content, would be required to double their equipment investment in order to produce residue fuel oil with 0.58 sulfur content (1). The 20-60% of the sulfur that is organically bound in coal cannot be removed. 4. Replace coal and oil with natural gas. Natural gas has low sulfur content. It is presently used to produce 27% of our power. But supplies are short. Our reserves in 1977 are at the lowest value in years. We only have a reserve of 10.5 years. If New York City alone were to use natural gas instead of coal and oil, an increase in the total

Supply of gas of 260% would be required. So anyone can align with the problems of increasing natural gas production, nuclear stimulation of gas wells (a very attractive possibility). Some estimates say that nuclear stimulation would immediately double our reserves of natural gas. Corporates feel that nuclear stimulation is a worthwhile investment. If pollution standards were set and enforced, the value of natural gas would probably increase and make nuclear stimulation even more valuable. In an idealized, cylindrical model of a gas reservoir, the gas flows uniformly from the reservoir to the well bore. A given particle of gas must flow through every cylindrical element of the reservoir. At the outer boundary of the reservoir, the resistance to flow is small because the area available for flow is quite large. But near the well bore, the resistance is considerably high because the area is drastically reduced. The purpose of nuclear stimulation is to remove as much of the resistance as possible by enlarging the radius of the well bore. Let me show why this is true. One begins with Darcy's Law for flow through a porous medium.

The velocity of flow based on the entire area K = permeability of the medium * viscosity of the fluid ΔP = the pressure difference across the element, Δx = the thickness of the medium.

For cylindrical coordinates, radial flow only, the following assumptions will be made:
1. Steady state model

2. Linear flow
3. Constant viscosity
4. Uniform temperature throughout the reservoir
5. Constant permeability

The equation of state of the gas is given by PV = nRT or P = (n/V)RT. When examining a period of time that is relatively short compared to the total production time, we can consider the reservoir as being at steady state. Then the following continuity equation must hold:

■ = constant

Where ■ = mass flow rate of natural gas, P = density of the gas.

The continuity equation is proven existent for A and v gives: μ = ...

(AGrm\ey co) | | ---Page Break--- uo hy = height of the reservoir 1 = temperature of the reservoir Separation of variables and integration gives - Mh kp? - Pe?) BHI jp «1 le) o args here radius of the well bore rg = effective radius of the reservoir z jure at the well bore the pre Pe = the pressure of the reservoir at re. Conversion of the mass flow rate to a volumetric flow rate at standard conditions and subsequent combination of all constant ceras gives x (@o? - Pe?: eee ” From Equation (8) it is evident that the production rate can be increased either by decreasing the pressure in the well bore or by increasing the radius of the well bore. A decrease in Py increases the pumping cost and becomes unreasonably expensive before substantial gains in production rates can be obtained. The size of the bore can be increased in the following ways: 1. Drill a larger hole. This is very expensive. 2. Conventional explosives can be used to fracture the rock around the well and increase the effective radius. Increased production rates of five times that obtained without shooting have been achieved. 3. Hydraulic fracturing. A liquid under high pressure is pumped into the reservoir to fracture the rock. Sand is mixed with the liquid to hold the fractures open after the pressure is released. Hydraulic fracturing supercharges initial production rates by a factor of 10. In low permeability reservoirs, production gains are rapidly lost after an initial flush in production caused either by conventional shooting or by hydraulic fracturing. 4. In limestone reservoirs, the size of the well bore can be increased by pumping HCl into the hole to dissolve the rock. This is clearly limited in possible applications and is very expensive. 5. Nuclear Stimulation. The U.S. Atomic Energy Commission, the U.S. Bureau of Mines, El Paso Natural Gas Company, and the Lawrence Radiation Laboratory have investigated the possibility of stimulating a gas well with nuclear explosives. In October of this year, the first actual test conducted.

the program, Gasbuggy, will ‘tm northern New Mexico. (Data for Project Gasbuggy are given in Reference (3).) The site selected is in the central section of the San Juan Basin. The gas bearing portion is called the Pictured Cliffs formation. This formation is 300 feet thick between depths of 3850’. The site is remote, but accessible, the nearest house is five miles away and the nearest city, Farmington, is 70 miles away. The population of Farmington is 23,000. There is enough drilling in the area so that the reservoir is well classified as to gas content, permeability, etc., but only one gas well is near enough for shock damage. Another advantage of the location is the fact that the people and government of New Mexico have accepted nuclear testing. The conservation commission will probably permit some shifting of allowables between other producing wells so that maximum production can be studied. There will be two preshot holes, 100 and 200 feet from the emplacement hole. These are to confirm: 1. There is no mobile water in the vicinity of the shot.

---Page Break--- 2. The gas content and permeability at the site 3. The performance of an unestimated well These two holes will also be used to study the extent of fracturing. The shot will be at the bottom of the Pictured Cliffs formation which consists of sandstone and shale. The proposed device is to have a yield of 10 kilotons. The expected effects of the detonation are given in the following table: convey Radius 6ft Rubble Chimney 300ft Vertical Fracturing 390ft Fracturing Radius 195ft (conservative) 430ft (optimistic) The predicted gas recovery over a total production period of 20 years and with 160 acre well spacing is expected to be Conventional Stimulation 537 x 10^8 ft³ 10% of total gas present Nuclear Stimulation (conservative) 3520 x 10^6 ft³ 67% Nuclear Stimulation (optimistic) 3748 x 10^8 ft³ 71% A study (4) was made of the economics of nuclear stimulation. The study was made for the proposed Dragon Trail project to be conducted by Continental Oil Company. In

this particular case, it is projected that a well stimulated by nuclear explosives will produce about the same amount as four conventional wells. These four conventional wells cost $100,000 and the return on the investment is 29%. The return for a nuclear stimulated well depends entirely on the cost of the device. If the figures given in Reference (4) are used with an estimated cost of $50,000 for drilling the emplacement and the re-entry holes, the following relationship between the cost of the device and the return on the total investment is obtained. ---Page Break--- Cost of device $600,000 a $225,000 $113,000 at ‘The AEC has announced a price of $400,000 for the 40 kiloton device to be used in this application (5). This would give a return of somewhat less than the 29% for conventional wells. The attractiveness of nuclear stimulation would be considerably greater if the cost of the device could be lowered. There are several sedimentary basins in the Rocky Mountain region that have more gas than Pictured Cliffs. Conventional stimulation cannot recover it. If Gasbuggy proves successful, this region alone could use 30,000 devices. If they were produced in such great numbers, the cost of nuclear explosives would surely decrease. Contamination of the atmosphere by venting radioactive gas through fractures or through a failure of the steaming in the emplacement hole is considered remote based on the experience of previous tests. Shoal had a yield of 12.5 kilotons at a depth of 939 feet. There was no venting. We can compare these figures with those for Gasbuggy whose yield and depth are to be 10 kilotons and 4150 feet, respectively. All geologic studies of the area indicate that there is no mobile water. These conclusions will be checked by the two preshot wells. The nearest water wells are 50 miles away and take their water from a level 1700 feet above the test site for Gasbuggy. If there is an aquifer near the formation of interest and either the rubble chimney or extensive fracturing breaks through to the

water, there is a possibility that the cavity and rubble chimney would be filled with water thus rendering the well useless. No trouble of this type is expected in Gasbuggy. For the 10 kiloton device to be deployed in Gasbuggy, residential plaster would crack within 1.6 miles. There is only one gas well near enough (500 feet) to be damaged by the blast. This well will be considered part of the expert assessment to determine the range and extent of the shock damage. Radioactive solids will not be a problem. Nearly all of them will be trapped in the melt at the bottom of the cavity. The gases that will be troublesome in an all-firston explosion are Krypton 85 (10.3 years), Xenon 133 (5.3 days), and Iodine 131 will be present, but it can be removed by decontamination procedures. After about 10 months, the radioactivity from Xe and I would be negligible, but Kr85 would be 690 times the amount permissible to the general public. The first step will be to bleed the well and dispose of the initial radioactive gas. This might be done by burning. The best dilution in the rubble would be accomplished by evacuating the well bore and letting it refill in cycles. In this way, the entire volume of the chimney would be used to dilute the radioactive gas. Another dilution will occur when the produced gas is fed to pipelines carrying gas from other sources. The dilution here is about 1000 to one. As soon as the mixture (gas from Gasbuggy plus gas already flowing in the line) has a radioactivity low enough for LEC (Limited Exempt Contamination), Gasbuggy can begin producing. The level of radioactivity permitted to the general public is 1/30 of the LEC. But when natural gas burns in a house under the worst possible conditions, it is diluted by a factor of 200 to 1. The resultant radioactivity would be 1/7 of that allowed the public. Tests: The Gasbuggy test was successful, and it is presently planned to conduct Dragon Trail about three months later. This test will be conducted by Continental Oil Co.

after the in a formation 400 feet thick at a depth of 2700 feet in western Colorado. After Dragon Trail will cover Project Rulison (5)- It will be in the very deep, thick, impermeable Mesaverde formation in Colorado. The plans for Rulison specify two vertically placed shots detonated by 1000 feet in elevation. Possible improvements of nuclear stimulation beyond these three tests! The development of explosives having a diameter of seven inches. This would permit the use of existing wells as emplacement holes. 2. The development of technique for directing the force of a shot into the more productive formations. This might be done by an array of devices fired simultaneously or in sequence. LITERATURE CITED IN LECTURE. 1. Sulfur Units Micro Utilities in Thermal, Chemical and Engineering News. 45, No. 29, p. 28 (1967), 2. Indig, J. W. and Spatie, P. W., "Control of Sulfur Dioxide Pollution," Chemical Engineering Progress, 63, No. 6, p. 82 (1967). 3. Project Gasbuggy, El Paso Natural Gas Company, El Paso, Texas (1965), 4. Coffer, Testy, Retroteus R Stimulation by Contained Nuclear Explosions, A. The Gh. E, Taped Lecture Coa. 5. Teller, B., WK: Talley, H. H. Higgins, G. W. Johnson, The Constructive of Nuclear Explosives (in press). 5. Chemical and Engineering News, 45, No. 7, p. (1967). ---Page Break--- 16 MINING APPLICATIONS, Mufos-Ridadenetra Introduction the possible applications of Plowshare technology for copper mining that have appeared in the Literature are: 1. 2. 3. Preparation for open-pit mining: removal of overburden Preparation for block-caving, shattering the ore body to facilitate removal Preparation for in-situ leaching, rendering the ore body permeable to leaching Block caving and leaching in situ are to be discussed in this section. We are going to concentrate on leaching in situ due to the fact that it eliminates major disruption of the geological systems at the surface, since no overburden need to be removed nor solid gangue dumped. Spent leaching and possible cementation solutions must be disposed of.

made rich enough and the ore body large enough to make electrowinning practical, waste products can be reduced to minimum. As an example, if the ore body has copper: an ore body of sufficient size and copper content of at least 0.3%, the ore body composition and structure should allow physical penetration of the leach solution. Toward acid consuming gangue, a contained environment which provides for recovery of the leaching solutions is necessary. Copper must be present in a readily soluble physical and chemical state. These conditions either must exist initially or should be achievable by reasonable engineering procedures. Further, the following supplies and services must be available: 1. Sulfuric acid or other suitable leach liquors at low cost and in adequate supply. 2. For concentration, thin iron sheets. 3. Liquor which is rich enough and abundant enough to justify the capital investment in electrowinning of the copper. Now, if we consider in this process the application of Plowshare in situ leaching, the following requirements should be fulfilled: 4. An ore body that extends to sufficient depth to permit the deep emplacement of the explosive. 5. Substantial overburden to assist in trapping any radioactive effluent and make the ore body relatively unattractive economically for any other technology. 6. An ore body of significant size to allow for significant tests, such that the logs as a result of the test would be significant in the total copper resource. 7. Location where the combination of deep emplacement, heavy overburden, and low surface population density with few surface structures would make the potential damage by the test shot reasonably small. We will see later how we can meet all these requirements. Copper Bearing Areas in Puerto Rico. The known copper deposits in Puerto Rico are found along the southwestern edge of the Uruado pluton which is an intrusive complex of granodiorite, quartz, diorite, and minor gabbros.

copper mineral i.e. chiefly chalcopyrite ($CuFeS2$) and there are also chaleoctite (C28) and Covellite (CuS). To the northward, the Cretaceous-Paleogene wells, including the Pluton, are overlain by a thick series of limestone sediments. The copper ore is located in a zone of hydrothermal alteration. The general structure trend is WNW-ESE. A test hole for ore was drilled to 6434 ft at a point about 10 km ‘east’ of Arecibo, near the coast, and it penetrated 5580 ft of limestone sediments before encountering volcanic sandstones or plutonic rock formations. This is the only direct evidence that the older rocks continue under the cover of the limestone sediments. This does not necessarily imply that the pluton and the accompanying hydrothermal zone continue any considerable distance north. There are also the probabilities that it may end in a short distance or that it may increase in size. In Puerto Rico, we have to consider the following facts: 1. Limestone does not appear to be mingled with the ore body. 2. The structure trends fairly deeply as far as 5000 ft, and the overburden might be turned to advantage. 3. Chalcopyrite is a very insoluble copper ore in diluted sulfate acidic solutions, but shock-heat effects may change completely the solubility problem. This is uncertain as well as the physical location of a suitable ore body and characteristics. 4. Land evacuation, shock, and earthquake effects, as well as socio-political problems may exist. 5. Pollution problems are currently reduced, and no damage to the landscape is expected, but both problems are becoming a great issue in island politics. In the case of leaching in-situ and in block caving operations, the nuclear explosions are completely contained underground. ---Page Break--- IV. Considerations of Nuclear Effects As a result of a completely contained nuclear explosion, a short-lived cavity would exist. The roof of the cavity would collapse and the caving would progress vertically upward. We are interested in knowing the dimensions of the cavity and chimney, the.

properties of the material inside the chimney, the economics regarding leaching in-situ of the copper, and possible ground water contamination. A. Dimensions of the chimney and other parameters The dimensions of the cavity are given by the following formula: us nee Soe o tere yews ws yea © denote b= overburden that reduces to us nee H ay a or © 49 « constant depending on gamma, or on the quality of the environment in which the device is exploded. The height of the chimney is related to the radius of the cavity by the form HORR @ Where K is another empirical constant. The depth of burial for which venting is prohibited is given by: Dob = 450 w'/? (rey) | | er ---Page Break --- 20 calculations for depth of burial with respect to yield of explosives are given below: TABLE 1, Calculations of Depth of Burial W 1 5 10 25 100 200 ws 1 Ln 2.16 2.93 4.65 5.85 by fe 450 770 973 1320 2160 2630 It is clearly seen that we need a minimum depth of about 1000 ft for a 10 Ke explosion. Since we are interested in using the highest possible yield without causing damage we will use 950 ft as Dob and calculate the cavity and chimney dimensions using the following parameters € = 59.0 K = 435 P= 270 Dob = 950 = (3000 ft) TABLE 2. Calculations of Cavity Chimney Dimensions and Economics j@eyw 1 5 10 23 100 200 Ke Ws 1 un 2.16 2.93 4.85 5.85 aR oot 15.50 19.6 26.8 42.4 53.2 eH 39.6 37.50 85.5 us. 186 232 with wv 1.010 = 310% 1.04109 2.16x105—9.25u109 187x108 Ton 27x10 —1.168e10?—2.76x109 585x109 © 2.santo® —5.65n108 Kg 2.7107 11808 2.76108 5.85108 264x109 5.65u199 1ncu 2.70105 tteao® 2.76108 264x107 — 505x107 Recup.50% Cu 1.35105 0.59x10 —1.38x10® —2.9510® —1.32e107 205x107 Pete $.926/Rg L.25u1050.s4xto® —L.a7ato® = a.7axto® §—L.zaeto? 236x107 Price WE, 3.5x1093.50x107 —3.50n105 3.92109 S105 8105 Profit® No Wo wes ve Yes Yes "For economic profit we consider a ratio of 1 to 3 between the price of the nuclear explosive to the total price of the copper recovered to be needed. ---Page Break --- ra ‘These calculations

inéteate that we need 4 10 Xt explosion. ‘This will require an ore body of at least 40 m wide by 90 m high. 3. Sentente Considerations A damage threshold for plaster cracking of 810 cm/sec surface velocity has been agreed upon. Due to the dense population of the Leland (about 300 persons/Rx?), we must even Xm the maximum distance to which we may have the maximum surface velocity greater than 9 cm/sec, at us consider the yields of explosives related to the surface velocities, calculated according to the following formula: Ven, WO67 pets where = constant ¥ = surface velocity R = radius (m) w = yield (ton) (0-4 function of the material = 0.082 for granite TAH 3, calculation of Surface Velocities con) tonto? asuio? 100210? 200m10? wos7 470 1000 2250 3631 tio Las ase bas as ¥s ae 10 16 28.4 Placed population in 10 Km = x10%x300 = 94.200 3 im = 1257x300 = 23,600 ‘These results basically indicate that, due to the Leland density of population, we are forced to use explosives with a maximum yield of 100 KE for no damage located outside a radius of 10 Xm, or a maximum yield of 25 Kt for a radius of 3 ha. | ---Page Break--- we ©. Characteristics of the Rubble Inside Lanes The chimney rock fragment size is a function of the cavity size, distribution of original faults and fractures, mechanical and thermal stresses applied by the explosion and the breaking and grinding action during collapses. ‘The formation of rubble filled processes involves a number of random processes so statistical techniques are appropriate in estimating the rubble size distribution. In practice, rubble fragments have been found to vary in size from that of sand or dust to a maximum dimension of approximately 1/4 of the cavity radius. The particle size distribution varies through the chimney with smaller particles concentrated at the sides and bottom of the chimney where crushing and grinding may be expected to be most pronounced. ‘The following operational formulas have been used for determination of the parameters needed in the calculation of the specific

surface and permeability; assuming a logarithmic distribution, the formulas are 2a o == Many - i Be In Dy 7 (lo Day = In Dy) o) WB S Hin Dy 6 We ® Tai + en [a Soe oy This means that with formula (6) we know (5) and then (7). The calculated values are substituted in (8) and the average diameter in relation to surface/volume is known. We also know that: Asap o vee - qo) ---Page Break--- 123 So the surface area to volume ratio is given by ~set geay.y, Are + SEM Set0 « oy ay Svs has the dimensions of cn“l. If we divide it by the density, we have the dimensions of en®/gr. O a/v = 6 for spheres and 7.7 for sharp particles. This latter value will be used since sharp rubble particles have been observed in the sentence. Therefore, Sve = 7.7 Be (ay ‘The permeability of rubble to fluid flow is given by: 3 oo 13) 50-68, < Where K is the permeability and ¢ the porosity. Due to a nuclear explosion, the effective porosity of the rubble is permitting penetration of the sulfuric acid solutions more easily, greater than the original rock giving us a result an inert ---Page Break--- (GROTWRRMAL HEAT AND SALTWATER CONVERSION K. Pedersen Review and critique of an article by George C. Kennedy, University of California, L. A. 1, Availability of Geothermal Heat ‘The mean heat flow from the interior of the earth in continental North America is approximately 1.2 x 10° cal/en? sec. ‘Areas with 5-10 times the average heat flow are known. One such area extends from the Easter Islands in the Pacific into the southern part of the United States. This is an area approximately 50-100 miles wide and several thousand miles long. Whereas in an average area the temperature gradient is ~1°C/100 ft, based on the heat flow and the average K for rock, in the areas of high heat flow the gradient must be ~10°C/100 ft. The areas of high heat flow are exclusive of those with hot spring activity or recent volcanic action. The latter show themselves by hot springs or steam rising from the earth. It is postulated that the mechanism for these cases is that water of #

meteoric origin and at depths on the order of 1000 ft cools the magnetic body and carries the heat upward, thus heating large volumes of rock. The heat is stored in these enormous quantities of rock which may have volumes of 10's of cubic miles. In some of these hot spring regions, temperatures up to 500°C may be found at 10,000 ft or more. The heat of interest in a plowshare project is that which does not appear at the surface and is therefore not readily available by conventional means. TL, Availability of Nuclear Explosives | Since we are talking about proposals for the extraction of this heat where it does not appear at the surface, it is necessary that the heat bearing rock at large depths be broken up to provide larger heat transfer areas and at the same time smaller distances for thermal conduction and also to provide access for the cooling fluid, be it fresh water or salt water, and finally to allow the steam to get out. At these depths and with these energy requirements, nuclear explosives are the only energy sources that can be considered. Kennedy has worked out an example where a 5-ton device is detonated at a depth of 10,000 ft, producing an initial cavity with a diameter of 1,000 ft, and a volume of 5 x 10^6 ft³. With an assumed post-shot porosity of 12%, he calculates a rubble chimney height of 8,000 ft, leaving a 2,000 ft "cap" of relatively undisturbed rock. The calculation of the rubble chimney is incorrect because he has taken the total porosity created by the shot and converted it into a cylindrical rubble cone. It is a fact, however, that a large portion of the porosity is due to crack formations emanating radially from the shot and, therefore, not contributing to the chimney. Extrapolation of Fig. 6.3 in CUNE by Talley et al. tells us that we may expect a chimney height of ~ 1,200 ft and Table 4.1 in CUNE allows us to estimate a maximum chimney height of 2,000 ft. Even these estimates are probably optimistic because Project "Wander" gave an actual rubble cone which was

~ 301 shorter than would be predicted from the “Scaling Lava.” The effect of the miscalculation of the chimney height may be to our advantage because it means that it is not necessary to emplace the device at 10,000 ft. Thus, provided we can find heat-bearing rock at shallower depths, considerable savings may be realized. Kennedy has calculated the energy available at temperatures over 100°C to be ~1.8 x 10^16 cal. Since the heat liberated by the explosive is ~5 x 10^15 cal, the total heat available is approximately 5 times the energy of the explosive. ---Page Break--- 126 This will produce ~10^11 pounds of superheated steam, or enough to generate 50,000 KW of electricity over a period of 10 years. The cost of steam A direct comparison is made with steam plants operating on similar steam to obtain a value of the energy available from the cone. The Pacific Gas and Electric Co. is buying steam from wells at the Geysers in Sonoma County, California. This steam is low-pressure, low-quality and costs $1/900#, which amounts to 2 1/2 mills/KW hr generated. The total cost of the power is 5 1/2 mills/KW hr at the consumer. The cost of the steam is essentially due to the cost of emplacement and the cost of the device. These are estimated at $4 million and $1 million respectively. Considering the worth of the steam, Kennedy reasons the project will be economic by a factor of 2. No cost has been considered for post-shot and several factors of grouting which may have to be addressed as crud forms inside the chimney. It is possible, however, that it may cost only half as much to emplace the device, since the rubble chimney will be but a fourth as high as calculated by Kennedy. This saving may indeed make the project even more economically feasible than first conjectured. Since we are mining earth heat and not heat introduced by the device, we may remove it at any desired rate and would actually have more heat available if it were removed at a slow rate. Energy may continue to be extracted after the first cone is exhausted by detonating a second device.

slightly more than one crater radius away from the first one. If we still introduce the water through the first cone we would presumably have preheating of the water. IV. Problems which be

Encountered 4) Ground motion associated with large nuclear detonations. Particularly with respect to consideration of sequence of shots. ---Page Break--- 17 Deep circulating water which may enter rubble and flash into steam. It will be necessary to know beforehand whether this possibility exists. >) Behaviour of rubble cone as a function of time. At 10,000 feet the pressure is approximately 500 atmospheres and some of the softer rocks would lose the induced permeability long before the heat could be extracted. ©) Radioactivity in steam. For a 5 Mton or similar device the energy would be supplied mainly from fusion. Considerable tritium contamination of the steam would occur. The tritium gives off ~ 0.018 MeV which would present no problems in a closed-cycle power plant. If the water were to be used for drinking water a secondary heat exchanger (~ 90% efficiency) would be the simplest solution. SALTWATER DISTILLATION If we continue to use Kennedy's rubble cone the pressure would vary from 1080 psi to ~ 8400 psi from the top of the cone to the bottom. Thus the thermodynamic conditions for flashing the saltwater into steam are particularly favorable. This is enhanced by the fact that at the temperature of the rubble (average ~ 60°F) the constant temperature line of the T-S diagram is asymptotic to the saturation line at approximately 3000 psi. These two conditions coincide with the critical point. The advantage of the critical point lies in the fact that minimum energy would be required to flash the water into steam. If the "free energy" G is used to measure the amount of work done in the change, and G = UTS we see that since Rgg = 0 at the critical point, and the change in entropy is usual because the entropy decreases with increasing pressure of the steam, the minimum amount of energy is expended near the feat point. Above the critical point, however,

the water does not flash and since most of Kennedy’s calculated rubble cone provides for above the critical pressure all of the steam should be produced at ---Page Break --- 8 that depth below the surface where the pressure coincides with the critical pressure. This will probably mean that all of the crud (including the salt) will settle out at that level and render the rubble impermeable. SIMULATION - SCALING. Subject of Scaling can be based on: 4a) similar equations (analogies) (necessary to be able to write differential equations) dimensional analysis. Dimensional analysis is in turn dependent on our system of measurements. All general equations, in order to be valid, must be dimensionally homogeneous. We may write any unknown quantity X in terms of its base dimensions. Likewise, all of the variables on which the unknown quantity depends may be written in terms of basic dimensions, and it can, therefore, be shown that the unknown quantity X may be written in terms of the independent quantities raised to appropriate powers. Thus X = f(I, Tf, XS, etc.), where I stands for independent quantity. According to the Buckingham Pi theorem we may express a set of M quantities which have N dimensions as a functional relationship between N-N dimensional terms called Pi terms. Thus T = f(I, W, T, ...) where usually the unknown quantity X will be contained in T. The Difference Between Modeling and Scaling By scaling is usually meant that a certain consistent relationship exists between all of the variables in an expression. However, as we have seen with the scaling law applied for experimental writing, we in effect use it as a means of extrapolating on one dimension with two or three other dimensions known. ---Page Break --- 129 By modeling is meant that the independent Pi terms of model and prototype are identical, and that therefore, also the dependent Pi terms are equal. Thus, there is no extrapolation. An example of “scaling” and modeling: The example will presumably be based on experiments done on known data to predict what will

happen to an unknown system. Assume that we want to know the deflection at the end of a given uniform rectangular cantilever beam subjected to a load at the end. We guess that the deflection must be a function of the length of the beam, the size of the load, and the moment of inertia of the beam. We may also guess that it is a function of the Young’s modulus. Assume that we have several beams and loads available but of course not one the size of which we want to predict. We might then start by holding all but one of the variables constant, and plot the deflection as a function of that variable. Let us say that we plot deflection versus length and obtain a family of curves. Now, if the beam for which we want to predict is longer than any of the other beams, it becomes necessary to extrapolate. Even though our curves are “scaled” in the sense that the other parameters may correspond to what we want, extrapolation past a measured point is risky at best, and may be completely erroneous. If, instead, we use the Buckingham relationship we find that Y = f(P, L, I, E) which, expressed in two dimensions gives us three pi terms. Thus, if we can show that the function would be pnd Eps(Gf) = BBE. A few plots, using no more than 2 beams, would show us what is more, without finding the formula we are able to locate our unknown beam in the range of the measured quantities, so that it is no longer necessary to extrapolate. This is the most important point about modeling: that if it is performed correctly it is theoretically possible to predict any phenomenon. Mathematical Equation and Dimensionless Equation It is obvious that the Pi theorem by itself cannot provide us with a complete solution to any problem. It is necessary to perform experiments to obtain the functional relationships of the Pi terms, as well as provide the necessary numerical constants. However, for those who believe blindly in differential equations, and not at all in dimensional analysis, let us look at the similarities as well the

differences. Statlaricies bigference Some number of independent variables 1. For relatively stable equations Some functional relationship between with sufficient B, C. the different variables equation will yield the solution in a more satisfactory manner. 2. For very complicated phenomena for those who do not lend themselves to analytic solutions the dimensional analysis and experiments give us fewer variables and solutions whereas ordinary methods may not. The two methods are, therefore, complementary rather than competing. ---Page Break--- 1h COMMERCIAL RADIOISOTOPE PRODUCTION Radioisotope production by a nuclear explosion is expected to be much cheaper, and yield much greater quantities, than is presently possible with nuclear reactors. The recovery of isotopes produced in an underground nuclear explosion is a formidable and challenging undertaking. One proposal which shows promise is to use a salt strategy, dissolve the salt formation after the shot, and then use chemical processes to recover the isotopes produced. ---Page Break--- APPENDIX C HOMEWORK PROBLEMS IN NUCLEAR CIVIL ENGINEERING As a guide and teaching aid, a set of typical problem assignments have clearly been compiled. The problems are keyed to "The Constructive Uses of Explosives,” by Teller, Talley, Hixsine, and Johnson. (1.1) If one mole of particles is confined to 1 cc and heated to a temperature of “1 electron volt," what will be its pressure, in millions of atmospheres? (1 eV = 1.602 x 10^-12 ergs.) (1.2) In chapter 3, we find that deuterons can combine to yield 2 protons, 2 neutrons, 2 helium-4's, and 42.2 Mev. For devices, the energy yield from the fissioning of a single uranium-235 atom is 180 Mev. (a) On a kilogram-to-kilogram basis, what is the ratio of energy released from the complete fission of uranium-235 to the complete fusion of the deuterium in D-T? (b) Use the figures of $12,000/kg of U-235 and $360/kg of D-T and compare the costs per kilowatt-hour for both fuels. (1.3) If the 95% enriched U-239 costs $12,100/kg, what must be the cost

of 0.7% enriched U-95? (2) A collection of particles, each of mass m, starts at x = 0 with v = 0 and moves under the influence of a potential V = -ex. (a) Now let the particles have an energy spread from E to E + ΔE, and draw the path of the system in phase space, p versus x. (b) Consider the phase volume (area) bounded by Py and Pp at any time, and show that this area is the same at any later time t. Consider a system of 3 indistinguishable particles which can occupy 7 different energy levels. The levels are equally spaced and differ by E units -- with the value of the first level being E. If the total energy of the system is 9E (a) What is the average energy per particle? (b) Prepare a sketch of the energy levels and show the different ways in which the particles can be distributed among them. (c) Prepare a plot of the frequency of occupation of a level versus the level number. (That is, in one arrangement you will find all three particles in level 3, in another you will find one particle at level 4, one at level 3, one at level 2. You then would say that, so far, level 3 is occupied four times, levels 2 and 4 are each occupied once.) (d) Compare your plot with the curve 9E/3. (2.3) A strong shock moves up through the ocean floor. Both the earth and the water obey a power law. At the hydrostatic pressure of the sea bottom (2 x 10^5 dynes/cm^2), the water has a density of 2.5 g/cc and the earth has a density of 3.0 g/cc. The water is more compressible ($\gamma = 2$) than the earth ($\gamma = 3$). If the shock velocity in the rock is 4 x 10^6 cm/s, what will be the shock velocity in the water? Assume that the shocked rock remains at P/ρ = constant. (2.4) Plot the penetration of the wave as it travels through a vacuum interface that is a distance 2m from the origin. Indicate the points of penetration where the material just goes under tension and where the tension first reaches the maximum. (2.5) If a sawtooth wave, A, and B, create exactly 3 scallops, what is the tensile strength of the material?

material? What are the velocities of the slabs? (2.6) A stress wave moves to the right with a velocity of 500 m/s; at the front of the wave is 1 meter from a vacuum interface. The wave is one meter in length and is of the form 0 xe sore ye) = 500 e KE SIDE TT ° sor lex Undefined for x >? When will a spall occur if the tensile strength of the material is 27? (2.7) Perturbatively, the relation P = C + DICE = UF, for strong shocks reflected off a rigid wall. (2.3) The following table represents the results of solving the Thomas-Fermi equation at absolute zero for hydrogen: 2 (oars, vx 10^26: 2 (oars) vx 10^2 ce) 3360 9.549 730 Lar zato 808 6s La? ! 2400 570 320 145: 2120 “730 422 1.37 as, -790 348 1.69 1634 +350 307 hat 1430 nt 269 1.96 nan on 239 2.08 1100 1.03 212 238 1000 1.09 187 2.30 940 Las 13 2.42 405 Lat . (a) Use these results to plot a P-v diagram for H2Fe between the densities of 12 and 26 g/cm^3. (Py = 29/9 Py, Vg = 1 Vyde) (b) Estimate the work for such a compression at absolute zero. (c) Is this work greater or less than the real work needed for such a compression? ---Page Break--- 135 (2.9) Show that if the potential is of the form V = L/r^M, the Virial theorem: “nBpot * 2 Brin = 3 V. (2.10) Since the Virial Theorem, as derived, holds for inverse square forces, why can we apply the results to the perfect gas? (GA) In Chapter 3 we present 8 possible exothermic reactions. The energy releases are given to one decimal place accuracy. Use a chart of the fuel isotopes of the Handbook of Chemistry and Physics, the relation E = c^2, and c^2 = 931.2 MeV/AMU to obtain the energy releases correct to two decimal places, note that c^12 = 12.003%5). (3.2) Plot, as a function of the number of atoms, the cost of a 10 kt explosion if W295 is used at a cost of $12,000 per kilogram. (3.3) Table 3.1 presents the radioactivity due to each radioisotope from a 1 kt fission explosion, as a function of time. (a) Plot, on log-log paper, the total radioactivity due to this as a function of time.

(b) Pind Ay and n tn Aceet) = ay oP (2.4) If venting occurs, we might find a region near the site where the fallout is due to the intermediate group (see Table 3.2). Plot the activity expected from these elements. Does the radioactivity decrease faster for this group than for the total yield? Why? (Hint: The limit 0 for any finite m.) + 8.5) A e041 Hy the dose rate near a nuclear explosion is 13.8 R/ME. Construction workers are to go in and work 5 consecutive shifts - 9 hours on, 16 hours off. If their total exposure cannot exceed 40 mR, how many hours after t = 0 can they start the first shift? ---Page Break--- (a) 5) ws) a) =——————__ee (a) What yield should we use? (b) What will be the cost per cubic yard of rock broken in the chimney? Two detonations are planned, both of 100 kt yield. One is to be performed on the Earth and the other on the Moon. We assume that the lunar density is 3.34 g/cm^3 and that the Earth has a density of 2.38 g/cm^3. The acceleration due to gravity on the Moon is 1.62 m/sec^2. (a) If the Earth shot is buried 300 m, at what depth should the lunar shot be emplaced to produce the same size cavity? (b) If the device were buried at 200 m on Earth, at what depth should the lunar shot be buried to produce the same size crater? Assume that air drag is negligible on Earth so that the two craters are of similar shape. Assume apparent crater shape is a paraboloid of revolution. Given the scaling law of 1/3.4, and the fact that the Sedan crater (100 kt, DOB 635 ft) had a volume of 5.6 x 10■ yd^3, assume that a 10 MT yield has a variation of + 10%, that the scaling law varies between 1/3.2 and 1/3.6. What are the upper and lower limits on the volume, the radius, and depth of the larger apparent crater? Overlay three curves of maximum apparent crater volume versus yield, one based on a parabolic relation between depth and radius, another based on a hyperbolic relation, and the third based on a spherical relation. State all assumptions and give the equations or curves you have used as your source material. Develop

Construction count estimate curves for placement of nuclear explosives for producing a crater or aquifer on San Clemente Island. Assume that rotary drilling is used. List further assumptions that you make and discuss your reasoning. Reference: TID - 7695 ---Page Break--- 137 (.2) Current philosophy in the placement of nuclear devices requires that ‘the boring be dry.’ (1965) Determine the wall thickness required of the steel liner 60" inside diameter, 1000 feet below the water table. The lightest weight design is a reference: Timoshenko, “Theory of Elastic Stability.” (7.1) If one assumes B-decay and assumes that the cross section for neutron capture is constant, show that the equation governing the time-rate-of-change of nuclei with extra neutrons is dN/dt = m + 0, where the scale time, τ = e Gt; for the capture cross section, ϕ is the flux of neutrons, and t is time. (7.2) (a) Verify by direct substitution that the solution to this equation is correct. What value of the scale time will the number of nuclei with one extra neutron (f = 1) be a maximum? At what value of the scale time will the number of nuclei with two extra neutrons be a maximum? Extra neutrons? ---Page Break--- ---Page Break---