PRNC110

PRNC - 110

PUERTO RICO NUCLEAR CENTER

PLOWSHARE WORKSHOP

July 1 through August 15, 1967

Conducted ty

+ As Cheney and

/- K. Talley

University of California, Davis

offered ty the

Diviston of Nuclear Engineering

Donald 6. Sasscer, stead

Kmid B. Pedersen, Bittor

OPERATED BY UMVERSIT)

'Y OF PUERTO RICO UNDER CoNTRAcT

NO. AT (40-0183 FOR

US. ATOMIC ENERGY Conmtsson

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TABLE OF conmmITS

Pe 3~ Sequence of Lectures in Flovshare Workshop =

Muerto Rico = 1957.,..1owsnare

APPENDIX B

---Page Break---

yERTO SECO NUCLEAR CENTER PLOWSHARE WORKSHOP, 1967

NTRODUCTION

in 1964, the third Plowehare® symposium was held on the Davis Carros

of the University of California under the sponsorship of the Lawrence

1 Radiation Laboratory at Livermore (LRL), the Atonte Energy Comission,

?the Anerican Kuclear Soctety, the Averican Society for Engingerins Educa

tion (ASEE), and the Department of Applied Setence, U. C, Davis. An ASEE

committee used the papers presenced at the symposium to assess the sui tabi]

ity of introducing Plowahare technology into acadentc curricula, The come

mietee?!? felt that such action vas premature, Their contention vas that the Held vas still in the research and

wwelopment stage. Further, they

foie that the seience end technology of nuclear explosives was nor sufti-
eiertsy codified for instruction, and that the expertise £0 do so was

availabie ony {na feu laboratories, such as LRL and Sandia,

Po

cation of the aynposium papers and & proving awareness of the

potentials of che auciear explosive

19 engineering too! have modified

the situation. Since 1964, several schools have added dt

eriptions of

che effects and wnea of underground quclear explosives to regular engi

neering courses or have started formal instruction in Nuclear Civil

2,346

Enginccring.2??4) yo of these innovations are within 150 miles of

FRE PFOA to make constructive use of nuclear explosives Le known a8

?the Plowshare Project.

(Dg, 5. cotaberg, ?The Third Flowshare Symposiua,"" J. Eng. Educ., 355 4,

100 (1964).

. @)p, xeuger, ?A Graduate Level Course in Nuclear Civii Engineering,? Trans.

?ans Sues $0c-, 9, 1, 208 (1966).

©,

k. Talley, "Plowshare in University Programs

9, 1, 312 (966).

rans. Ag. Bue. Soe-,

(ip, 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 Californte at

Davis. The Stanford court

{9 a 30 quarter hour lecture serie taugir by

Prof. Paul Kruger of the Civil Engineering Department. (The coctent of

this course is briefly described in reference 2 and is available in the

form of & syllabus -- see Teble 1.) At Davis, the phenonenology end

Phystes of nuclear explosions is given in 30 quarter houre in the Departs nent of Applied Science. The us

of these conpact energy sources ts given

in a subsequent course (also 20 quarter hours) taught in che Civil Engineer=

ing Department. (The content of the:

courses include good deal of the

topics presented in Table 2. The main text for both courses is The Cone

structive Uses of Nuclear Explosives -+ see Table 1.) Both Stanford and

Davis restrict their courses to graduate students.

Te has been slightly more than «

since the Plowshare program

farted at URL. Large-scale excavations, such

4 new set-tevel

ra

svhnian canal, have been studied carefully ae to their practicality.

?The personnel at LRL, in cooperation with other researchers, have performed many of the experiments needed to provide date for engineering design. A Presidential Comission ie currently studying possible routes and construce Hon methods for a sea-level transisthnian canal. Wo routes proposed would use muctear explosives

While such spectacular excavating projects tend to attract public attention, there mty be sore potential tn the development of the techoology of completely contained underground explosives. Such an explosion must be deatgned to reduce structural danage due to ground motion, but the hazard of radioactivity release can be elininated. Project casbuggy, acheduled for fall, 1967, will teat che ability of nuclear explosives to stiqulace

Production. Other experiments, planned or propos

will a

---Page Break---

fo add to the exploitable resources of the vorlé: o{1, ofl shale, minerals,

water.

SOBER WORKSHOP PROGRAM AT UPR/FRNC

In addition to acting as « center for Latin American research in nuclk

jotence and engineering, the Puerto Rico Nuclear Center (PRC) Le charged by

*

the Uniced sea

Atomte Energy Comission with the dlesentnation of nuclear

fechnology throughout Latin America, This includes instruction in the nuclear

setences and engineering. The dual purpot

of the PRNC Join naturally in

the transisthaian canal: when the canal ie built, Latin Avertcan engineers

Will play 4 large role and, if nuclear explosives are used, there mist be available « local training center well versed in Plowshere technology. ?The Wuclear Center and the Engineering Faculty of the University of Fuerte Rico wlehed to broaden their role in nuclear engineering and science and at the sane tine prepare the University of Puerto Rico to be a Plowshere training

Dr. Henry J. Gouberg, Director of the FRNC, invited Profs. J. A. cheney

fand W. K. Talley to lead a three-month workshop at the Mayaguez branch of

FANC. These two people were responsible for the developsent of the progran

in Nuclear Civil Engineering at the University of Californie at Davis, The

Purpoee of the workshop was to provide « complete background for senbers of

the scientific stafé of the PRNC and for the faculty meabers of the UFR

?the sctentific ba

+ the phenowenotogy, the engineering principles, and

the constructive uses of muclear explosives -- and to thea let the UPR design

4 course for its om students,

?he effort was interdtsctplinary; there were representatives fron the

departments of chentcal, etvil, mechanical and muclear engineering, phystes,

and ataff menbere from FRNC. Despite the fact that most of the projected uses

---Page Break---

fall into the traditional province of the civil engineer (excavation, minins, petroleum reservoir stimulation, aggrepate production, water resource develop nent and conservation, ete.), all other engineering fields are touched by

the technology of nuclear explosives. This is because the nuclear explosive

te not simply a sceled-up conventional high explosive, but introduces ite

own peculiarities, e.g., energy denettii

in the megabar range, shocks

?strong enough co vaporize rock, large earth motion due to spalling, neutron induced radioactivity, fleston product radioactivity, etc.

LECTURES IN NUCLEAR CIVIL ENGINEERING

?the choles of material covered during the workshop was governed by the

fantitarity of J. A. Cheney and W, K. Talley with their courses at Davis.

re vas recogalzed chat the partictpante were well grounded {n one or sore

of the topics pre

eed (@.g+, baste nuclear actence, or hydrodynantes, oF

construction practict

or structural engineering), but no one person was

fantltar with then all. Table 3 presents the hour by hour lecture topics

given to provide an introduction into all the areas cover by mclear

civil engineering; perhaps more Lsportantly, the program provided the

faculty group vith « comon vocabulary. The source material vas either

from the text by Teller, Talley, Johnson and Higging (Wo. 1 Table 1) or

from notes ncluded in Appendix A of this report.

?the notes comprise an introduction into etvil engineering to persons

vorking in the Plovahare technology, uho have little or no civil engineering

background. They serve only as & brushing of the surface in order that alt

the participants will have # beste understanding of the approach taken in

civil engineering to certain basic problens associated with che constructive

use of nuclear devices.

---Page Break---

?The first two lectures were concerned with the probleas of organiza

tion and managenent of @ large construction project. This was folloved

by twelve Lecture

fon engineering mechanice and soll nechantes as applied

to problens associated with the destga of nuclear efvil engineering projects

?The topics include the theory of elasticity, elastic waves, failure theories

and mechanice, the st

ltty of slopes, ground water flow, the transient

response of saturated oil, the dynente analysis of structures subject to

ground motion or atr blast.

?The last two lectures included in this set of notes deal with the

Grilling cote for large dianeter holes in soll or rock and the problens

of numerical instability associated with conputer solutions.

As each topte was presented, it was contr é and compared with the

eed An a

sare topic as it would have been pre raditional? engineering discipline, Two examples say sake this clear:

In developing the Rankine-iisgontot equations for shocks, a compressible flutd was used for an anslogy. When use vas made of the resultant equations to discuss phenosenology, {t becane clear that « hyérodynante shock traveling

through rock 4# not entirely analogous to one ina fluid. In granite, asthe

atreae level of the shock declines, there te formed # sonic, elestic 40

Kilovar wave that precedes « slover, several hundred kilobar plastic wave.

At etre

Levels above 300 kb and at those below the elastic limit, there

As but one compression wave.

In the dlecussion of engineering practice {t vas pointed out that on

construction projects contractors would be likely to subatt fixed price

bide, {f conventional methods are to be us

om the other hand, if ouclear

explosives are specified, the bid 1s likely to be cost plus fee, Hence, tvo |

bide for doing the ease Job should not be conpared directly when one ts

based on using nuclear explosives and the other ta based on the use of

---Page Break---

outline for the content of # graduate course in nuclear civil engineering

ko 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 amd Johnson comprise the material

im satisfaction of the firat iten above,

presents

?A one seneater (40 contact hours) course is suse

ed for the spring

senaster 1968 to be offered ih cooperation between the Departnents of

Wuclear and Civil Engineering, Te should be « graduate level course

(600

wries), carry three unite credit, and constet of the topics listed

fn Table 2. In order to fit in the tine Limit of one senester the toptes

of Thonas-Fermi Nodel, Hydro Codes, Equations of Hydro Dynamics

Planning

and Organt sation of Construction Projects and certain scientific applica-

tone had to be omitted. However, it was the consensus of the élecussion

near the end of the workshop thet « treatnent of sintlitude and rodeling

should be added.

?the expanded outline of thts course as suggested by Mesers. N. Beyleriay

J. As Cheney, K, Pedersen, and W. K, Talley S¢ piven tn Table 4, Also, in

order to facilitate the instruction of the cour st of typical hone wor!

problens have been compiled and listed in Appendix C.

?To accompany this instructional progran and to provide the

toptes

for their graduate students, the faculty are widening thelr research

Antereste to include problens in suclear ctvil engineering, Por exanple,

?they have been conducting research on the solubility of certain copper ores

to determine the feastbility of mining large, low-grade ore bodies in in-

attu leaching. They are now plansing co subject ore samples to transient

?shocks in the 10 to 100 kb range and will determine what effect, {f anys thie will have on solubility, ?These stress levels can easily be produc

tn an ore body by the use of nuclear explosives.

---Page Break---

?The crossing of traditional departuental boundaries, often required

perhaps an additional advantage to the

4m research such as this,

University, of prograns in nuclear civil engineering.

Beylerian

Figure 1

---Page Break---

somces '

Thewical Thock wave Brie, wish

Explosive Generation Ste }???_?+@)

crater

?Suatsriog [>] Sheets,

? Sand-tox, Colliding piates,

black powder, focused. shacks

Hiailttade

?ARRAYS.

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asrays of ch. |_| Tined detonation

expl. in 2 and |} of biack powder

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Anglytic work

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Review of sethods,

Analytic work on

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one-dimensional tuations

Pigure 2. Project Network

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?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

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other places,

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Preparation|

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Steady State Fracture

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Characteristics ?changes due

of rocks to shocking

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?Analysis of construc-

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Eraneient shocks;

Liquefaction

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/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)

we following basic texts have served ap useful references for the aon-civil

engineer studying Nuclear Civil Engineering:

8, "Baste Soil Engineering,? 8. K. Hough, Ronald Press,

Mew York, 1965.

9, "Project Management with CPM and PERT," J. J. Moder and C. R. Phillips,

Retnhold, New York, 1964.

10. "Construction Planning, Equipment, and Methods

"RL, Peurtfoy, MoGrawe

HEI Book Co., New York, 1956.

11, "Handbook of Engineering Nechantes

"W. Flugge, MeGraw-HL11 Book Co.

New York, 1952

---Page Break---

TABLE 2 (Cont'd)

Scenes tte Applications

? Earthmoving Applications: Neutron physics

: Canale and mountain cuts clear structure

arbors Setmolony

Water resource development . Meteorology

Contained Applications chentatry

Asgrepate production Material sctesce

Fetroleus reservotr stimulation

Underground storase

?ar tande and ofl shai

Mining

---Page Break---

TARE 3.

SE/UENCR OF LECTURES IN PLOWSHARE WORKSHOP - PUERTO RICO - 1967

con:

Notes

Participant's lectures

Source

6

Topic

Brief History of Plovsiure Project and Comparison

of Enerry Sources

Orcantzation of 6

il Engineering Construction Project

Nuclear Radiation and Radiation Hazards

Basie Equations of Hyérodynantes

The Critical Path Method of Scheduling and Project

contrat

Foundations of Statistical Mechanics

?Thermodynanten, Compressibility and the Virial Theoren

Basic Equations of the Theory of Elasticity

Rankine-Hugoniot Equations

Equations of Stal

Waves in Elastic Media (Basic Equations

Solutions to the Elastte Wave Equations

Reflection and Interaction of Shocks

Radiant Enerry Content and Transport

Fetlure Theories (n Mechantes

Failure Theory in Soil Mechanics

Rudinentary Analysis of Slope Stability

Drilling of Larre Diameter Holes in Soil and Rock

Wuclear Explostves: Size, Shape, Wetehe, Cost and Yield

Production of Radioactivity - Fi

ion and Fusion

Flow {n Porous Media

Seepage Forces

---Page Break---

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TABLE 3 (Conta)

opte

Nuclear Excavation ~ Fallout

?Transport of Radioactivity tn Groundveter

Settlenent in Saturated Sotle

Phenonenotogy: Contained Explosion

Phenonenology: Cavgty, Ghisney, Crater

Movie: Project SEDAN

Structural Dynantes

Structural Re

ponse; Spectral Analysis

Geolopical Description of the Island of Puerto Rico

Structural Response: Setante 1

Phenonenology: Craters

Measurenent of Explosions: Instrumentation

Prediction of Explosions: Hyérocoden

Shock Wave Neaturecente and Predictions

Mathenatical and Physical Instabilities

Mazards Evaluation - Groundshock ané Blé

Neutron Physics

Other Engineering Paraneters

Teotope Production, Seismology |

Barchooving Applications; Water Resource Conservation |

and Developoent

Meteorology; Upper Atsosphere, 5

Fracturing, Rubble Size Distribution, Chimey Tonage,

Agerezace Production

Tar Sands ané Oi1 State

?Transtothmian Canal

---Page Break---

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?TABLE 3. (Conta)

mepte

Carryall (itsheay Cut)

Chariot (arbors)

Gasboggy (Ca well atteulacion)

Mintng

Ceotherna! Heat/Simulation

Neutron Diffusion and Isotope Production

---Page Break---

TABLE 4.

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COURSE SCHEDULE IN NUCLEAR CIVIL ENGINEERING AT UPR

Toate

The Plowshare Project

Nuclear structure and energy sources

Nuclear radiation and hazards

Cost, eize, shane, and explacenent

Deternination of yield and production of radioactivity

Distribution of radioactivity: fallout and groundwater

?Thermodynantes and coupressibtiieies

Theory of elasticity 1

Waves in elastie nedia

Ranikine-Hagontot relations

Shocks and shock adtabate

Spallation dve to shocks

Interaction and reflection of shocks

Contained explosions: cavity, chimmey, scaling

cratering expt

tons: apparent crater, sealing

Stuilitude and modeling

Mediue properties and instrumentation

Structural dysanies

Wazards due to groundshock and atrblaet

Fatlure theories in nechantes (eotls)

Slope stabiisey

---Page Break---

TABLE 4 (Conta)

Topte

Flow in? porous media, seepage forces

Settlesent of saturated sotls

cm

Canals, mountain cuts, and harbors

Water resource development

Aggregate production

Petroleum reservoir atimulation; underground storage

Tar sande and of! shale

Mining

Nuclear physics

Seterology

---Page Break---

APPENDIX A ?

LECTURES IM NUCLEAR CIVIL ENGINEERING

Delive

by Janes A. Cheney at

PUERTO RICO NUCLEAR CENTER

University of Puerto Rico

Mayaguez, P. R.

?coNSTRUCTION mecHoLoGr

troduction

Construction £6 the ultinate object of design. In many cases, as in tthe peaceful uses of atonic explosions, the construction technique {8 the

fubject of research and developsent. Destgn must take into account these

nev construction methods and techniqu

The techniques proposed by the Plovshare project at Livernore Radiation

Laboratory require projects of incredible magnitude in order to be econontestly feanibie.

Butléing an Iethatan Canal by a single row of charges, butlding « harbor i basin in one explosion, and others, require immense eneray release and are only feaatbie because such an explosive, nanely the nuclear explosive, ts avatlable.

?The purpose of the Flovehare Sumer Workshop 1s to see how this new technique fits into the construction industry as a nev method in competition With extsting methods of construction.

?The Engineer and Construction

The engineer 18 that person who prepares the plane and et fLcations

and supervises the construction of a project. In the case of the uaual design project, the engineer is constantly concerned with reductton in coste if he ts

performing his service conscientiously. Wovever, he te faced with the probles

---Page Break---

chat cheaper, nore efficient techniques of construction are sonetines not effected because the construction contractor does not recornise the economies of the nev construction technique or unusual design, Contractors will bid higiv on thioos unusual or uncommon because they fear the unknown

Usuatly when a prolect fnvolves many uncertainties, the contract ay be mvarded on the baste of cost plus a Clxed fee, Undoubtedly this vould be the case in the Plowshare applications. Sut this leads to an unfair comparison in that the project by conventional methods would be by free competitive

bideing. The former method has the dlaadvantaye that the contractor {8 not concerned with keeping the costs down.

conte may be considered divided into five ttens, naterials, Labor, equip: rent, overhead, supervision and profit. The last is not controlled by the fencinecr, but the others are influenced by the engineer and require that he ta knowledgeable of construction methods. The Plowshare engineer is faced with the problem of comparing a new technique with current techniques. Some knowledse of current techniques te needed.

A basic knowledge of construction principl soll dynanten

+ soll mechante

and nuclesr explosion phenosenology is required for the simplest of cost and feasidsiiey evaluations.

copetruction Organtzation

?The organization of @ construction company in the United States of North Anerica consists in sost cases of # single contractor who employs @ small proup of trusted people who may include « bidder, « foreman and a tine keeper and accountant. Larger organisations, vhich would be more Itkely to enbark on @ project involving nuclear power in construction, have adniniatrative

groups in thet main office that carry out the same work.

---Page Break---

Se often

A typical organtzation may be shown in an organization ¢ art,

done in industry.

Contracting

. Company

?Accounting Bidder

Public Relations } ??f Construction Taginesr

Superintendent

Project Parchestng Chie? Clerk

Engineer ?Agent Tine keeper

Carpenter {Ritontractore

Forenan ereonereceore |

Concrete

Wetaforetar 4 Electrical

Foreran Ete.

Eee. .

(CONTRACTOR ORGANIZATION CHART

?There axe problens that merit discussion {n each of the areas in block

Gtagran above. The features which bear discussion involves

. Public Relations

Labor Law

Labor relations

Performance Bonds (Insurance)

---Page Break---

4

Public Liability Insurance

Hidden Costs

Lost Tine

cost of bidéin«

MiseeLaneous Losirrance

veprectation

Ineerese of capital investnent

Accourtiny methods and cost control

Safety promrans

the discussion as applied to Nuclear Civil Engineering will be centered

that of bidding. This involves knowledge of all the other

of managenent at they affect cont and also requires knowledge of the construction scheduling. A good bid will include # project schedule which should be used to determine the relative progress during construction.

In preparing # bid for # consteuetion project, prebidding studies are required to determine the influence of

Toporraphy

Geology

cline

Sources of Materials

Access to the project

Housing factitcies

Storage fact}ities for materials and equipment

Labor supply

Focal services

tn the case of # Plowshare project many, {f not all, Living accomodations

nay have co be supplied by che contraccor.

---Page Break---

2s

?The use of substicute construction equipment having higher capacity,

gh effictenctes, Mgher speeds, nore maneuverability, and lover operating

coate should be considered. Ronuses to key personnel for beating dead lines,

use of radios for quick communication, and periodic conferences with key

personnel to discuss plans, procedures, and results, should aid morale and

Le tn better coordination anong vartous operations

?The Project Schedule

UUneti Just a few years a

, there vas no generally accepted fornal

procedure to aid in the managenent of projects. ach contractor had his foun scheme, vhich often involved Limtted use of bar charts, The firet formal procedure for determining a project schedule was PERT (Progra

Evaluation and Review Technique) (1956) and elk

Ly followed by CPM (Critical Path Method) (1959), The firat was developed at Lockheed Missile and Space co, in connection with the development of the Polaris weapon aysten and the

latter was develo

by the DuPont Company. Since that tine the methods have been applied largely throughout the construction industry.

?The princtpel feature of PERT {ea statietical treatment of the uncer-
tainty tn activity performance tine and includes an eatinate of the proba-
biltty of meccing spect tied acheduled dates at vartoun stages in the project.
?The object of CPM Ls to determine how best to reduce the tine required to
perform routine construction work.

?Te nuclear civil engineering project te nore likely to tavolve the CPM
?approach, although certain development aspects of the devices thenselves and

the determination of the scaling lava or computer codes might be appropriate

ground for PERT procedures.

?The Project Net Work

?The project network 1 the heart of the CPM and PERT procedures. It (#

---Page Break---

best explained hy an example, We fire! stare wich statements whic) cencribe

the sequence of operations malty .9 @ prosect. This nay he given in ?he form

of # chore.

Activiey Depends or aetiet

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The node or eirete notation pl

the activity network Junctions. The firec

actenpt at making # network is bese done by connecting the operation, denoted

hy evreles, with directed arrows indicating fine sequence. Thus for the above

@ Po e

OX

©

Later this nay be cleaned up to give « neater appearance and the arrow hea

seay be dropped since

youence nay be atsociated with position.

---Page Break---

ar

Determination of the Gretel Path

To deterntne the critical path the activities oust be given tines of

completion. Usually the times given by a contractor vould be tho

for the

?most economical production and, therefore, represent the minimum cost. ve

coste ?normal? co

?The folloving table will be made and

Normal Tine Ea.

a 5 ° 3

3 10 ° 10

? 10 5 3

© 20 5 2s

> 1s 1s 30

® 20 30 50

r 10 30 40

® 7 30 7

5. and E. P. refer to the Harliest Start tine and the Earliest Finish

time for each operation. These tines

ernined by considering the normal

time for the operation and the project network. A and 8 depend on nothing,

therefore, start at zero, 6, hovever, may not start until A is fintshed (

the network) therefore, the

S. for G te the B. 7. for A. If the start tine

for an operation depends upon more than one operation being fintshed, the

later finish tine of all preceding operations must be used. Thus, the B. §

for D ts the B. P. for C rather than B. The procedure leads to the mintous

under of days to complete the project, 57.

L, 8. and L. F. refer to the Latest Start tine and Latest Finish cine

that an?operation nay have and still complete the project in earliest possible

time, i.¢., 57 tn the example. These numbers are obtained by starting at the

---Page Break---

last operation ard deterrining how lace Ce aay be started and moving wiward

to determine this for each 2peration.

Operation Yoraal Tine Le ue

a 5 5 o 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

Yor exanple, F may fintah at 57 along with Wand, therefore, have @ start ac 47, E just finish 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 then must be used for the latest Finish of the preceding operation.

?the lax tine is defined as either the difference between L.S. and £.5. or

LP. and £.F, Those with zero lag tine are said to be critical and the network

path connecting eritieal operations {a a eritical path. Thus, operations AGDEH form the critical path. ?The significance of the critical path is that in order ko shorten the total time for # project sone oenber of the critical path must

be shortened.

?the above analysis hae used the ctrele notation in the project network.

Te should be pointed out that another notation is cononly used for applica:

tion wtth the high speed dixital computer. The operations are represented by

arrows with each arrow represented by a number at its cail and a larger number

---Page Break---

at Lee head. Operations that have the etre pi

Hing operation cerry che

start number corresponding to the finish nunber of the preceding artow.

?Thus, the example above nay be depicted

2454s

L Dummy: x

" 7

a

?An anomaly occurs where operation & follows ¢ and D, but P follows

Just D. If E and F both had the sane start numbers there would be no way

of showing the proper sequence. The anonaly is solved by inventing an

operation called Dumy which takes sero tine, but parates the start of

© from the end of D.

Shortening the Project

Since the normal tine schedule was defined as giving sintoun cost, short-

ening the project (or for that matter, lengthening the project) will increase

the cost of production. Presunably there will be maxinun cost associated vith

every operation being performed as fast

possible. The operation tines for

hat oa

are called crash tive and the

sociated cost the crash cost. A

eritical path analysis nay be made for the crash progran and {s given bel:

Geitteal Path for crash Program

Qeeration Mortl Tine £8. 27. 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---

We nay note tomediately that those operations in the erash rogram which

have Jai) tine would he done fooltahly since their time could be extended thus

redueine

we shait fot

froject Shortentag

?Three points on @ cost-tine plot are available to

ow ig to interpolate Hnear!y heeween eras vst without choiping the duration of the project. The procedure

from the above

laiyeis, Naneiy, the normal Eine, crash time and the optimum crash tine,

land nornal tine for

?The optimun exash Eine cost {8 obtained by lengthening those operations which

fare not on @ critical path co eliminate the lag times.

too

70

Tine

First we 1ist che cost/day of shortening in order of increasing cost.

07

Sost/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 Hat that te also on the eritical

1th. Take happens to be

Gor H, There are two restrictions on the anount of shortening. Either the

?operation ie shortened to erash tine or the lag tise 1s used up in « parallel

path vhichever is analler. This later imitation is determined by noting

those operations whose lag tine could be reduced by # reduction in operation

tine of G. Thus, operation lag tines on C and B would be reduced by one day

for every one day shortening of G. Since the maximum shortening of G (crash)

te 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/tine curve.

The next one to shorten is H, hae a crash limit of 2 days, but it

affects only F vhich has a lag of 2, a0 the project {8 shortened by 2 days

?ar an increase in cost of 200, The next cheapest reduction ie either B and

©, or D. (B te on the ertetcal path nov, but it can only be shortened Lf A oF G 4s shortened too, but A cannot be shortened.)

Operation Cost/Day

BG 500

?loo_

?9600

D $1,000

?The posbination Band G has a eneller cost slop but can onty be

shortened to crash tive for G, which fe 1 day at an increase in cost of

9600. D pay now be shortened to crash tine leaving « lag of 4 in operation

©, reducing the tine by 10 days at & coat of $10,000. We thus arrive at the

optimum crash progran from the normal time point of the cost tine curve,

ee

---Page Break---

Concept of che Continuum

?ho continuua {s an asemption that racroscople properties of waterials

are correct for microscopte elements of the object. This assunsticn permite the eliviaation of ar-ureats concerning the interaction of repulsive and

attractive forces between atone which when viewed from the gross scale may

ve treated af averave properties.

?The enuations that we write denend uvon the coordinate

cartesias coordinates the elenent ts rectengoler.

fe a

eae oy

for 2a oy

hans Fr Os *

?The letter @ shall be used co denote str

2. A stress is positive on a

back face if it ts directed opposite to the coordinate direction and positive

fon a front face if it is directed in the coordinate direction. Te first

subscript defines the face upon which the stress is acting and the second

subserip? the direction of the stress component. In order to not clutter the

Fine ve lave shown the stresses on tvo parallel planes. There are sintlar

corm sf stresses on the other planes. Por each of the coordinate directions ve

ay write the summation of forces, Por example:

---Page Break---

3

de,

s+ Sivay)aae? oyyanae

+ (ys Bs aadonay = My anny

®

? + Gays ee Apayan ery oyon = anager dts _

te 8

oe

where ys the dlaplacencat in the y direction. te a body force.

Jn addition to the sur of the forces we may also set the sun of the

pocents shout any axte equal to zero. Por 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 |

Weglectin« teres of hisher order we obtain

Tyee

%

Similarly

Cay Oye

Ours Cay

The above relations may be combined with the other equilibriun equations

to give

---Page Break---

4

mese axe the equations of motion in terns of stress. Lf acceleration Is zero

they become the static equations of equiltbriun,

?Stress-Strain Relations

?The constitutive relations (Equations of State) relate the stresses to

appropriate strains. We shall use Hooke's lav for these sere

erat

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

Ataptacenet:

ve ean 2

eer Eby GE) Cae Se

~ oe yee. Oey Qu, ,aw

Gays Set Sz) Gero Se 5 bo BEE

hese equations afe sonetines 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»

?Tere are six such relations possisie.

Gyelse-Suhses tution

Lt {2 often Nelpful ?o note thee any equation in elasticity theory ay

bbe changed by a gyclic exchange of gbecripts and displacenents to yield

another equally valid equation.

« x

wD i. I;

agement of Bqusto

For the purpose of inventtpating the exiatence of elastic waves, ve will

rearrange the above three sets of equations (Equations of Motion, Equations

of State, Kinerutic Relations). The Equations of State (stress-strain iav)

nay be solved for stresses

g,

Toe [orn eee + Egy seas]

aN

?

Cry pnt [OP bas eee een]

7 fe

aa Gazonas Thayer és)

fy GE ny

4

ee Gey

ye

2 Gbxe

o£ Gan tye baa) org Fee

Gann (om sar heal er

TEs

5 48 + fee)? 7

38 kaye gy? Cee

Goren? *

?

SE _ (Eas O yy ae? ie

ene

---Page Break---

For convenience in writing some nev eynbols nay 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

Tuese equations for stress may be substituted into the equations of sotion, resulting in

(ava) 22. G Sage +33)- tt o

rade +aGR+ He SE)- Eo

Car oge (GE + BF SS)- CHrro

These are Sn the abaonce of body forces, Ky Yor 2. Thee equations nay 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 r

pect to x, y

and z and then add then together. We obtain

Q-+eaa)vte - pre

ro

This defines the proparation of a disturbance of volune, The above relation=

sip aay also be derived on the basis of considering the type of motion witch

is free of rotation. Hence, the waves resulting

re considered irrotational,

Gtlatational 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. sero

av? o- eRe,

?The above expressiorsde permit shear distortion; hence, these disturbances

are called

yutvoluninal, shear, or $ wav

reity of Pr 8

The wave equation has the form

aro

Sie ws

wherein ¢ 10 tbe velocity of propagation. ence, 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

ave fronts of these tvo vaves nove farcher and farther apart as they sove .

from a source, Given a epecttied étatance from the source R

Retalartils :

Ate ty-ta

shen

bt: BR R Sar SsQ

ta *

te tne eine dttterencebecwsch the SETA of the dtLatattonal wave and the

shear yave {# meanured

cal

Canes

Rez ot

This relationship fe used to determine the distance of an earthquake from a observer. Several

rations are required to pin point the actual location.

?the determination depends upon the accurate knowledge of Cg and Cy for the

earth.

?the étlatational wave arrives firet, hence ts called prisary (P), and

the shear vave arrives second, hence secondary (S). Por example, in steel

cq = 18,000 fpe, Cy = 10,500 fpe, whereas in granite Cy = 16,000 fps and

Gy = 10,000 pa.

Surface Wav

fe reflected from « eurfece of discontinuity in the medium. In .

general, the incident wave produces four waves: a reflects

dt latational wave

?and shear wave, and a refracted pair. Of course, amplitudes and angles with

respect to the eurface of the subsequent waves must be such that the stress

components acrose the surface be continuous.

---Page Break---

0

From the requirenent of continuity of dieplacenent

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 vaves fron the intertor strike a free surfs

4 special type of wave

occurs which hae been called the Rayleigh wave, If the x-r plane is assumed

to colneide with the free surfac

?and propagation ie

sumed ko be in the x

direction, WO {s implied. Since neither dilatational or sheer vavee satiety

these conditions, a new type of wave must be develoy

Actually the surface

wave developed by Lord Rayleigh {¢ 4 combination of the evo waves previously

described. The derivation made by Lord Rayleigh vill

outlined briefly and

the results discussed.

?The folloving expressions for dilatational vaves were assuned:

Mat se TF sw (pt- se), Uys 2 cos Cpt ax) wero

and the following for shear waven:

Us. be? sivlgt-se)s Bs > se? ere (pt -sx)

w,

---Page Break---

40

Te can be shown that the expressions satisfy the conditions for the tuo respective

A nore general type of plane wave ts 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) .

wee

?he constants A, b, py Fy # have co be evaluated to satiety the boundary

conditions. These are to express mathenatically that on the surface y ~ 0,

the noreal stress fs. and shearing stress fy, are rer0,

Using the expressions developed for stress we obtain th

Le F?G Eso

Esyre

?yero

or tn tern of arlgcnent, wish wo 0

Qty ge)raa

ds, oy,

ay

wntte Ey2°O fe identically sattefted.

Xf the wo sete of solutions are substituted into the étatattonal wave

equation and the shear wave equations, the folloving relationshtpe mist hold:

vase Pp

yrae .

ee Se dg

@

---Page Break---

a

the velocity of propagation in the x direction te

ont z

r s

Substituting our proposed conblned solution into the Boundary condtttons,

eliminating the conscant A, and introduetne previously determined values of

4 and Ca, we obtain ee

ce YY Ce \(_ +)

(-2) sre (i =)\(e"

since

Cl leat

Ca aus)

and taking,

Cr

?: @

cS

ve obtain . jae

ao Fay 8(3- (1 ater) 7°

Te roots of this equation define the velocities of propagation. The results

ray be compared in the following figure.

---Page Break---

mus, we see that Rayleigh waves always are slower in velocity of

propagation than the other two types.

ALLURE THEORIES

e Ser oF

.

We have already deait with the stresses acting on an elemental cube. The

entity of all stresses assoclated vith one point regardless of orientation of ?

the elenent is called the stress field, It my be expressed as ¢ aatrix or as

?The matrix form:

St fen ts

Se es

?the tensor form {8 simply o>*

?an entity Ln 4 tensor if (t transfores according to # certain transforma

tion law, Manely, if we rotate the coordinate aysten by an angle ©

Cue eG caste + Cy SWE FAM, Cove We

tye Gyeterdeon ome e 4 Say Ceosten 1088)

Oygie Gay Et + yy Conte = Ary con OYE

where in x!, y! are the new coordinate directions. 4 % i

Note chat a vector tranaforns alaply

T,

Ty cose + Tyme

Tye -Tasiw0 + Ty wove

or in matrix notation

Tr) (cose swe) [1

ry} swe cose} [7

---Page Break---

4s

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 atsoctated with stress vectors P also transforn

vectortally.

ue, UGE El

te: (1 Le] + Le] Lx]

, @] GAIL]

weerein [6] = (em = the sector trtnafore and aF ke the

tranapose of a.

?Tite may chen be writeen simply.

(oJ. [ayforte')

above is called « tensor. Essentially a tensor i# an entity that ts the

fcoduet of two vectors.

$e ?EB

---Page Break---

train te a tensor quantity. ?The displacenente Lf kept snall are vector quancitien Ceransforning « vector for rotations of the coordinate ayeten), The lengehe (sides of the element) are also vector quantities and the inverses of

tthe lengths are algo vector quantities leading to

fe]+ (s] Celle]

Scress Invari ed Yield crits

certain quaneieies aay be found which reaain constant when « transforma

tion is made. One of these ie called the trace

Gee + Cys Tea t 9F

ys matrix nay be written as

Cie Sey See

wherein Ugg = Cacdete:

Fas

Another invariant is

hydrostatic str

et. (& oss)" a Gy

this can be interpreted as the equation of circle (Mohrs circle) in coordicate ayaten Oge gy 80 ay

Mohes Ciecis

---Page Break---

oy

vents the orientation with respect to the principle

wherein the angle © repr:

those planes having zero shear stress. In general, 3 Mohre circles

can be draw for rotations about the three coordinate directions:

te

Mohr Circle in Three Dimensional Strese

aterial parts of slips. Thus, two limits my

Failure nay occur becaus

be drawn, one Limiting the maximum shear, the other lintting the maximus tension.

The waximum shear eriterion for ylelding 1a due to Tresca and te called the

?Treaca Yield criterion, The tensile lintt {4 really « rupture criterion.

?Another type of rupture, that {e slip ie predicted by the Mobr envelope. This

Ca

Shear Ultimate

CTmenen)

Teosue Untiuare

(Fanewne)

---Page Break---

forms the strength criterion for moet sotls. In general, the strength critert

to the stress invartents Lf the material is

for a material must be relat

Aeotropic. A stress invariant 1s 4 relation involving the stress components

?that remains constent during 4 rotation of the coordinate system. In general, for ssotropic materials

here are three independent stress var

Ue +e ye 8F .

trendy nenttoned ay .

dae 4 [eee-8" (@y-5)* + G_-F) Teor ty. Se

= E[-crt re a" Ce, -«)]

which may be related to the radius of the Mohr circle being constant

dye EGBG -BN,-F)

erein 2,3 #86 the principal stresses. The tohr eavelope ertterta for

yield implies that the mean sormal stress ts iaportant. This may also be

true in materiale at extremely high pressure, Thus, # general yield theory

Anvolves all three stress tnvariante.

?the most comonly used yleld eriterta are: Tresca (Maximum Shear Str

G,-C,+ ak

where Tze, 20,

.

wok

cuckes Pras .

---Page Break---

a

?The latter being a generalization of the Mohr envelope or Coulomb's Law for

sot

Degood

Jie aagd,? = kt

?The latter vas obtained eupirically from te

fon alusinus tubes.

The von Mis

criterion was originally proposed as 4 mathematically enooth

approximation of the Tresca criterion. In three dimensions using the principal

© 1, © 2, Gy, we can plot the von Mises yleld condition as « circular

cylinder of radius JFK vhowe axis ie equally inclined to the three prinetpal e,

The Tresca yield criteria matches the von Mises criteria at six points,

but fe formed of straight interaction lines rather than curved.

Thenonenology of Streee-Strato-Tive

?The foregoing criteria for yielding attempt to predict at what value of

stress the stress-strain curve for the saterial subjected to biaxial and

triaxial loading vill become non-linear.

Yor many years work has been carried out to explain vhy after the yield

Point {8 reached and plastic action ts occurring the stress continues to rise.

---Page Break---

os

ite behavior has been called work hardening. The reverse question, "Vhy ts it noncLinear at all?" was not asked. Tt s the answer to this question that gives the most Light to the subject.

If one asks vat should the breaking strength of metals be, bated upon che

forces of attraction between particles, the ansver from the physicist is that

the breaking strength is {n the order of Young's wodulus, t.e., 107 pai. To anewershy-this strength 1 not achteved, a new theory was proposed called Dislocation Theory. ?The basis of dislocation theory is that, if an element

in an array of elenents ts tt

ng then as the array is distorted by shear, a certain strain 1s reached (elastically) where a neighboring elenent is Likely to jump laterally to fill the wold. Essentially the votd or dislocation moves crows the fleld untti t reaches # boundary leaving behind « permanent set in

the strain, Avetal ie visualized as being strem with such dislocations that perait plastic flow, This plastic flow takes tine to occur, however, and also

probabtlity enters into the occurrence of each dislocation jusp.

From an engineering macroscopic view there are two types of behavior

occurring with each addition of load: an elastic stretching which takes place

Anetantaneously and a plastic or creep stretching vhich takes tine, Creep

tests can be run where the load ie applied suddenly and the material then

Allowed to creep for long periods of tine

?Sreaw

Thue

---Page Break---

A cross plot of these curves for a given time since loading yields {so-chronous |

stress strain curves

?

The usual str

rain diagran may be generated from th

curves. The

Rest machine generally operates at « constant atrain rate. Once the stress |

Level {8 above a pl

tie threshold, a certain amount of er

occurs depending |

upon tine at the etre

level for each Loading at

We can approximate the

behavior by connecting points on the ?sochronous str

strain dtagrams

corresponding to creep tine and total strain.

?The important point here is chat the etre

strain diagram depends upon

the rate of loading. The more rapid the loading the nore elastic it behaves

?and may under extremely rapid loading behave as 4 brittle material and shatter.

SOrL varcuantcs

> Strength

Im the discussion of fatlure theories it was mentioned that the Hohr

envelope or Coulomb law Le used in Sofl Mechanics.

There are two types of

sotl tests

fed to determine the basic strength parameters in the Couloab law:

the direct shear and triaxial covpression test. The dixect shear teat takes

---Page Break---

a block of the soil, places @ normal load on the block and then determines

the force necessary to shear the block in tw.

N 6,

: -

9,

?

N &

the triaxtel test takes a cylinder of the soil, usually sealed by « thin

robber senbrane, places it in a hydrostatic pressure and then applies an

?axial loed to failure. tohr's circle can be dram for etther loading sttua-

lon and enough variation made in the sornal force or the hydrostatic pressure

to define the Wohr envelope.

?the vor envelope may be curved. lovever, for purposes of sinplicity it te assuned to be Linear in the range of interest, namely in the form

wherein { cHttCAL SUFERCS 4, che shear strength on the failure

came? 672TH? Ge

¢ {4 the coheston

Ls the normal strese on the failure surface

tants

the coefficient of internal frtetton

C Oe the eftective friction angle)

Rankine and Coulomb

?the earliest work done on slope stability and the stability of retaining

walls was by Rankine and Coulomb, Eesent{ally they used the above equation

and assuned « straight sliding surface.

---Page Break---

?The surface that gave the lovest factor of safety ie considered critical.

Tre factor of

ty La defined as

sur. = QAR BE) tata

Fellintus (in Sweden) noted that typical elope fatlures

straight failure surface but, rather, curved. He, therefore, suggested and

weed a circular are of fatlurt

The factor of safety bere ie defined ae

£ resisting Hovents

?© Driving Moments

?The slope {8 divided into vertical slices (hence the common name: Method of

Slices) as

the forces on the trial sliding surface are determined ignoring 1

the possibility of interaction between the slices themselves. The Wis

deterained as the volume of the slice tines the unit moist weight. The local

angle @ must be measured for each slice and the resisting moments sumed

---Page Break---

% -e (Se +Aweose tan d]®

?The driving monent may be determined by suamation

my EWR IO

?ro other types of safety factor can be calcula

Safety factor with respect to helsht:

as

fe

-& ise ?

? [ow sive-awees tang]

Safety factor with respect to friction

2 Aw cos 6 tang

= Z4w cose tone

eowsve-¢ *

cose

he Felliniue wethod in principle can be applied for any loading conditts eon.

Aneluding seepage and sround accele

Buemple: Consider the case of # saturated soil immediately after the formation

ve. The normal effective strt

of @ slope by an explo a trial eliding

surface will not have had time to change while the full saturated vetsht of

sot] acts in the driving moment .

sarvaare

A phys wrave

---Page Break---

sa

Flow Tarovan POROUS MEDIA

?Darcy's lay

anion

wearein

4 flow rate

k= coefficient of permeability j

4 = hyérautte gradtene

A = cross sectional area

The bres gratant for ?nearest Ian 8 even by sce he eb tonne wm dsb nr a fo

barom,

The pressure ts given by

po hye, i

Manca in terme of p

2

ne tiye

%

?Sonbimutty

Stutf ta = stutt

---Page Break---

se

?Aawune incompressible flow:

Roper errors Se ttre t

avs 4 8

OD ax)oyoas (%y Bers) oxox y+ $m arora

whitch reduces to

08. | 3% de

We Ty TO

sunereticins Vy 2(A/q), into the continutty

equation

din, wy, IN,

a a te

o

* 7

vtheo Leplacie

If ve define our aysten in tvo dimensions the following argument can be

ase:

consider the flow past? two points in a tws dimensional flov. The flow

across s

?THF 10 the sane as the flow across AGF by?continutty. Let the function denote the flow rate from left to right across any path eanoseting A and P, If we

take another potat p' the added flow rate would be Yat P' minus Sy at P

---Page Break---

35

or YY. Lae PP! be dy, then

Viody. Oy

fy

Stntlarly, for an elenant PP" = dx.

dy

But continuity requires that

WM ayy

ax Oy

Me see chat Y satiation continutty {dentically. Thus the velocity componente sty be given by

Vays ad, av

ae oS

Vy koh. _aw

ay) oa

Proe this relat

and from previous logic the stream Lines (lines of constant

Y) are at right angles (orthogonal) to the aqutpotential Lines (h = const.)

?SKETCHING BQUIPOTRNTIAL LINES

Consider the flow to be in the X direction ina

sea having « total head

drop of H. The equipotential Lines can be drawn so that each represents

4

equal drop Ah where: She ©

?The hyéraulie gradient ts then

véraulte gradient aT

ax

aw

a

|

---Page Break---

?The velocity across the eleneat fs

ow

Bee ke Or

The {low ts

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 Veloctt:

If we wish to know vhere @ particular particle of water is after a length

of tine t, we must know the true velocity at all times. But thie varies from j

point to point depending upon the constrictions through which the water flows. i

---Page Break---

3

One approach ie to take an effective tube size that Le equal c= gross area (A)

times the porosity (n) of the permeable material. Porosity being

Ve

. Vets

: where in Vo = vote of vot

Vy = volume of solids

In thie way the average particle velocity te given by

Fle

Gost tietent of m

The coefficient k may be written

coeffictent K divided by the

Viscosity su wherein E is a property of the porous material, having unite

of ienuth aquared and je Le @ property of the fluté, having untes of 1b-

Forces Due to Seepage

mm

fe are two

eens of forces: forces in the water phage, and forces

between the particles (or effective stn

3 er 38 ?Vv

BPrasvogerrioreyor -¥

4 ?4

. rie 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 ve may reach @ Quick Condition vherein Oy*O

2 Ved /a,

everyvbere, Then Yaigray and

or Ho,

ce, he ve,

Anisotropic Permeabi

yes ah My? ky Po were

shen

fe Thy kik oA BAO

ranatorm che Giewaston so hat

then

---Page Break---

59

hy {

ay %,

Jee Susus Law

eos

Contours tn Ky region must be closer together all other things remaining the

same. Saaller K means greater resistance to flow. But the

potential Line

?SURE match at che contact, Bene

4 refraction of flov is required,

Sonsoltéation Theory - Incompressibie Piuid, Compressibie Media

Consider the soil to be a compe

the str

ble material, The relationship between

?container being filled with water. With the drainage cock turned off the water

be es 1

=p

---Page Break---

will carry @ portion of the load until tt reaches equ{ltbrium with the load;

Ae then carries all the load, the water carrying none.

We need three chings: the constitutive equation for the solid phase

function of pressure (Darcy's

relating volds to pressure, the rate of flow

Law) and the continuity equation.

ton Te

The consol

A block of soil ced by applying # sudden load and recording the

virtually stopped. Two things

setclement ve eine until the settlenent he

fare determined from such a teat. The @ vs p curves for final settlonent

are determined fron che end points of the aettlenent for each application of

load, but also the tine delay in deflection gives data from vhich the effective

pernaabtiity or consolidation costfictent may be determined experisentally.

This latter te important since permeability in clay ts 40 small as to make

other methods for deternination impractical.

Yor clay 1 appears that after reaching the original state of stress the deflection (or volume change) 18 an exponential function of p, nanely

e+e uplp

(on seni-log paper this plots as « straight Line

e |

|

ver a seal range of pressure change ve may Lincartze2? to be :

de P j

se-te

oe

?The rate of flow is given by Darcy's Law

Q: ki

---Page Break---

?Assuming only flow up or down,

Gan Que» 2

is Qhes . ius = head in excess of acendy state

sO flow or equilitrion

?The settlenent progres

with the water in the space between the solid,

bekne pushed out, governed by Darcy's Law:

Qu Ri ar ay

Gore ho as

3.42) oxay

ct

SE avoqons Qu Qu

ee

de Cw dp = we. oka,

Yey GAs. bk ota,

te ee

Fp Shes St oroy

Ohas bo othe,

oe Yen oe the de

| Ff ester ee

---Page Break---

2

?This can be generalized to three dimensions

Ohas k ty

? VF has

de OH

STRUCTURAL DINAKICS

ngroduction

he use of orthogonal functions in aolving dynamic problens in structures

and books

giving detatled discussions and examples of the method. However, ax yet, civil

the procedure in the analysts of buildings under

engineers have not adopt

earthquake and blast loading, In the case of earthquake loading, the most

jsuned hortzontally applied load equal

common procedure 12 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 Judgement of

Blast design, being of general interest only recently

practicing engineers.

due co (ee application tn efvil defense, has been treated more fully from the

theoretical stanépoint than has asetanic design.

However, as vill be pointed out in this section, the theory and solutions

?obtained from blast problene are equally applicable to earthquake problens.

conversely, wethods used tn the analysis of the response of structures to

ground eotion, say readily be used to analyze the response of structures to

blast, A great deal may be gained by comparing progress nade in both fields

Jction is to present the roraal mode sethod of

?The purpose of thie

analysis in a simplified fora. Le {s hoped that the staplified equations

involving paraneters having some physical significance will clarify the

approach end make {t wore anenable to use in general design.

---Page Break---

?Mopenelature

ne

re

Le

yy

Certain basic quantities used in the derivation to follow are shown in

Figure 1. Other symbole will be defined af they are fir

0

Fee

Modulus of 1

etetty

Flexural Rigidity

?Bane of Natural Logerithae (2.73)

Acceleratt

Doe to Oravity |

Moment of Inertia

Length of che Bean

Mans Par Unit Length

Bending Yoment

Force

Generalized Force

Generalized Coordinate

Tine

Rloteie Eoersy

Potential Roersy

Shear

?Distance Along the Bean |

Displacenent, Velocity, Acceleration

??? ?=?#R

---Page Break---

of

For the purpose of presentation, examples will be limited to

Involving structures which may be approximated by uniform beans.

ferential equation of motion of « bean neglecting shear deformation and

rotary inertia, has been derived many tines. TMo of the more convenient

references are Tinoshenko!? and Karman and Btot?, Thie differential equation nay be nolved by any one of the classical methods. It {8 known that these

srles of charac

methods lead to unique solution in terms of an iafinite

teristic functions (gorml andes) vatch are orthogonal. Much labor can hence

be saved by adopting the common procedure of assuning the forn of the solu-

tion and evaluating the cocffictents of each term (method of normal coordinates).

the case of a bean subject to motion at the supporte will be treated here,

and eintlarteies between this and other types of loading vill be pointed out.

to end conditions for the bean, hovever, it

Wo restrictions will be aa:

will be postulated that all supports will undergo the sane dtaplacenents, Expanding the deflection of the bean relative to ite supports in terns of

generalized or normal coordinates, ve obtain,

Yur HOO +E by Zeer Y

te

where

Yol,e)? notion of the supports

ice) = characteristic function

Jol) = geveratized coordinate

?the equations of notion of # bean in terns of ite generalized coordinater

are Lagrange's equations?

euperscrivts refer to references given at the end of the section.

---Page Break---

6s

&£G 2 Wg. Geena ce ey

a

4£(80)_ or. wy @)

Od Gg Hye

ee

ae Potential Energy (3)

Kinetic Enersy @

£

% of Poe Oy, & Generalized force (5)

t

Gof C64) My,

Substteuting Equation (1) in Equations (3) and (4) results in

FE CY aw ®

2 ft

EEE my Zgfacrdee ligt

In the case being considered the only force applied to the bean is ap}

£0 the oupports. However, the motion of the supporte is not a function of

Pie Teretore

4

% [Po ge axso ®

fo a

Substituting Equations (6), (7) and (8) into Lagrangian equations are

obtained:

ft Ly \

MIP) dee ml + lp (YIM) dz 20g |

---Page Break---

?The characteristic function represents the shape of the harmoatcally

vibrating beam in the absence of external excitation. This function has been established ae

$: (x) + Hew Bee B cos fe + Cah Burdeossa

Yom

where! $+. ?This may be verified by study of reference aumber 1. The

srblteary constants are decerained by the boundary conditions Laposed on the

bean and the condition of orthogonality, naaely

4 oe

hero Sor bay

w= 1 6. (1) he » so aD

Jf, #1 6:9) Arbitrary reas ©

For the case inj, 1¢ ie conventent to normalize the equation by letting the

arbitrary value of the integral be equal tom. It follows then that

4

Lm O28) ml ?

f FAY se tort tron ruttons (0) ant 1) at vetining Bae

Equation (9) becones

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 vibra-

tion and chat for conditions of zero velocity and acceleration at time equal

zero, Equation (14) hae the following general solution:

t

sed aft as)

Bee BL Kept [Ose dete,

---Page Break---

7

ae & e (ae)

Gee: a2 Peon he Ghegy ie Cb addy ;

Te shove equations solve for the unkmow funetion gc, and theoretteat ly

. fe problen Ls solved. LE the aare procedureawnre followed for the case of

0 arbicrary impulsive Load on # beam, the follovins solution for q: would be

derived:

> f t

FOE [tien Do) dew: fh) fewclegid, 0

where the applied load wr (e, &)

2 WWF) aay

£

Py s+ Maxinun total blast force:

Gi(qy --+ Seace dtvcetbation of force.

F(¢) + Toe variation in the force.

Im the above solution for bi

t loading it has been assumed that the

load may be broken dows im che manner indleated. If for any reason the space

statribution of force is « function of time or the time variation of force te

4 function of {stance the above solution is invalid. However, many tines

blast loadings may be approximated closely by the above assumption.

Simplified tquatto

Im fairly recent years studies have

in made which simplify the nunerical

Work involved in using the normal mode approach. One of the most important

. Publications has been the tabulation of characteristic numbers, charactertattc

Funetions and the successive derivatives of the cheracteriatic functions.

?These tables are due to Young and Felger and have been published by the

se

---Page Break---

6s

university of Texas.) Other investigators, such ae G. Ws Housner* and W. T.

tonsont# have applied electronic computers in solving the time varying part

5

of the nolution.**

In order to see how these various ?avestigations ft topether, it ts

convenient co express Equations (10) and (17) in the folloving 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 Ghe ce.cietun of ic Kaetor Gy at ef the above coetttetants are non-dinensicnal, Sy conjarison between the Evo columns Lt 18 yosatble to see

tthe sins crities as well as the essential differences between earthquake and

blast response.

Partletnation Factor

?he coeftictent ky deternines to vat extent various eodes participate

tn the scaticat deflection for the blast case. Te is, therefore, called the

partletpation factor, The value chts factor takes ie « weighted average of

the characteristic function #r(y - When the exctting force 19 unttoraly

ddeteLbuted over che tengeh of the bean, Wg) + /, and the partiotpatton

TFrofersor of Applied Mechanics, California tnstitute of Technology.

4s Professor of Engineering, University of California,

---Page Break---

69

factor for blast becones a ateaight average of Dy/y) «

?As may be seen from the coefficient C, the weight of the structure te

analogous to an exciting force, in the earthquake case, In as much as a

\nttom bean Ax unier covelderation, Lt I eonstatent that by for the ectthe

Authe cane {6 shown an a aceaishe averase of (a): Tf the beam had a

Aiacrtoution of weight Wea) , the ky for carenquake would be the sane as for

ase.

Dmmanie toad rector

A armani Load factor 4 ao corned becaute At tells how mich the statte

Fesponse {a cagnified to obtain the dynamte respor

+ This te precteely what

the factor D, does. For the blast case the integral involved the tine varia-

percentage of gravity) te substituted. It should be noted

that the dynamic load factor aust be applied to the response of each node

separately, since in general Dy will be different for different nodes.

Por deste purviscs Lt {e the maxtnua value of Dy that ie of inter

Although there Lem) certainty that the maxim values of Dt will occur at

?the same time ior various modes, the tines are not greatly different and one

must always consider the worst probable condition in design. the determina:

Sion of the dynante load factor for all but the most simple loed histories

becomes a very difficult nuserical task. 1¢ is here that analog computers

have come to the aid of the engineer,

GW, Housner ot

that the quantity Dy represented the acceleration

?in percent of gravity of « one degree of freedon structure of frequency Wy.

Ssbacicuting real earthquake accelerograns for the term Ys and determining

the maximum valve of the integral for all reasonable values of frequency,

@ dtatr{bution of acceleration versus period could be drawn vitch Le sintlar

---Page Break---

to a distribution of Light intensity versus wave Tength, For thts reason the carves of naxtmum Dy versus period which have been obtained by means of electronic computers have been referred co ax earthquake spectra.)

panping cay be Included in the differential equation of mtion of beam by including @ force term which {# proportional to velocity and in phase with ?the deflection. This results tm the addition of an exponential tera in the

Aynanic Lond factor, namely

e -

2.2 Fay OE OM sw ws legs th 0)

where n is the per untt of critical danping. ousner has shown che effect of the inclusion of dasping on the earthquake opectra

Most of the published work giving actual values of maxisus dynamte toed factors has been for earthquake excitation. However, the analog computer

Je to bl

techniques are equally applict it exettation, W. T. Thomson has

been carrying on research at the University of California along these Lines.

Character etic Valu

There ove two charactertatic values that enter in the solution which are

properties uf the freely vibrating bean. One of these values 40 the chara

terintie function (a) + vhich describes the shape of the 18 mode, The

other value is the characteristic mmber g, £. For uniform beams the charac

teristic 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 alt conbinations of clamped, planed and free end condt tions

with the exception of the pinned-pinned case which results in a simple sine

funceton, The primed values are the successive derivatives of #. (qdsvided

by successive povers of (js ta order to retain non-étnenstonality.

---Page Break---

n

nt and Shear

fe Substituting the factora 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 ie usually more interested in poments and shear

than in deflection. Since Qy (y ts the only variable quantity in the equation

above thar {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 eost engineering purposes these effects

eg

---Page Break---

n

axe negligible.

Application

Earehguake

ste Southern California earthquake of July 21, 1952 resulted in

widespread daaage in the region of Arvin, Tehachapi and Bakerefield, California,

Mich of this damage was due to the lack of resistance to Lateral forces. Sone

never structures, however, had been designed under the earthquake provisions of modern bullding codes, he perfornance of this latter group of structures Ae a true test of the validity of design techniques, As an exanple of the normal node nethod of analysis, the Arvin High School Administration Dut ding will be studied.

?The Arvin Wigh School Administration Butlding is a two story reinforced concrete building vith brick veneer except that the second story wall at the vest

?end was 8 1/2 inch reinforced grouted brick masonry without openings.

Following ie a descrtption of the danage:®

?The west end second story wall was fractured. Subsequent shocks

increased the damage and the wall becene badly cracked. The adjoining concrete

wall on the north wall (faced with brick veneer) cracked along « horizontal construction joint, After the weet wall cracked, later shocks caused plaster

Garage and spalle to metal lath and plaster er peréitions which attempted

to ester forces for which they were not designed, dependence in design having

been placed on the exterior west wall. There vas also evidence that the second

story vall at the south rocked somevhat because there were minor brick spalle

at their base. There was no collapse.

Investigators studying the cause of the danage stated that the wall

sms of faulty construction although there wae reason to believe that the

Hlextbility of the 200 foot long roof diaphragn contributed to the fatlure.

---Page Break---

By

The plot plan and section of the Adninistration Buildin: are shown

in Figure 2. The loads entering the end wall during an earthquake aay be

?approximated roughly by analyzing a uniform heam of sintlar dimensions to

the roof slab. The moment of inertia Ls anjroximately 90x10 taches*,

The force entering the end well nay be computed using Equation 25,

. Ve omeg 4X Pil ke Over 0)

4° Ss ea

Te shall also be essuned that the interior columns and partitions give vertical

Support to the diaphragm, but do not offer resiatance to lateral motion. The

ataphray

may be considered to be a bean with end conditions Lying soevhere

between full Fixtty and simple support. The condition of

imple support will

be

founed fret,

The characteristic function for a simply supported bean is given y

ins

Git © VE an FF e@n

he characteristic muber ta

2.

Behece co

The following ts 4 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 fundanental pertod of vibration ts 0.34 seconds wherein the

following values were assumed:

E+ 2asxwt

ZL 90 vio tmches*

me ny Bnsee

ae

4

Since there 46 no spectrun available for Arvin in the shock of

2900 weres

?oly 21, 1952, the spectrum for EI Centro in the shock of May 18, 1940, component N-S will be used, See Figure 3A. Therefore, asmuming « damping factor of 0.10 we aay pick the dynamic load factor off the apectrun, This yields a value of approxinately

oes 08

Since the fundamental period of vibration is by definition the

all other values of Dy nay be taken as 0.

longest period excitable

Substituting into Equation (25) gives the folloving resulce:

song {epee . ono + tt . }

smn seay coof TQM ., EC oa} i

7 or

2 265,000 * |

?The area of the wall cross section te approximately 3000 square .

?on the end wall te 89 pat,

inches, ?Therefore, the average shearing stre

?vhich could cause fatlure. Wowever, the partitions should help to reduce

thts atrees and the éynanic load factor at Arvin may have been less then at

EL Centro tn 1940.

---Page Break---

1s

Lf in the above analysis end conditions of full fixity wre assuned the some ansver would result since increased restraint tends to decrease the period of vibration.

?A very {eportant 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 Fesponse is multiplied to obtain the dynamic response, Structures having long periods of vibration take advantage of the reduction in the value of Dy ae

shown on the spectrum.

Blase

?A somewhat more hypothetical example for blast type loading could be obtained by analysing the above structural elesent under an impulsive loading. Tf ve assune a pulse type load of 0.3 seconds duration tine, the saxtmum 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 secor ls, the dynamic Load

factor for all nodes is roughly 2.0. In other words, the dynamic response te

twice the static response under the maximim blast load.

?concLuston

Im the foregoing discussion tt has been shown how the res

under dynante loads may be expr

sé 40 @ series expansion involving four

non-dimensional paraneters ai

fone dimensional constant, The equation takes the folloving form:

2 Pw Ki di

fe (BAY

@s)

---Page Break---

%

This form of solution is not Limited to beams. In fact all structures subject

to dynamic excitation, vhere the principle of superposition is valid and loads

nay be broken up into a tine variation tines a space distribution, may be

analysed using the above form of solution.

Prototype structures must be approxisated by sisplified models in or

to satiefy the above conditions. Structures having uniform dtetributions of uch as stacks, silos or individual structural elenents my be approxiaated

by bean theory. Buildings where weight {# concentrated at floor levels may be

approximated by the so called shear building. Structures having large shearing

deflections in comparison with thelr bending deflections may be approxinated by

tthe 90 called shear bean.

1, ?Muoshenko, S., Vibration Problens in Engineering, D. Van Nostrand Co., 1938.

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3. Young, D. and Felgar, R. P., Jr., Tables of Characteristic Functions Representing Norasl Hodes of Vibration of a Bean, Eng. Research Seri No. #4, Bureiu of Segearch, University of Texas

4. Houser, Martel and Alford, Spectrum Analyste of Strong-Wotion Earthquakes,

Bulletin of Seienological Society of America, Volume 43, No. 2, April 1953.

5. Tomson, W. T., Impulsive Response of Beans in the Elastic and Plastic Range, Journal Applied Mechanics, Sept. 1954.

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n

SfCTION A-Aw

Figure 2 - Arvin High school, :

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78

20

UNoANPED NATURAL PERIOD ~ 3ECONOS

Figure 3A = Aoceloration spectrum for El Centro, California

Earthquake of 18 Fay 1940, Couponent W-5

ve bumsr remeron

Where te + 0.3 see

I |

° Os 70 1s 20 2s 30

UNDANPED ?NmrumAL PERIOD -T IN SECONOS

Figure 32 - Yaximun 2ynamic load factor for step function

shock o7 ?uration 0,3 seconds versus undazped natural

portot ~ 2,

---Page Break---

\ARCE-DIAMETER DRILLING FOR EMPLACEMENT OF NUCLEAR DEVICES

Ref: Proc. of Third Plowshare Symposium p. 239-268

Drilling Methods Diapeter Depth

. 1. Churn Dei tting ? 600-500"

30" requir

one pa

30° 11 more than one pass

Penetration rat

28" 12'/nr to ¢6 "syne

?A percussion type drill consisting of a long si

1 bie hat is

wechanteally Lifted and dropped to 4

grate the rock.

2. Auger Detiing 1s" 65°

»

Ueeful tn soft material that can stand open during értiting. tovever,

drillers mud or casing can be used in softer materials 36" hole 100°

3+ Gore Dettitos o 200"

Chilled steel shot te used as cutets

naterial,

See p. 252 Peurifoy, Construction Planning, Equipment and Methods

Rotary Drilling 130" 570"

30" 1400"

25" 1700"

Like of} well dritling.

Sone

1 8 Det sro/ee = = saoyee.

2. Auger § Use for 36° sote

$20/ft for 72° hard

3. Gore Dritiiag $12/Ee - $120/? soft to hard for 36" hole

. 4. Rotary Drtiting

26 hours,

---Page Break---

epth/fore Dlaneter

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 vill consider

the following dimensions

Bane Depth

21D 100"

38 750

65" 2500"

weanple 33) @ 750"

se

Third vlovshare Conf. Proceedings p. 239-250

Actual sorting will be 48* tn diameter and will be drilled oy # drill rig

?with 700 input horsepower. The drill rig cose will be $1200 per day operating

?and $800 per day non-operating.

1. Rig Mobs Licatton

a, tauling 1000 fies @ $10/atte 10,000

b. Rig cost = 250 miles/day, ¢ days @ 800.00 __3,200

Total 913,200

Site Preparation

32 dozer hours @ $15.00 480

Rig

?4 Rig tine 3.1/2 days @ $1200- $4,200

anler support 200

Sub Total $5,400

Surface Hole - 56" deep

8, Detling 54? hole

---Page Break---

6B.

(1) Rig tine = 15 hee @ $50.00

@) cuttercoste = 50' @ 21.00

(3) miata conte

b. surface Pipe

(1) Pipe - 6596 1b @ $0.20

(2) coment = 115 £3 @ $1.50

(G) Rig time - 2 days @ 1200

Sub Teal

Drill 48" hole 50° - 750

4. Rig time 200 hours @ $50.00

>. cutter costs - 700 @ $15.00

©. Flutd Costs - 2500 Bois @ §2.00

+ Condition bole and run heavy casing

4. Casing Cost ~ 750" of 3/4? wall 226,500 Ibe

@ $0.20

b. Casing welding cost $36 Joint for 19 joints

Cement cost 3700 £3 @ $1.50

4. Cement pumping

Rig time - 8 days @ $1,200

Sub Total,

Run light perforated casing

4, Casing cost 750° @ $10.50

>, 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

«00

2.800

960,834

97,875

2,400

$10,275

a

---Page Break---

82

Tear Down

4, Rig time, 3 days @ 91,200 3,800

b, Ranier support 1.000

Sub Total $4,600

8. Rig demodtiization 13,200

9. Total Coste

a. teavy Casing 129,565

or sura/te

b. Light Casing 79,006

or s10s/te

MATHOMATICAL INSTABILITIES

Because practical problens in hydrodynamics are usually

terns of non-linear models and because the physical situations are two or three dinenstonal, analytte solutions are not to be found. Munerieal analyse can produce sone anawers, but even this technique fatle at tines, For instance, the two dimensional pressure profile of atx etrculation about an infinitely long ving can be obtained to any required accuracy by use of a digital computer. But when the wing 4s finite, the probles becoves three dimensional and in beyond the capabilities of present day high speed digital computers. ven the relatively simple problea of one-dimensional tine dependent flow,

which actually can be handled by compu

EH, requires sone spectal care. Thus numerical analysis can introduce instabilities which have nothing to do with the physics of the situation. We can best illustrate the potnt by outlining the ounerical solution of particular partial differential equation, the hyperbolic equation:

fewmore

ulat)so a)

---Page Break---

a

which is the staplest general equation describ:

hydrodynamic flow. In the

Beneral case, c itself depends on the derivatives of the étsplacenent u and

thas (1): becomes non-iinear, Let us

juppose that ve try a solution to (1)

of the form u + ?, where u eatisfies (1) exactly and ? Ls & small additional

tera, introduced, cay, by rounding-off error

Substitution of the trial

solution u + ? into (1) produces

BE CE Corso 7

wher

© ts knows from the solution of (1). Since ? is mall, the dependence

of con ? aay be neglected and (2) can be treated as @ Linear equation, We

?Are concerned with the behavior of this error, ? , as x and t chang

The numerical differencing technique used to deal with (2) {s pictured

im the Figure: a lattice te construct

uch that as ve move upward we are

soving forvard in time in increments of 4, and if we nove to the right of

left we move in the positive or negative x direction tn increments of & x.

Note the notation wud: ? yy means the value of ? at x= max and t= nat:

naturally, ? (5

?sui.

?The lattice used for finding the behavior of ? by means of « difference

lequation.

---Page Break---

%

Aasune that ? in known at every po{at in space for all tines up tot = 0

We can then move forvard in tine and calculate ? at any point, Actually, our assumption ts unnecessarily strong: (2) {8 @ second order equation in time, to {t will autfice to know ? , and ?,. _; for all m, that fe, for ail x at k= Oand t= -At. Let us study a general Fourter component of the error. Since (2) te Linear the solutions can be obtained by the superposition of Fourier components, Thus we shall be able to predict the behavior of alt possible error.

We consider

Emo * Cote) etemet @)

and

Ca EG OOH w

vhere j= 71, k te a wave mumber, and ? 5

coefficients independent of space and tine.

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). Bquating (5)

and (7) produces the difference equation corresponding to the differentia

equation (2):

act

Lor 2oetbon* aoe ey [ees kan] ©

(ae.

oF using (3) and (4),

?,- 2046, 22 ©, [cos kan

7 o

(ay

from whieh {¢ follove that

6-22. [eos Kon-] + 2e,- ?, ao)

at

Ingertion of @ word or two concerning the validity of (10)

wns appropriate,

As_ox und at approach dx and de, the difference equation approach aif ter-

edttal equation and hecones

ict. For finite & x and At, (10) Le an approxi-

mation in which terms of

cond order in Ax and Ot have been neglected,

Surprisingly, even for snail & x and AC, we shall eee that vhat matters in the

Dehavior of the error term is the ratio of &x/at toc.

rer et ce (22) (10) becomes

6.2 2e-6, + (onal corrections).

AC each step forvard in time (renenber that the indices in (10) refer only to

the time increments) the influence of the side points vill be very weak. ach

step represents

4 very small extrapolation into the future and the situation

---Page Break---

85

ie similar to that of a total differential equation depending on tine alone.

This result appeals to common sense: while &x and At aust both be small,

tf Ax CQ eRe, a atgnal from the efde points cannot arrive at the point of

Amterest until long after the time increnent step hy

been completed.

For ct an (20) becomes

?

? feos kax-i] + (enait corrections) a2)

?There will be no problem if there {# not such spatial variation in the error.

?This corresponds to a small wave munber, k ~ 0, a very long wave-length 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

begine to die out.

On the other hand, there will be some value of k such that cos kax ? -1:

the value of ? changes sign a# we move horizontally across the grid. (12) is

hen

65-4

@*

?Thus ?1 is greater than ?g and the error srovs exponentially as tine increast

Physically, vhat has happened 4s that before the temporal step is finished, signals reach the nev point from points far to the aides. The calculation, which is Uited to neighboring points, ignores this fact. There are at least tyo ways to cure the problen. The first {s that tince the space and tine incresente are dguch that "sonic" etgnals from more than fort netghboring pointe reach the new

point of interest, simply include the additional terms in (10) needed to

---Page Break---

#7

account for the other signals. The dravback to this aethod {s that the

recursion relation becomes auch sore complicated. The secotd eethod te 0, ,

alter the size of the lattice spacing s9 that Ot & Ax/e, vhich has the

lstinct advantage chat it keers the simple fore of (10)

The situation just described is the well known Courant Instability,

Other mathenattcal instabilities arise in the neighborhood of shocks and

SULLI others must be consi

Fed vhen two dimensional {low problens are to

be solved, The electronic computer will becone an even nore inportant tool

in hydrodyeamtes. But it can be useful only when handled vith caution and

mathematica! insight. The use of computing machines requires ingenuity

which {8 most un-eachine-Ltke.

---Page Break---

as

APPENDLX

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 (itghway and Rattroad cute)

N. Beylerian, Department of Civil Engineering

Project Chariot (Harbors)

D, Taylor, Department of Chentesl Engineering

Project Gasbuggy (Gaewell stimulation)

F, Mutloz-Ribadeneira, Department of Chentcal Engineering

Mining Avplications

K. Pedersen, Department of Nuclear Engineering

Geotheratl Heat and Salt Water Conversion

M. Saca, Department of Physics

Teotope Production

|

---Page Break---

89

T, Interoceantc See Level canal

. AL On site aurveys:

to stare January 1967 (U.S. Covernment)

Acoustic Wave Progran: Rockets 100,000-200,000 ft (U.S. Government)

: metal chaff.-radar tracked

Radiological Safety feasibility of using

?nuclear explosives i

1. Marine phystochentarry and biology

2. Fish resources in estuaries and oceans on both sides of the

iethous

3. Terrestrial, freshwater, agricultural, and marine ecologies

Radtohydrology

5. Runan ecology

Radiation dove eetinatton

D. Meteorology: Transportation and deposition of radioactivity

Studies: vind patterns and rainfall two weather

stations

m sseareis lopment

A, Spectal Explosives and Baplacenent Techniques

3. Cratering Calculations

C. cratering Experiments

TIT. The Transiethnian Canal

Froblens: Raottonal

Political

: All economic consequences are predicted; complete safety is

asnured.

. IV. Wuclear Explosives: Cheapest vay of moving large quantities of earth.

---Page Break---

Ghentcal _Mucleae

size tare Seal

Eersy Density Salt Large

Temperature tow Very igh .

Pressure High Very. High :

?The largest conventional explosive ie larger than the snallest nuclear

explosive.

Prices: $350,000 - 10 kt

?Acaing and firing included

$600,000 - 2 Me

20 Kt of Ter = 94x10?! ergs

= 7.961009 aru

= raxtol? ators:

Immediate Danger fron Explosions

HW. E, ? blagt and throwout

seve, plus thermal and nuclesr radiation

Termal radiation {8 not emitted because the explosions are contained.

The miin immediate danger {a from falling debris and, over « bigger distance,

from shock transmitted through the air. Fifteen miles vill elininate any

?actual danger of these types, ££ 10 ME Le upper Limte on ytel

Excavation Technology - Technical Questions

1. How does crater size depend on geological properties?

can data on crater size, seiente effects, acoustic waves, and

radioactivity distribution of lov yield experinents be extended

to megaton range?

3. How do nuclear charges in a row interact?

---Page Break---

4. Gan projects for nuclear excovation of channels through torrain

varying, in oct type and elevation be designed with confidence?

VI. Interoceanic Sea Level canal

Aclantie-Pacitic Interoceanic Canal Study comntssion

Investigation by AEC

U.S. Aray Corps of Enge.

Panaoa Canal Co

Routes

Route 17 - Sasard(- Norti - Darien - Panama

Route 25 - Atrato, Truando - choco - Coloubia

VEL. Crater Design - Parabolic Approximation

---Page Break---

2

?PROJECT CARRYALL

3. Rfos-Carva jal

?SOURCES OF IKFORMATION

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Desiga Studi

ina Nuclear Excavation Project Carryall.? Presented at the

?43rd Annual Meeting of the Highway Research Board, Washington, D. C., January

13-17, 1964, Abridgnent tn UORLA7632, pp. 11-16.

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Departnent of Civil Engineering, Stanford University, Stanford, California,

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Zodtner, Uarlan, ?Operating and Safety Problene Associated with &

Nuclear Excavation Project," Presented at the 43rd Annual Meeting of the

Highway Research Board, Washington, D. C., January 13-17, 1964. Abridgnent

fe VORL-7632, pp. 17-20.

4, Prentice, H. C, and Peterson, E. T. Ls, Jr., "Construction and

Feasibility Associated with Nuclear Excavations.? Presented at the 43rd

Annual Meeting of the Wighwy Research Board, Washington, D. C., January

13-17, 1986. voRLA7632.

5. Talley, W. K., Rattzoad Engineering

1. Rerouting

14, Expansion of bighvays and ratlroads have been Limited by tools and

equipment avatlabte.

>. Changes in routes pay through savings in fuel, wages, reduced time,

reduced distances, ete.

IZ. Proicet Carryall

4, On a portion of the transcontinental matn Line, 165 miles tong,

between Needles and Bastow, California, there is a 78 miles stretch of

---Page Break---

9

Fallroad 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 Dese:t.

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 Gokfs toa Low point of 200 fe at Cadiz and chen

Fising to an elevation of 1900 ft at Ash RLLL,

+ Cutting through the mountains on a direct Line woul

1. ahorten the distance 15 mil

2. maximum grade would only be 1 percent with « maximun curvature

of only 1 deg.

would save an hour in travel tine

Pa

se would require 4 2 atle long tunnel (using convention#l means

for Lts construction),

1. Main dteadvantage: expensive and costly to aatatain

©. Californta Division of Highways

1, wan snvertigating possible shorter routes for U. 8. Highway 66,

which wil becone Interstate iighvay 40,

£, Joint feasibility study for the purpose of utlltsing nuclear excava-

. ton eechoology was undertaken by che rallroad company and the highway

diviaton with the technical a

ance of the ABC and the Plovshare

Division of UCRL. (Code nane - Project Carryall.)

---Page Break---

mr.

Details of Project Carryall

The cut was to be about 2 miles long vith a maxisun depth of about

360 ft and a top width ranging from about 600 to 1300 ft.

A total roadway width of about 330 fr was to be provided with the railroad (double track) located along the toe of the southerly

slope, the eastbound highvay (2 lanes) through the center, and

the westbound (2 lanes) at the toe of the northerly slope. Ultinate ?expansion of the highway to a total of eight lanes was taken into consideration.

Geology of the area

1. consists of soft voleante rock underlain by meta-granite

rock.

tthe use of 22 nuclear devices

Moclear excavation design contenplat

ranging in yleld from 20 to 200 ke (eotal yield: 1730 ke), and

arranged in a ro (vould 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 vith © 100 kt nuclear explosion.

Radtological Safety

1. The cloud of dust resulting was low radio~

inated to po

activity levels, not sufficient to be harardous.

2, Entry for an S-hour work day should have been possible within

4 daye,

In Ae Bla

1, Town of Anboy - major problen but still no damage was expected

1. below the threshold of danage

Ground shock

1, Some minor damage, auch ae cracked plaster was expected at Auboy.

2. Another problem - 900-psi gas Iine located 2 1/2 mil

south of

the cue.

---Page Break---

9s 4

WW Sonmtrustion Coats (Crom Wuclear Civil Engineering by Paul Kruger,

Technteal 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-thot construction (holes) 2,289,000

?Wuclear excavation costs 21,940,000

Poat-shot construction of RR 2,874, 000 |

Post-shot construction of Righay ?£4232.009

916,765, 000

23 devices @ $0.5" (eat') ?11.300,000 j

wnas.

SanceLlation

4, Project Carryall was cancelled,

---Page Break---

9%

cuantor PRosECT

1M, Beylertan

ARBORS:

In order for nuclear devices to be economical

ctvil engineering

tools, a project must be of extremely great magnitude. A large scale canal, a mountain pase, & harbor are at thie tine the most likely targets

1s harbor project -

of application of suclear energy. We shall concentrat

?ogect? CHARIOT.

Unfortunately, natural harbors do not occur vhere they are needed most,

although man hae LE to this fact by settling where they do

?occur naturally. Nevertheless, nev horizons open, and regions hitherto

hostile have to be explotted for their wealth. Since sen transportation reaains the least expensive neans of transportation, harbor factlities are needed carly in the development of an area.

The choice of # site for « future harbor, and ite mathod of construction

will be decided after weighing several factors, such

cost, safety, urgency,

and a host of intangibles (euch as politics). From an engineering view-potne

consideration must be given

a. expanding already existing factlities, 1? aay,

b, Improving extating natural features, auch as deepening and widentog

of a river mouth,

lowering the ocean bottom,

@. construction of wave breakers,

2. carving # harbor froa the lend,

f. satatenance protest,

other considerations.

---Page Break---

7

As for the choice of the method of construction - that (#, using nuclear

devices or not - we may note that under only few condi tions

re nuclear devices

considered fea

ble at this tine. However, sone tines those conditions do exist,

and nuclear energy aay yet prove to be the practical solution for harbor construe

lon on the West Coasts of Alaska, South Anerica, or Australia. Sone of the

: Feasons common co those areas that nake this method of construction practicable

4, Freedom of choice of site, rather than dependence on natural features,

>. Sparse population; making relocation costs aintnal,

+ Generally deep ocean approaches (or freedom from exct sive sedinenta-

Eton). We may note that cratering under the ocean floor is not an

economical process, since craters will be shallow and wide. Te wae

considered on the Eastern Cost of Australia, and abandoned.

4. A need for « hartor.

The Alaska site satisfied the first three considerations in general, but

ice use and need were questionable. It would probably becone an inportant

area for che population in tine, and fishing boate would find refuge in the

harbor {n eine of need. But those vere not considered to be enough, and no L

clear evidence was

fen that a harbor would in a

?apprectable nessure boos 1

the econcay of the

rea. The area has no mining prospects or tinber Lands.

?WOCHTON IN ALASKA AND GEOPHYSICAL CHARACTERISTICS OF THE AREA:

?The particular site chosen on the Western Coast of Ali

ka has appealed

to engineers for the following reasons:

4, Te Lo centrally located, that is to aay, ¢ would serve « coastline

. fo the north and to the south of the site, from the Bering Straite i

to Barrow.

D. This site fe relatively ice free, and the Chukcht Sea ie relatively

can in this ares.

?The area ts thinly populated i

??? sss

---Page Break---

4. The approaches are naturally de2p enough for fishing boats sailing

im the Chukeht Sea,

?the geophysica! characteristics of the area can he summed up as follows

Qeean chatacteristice; The Chukchi Sea ie, in general, « rather shallow nea, ft hao # depth of about 50' at aboue 2 miles from the coast, and depths

?of more that 150" anywhere between Alaska and the Northeastern coast of Siberia .

?are rare, Near che Chariot site, ocean depth reaches 15-20" imedtately, then

gradually reaches 50' at a distance of 2-4 niles.

Gurrents: Currente are northwesterly, about .5 stles/hr, paralleling

he dott

contours. In general, surface currents seen to have the direction

of the winds, when the latter are strong.

Goastel Features: Though the coast north of Point Hope te rapidly being

eroded by atrong winds and waves, the more protected shore near the Chariot

Site docan't seem to be eubject to any fmportant 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" (hundreds of cubic yards

per hour), to be deposited back when calo roturne.

Floating fee is Cound 6 sonthe # year, nevertheless, the area te noted for its relatively large amounts of open water. In Juanuary and February ice cay fora very rapidly. Average thickness of ice aay be taken to be about

5-5". Exceptional cases occur when icebergs are brought to the Alaskan

coast by high winds.

Climate: This region of Alaska {s in the Arctic Tundra belt that covers the northern coaste of Alaska, Canada, and Siberia. Ic hae a rather severe

clinate with etght sonths of winter and four sonthe of epring type weather. , in vines, low teaperacures may be -40°F and high tenperatures around

Exeering. In summer, freezing temperatures may occur any day, high temperatures

---Page Break---

9

over 70°F are also possible. In winter, there are 26 days without « suariee,

and {n sumer there are 54 days without « sunset.

wing

In winter, northerly winds may reach gust velocities (over 80 mph),

feven in summer 30 mph winds are not uncommon. Storms may he expected half the

?ine even in sumer. Surface winds seen to have @ depth greater than 1500",

Of great importance to us, since any fallout will depend on it.

Hydrology: Average annual precipitation 48 about 8? in the form of snow,

that will melt in sumer to forw che many rivers and creeks of Alaska. In

{the Chariot site the Ogotoruk Creek my discharge much a# 1260 cu ft/sec

st tte hetehe. Te summer average {2 50 cu ft/sec, From October to May there

14 no flow.

Although not in any large quantity, groundwater is found to be present

in the permafrost and under it; some velle

nd aprings are supplied by those

waters. The creeks, rivers, many lakes or ponds form pert of the overall

water s{tuation. In sumer, sone rivers a

wells are utilized to supply water

for hunan consumption, but in winter snow {e the primary source, as vell a daring hunting and fishing trips.

* The Soll te mudstone (

pernenently frozen starting at a depth of 1' or 2' to a depth of about 1100",

1d sandstone) around the chariot site. te ts

Within 100 yards of the coast thie depth 1s nearer 950?, This means that all

devices would have to be detonated in frozen sot}.

Tests near the surface show that frozen mudatone has about 12.5% motature,

Te Ls ehoupht co be somewhat leas at burial depths.

The specific weight of thls sol} ranges frou 2.5 to 2.74,

More exact data on porosity, water content, ete., should be avail,

by now.

---Page Break---

BIOBNVIRONMENTAL FEATURES

Te Se found that the Chariot site was almost continuously habitated by the Eskinos from the aiddle of the 18th century until recently. Nowadays, the nearest communities are at Point Hope (32 miles, pop. 300), Kivalina Go miles, pop. 140), and Nostak (75 miles, pop. 270). The Eakinos have traditionally been hunters; they st{I1 depend on hunting for thete food. Miebing in the Chukchi Sea seems to be a recent development. The many Laker

fend ponds 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 extet here. Out of 60 know species of

amais in Alaska, 31 were found in the area (polar bear, walrus, seals, vasles, caribou). Fifty-five epectes of freshwater and marine fishes, 300 epectes of Flowering plante, 120 species of inland bixée, and more than 1400 species tn ?other groups also exist here.

Land animals are fev in nusber (hundreds of caribou), but nine species of birds have @ 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

tvo miles of ground sero.

?At thie tine £¢ must be acknowledged that under the guidance of the ABC wore than 40 separate investigations were conducted to obtain information on uch varied features as:

Climatic cycles in the atmosphere and in the? sot,

Geological and hydrological features,

Mechanical properties of the soil,

Chentcal composition of the soil and bodies of water (contents of calcium,

nagnesim, potassiun, sodiun, atrontiue, etc.),

Complete ecological surveys of the land, the bodies of water, and the air,

---Page Break---

Radiological analyses of all types of Living organiems, and terri

erst

materiale, (Such as deternination of radioactivity and stronttun-90

fod cestua-137. levele in Alaskan ant:

DESTGN CHARACTERISTIC:

soll, and air.

?The harbor would be carved out of the land by detonating four 20 KE

. devices to ake an entrance, and one 200 Kt device inland was expected to

Provide a cireular harbor of 1800" dianeter. However, recent ti

8 have

indicated that the harbor would be closer to 1500",

?Te Cree 20 Ke device would be placed near the mouth of the Ogotoruke

Greek, at about 200! from the const, at a depth of 400". The other three

20 Ke 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 1

20 Ke

device tm the WW direction, at « depth of 800',

Taking che Depth of Jurial as the baste, and using Pige. 4-50 and

4-51 (Cum) with 400/20!/3 4 «50,6 mperl/3-4,

+ obtain,

Apparent Crater Radive: 45x2,41x3.28 = 380

Apparent Crater Depth:

25x2 4123.28 = 200!

Other Data: Lip Hetght: 50?

Depth of True crater: 520°

Radiue 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 attch.

>, No thermal effects are expected,

~ Sy AE Blase: Fig. 4-55 (CUMR) may be used to draw the naxtoum air

Hast ve distance curve for che total 280 kT charge.

; (CONE), the abscissa is divided by aol! and the ordinate is

In Fig. 4-55

eee

---Page Break---

Atvided by 5, since atr blast seens to be only 20% of what it would

be if the blast were in the atmosphere. See accompanying graph.

4, Selsete Disturbances: In alluviun the surface velocity is given by

Equation 4.3-2 a8

veo BR catee for tm 8 30h

at closer ranges (fr:

the chone 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 ailes using Eqn. 4.3-2 (not applicable)

IE the 10.en/aee velocity 1 accepted as the plaster cracking Lintt, then no damage would be expected in any of the settlenents in the

neighborhood, eapectally since no plaster existe there.

?. Throwout (very epeculative)

Dowwind 1/4 mile alsost 120"

Crosavind 1/4 mite 40?

Downwind 3/49. almost 1/4"

Crosewind 3/4 m. 04

lout: Approximately .5% of total produced r:

carried by winds (S knots), and 80% of this vould fall within 20 miles

downwind.

The explorions were inlttally acheduled 40 that fallout would be over the

land. However, those winds were not considered reliable, and finally it vas

anreed upon that northerly winds vould be utilized despite inherent difficulties

tn collecting samples after the event.

---Page Break---

---Page Break---

rate after one hour -

Point Hope

Chariot Site >

Estimated Dose Contours

---Page Break---

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PROJECT CHARIOT:

if

carried out ae planned, the fol lowing would be a sumary of effects,

as anticipated:

b

There would be no need to evacuate any of the settienents,

No structural damage was expected due to setamie effects or air blast.

Though

fed on statistical analysis, some windows might be broken as

far avay as Kotzebue,

In the imediate vicinity of the site, all Life might be assumed

destroyed within « 1/2 mile radius. In case vinds were seavard,

deatruction of aarine Life would be snaller, oving to the cushioning

effect of the sea, and already spar:

marine Life, Plante would be

buried under throwout material tn this ares,

?The greatest ecological change might be due to slides of the sea cliffs harboring the five colonies of birds. Particularly, {¢ the teste were performed during the nesting season, damage to egge aight effect tmportant changes {n the bird population.

Due to lack of experiments under ainilar etrcumetances, conditions at the entrance to the harbor can't be estimated yet. tndlxtrene cases,

the entrance may be blocked completely by throwout witertal, 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, tt would take che ocean a few hours to LIL the harbor.

The Ogotoruk Creek would be dammed about 2000' upstre:

thus forming
4 lake. Another dam would be created at the present location of the Cpotoruk Creek mouth. Rither a second lake would fora, or the creek ould erode sone of the present coastal zone and form a lagoon, as te

the case presently.

---Page Break---

i

}

~ 106

concLusron:

The Chariot Project was shelved several years ago. Thus: engineers have

been denied the chance to apply nuclear energy to 4 useful project at a very

?seall ecological cos!

btologte

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 fora, following

the formation of the harbor.

---Page Break---

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PROJECT cAsnvCcY

D. Taylor

Coal and fuel of1 are used to produce 60% of the electricity in the
U.S. (1), The burning of this fuel contributes about 64% of the S02 entteed
to the atmosphere, In 1963 this amounted to over 10 atilion tone of $0, (2).

The Health, Education, and Welfare Department has already set tight
sulfur content Levels on fuels burned by federal installations in sone sa jor
citien, It has been eatinated that {£ the sulfor emtesion standards of fuel
Teatrictions nov recomended by HIV vere to be mde effective at this noment
throughout the U.S., more than 90K of the 240 million tone of col presently
Purchased by electric uttiteten could not be consumed (1).

?Tere are four possible ways to solve the problem of $0; entssion.

1, Wuctosr Power. The use of nuclear pover 4s expendi:

at a very rapid

Fate. About one half of the new pover plants being ordered are nuclear.

Some

eimates forsee that nuclear energy will produce 20% of our elec-

ertesty by 1980, Even then, tnereas

demande for power will cause

75% tnereas

An foustt fuel consusption.

2. Sulfur dioxide reaoval from stack gaat

Much research hae been done

on this aspect of the problem, but « large scale, econonic solution hhae not been found.

3. tamovat of wslfer frm ott nd coel before tt ts burned, poe ott tie

ts povetble but expentve, The caribbean reftnerien, antch treat

crude vith 4 igh eulfar content, would be ramutred to double thete

. feuipaent {avestntnt i order £0 produce restdue! fuel oft with 0,58

sulfur content (1). The 20 80 60% of the sulfur hat ta organteatty

bound in coal cannot be removed. |

|

$$

---Page Break---

peptace cont and off with natural pas, Toeural gas te tow (o sul

content, It is presently weed to produc. 27% of our power. Bat

aunriies are abort. Our reserves tn 10:7 are at the Lowest value ti

L yeara, We only have a reserve of 10.5 years, Tf New York City alone vere to use natural cas {natead of coal and ofl, an inerense tn che total supply of yan of 260% would de required.

so anyone fant line with the probles of increasing natural gar production, quctene sriulation of gas wells (sa very ateractive possibility. Sone cstinces soy that nuclear stimulation would imedtately double our reserves of natura! cas. Corpantes feel that quclear etisulation (x a worthwhile ivestnent. 1 pollution standards vere set and enforced, the value of natural gas vould probably (nerease and make nuclear stimulation even sore valuable.

tn an idealized, eylinérteat sodel of # gas reservoir the gas flows Lacunily from the reservolr toto the well bore. A gtven particle of pas sust flow throueh every cylindeteal elenent of the reservoir. At the outer boundary af the reservoir, the reststance to flov 1s anall because the area available for

Clow {a quite Large. But sear che vell bore the restatance is considerably

1

ve because the area is drastically reduced. The purpose of nuclear stimu

lation is to remove as ouch of the resistance as possible by enlarging the

radiue of the well bore

Let ve show vby this

fs true. One begins with Darcy's Lav for flow

ehrough @ rorous medium.

?me x) a

velocity of flow based on the entire area

K = porveabiltty of the medium

*

viscosity of the flutd

bb = the pressure difference across the elenent, 2

x the thickness of the median

---Page Break---

tos

Me ox ? 90,

car

+ fg @

For cylindrica! coordinates, radial flov only,

2 ye-ka@ o

=

the folloving atsumpetons will be nde,

Le yltndeteat aodet

2+ tamtner flow

3+ constant viscostey

4+ Uniform temperature throughout the reservoir

5 Constant paraeebiiity

5+ The equation of state of ee gar te

mm

Pv = ant or po BL ?

Bron po Be ?

HE we enamine period of tine that Ls relatively short compared to the

total production tine, ve can coneLder the reservoir at being at steady state,

Than the following continutey equttion must hold

= Pav = constant = 6 6

Where

. ?@ ~ mass flow rate of natural gas

? P= density of the sas 1

Seetaeng tno ce comity eution te prone exrestnt for

: A, and v gives |

mu a eh) (- i

(AGrm\ey co) |

|

---Page Break---

uo

hy = hetght of the reserwir

1 = tenperature of the reservoir

Separation of variables and integration gives

- Mh kp? - Pe?)

BHI jp «1 le) o

args

here

radius of the vell 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 toa volumetric flow rate at standard

conditions and subsequent combination of all constant ceras gives

x (@o? ~ Pe?:

eee ?

From Equation (8) 1¢ da evident that the production rate can be increased

either by decreaeing the pressure in the well bore or by increasing the radius

of the well bore. A decrease in Py increases the pumping cost and becones unreasonably expensive before substantial gains {n production rates can be obtained.

?the size of the bore can be increased in the following ways:

1. Drill a larger hole. Thts 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 tines that obtained without shooting have been achieved.

3. Wydraulie fracturing. A liquid under high pressure is punped into

the reservoir to fracture the rock. Sand is mixed with the Hquld

to hold the exacke open after the pressure ts released. Hydraulic

---Page Break---

u

fracturing soperines tnert

ses {nttial production rates by a factor

of 10. In low permeability e

VOLTS production gaine are rapidly

lost after an taitial flush in production caused either by convene

onal shooting oF by hydraulic fracturing.

4. Im Limestone reservoirs the size of the well bore can be increased

by pumping HCI tnto the hole to dissolve the rock. Tite is clearly

Himited An possible applications and ts very expensive.

5. Nuclear Stimlation

The U.S. Atomic Energy Comtesion, the U.$. Bureau of Mines, BI Paso

Natural Gas Company, and the Lawrence Radiation Laboratory have investigated

the possibility of stimulating a sae well with nuclear explosives. In October

of this year the first actual t conducted

eof the progran, Gasbuggy, will

?tm northern New Mexico. (Data for Project Gasbuggy are given in Reference (3).)

The site selected t6 tn the central section of the Sen Juan Basin. The gas bearing portion is called the Pictured Cliffs formation. This formation is 300 fect thick between depths of 3850?. The atte is remote, but accessible, the

nearest house 43 five a

usmy and the nearest city, Faraington, is 70 ati away. The porulation of Faraington is 23,000. there {s enough drilling tn the

area eo that the reservoir ta well el

ified as to gas content, permeability, fete. but only one gas well 18 near enough for shock damage,

?Another advantage of the location 18 the fact that the peoole and govern- ene of New Mexico have accepted nuclear testing. The conservation coutasion

Mill probably permit sone shifting of al lowables between other producing welle

imo

nF that maximus production can be studied,

There will be two preshot holes, 100 and 200 feet fron the enplacenent

hole. These are to confirm.

1, There 18 no mobile water tn the vicinity of the shot.

---Page Break---

2. The gas content and permeability at the site

3. The performance of an unetimlated vell

These two holes will aleo be used co study the extent of fracturing.

?The shot vill be at the botton of the Pictured Cliffs formation which

consiete of sandstone and shale, The proposed device 1s to have a yield of

10 Kilotons. The expected effects of the detonation are given in the .

folloving table:

covey Radiua 6st

Rubble Chimney 300"

Vertical Fracturing 390°

Fracturing Radius 195" (conservative)

430" (optimistic)

The predicted gas recovery over 4 total production period of 20 years

fand with 160 acre well spacing ts expected to be

Conventional Stimlation 537 x 108 fe 10% of total gas present

Nuclear Stimulation (conservative) 3520 x 166 fe 67%

Nuclear Stimulation (optimistic) 3748 x 108 fe? 71%

A atudy (4) was made of the econcaice of nuclear stimulation, The study

was sade for the proposed Dragon Trail project to be conducted by Continental

041 Company. In this particular case, it is projected that a well stimulated

by miclear explosives will produce about the same anount as four conventional

wells. These four conventional wells cost $100,000 and the return on the

{nvestment ie 29%, The return for # nuclear stimulated well depends entirely

fon the cost of the device. If the figures given in Reference (4) are used with

fan estimated cost of $50,000 for drilling the enplacenent and the re-entry holes, .

che fcl!oving relatfonshtp between the cost of the device and the return on

the Eotel tnvescccnt Ss obtained.

---Page Break---

us

Goat of device eure

600,000 a

$225,000 wee

$113,000 at

?The AEC has announced & price of $400,000 for the 40 kiloton device to

be used in this application (5). This would give @ return of somevhat 1

than the 29% for conventional vells.

The attractiveness of nuclear stimulation would be considerably greater

Af the cost of the device could be lovered. There a

several sedinentary

basing in the Rocky Mountain region that have more gaa than Pictured Cliffs.

Conventional stimulation cannot recover {t. If Gasbugsy proves successful,

?enis regton alone could us

30,000 device

TE they were produced in such

great numbers, the cost of nuclear explosives would surely decras

Contantnation of the atmosphere by venting radioactive ga

through

fractures or through a failure of the steaming in the enplacenent hole te

considered remote based on the expertence of previous teste, Shoal had «

yield of 12.5 kélotons of a depth of 939 feet. here wes no venting. We

can conpare these figures vith those for Gasbuggy whose yleld and depth are

to be 10 ktlotons and 4150 feet, respectively.

All geologic studies of the ares indicate that there te no mobile water.

These conclusions will be checked by the two preshot welle. The near:

water wells are 50 niles avay and take thelr vater froma level 1700 fee

?above the test site for Gesbussy.

. Tf chere {9 an aquifer near the formation of interest and either the

rubble chimney or extensive fracturing breaks through to the water, there {8

4 possibility that the cavity and rubble chimey would be filled with water

thos rendering the well useless. No crouble of this type ie expected in

_? ss

---Page Break---

ne

Gasbussy.

For the 10 kiloton device to be exployed in Gusbugay, Festdential plaster

would crack within 1.6 miles, There is only one gas well near enoush (500 feet)

to be danaged by the blast, This well will be considered « part of the expert

reent to determine the range and extent of the shock danage.

Radioactive solide vill not be a problen. Nearly all of then will be

trapped in the melt at the bottom of the cavity. The gases that will be

troublesome in an all-firston explosion are

12 aig

Krypton 85 10.3 yeare

Xenon 133 5.3 daye

Todine 131 will be present, but tt can be renoved by lecontanination

procedures. After about 10 months the radioactivity from Xe and I would be negligible, but Kr®5 would be 690 tines the asount permissible to the general public.

?The first step will be to bleed the well and dispose of the initial radio-

active gai

Tis might be done by burning. The best dilution in the rubble

would be accomplished by evacuating che well bore and letting tt refill in

cycles. In this way the entire volune of the chisney vould be used to dilute

the radioactive gat

Another dilution will occur when the produced gas {s fed to pipelines carrying gas from other sources, The dilution here {8 about 1000 to one. As soon as the mixture (gas from Gasbuggy plus gas already floving in the ine)

hi

a radioactivity low enough for LEC (Ite

Exempt Contamination), Casbugsy 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

---Page Break---

ns

Fadioactivity would be 1/7 of that alloved the public.

oro Tests:

TE Gaabu

yy {8 successful, {¢ te presently planned to conduct Dragon

Trail about three months ater. Tis test will be conducted by Continental

O11 co. the test afte te in a formation 400 feat thick at a depth of 2700

feet in western Colorado. After Dragon Trail will cove Project Rultson (5)-

Te Will be in the very deep, thick, iaperneable Mesaverde foraation in Colorado,

?Te plans for Rulison specify tvo vertically placed shots ve

fated by 1000

feet in elevation.

Possible improvenents of nuclear stimulation beyond these hree tes!

?The development of explosives having a diameter of seven inches.

?This would permit the use of existing wells as emplacenent holes,

2. The development of technique for directing the force of @ shot

{nto the moe: productive formations. This might be done by an

array of cvices Cred simultaneously of in sequence

LETERATIRE CLTED INT < LECTURE.

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16

MINLNG APPLICATIONS

¥, Mufos-Ridadenetra

Introduction

the

possible applications of Plowshare technology for copper mining that

have appeared n the Literature are:

1

2.

3.

Preparation for open-pit-aining: removal of overburden

Preparation for block-caving, shattering the ore body to factittate

renoval

Preparation for in-situ leaching, rendering the ore body permeable

to leaching

Block caving and leaching in-eltu are to be discussed in this section.

We are going to concentrate on leaching in-eitu due to the fact that it

eliminates major disruption of the geological systens at the surface, since

no overburden need £0 be removed nor solid gangue dumped. Spent leaching and

possible cementation solutions must be dispos

?can be made rich enough and the ore body {# large enough to ake electrovinning

of, but, Sf the leached 1iquor

practical, waste products can be reduced to # sinioum.

mt

Re

re

6

Arenents coastal ation

an example, Lf the ore body has copper:

?an ore body of suffictent size

copper content of at least 0.3%

ore body composition and structure vhich allows physteal penetration

of the leach solution

Tow acid consuning gangue

?A contained enviroment which provides for recovery of the leaching solutions.

copper preset in a readily soluble physical and chemteal stat

---Page Break---

These conditions either must extet initially oF should be achtevable by

Teasonable engineering procedur

Further the following supplies and ;

services mst be available.

7. Sulfurte ackd or other suitable leach liquors at low cost and in

adequate supply.

. 8. for concentration, thin tron sheete

9+ Liquor which 4s rich enough and abundant enough to justify the

capital tavestoent tn

Lectrowinning of the copper.

Wow, 1f we consider in thts proc

the application of Plowshare tn

itu leaching, the following requiresents should be

Folfitied.

10. An ore body that extends to suffictent depth to permit the deep

?emplacenent of the explosive. |

M1. Substantial overburden to assiet entrapping any radioactive effluent

?and make the ore body relatively unattractive econonically for any

other technology.

12.

?An ore body of significant size to alloy for significant tests, such

that the logs as a rt

Lt Of the test would be significant in the

total copper resource

13, Location where the combination of deep enplacenent, heavy overburden, !

low surface population density with few surfa@§ structures would make

the potential danage by the test shot reasonably snail, \

We will see later how we can meer all these requirements.

TIT, Copper Bearing Ares in Puerto Rico

. ?The known copper deposits in Puerto Rico are found along the south western

?edge of the Uruado pluton which 18 an intrustve complex of granodiorite, quarts,

Storite, and minor gabros

---Page Break---

us

?The copper mineral ie chiefly chalcopyrite (Cu FeS2) and there are also

chaleoctte (C28) and Covellite (CuS). To the northward the cretaceous-Bocene

wells including the Pluton are overlain by a thick series of limestone

sdiments. The copper ore is located in a zone of hydrothermal alteration.

The general structure trend e WiW-ESt

A test hole for oft was drilled to, 6434 ft at @ point of about 10 Ka
?east? of Arecibo, near the coast and thie penetrated 5580 ft of Linestone sedt-
ments before encountering volcanic sandstones or pluton rocks formation. This
Aa 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 hydrotheraal zone continues any considerable distance north-

?There are also the probabilities that it aay end in a short distance

or that it may increase in size.

In Puerto Rico we have to consider the following facts

Limestone does not appear to be mingled with the ore body.

2. The structure tende fairly deeply as far as 5000 ft and the over-
burden might be turned to advantage.

3. chalcopyrite {e a very insoluble copper ore in diluted sulfurte acté
solutions, but shock-heat effects may change completely the solubility

problen. This ts uncertain

vel as {9 the physical location of «

suitable ore body and characteristics.

4, land evacuation, shock and earthquake effects, as well as socto-

political problens may exist.

i 5. Pollution problens a

co

ely reduced, and no danage to landscape

As expected, but both problens are becoming a great issue in Island

poltetes.

Im the case of leaching in-situ and in block caving operations the nuclear

explosions are completely contained underground.

---Page Break---

ne

IV. Considerations of Nuclear Effects

?As a result of & completely contained nuclear explosion # short-lived

cavity would exist. The roof of the cavity would collapse and the caving

would progress vertically upward. We are interested in knoving the dimensions

of the cavity and chimney, the properties of the material {nside the chimney,

the econoaies regarding leaching in-situ of the copper

wnke effects, and

possible ground water contamination.

A. Dinenstons of ty, chimney and other parameters

The dimensions of the cavity are given by the following forsul:

us

nee Soe o

tere

yews

ws yea

© denatey

b= overburden

that reduces to

us

nee H ay a

or

© 49 « constant depending on gamma, or on the quality of enviroment in which

)

the device is exploded. The hetght of the chinmey is related to the radius

of the cavity by the form

HORR @

Where K Ln another enpirical constant.

. ?The depth of burial for which venting 4s prohibies is given by:

Dob = 450 w'/? (rey)

|

|

er

---Page Break---

20

calculations for depth of burial with respect to yield of explosives are

siven 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

Tt ie clearly seen that ve need a mintaun depth of about 1000 ft for a 10 Ke

?explosion. Since ve are interested in using the highest possible yield without causing seiamte damage ve vill use 950 ate as Dob and calculate the cavity and

chimey dimensions using the folloving paraneter

? = 59.0

K = 435

P= 270

Dob = 950 = (3000 fe)

TABLE 2. Calculations of Cavity Chimney

Dimensions and Econouics

j@eyw 1 5 10 23 100 200 Ke

Ws 1 un 2.16 2.93 485 5.85

aR oot 15.50 19.6 26.8 42.4 53.2

eH 39.6 37.50 85.5 us. 186 232

wrth 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

"Yor EcononTe 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 eed 4 10 Xt explosion. ?This vill

Fequlre an ore body of at least 40 m vide by 90 a high.

3. Setente Considerations

A Gamage ehresholé For plaster cracking of 810 ca/sec surface

velocity h

been agreed upon.

Due to the dense population of the Leland (about 300 persons/Rx?),

ive or ven Xm te che maximum distance to which we may have the maximum surface

weloctty sreater than 9 cn/eee, at us consider the ylelds of explosives related

o the surface velocitiea, calculated according to the folloving formula:

Ven, WO67 pets w

where

= constant

¥ = surtace vetoctey

R= radtus (ta)

w= yiete (tone)

(0-4 fonction of the matertal = 0,082 for granite

TAH 3, calculation of Surtace Velocities eon) tonto? asuio? 100210? 200m10?

wos7 470 1000 2250 3631

tio Las ase bas as

¥s ae 10 16 28.4

Pteplaced population in 10 Km = x10%x300 = 94.200

3 im = 1257x300 = 23,600

?These results basically indteate that, due to the teland denatey of Population,

we re forced £9 use explosives with a saximin yleld of 100 KE for no damage

Tocated outolde a radius of 10 Xn, oF « maximum yield of 25 Kt for « radive of |

3 ha.

|

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we

©. Gharacterietics of the Rubble Inside Lanes

Te chimney rock frageent size is

function of the cavity size,

Aistribution of original faults and fractures, mechan{cal and thermal stresses

applied by the explosion and the breaking and grinéing action during collapses.

?The formation of rubble filled proc

ee {nwolves & number of random process

so statistical techniqu

are appropriate in eatinating the rubble stze

diacrtbutton.

tn practice rubble fraguents have been found to vary in size fron

that of sand or dust to & naxisun dimension of approxinately 1/4 of the cavity

radius. the particle size distribution varies through the chimey with emaller particles concentraté

at the sides and bottom of the chimney vhere crushing

and grinding may be expected to be most pronounced.

?The following operational formulas have been used for determination

of the paranetes

needed in the calculation of the specific surface and

permeability; aseuning @ logarithmic distribution the formulas art

2 a

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) ve know (5) and then (7). The calculated

?values are substituted in (8) and the average dianeter in relation to surface/

volume {s known. We also know that:

Asap o

vee

- qo)

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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. Lf 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 aince sharp rubble particles have been observed

in tence. 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 perweabtitty and ¢

the porosity.

Due to @ nuel

sF explosion the effective porosity of the rubble ts

|

Permitting penetration of the sulfuric actd solutions more easily.

greater than the original rock giving as @ 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, Avatlability of Geothermal Heat

?The wean heat flow from the interior of the earth in continental North

?America is approximately 1.2 x 10° cai/en? sec.

?Areas vith 5-10 times che average heat flov are known. One such area

?extends from the Easter Aslands in the Pacific into the southern part of the

United States, This te an area approxinately 50-100 mtles wide and several thousand miles long. Wheres

in an average area the tenperature gradient i

~1°G/100 ft, based on the heat flow and the ave. K for rock, in the areas of

high heat flow the gradient must be ~10°C/100 ft. Thet of high heat.

Flow are exclusive of those vith hot spring activity or recent voleante action.

?the Intter show thenselves by hot epringe or steam rising from the earth.

Te Ls postulated that the sechanten for these cases 1s that water of # meteoric A

origin and at depths on the order of 1000 ft cools the magnatic body and carries

the heat upward, thus heating large volumes of rock. The heat ts stored in

these enormous quantities of rock which aay have volumes of 10's of cubte miles

In sone of these hot pring regions temperatures up to 500°C may be found at

10,000 ft or te

The heat of interest im a plovshare project ts that which does not appear

lat the surface and is therefore not readily available by conventional means.

TL, Availadiiey of Nuclear Explosives |

Stoce we are talking about proposal for the extraction of this heat in .

where it does not appear at the surface, it 1s necessary that the heat

bearing rock at large depths be broken up to provi

2 larger heat transfer

faxea and at the sane tine saaller distances for thermal conduction and also

---Page Break---

ws

to provide access for the cooling flutd, be tt fresh water or salt water, and

Finally to allow the steam to get out. At these depths and with these energy

Tequirements nuclear explosives are the only energy sources that can be

considered.

Kennedy has worked out an example where «5 Hton device te detonated at

44 depth of 10,000 fe, producing an initial cavity with a diaseter of 1,000 fe,

and 4 volune of 5 x 10° £c3, With an assuned postshet porosity of 12% he |

calculates # rubble chimey helght of 8,000 ft, leaving @ 2,000 ft "cap" of

relatively undisturbed rock. The calculation of the rubble chimney {8 incorrect |

Decause he has taken the total porosity created by the shot and converted it

into « cylindrical rubble cone, It ts « fact, hovever, that a large portion of

the porosity is due to crack formations enanating radially from the shot and,

therefore, not contributing to the chimney.

Extrapolation of Pig. 6.3 im CUNE by Talley et. al. celle us that ve may

expect @ chimney height of ~ 1,200 fr and Table 4.1 {n CUNE allows us to

?estimate a maximum chinney height of 2,000 fc, Even these estinstes are

probably optimistic because Project "Wander" gave an actual rubble cone

which vas ~ 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 Lt means that tt {9 not necessary to enplace the device

4 10,000 ft. Thus, provided we can find heat bearing rock at shallower

depths, considerable savings may de realized,

Kennedy has calculated the energy avatlable at teaperatures over 100%

to be ~1.8 x 1016 cal. Since the heat Liberated by the explosive is

~5 x 1015 cal. the total heat avatlable {8 approxina?

ly 5 tines the

energy of the explosive

---Page Break---

This vill produce ~+ 1011 pounds of superheated steam, or enough to

generate 50,000 KW of electricity over « period of 10 year

TIL. Gost of Stean

A direct comparison As sade vith steam plants operating on sintlar steam to obtain « value of the energy available from the cone.

?The Pacific cas and Electric Co. {a buying steam from wells at the Geysers in Sonona County, California. This stean is low-pressure, low-quality

and costs $1/900# which amounte to 2 1/2 mille/KW Hr generated. The total

coat of the power {#5 1/2 nflle/K lr at the consumer.
The cost of the steam {8 essentiaily due to the cost of emplacenent and

the cont of the device, These are estinated at $4 mill. and $1 mill. respec ively. Considering the worth of the steam, Kennedy reasons the project will

be economic by « factor of 2. fo cost has been considered for post-shot

1d several tf

Grilling which may have to be re as crud forms inside

tthe chimney. It {6 possible, hovever, that {t may cost only half as much to

emplace the device, since the rubble chimney witl be but a fourth as high as
ealeulated by Kennedy. This saving may tnéeed aake the profect even more
economically feerible than fleet conjectured.

Since ve are mining earth heat and not heat introduced by the device ve
ay renove {t at any desired rate and would actually have more heat available
Af {e vere renoved at a slow rate. Energy may continue to be extracted after

the first cone {s exhausted by detonating @ second device slightly more than fone crater radius avay from the first one. If ve still introduce the water

ehrough the first cone we would presumably have preheating of the water.

IV. Problems whic be Encountered

4) Ground sotion associated with large nuclear detonations. Particularly

with respect to consideration of sequence of shote.

---Page Break---

17

Deep circulating water hich may enter rubble and flash into steam. Te

LLL be neces

wry to know beforehand whether this possibility existe.

>) Behaviour of rubble cone ax function of tine. At 10,000 fe the pressure

1s approxinately 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 tritiun contamination of the

teen would occur. The tritium gives off « 0.018 Mey @ sbich would present

no problens (n @ closed-cycle power plant. Tf the #

were to be used for

Grinking water a secondary heat exchanger (~/ 90% eff.) would be the simplest

solution.

SALIWATER DISTILLATION

Tf we continue to use Kennedy's rubble cone the pressure would vary from

?1080 psi to ~ 8400 pai from the top of the cone to the botton. Thus the

thermodynamic conditions for flashing the saltwater into steam are particularly

favorable. This

enhanced by the fact that at the temperature of the rubble (ave. rv 60°F) che constant tonperatuve Line of « T-S dlagre

te asyoptotic

to the saturation Line

E approximately 3000 pet. These two conditions

coincide vith che critteal

int. The advantage of the critical point lies

im the fact that minimum energy would be required to flash the veter into

steam. If the ?free energy" G is used to measure the anount of work done in

the change, and G = UTS we ace that since Rgg = 0 at the critical point, and

?the change in entropy te sual because the entropy decreases with increasing

Pressure of the steam, the aininua amount of energy ie expended near the

feat point. Above the critical point, hovever, the water does not flash

» and since sost of Kennedy?

calculated rubble cone provides for

above the critical pressure all of the steam should be produced at

---Page Break---

that depth below the surface where the pressure coincides with the eritteal

pressure. This will probably mean that all of the crud (inclu:

ing the salt)

will settle out at that level and render the rubble impermeable.

SIMMLATION - STAELTTUDE .

L, Subject of Stntlitude can be based on: .

4a) similar equations (analogies) (neces

wry to be able to write diff, eqn.)

») dimensional analye

Dimensional analysis {2 in turn dependent on our systen of measurenents, ALL general equations, in order to be valid, must be dimensionally

We may write any unknown quantity X in terms of its baste dimensions.

Likewise all of the vartables on which the unknown quantity depends may be

written in terme of basic dimensions, and {t can, therefore, be shown that

the unknown quantity XK may be written (n terms of the independent quantities

raised to appropriate povers. Thus X= £(I%, Tf,

XS, ete.), where I stands

for independent quantity.

According to the Buckingham Pi theorem ve may express &

te of M quantities

which have N dimensions as a functional re

sttonsh{p between N-N dinenston!

teres called Pi terms. Thus T= £(1 9. W 5+ Ty -- Wy.y) where usually the

unknown quantity X will be contained in Ty.

TL. Difference Between Modeling and Sealts

By sealing {8 usually meant that a certain consi

wnt relationship exiate :

between all of the vartables in an expression. However, as we have seen with

the eating lave applied for era!

wring ve in effect use it as 4 means of extra-

polating on one dimension with two or three other dimenstons known.

---Page Break---

By modeling ts meant that the independent Pt terns of model and prototype

?are identical, and that therefore, also the dependent Pi terms are equal. Thus, there is no extrapolation, {

ixample of ?scaling? and modeling

?The example will presumably be based on experiments done on known 6;

to predict what will bappen to an unknown systen.

Assume that we want to know the deflection at the end of a given uniform

Fectangular cantilever beam subjected to « load at the end. We guess chat the

deflection must be a function of the length of the beam, the size of the load

?and the moment of inertia of the bean, We may also guess that it te « functi

of the Young?

modulus. Assume that we have several beans and loads available but of course not one the size of which we want to predict. We aight then

start by holding all but one of the variables constant, and plot the deflection

as « function of that variable, Let us

yy that we plot

flection va length

and obtain a family of curves.

Now, if the beam for which we want to predict is longer

than any of the other beama, it becomes neces

ry to

extrapolai

Even though our curves are ?scaled? in

4 the sense that the other parameters may correspond to

what we want, extrapolation past « measured point ts

risky at beat, and may be completely erroneous,

If, inatead, ve use the Buckinghes relationship ve find that Y= £(P,£,

2, T) which, expressed in two disensions gives us three Pi terns, Thus

$9 Gin shen 2

Pont ete fonction wou be pnd Eps Gf) = BBE

A few plots, using no more than 2 beans, vould show us

What is more, without finding the foreula ve are able to locate our unknown

---Page Break---

Bo

beam in che range of the seasured quantities, so that it is no longer necessary

to extrapola

?This is the cost important point about modeling:

% Tat Lf it 6 performed correctly it ta theorett-

+ cally possible to predict any phenonenon.

far Mas

THT, Mathematical Equation and Dimensionless Equation

It {s obvious that the Pi theoren by it

Af cannot provide us with «

conplete solution to any problen. It {s necessary to perform experiments

ko obtatn the functional relationships of the PL terms, as vell as provide the necessary numerical constants. However, for those vho believe blindly

tn differential equations, and not at all in dimensional analysis, let us

look at the sim{lartetes as vell

the differences.

Statlaricies bigference

Sane nusber of independent variables 1. For relatively staple equatio

Sane functional relationship between with sufficient B, C. the diff.

vertabies eqn, will yteld the solution tn

a nore satietactory manner.

2, For very couplicated phenomena

for thoue who do not lend thenselves

to analytic solutions the dimen:

sional analysis and experiment

sives us fever variables and

solution whereas ordinary methods

may not.

?The two methods are, therefore, complenentary rather than competing.

---Page Break---

1h

COMGERCIAL RADIOISOTOPE PRODUCTION

Radtotsotope production by & nuclear exploston ta

prpected to be auch

cheaper, and yleld much greater quantities, than ts presently possible vith

nuclear reactors. The recovery of isotopes produced in an underground nuclear

explosion 1s a forntdable and challenging undertaking. One proposal which

?hows promise 1 to use 4 alt strate, dissolve the salt formation after the

?shot and then use chentcal proc

to recover the Leotopes produc

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APPENDIX C

WOMEWORK PROBLEMS IN NICLEAR CIVIL ENGINEERING

?As a guide and teaching aid a set of typical problem assixnments have

clear

been compiled. The

Je problens are keyed t9 "The Constructive Uses of

Explosives,? by Teller, Talley, Hixsine, ané Johnson.

(d.1) Ef one mole of particles ie confined to 1 ce and heated to @ temperature

of ?1 electron volt," what will be ite pressure, in millions of atmo-

ket = 1 ev = 1.502 10"! ergs.)

spheres? (Three fijure accuracy, ples

(1.2) tm chapter 3, we find that > deuterons can combine to yield 2 protons,

2 neutrons, 2 helion-4's, and 42.2 Mev. Por devices, the energy yield

from the fiasioning of « single v?3> atom is 180 Mev.

(a) On kiloyran-to-kilogran basis, what [9 the ratio of energy releas

of complete fission of uranium-235 to the complete fusion of the

deuterium in 0307

es

(b) Use the figures of $12,000/ks of 95 and 360/kg of B20 and compare the costs per Kilovatt-hour for both fuels.

(1.3) TE 95% enriched 0239 costs $12,100/kim, what must be the cost of 0.7%

enriched U95?

(2) A collection of particles, each of mass on, starts at x- 0 with v= 0

and moves under the {nfluence of a potential V = -ex.

(a) Now let the particles have an eneray spread from Eto E +8E, and

raw the path of the syaten in phase space, p versus x.

() Consider the phase volune (area) bounded by Py and Pp at any tine,

?show that thie area (s the same at any later time t.

Consider @ systen of 3 indistinguishable particles which can occupy 7

different energy levels. The levels are equally spaced and differ by

E unite -- with che vatue of the fLrse level being ? . TF the total

---Page Break---

energy of the aysten is 9@

(a) What Le the average energy per particle?

() Prepare

?sketch of the energy levels and show the different ways

In whteh the particles can be distributed among then.

(c) Prevare a plot of the frequency of occupation of a level versus the

: level nunber. (That As, in one arrangement you will find all three

particles in level 3, tn another you vill find one particle at level

4, one at level 3, one at level 2. You then would say that, so far,

level 3 ts occupied four tines, levels 2 and 4 are each occupied once.)

(4) Compare your plot with the curve 9 78/3

(2.3) A strong shock moves up through the ocean floor. Both the earth and the

water obey a. -law. At the hydrostatic pressure of the sea botton

(2 x 10° dynes/en?), the water hes a density of 2.5 gu/cc and the earth

i

a density of 3.0 gcc. The vater Le more compressible (¥ y = 2) i

than the earth (F ,° 3). If the shock velocity im the rock 46 4 x 10°

col

e, What will be the shock velocity in the water? Arsume that the

shocked rock unlon

ae P/) = constant.

(2.4) Plot the penetration of che wave

2 ate x ot x ete

to =

dain W244) FE xe PD

ehrough @ vacuum interface that {a a distance 2% from the origin.

Indicate the potnts of penetration vbere the material just goes under

tension and where the tension fret reaches the maxisum.

. (2.5) Lf « saw tooth wave, @ , and A, creat

exactly 3 apalla, what is the

tensile strength of the material? What are the velocities of the slabs?

(2.6) A stress wave moves to the right with @ velocity of 500 a/;

eo ALES Oy

the front of the wave is L meter fron a vacuum interface, The wave is

id

---Page Break---

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fone meter in length and is of the fore

0 xe sore

ye) = Boeve®? 500 ee KE SIDE TT

° sor lex

Undefined for x >?

Wen will a spall oecur Lf the tensile strength of the material is 27

(2.7) pertve expiieiely ene relation Pep, FOE + DICE = UF, tor

strong shocks roflecced off 4 regld wall.

(2.3) the folloving table represents the resulte of solving the Thonas-Fernt

equation at absolute zero for hydrogen,

2 (oars, vx 1026: 2 (oars) vx 102 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 2,Fe? between the

densities of 12 and 26 galee. (Py = 29/9 Py, Vg = 1 Vyde

(b) Eatinate che work for such @ compression at absolute zero,

(e) Le this work greater or lees than the real work needed for such a

compression?

---Page Break---

(2.9) Show that Lf the potential 1s of the form V L/rM, the Virtal theore:

?

nBpot * 2 Brin = 3 V

(2.10) Since the Virial Theorem, as derived, holds for inverse square forces,

why can we apply the results co the perfect gas?

. (GA) Im Chapter 3 we present 8 possible exothermic reactions. The enersy

releases are given to one dectnal place accuracy. Use a chart of the

fue ides oF the Handbook of Chentatry and Physics, the relation

OE = clas, and c2 = 931.2 Mev/AMU to obtain the energy releases

correct to two decimal places, ote that c!2 = 12.003%5).

(3.2) Plot, as a funetion of 2 of atoms fi

toned the cost of « 10 kt explosion

if W295 ie used at @ cost of $12,000 per kilogram.

G.3) Table 3.1 presents the radioactivity due to each radtoisotope from a

1 kt f£esion explosion, as function of time.

(a) Plot, on log-log paper, the total radioactivity due to this

ae @ function of tiae.

(b) Pind Ay and n tn

Aceet) = ay oP

(2.4) Tf venting occurs, we might find a region near the

ite where the fallout

4s due co the intermediate group (see Table 3.2). Plot the activity

expected from these elenents. Does the radioactivity decrease faster for

this group than for the total yield? vay?

(Hines Me emt 0 for any finite m.)

+ 8.5) A e041 Hy the done rate near a nuclear explonion is 13.8 R/ME.

Construction workers a

to go in an work 5 consecutive shifts - 9 hours

on, 16 hours off. If thelr toval exposure cannot exceed 40 mr, how many

hours after t = 0 can chey stare the firet shift?

---Page Break---

(a)

5)

ws)

a)

=??????__ee

(a) What yield should we use?

(b) that will be the cost per cudte yard of rock broken in che chisney?

Iwo detonations are planned, both of 100 kt yield. One is to be performed on the earth and che othor on the moon. We assune that the

lunar density {8 3.34 ga/ce and that the earth has a density of 2.38 gn/ec.

?he acceleration due to gravity on the moon is 162 en/sec?.

(a) If the earth shot ts buried #00 m, at what depth should the Lunar shot be emplaced to produce the same size cavity?

(b) TE the device vere buried at 200 m on earth, at what depth should the lunar shot be buried to produce the sane size crater? Assume that air drag te negligible on earth so that the two craters are of sinilar shape.

Assume apparent crater {2 parabolo{d of revolution. Given the scaling

lav of 1/3.4, and the face chat the Sedan crater (100 kt, DOB 635 £t)

had a volume of 5.6 x 10° yea, Assume that a 10 ME yield has a variation

of + 10%, that the scaling law varies between 1/3.2 and 1/3.6, What are the upper and lover Limits on the volune, the radius, and depth of thie

larger apparent crater?

overlay three curves of saxioun apparent crater volune versus yield,

fone based on a parabolic relation between depth and radius, another

based on a hyperbolic relation, and the third baned on a spherical

relation, State all assumptions and give the equations or curves you

have used as your source material.

Develop construction cout eatinate curves for placenent of nuclear :

ewiosives for producing # crater or aqutfer on Sen Clenent Talend. .

Ascume that rotary drtlling ts ured. List further ansumpelona eae

you make and dtecuse your reasonton.

Reference: TID - 7695

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(.2) Current philosophy in the inplacenant of nuclear devices requires that

?the borigg be dry. (1965) Determine the wall thicknes:

required of

the steel Linear 60" inaide dtaneter, 1000 feat below the vater table,

fred, {

The lightest weight desig ts d

Reference: ?Tiaoshenko, ?theory of Elastic Seabtlit

? (7.1) 16 one tgnoces B-decay and

jsunes that the cross section for neutron capture Le constant, show that the equation governing the time-rate-

of-cha

of nucled vith extra neutrons is

EM My =m +0, bed,

where the scale time, r =e Gt; fe the capture cr

jection, 6 is

the flux or neutrons, and t 1s time,

(7.2) (a) Vertfy by direct substitution chat the solution to thie equation

() Ae what value of the scale tLse will the number of muclet with one

extra neutron (f= 1) be a caxioun? At what value of the scale |

Hime will che number of muclel vith two extra neutrons be # maxima?

Lextra neutrons?

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