COPD ~~[illegible]~~

UNIVERSITY OF CALIFORNIA
RADIATION LABORATORY

729661

R

~~Classified Document~~
Routing Sheet

ROUTING

NAME	COMMENTS
W. Brobeck	✓
RECEIVED	
JUL 25 1957 — A15795	
RAD. LAB. - M. E. DEPT. - 568 UNIV. of CALIF. - BERK.	

~~This document is not to be left unattended or where an unauthorized person may have access to it. Store in approved repository. It is your responsibility that information contained in this document is not compromised.~~

RL-220 1257835

5.2.4 D13 DUP

Nuclear Explosions

~~SECRET~~

COPD-57-55

~~DOCUMENT NUMBER~~

~~This document consists of 8 pages~~
~~No. 2 of 25 copies, Series A~~

~~July 17, 1957~~

AUG 2 1 '59 INV.

MEMORANDUM

TO: Distribution

FROM: W. Goldsmith

SUBJECT: Preliminary Proposal for Dynamic Stress and Strain Measurements during the RAINIER (Underground) Shot.

INTRODUCTION

Serious thought is being given to the production of a large number of underground nuclear explosions which are to be contained in a cavity of relatively high-grade rock. In order to determine whether the strength of such rock is sufficient to withstand the shock pressures created, it is necessary to obtain additional information on the static and dynamic stress and strain properties of the rock. Information of this type can be readily obtained under precisely controlled laboratory conditions by scaling the expected detonation pressures with high explosives. The projected underground shot (Rainier) seems to offer an additional opportunity to gain valuable information on this subject with a minimum of expense. The present memorandum presents a preliminary proposal for the measurement of these properties.

The immediate and obvious advantages of an underground shot as opposed to an air shot for this type of experiment lie in the relative ease of installation of the test specimens and measuring equipment. Focussing effects due to the interaction of ground and air will not be present and, further, the shock arrives through a medium whose properties are more nearly those of the test specimen than air. At least some of the test specimens in the contemplated experiment have a reasonable chance of being recovered. While scaling with high explosives would provide information over a wider range of pressures, one of the unique features of nuclear explosions, namely the much longer decay constant of the pressure pulse, can not be so readily simulated.

CLASSIFICATION CANCELLED OR CHANGED TO Unclassified
BY AUTH. DAR-1 1.1
BY [illegible] ADD DATE 9-12-95
BY [illegible] ADD DATE 9/13/95

~~RESTRICTED DATA~~

~~This document contains restricted data as defined in the [illegible] 1954. [illegible] contents in any manner to an unauthorized person is prohibited.~~

1251636

~~SECRET~~

If suitable recording equipment can be made available, the total cost of instrumentation exclusive of labor should not exceed a few thousand dollars. The instrumentation consists solely of pressure-measuring accelerometers, strain gages, wire and cables in addition to the fabricated samples of rock. The rock, which will have to be procured rapidly in view of the imminence of the underground shot, would consist of good grade granite or basalt, characteristic of the type of material contemplated as the container for the previously mentioned cavity.

TYPE OF TESTS

The tests described are intended to simulate standard engineering performance tests under dynamic conditions. It is believed that the usual uniaxial tension, uniaxial compression and shear tests ordinarily executed under static conditions can be reproduced dynamically using the shock wave from the nuclear source as the driving agent. In view of the short time available for planning, it may be necessary to limit both the type and number of tests in order to properly install the specimens and check the circuitry. In any event, a large number of additional specimens should be retained for subsequent static and dynamic tests of strength under laboratory conditions.

The Tension Test:

It is proposed to utilize the Hopkinson bar technique in order to achieve tensile failure in a specimen. The success of the method is predicated on the assumed large difference in compressive strength as opposed to tensile strength of the samples. This difference is known to exist under static conditions, where the ratio of these strengths is of the order of 10 or 20 to 1.

The proposed shape of the specimen, shown in Figure 1, consists of two cylindrical sections with diameters d and D, respectively. The enlarged section will have provisions for firm attachment to the side of the tunnel, perhaps by means of bolts or studs; the mounting bolts being so located as to leave an unobstructed plane path with respect to the actual test section, whose diameter is d and whose length is L. A fine, brittle wire is to be wound helically around the test section and bonded to its surface.

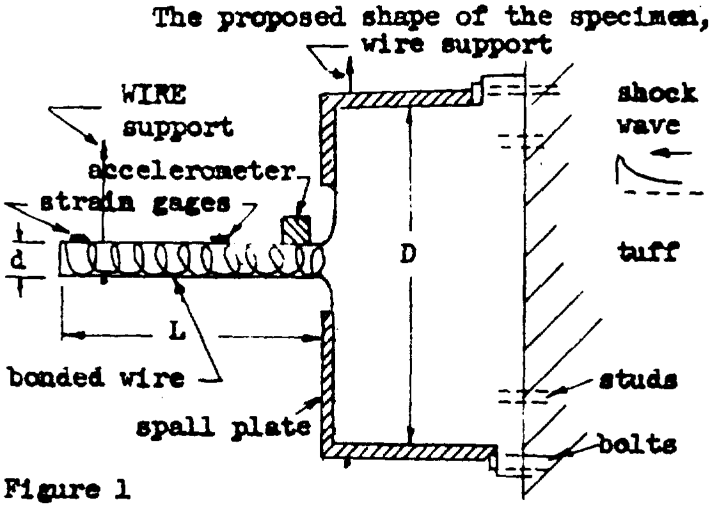


Figure 1

1257837

A piezo-electric type of accelerometer is to be mounted on the specimen. Preferably, this device should be attached to the actual test section, but alternately might be mounted on the enlarged section of the sample. Two or more strain gages of the post-yield type, which function for elongations up to 10%, should be bonded to the test section at suitable stations. In view of the transient nature of the impulse, the strain in the sample will not be uniform, and the delineation of its magnitude at several positions would be desirable. The brittle wire [illegible] be energized and electrically coupled to the accelerometer circuit, so that breaking of the wire would be recorded by a distinct signal. To prevent a premature spalling of the enlarged section, this portion of the specimen might be capped by a steel cylinder. The entire assembly should be mounted at the center of the vertical wall facing the explosion, and might be supported additionally by wires suspended from the ceiling in order to carry the weight of the sample.

The operation of the test would be as follows: The shock wave initiated by the nuclear explosion would pass through the tuff and enter the enlarged and subsequently the test section of the specimen essentially as a plane wave. The pressure-time (stress-time) history of the pulse would be measured upon passage by the accelerometer. It will be assumed that the initial passage of the wave through the test section will not produce compressive failure. Upon reaching the free surface, the shock wave would be inverted and return as a tension wave, fracturing the specimen when the superposed reflected tension and initial compression wave reach a tensile stress equal to the critical tensile fracture strength of the material. This fracture stress would be computed from the measured pressure-time curve, the measured time lag to fracture, the known specimen length and a known value of the shock velocity in the rock which will be assumed constant over the length of the specimen. It is likely that the sound velocity in rock will be sufficiently near to this shock velocity to be used in this calculation. The wave progress through the specimen is illustrated in Figure 2. In order to appraise the magnitude of the length dimension L of the specimen, a crude calculation was made to gain an idea of the order of magnitude of the pressures required to fracture specimens of reasonable lengths.

1251858

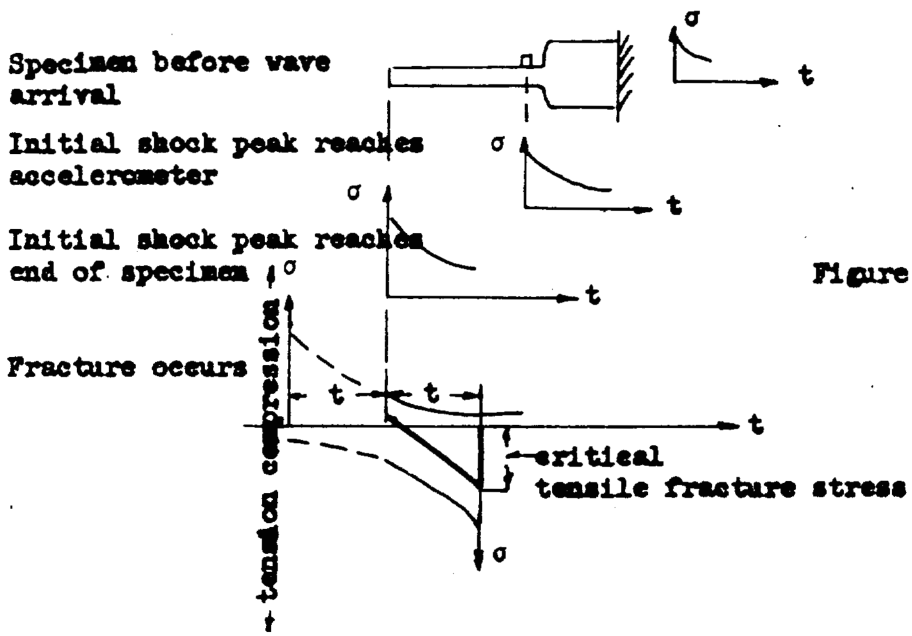


Figure 2.

It will be assumed that an exponential pulse of the type $p = p_o e^{-\alpha t}$ arrives at the specimen with time constants α of (1) 20/sec. and (2) 100/sec., respectively. The failure strength of the material in tension will be taken as (a) 1000 psi and (b) 5000 psi. The shock velocity = sound velocity = 6 mm/microsec. Then the specimen failure in inches from the free end is given by the following table:

p_o, psi	Specimen failure, inches from the free end (a) (1)	(a) (2)	(b) (1)	(b) (2)
1,000,000	12	2.4	60	12
500,000	24	4.8	120	24
100,000	60	24	614	123
50,000	240	48	1260	252
10,000	1200	240	8460	1660

It may be noted that, except for extremely high pressures, the calculation predicts specimen lengths which are absurdly large. However, inasmuch as the initial shock pulse undoubtedly carries its own tensile components rather than consist of a purely exponential decaying pressure pulse, fracture will undoubtedly occur at some time even for moderate gage lengths of, say, 24 inches. However, the interpretation of the fracture strength from the accelerometer measurements would be more complicated in view of the superposition of several reflected waves. However, it would appear important to place some gages as close to the source as practical.

1257839

If it were not for the question of interpretation, it might be suggested that the bars should either be notched or, alternately, be tapered toward the free end.

An indicator should be provided to insure that specimen failure does not result from crushing as the consequence of cave-in of the walls. The bonded wire should be capable of rupturing within a fraction of a microsecond. Preliminary tests with high explosives appear absolutely necessary, both for the sake of calibration and for feasibility studies.

Even if the specimen does not fracture, correlation of the stress- and strain-time records should provide very valuable information on the dynamic behavior of the rock in terms of an "engineering" equation of state.

THE COMPRESSION TEST:

It is proposed that the compression test be accomplished by squashing a modified form of the tension test specimen between the two walls of the tunnel, as a result of the differential motion between these two surfaces produced upon arrival of the shock wave. The shape of the proposed specimen is shown in Figure 3, and its installation is schematically represented in Figure 4. The center of tunnel wall A, which is exposed to the direct force of the blast, will exhibit significantly greater surface displacements than the center of wall B, since the shock wave must diffract around the corners of the tunnel, and will probably leave a region of low pressure at the center. This differential motion can then be utilized to compress the test section. Two accelerometers should now be employed, one at each end of the gage length, mounted either on the test section itself or on the enlarged cylindrical portion. Strain gages mounted on the test section and a bonded, helically wound wire would complete the instrumentation, and the operation would be similar to that described in the previous section, except that tensile components due to reflection at the free surface could not be generated.

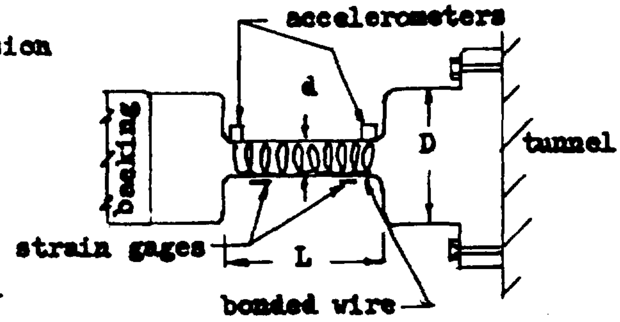
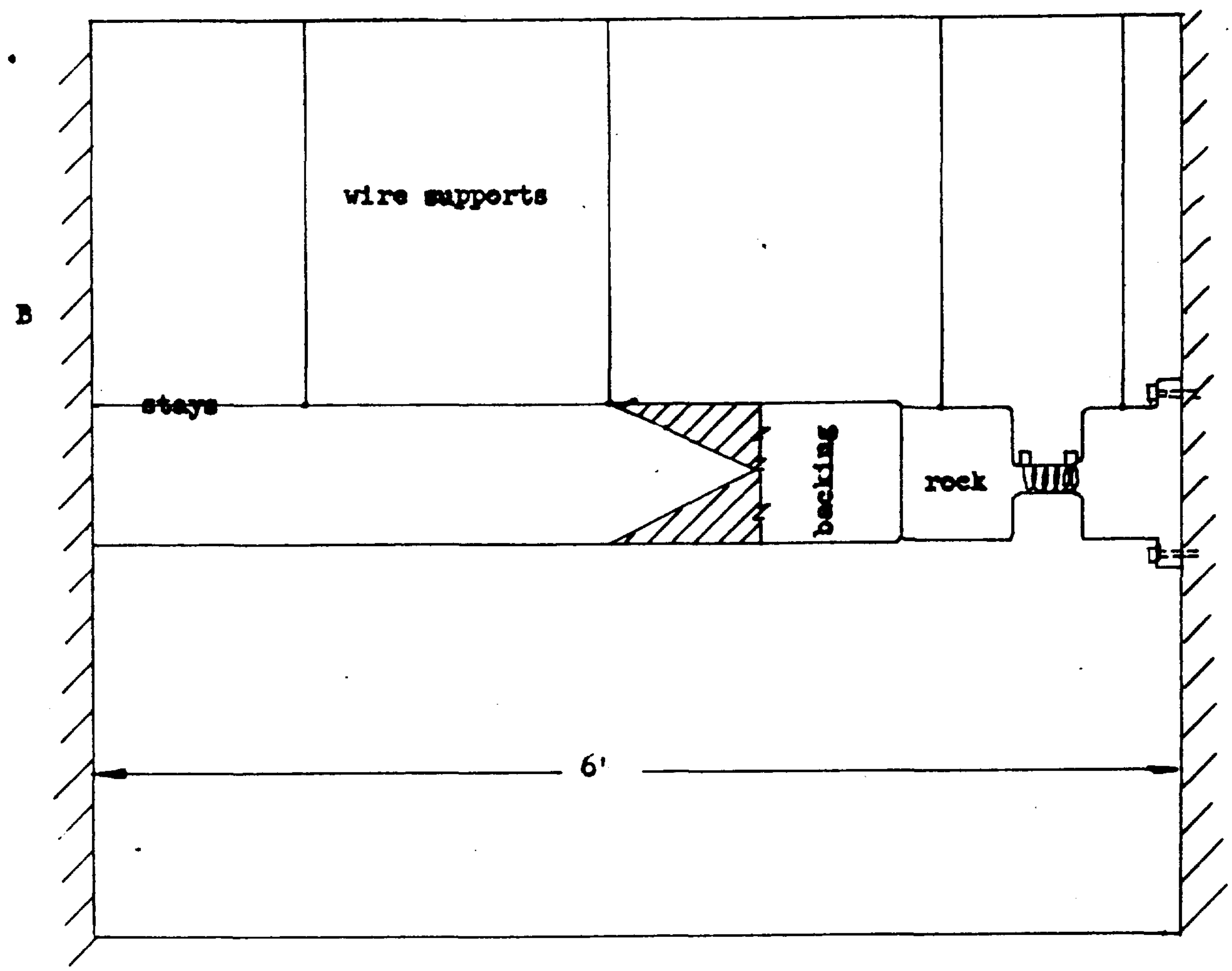


Figure 3

Ideally, the rock specimen would extend across the entire width of the tunnel, with a test section of perhaps 2-6 inches in length, since this parameter is no longer a governing quantity as far as breakage is



concerned. However, such an arrangement might lead to considerable construction difficulties, and it is believed that a symmetrical specimen such as shown in Figure 3 backed by a suitable structure will be adequate for the purpose of preventing reflections from a free surface.

The backing material should be such that its acoustic impedance ρc is the same as that of the rock. For example, assuming the velocity of sound in granite, whose density is 2.5, to be 6 mm/microsec., the acoustic impedance is 15 g-mm/(cc-microsec.). Aluminum with a density of 2.7 and a sound velocity of 6.2-6.3 mm/microsec. gives an acoustic impedance in the same units of 16.7. Although this is somewhat higher than the value for rock and would give rise to reflections at the interface, it is probably the closest available structural material relative to the acoustic

1257881

property of rock and may prove adequate. If this point is deemed important, better shock matching materials can be obtained, although this will vastly increase the cost of the operation.

The diameter d of the test section and length L should be chosen to conform to manufacturing and instrumentation requirements, since they are not governed by the nature of the pulse. Perhaps a ratio of D/d of 5 is reasonable.

The specimen will be mounted at a distance r radially from the explosion, and the peak compressive pressure at this point will be p. The maximum force on the cylindrical test section is thus $1/4\ d^2p$, Since the static compressive strength of the specimen is in the vicinity of 30,000 psi, it will be necessary to ascertain appropriate distances from the explosion for the most effective spacing of the gages. Pelsor gives the following values of pressure as a function of radius, which he believes to be a very high estimate: $\frac{\pi}{4}$?

Table 2

Radius	Calculated pressure, p_o	
ft	megabar	psi
100	.1	1,500,000
200	.02	300,000
300	.009	130,000
400	.005	75,000

It is probably desirable to place gages in the range of peak pressures from 10,000 to 200,000 psi. Since the results of the calculations in Table 2 may be high by as much as a factor of 10, it is seen that the desired range may be achieved by placing five specimens in the tunnel at intervals of 100 ft starting 100' from the source.

The operation and evaluation of this test is similar to that described for the tension test. Again, if some samples do not fail, it may be possible to derive an engineering stress strain curve under dynamic conditions. The compression test is not as significant as the tension test, since the actual failure of the specimen is of the shear type and may lead to some additional difficulties in interpretation.

THE SHEAR TEST:

The shear test is envisioned as substantially identical to the compression test, except that the shape of the specimen would be as shown in Figure 5. The crossectional area of the specimen should be such that the shearing stress across the section might range from 2000 to 20,000 psi. For example, with an incident peak stress of 10,000 psi and a square crossection for each bar of a = 2 inches, the length of the common joint "q" would be 10 inches to produce a shear stress of 2000 psi. The overhang of each bar should be sufficiently long to prevent reflections from disturbing the shear fracture. Two accelerometers will have to be mounted as shown, but strain gages can be used only as a check since the induced shear strain cannot be directly measured. The bonded wire should be placed in straight lines across the common joint.

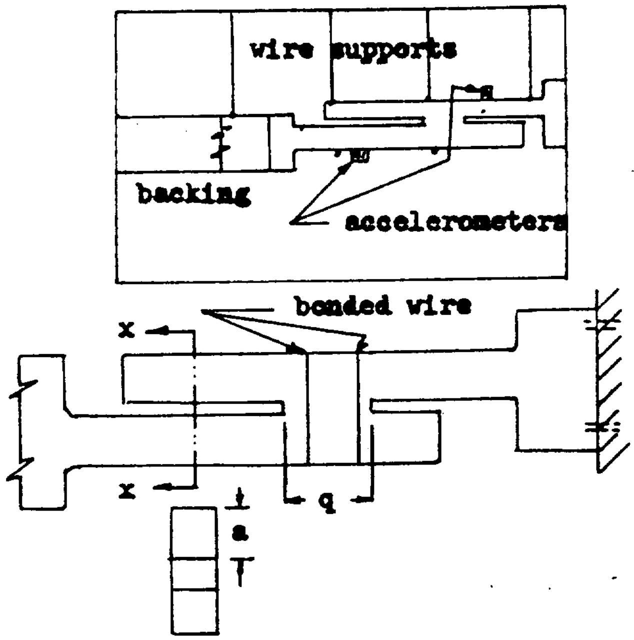


Figure 5

WG:ar

Distribution

Cy 1/15A F Bjorklund
2/15A W Brobeck
3/15A H Brown
4/15A R Christian
5/15A J Frank
6/15A W Goldsmith
7/15A R Goranson
8/15A C Haussmann
9/15A R Herbst
10/15A M Mills
11/15A J Nuckolls
12/15A G Pelsor
13/15A Dr. Poulter
14/15A R Westbrook
15/15A FILE