CALIFORNIA INSTITUTE OF TECHNOLOGY

SEISMOLOGICAL LABORATORY, 295 NORTH SAN RAFAEL AVENUE, PASADENA, CALIFORNIA

MAILING ADDRESS
P.O. BOX 2 ARROYO ANNEX
PASADENA, CALIFORNIA 91109

TELEPHONE (213) 795-8806

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FINAL REPORT

Summary and Conclusions

A three-axis quartz strain gage was installed in tunnel U12p within the Nevada Test Site for the purpose of measuring permanent and transient strains associated with large underground explosions. During the subsequent year, the site was maintained and the recording and control system was upgraded. Results on two large underground explosions are presented in the attached papers. Details of the initial installation may be found in the first of these:

Smith, Stewart W., Charles B. Archambeau and William Gile, "Transient and residual strains from large underground explosions," Bull. Seism. Soc. Am., 59, 6, 2185-2196, 1969.

Smith, Stewart W., "Earth strain resulting from the HANDLEY explosion."

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In addition to operation of this station, some preliminary analysis of other strain data at NTS measured by the ARPA supported strain gage program was undertaken. Some of the results are included in the paper above. The general pattern of strain associated with explosions has become more difficult to interpret with the accumulation of more data. This is always a bad sign in any experiment and causes us to look very critically at the previous measurements and their interpretation. There now exists serious doubt that the permanent changes reported are a direct measure of tectonic release, at least in the sense of a simultaneous earthquake occurring with the explosion. The reason for this is the widely varying distribution of permanent strain changes that have been reported. A more reasonable interpretation calls for these permanent strain changes to be very local effects, with characteristic dimensions of up to several kilometers. The problem of strain die off with distance seems to be resolving itself toward a model where the average behavior is like $1/R^3$ but the actual value at any station may depart significantly from the mean due to local stress concentrations, or slip on local fault surfaces.

The dynamic strain field has not yet been looked at carefully, but when it is used in combination with accelerograph data it may yield a clearer view of the displacement and strain behavior during and just after passage of the high amplitude elastic wave.

It should be pointed out that the initial installation of this apparatus, which was at that time a single component instrument, was made with the support of the AEC (AT(26-1)-421. Subsequent AFOSR grants made possible expanding the station to three components, without which we would not have been able to calculate principal strain axes. During the past year, the most important modifications involved a remote telemetered control system for centering the strain transducers without access to the tunnel. This has been a very successful arrangement and will no doubt be used in subsequent strain installations. Operation of the station for another 12 months is currently being funded by the AEC. The hope is to establish, along with other ARPA supported strainmeters whether region strain changes can be measured. This will be the first time in the history of strain seismology that enough instruments in a single region have been operated simultaneously to detect regional changes in the presence of extraneous surface effects.

It should be noted that one of the original concerns of this investigation was to provide an explanation of the triggering of motion on other faults. Such an effect was observed out to distances of 70 km during the Borrego Springs, California earthquake (M - 6.4) in 1968.

One of the tentative conclusions to be drawn from the work described and summarized in the Appendix is that such distant triggering is probably induced by the radiated field from the major event, in particular from the surface waves from the larger primary event. Since this applies to both earthquakes and underground explosions, where the explosion can be viewed as the large primary event, it is important to continue the present observational program in order to evaluate the validity of this conclusion for a large number of explosive events and, if appropriate, to set more precise bounds on the probability of occurrence of such a triggering process in a tectonic region.

Stewart W. Smith

Present address: Geophysics Group
University of Washington
Seattle, Washington 98105

Telephone: (206) 543-8021

Appendix

Transient and Residual Strains from Large Underground Explosions,

Stewart W. Smith, Charles B. Archambeau, and William Gile

Tectonic strain readjustments associated with large underground explosions have been observed at the Nevada Test Site. The BENHAM event of December 19, 1969 produced a peak quasi-static radial strain of 1.2×10^{-7} at a distance of 29 km. This strain transient was followed by an exponential return to the initial state with a time constant of 13 minutes, and is interpreted as the direct elastic response of the medium to a time varying pressure in the BENHAM cavity. An upper bound on the tectonic strain release was determined to be 0.7×10^{-8}. Using these measurements it is estimated that the permanent and quasi-static strains associated with this explosion could significantly effect local earthquake occurrences out to distances of about 15 km. The size distribution of aftershocks of this explosion resembles that seen in model experiments of brittle fracture, in which the distribution is controlled by the dimensions of inhomogeneities in the medium.

Tectonic Strain Readjustments as a Result of a Large Underground Explosion,

Stewart W. Smith and Charles B. Archambeau

Strain readjustments associated with the JORUM explosion were observed on a three-axis strain seismograph at a distance of 30 km. The measurement showed a transient effect of the cavity with a time constant of approximately 33 minutes and a "permanent" strain relaxation with the principal axis of tension oriented N12W. The measured extensions along the principal axis was 9.8 and 10^{-8}, and the compression was -2.0×10^{-8}. This result differs from that of the BENHAM experiment, a similar situation, in which no permanent strain changes were reported at this same station. To explain this observation there must either be a profound difference in the tectonic environment at the sites for these two explosions, or a significant change in the strain field must have occurred in this region, due to natural causes, in the time interval between the two experiments.

The functional dependence of strain on distance has been investigated for more realistic models than a point source in a half-space. A buried point source in a layer over a half-space produces significant deviation from the half-space solution only out to several layer thicknesses in distance. A more fundamental change can be seen when the model used is a spherical cavity of finite dimensions buried in a half-space. The presence of the spherical boundary, on which stress must vanish, alters the basic form of the solution. The asymptotic behavior of radial horizontal strain, for example, remains to R^{-3}, but tilts are shown to depend on distance as R^{-2}. The theoretical results confirm the experimental data presented for the BENHAM experiment.

<u>Earth Strain Resulting from the HANDLEY Explosion</u>, Stewart W. Smith

The measured strain accompanying HANDLEY was permanent in the sense that it was clearly not recovered during one month's contiauous recording following the explosion. The principal axes for this static strain change were N 03° W, 18.7 $(10)^{-8}$ tension and N 87° E, -23.8 $(10)^{-8}$ compression.

The principal axis of compression is thus only 10° off radial from the HANDLEY location. A transient or quasi-static strain was observed with a time constant of approximately six minutes. The principal axes for the transient strain are almost 45° off radial making it unlikely that this effect is a result of pressure decay in the cavity. A possible interpretation of the above data is that both static and quasi-static strains observed are a result of local stress release in the vicinity of the strain instrument. This local stress readjustment may be produced by the large amplitude elastic waves accompanying the explosion. A model is proposed by which the average properties of this local stress release can be predicted. Preliminary work makes it appear that the average strain field will depend on the amplitude and period of the Rayleigh waves from the explosion, and thus will be proportional to $R^{-3/2}$.

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13. ABSTRACT

A three-axis quartz strain gage with a sensitivity of 10^{-9} was installed in Tunnel U12p at the Nevada Test Site and has been operated continuously since October 1968. During this time, permanent strain changes were observed as a result of several large explosions in this area. In addition, transient strains with time constants of many minutes were observed following explosions and tentatively attributed to pressure decay in the cavity. Neither one of these phenomena are well understood, and significant differences of opinion exist as to their interpretation. In light of data collected from more than a dozen strain gages in this area, it now seems more plausible that the permanent strain changes are local readjustments near the recording sites triggered by the large amplitude elastic waves. The transient strains, which are not always compressive in the radial direction, may be either an affect of the cavity or a stress relaxation phenomena in the vicinity of the recording site. The most recent collection of strain changes which were produced by the HANDLEY event show that on the average, the maximum strain offset is proportional to the inverse cube of the distance. This reinforces the early speculation that the region over which an explosion may significantly alter the local stress field is quite small, being tens of kilometers rather than hundreds of kilometers.

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