MHSMP 6604

STUDY
EARTH SHOCK COMPARISONS
PANTEX PLANT

PREPARED FOR THE
U. S. ATOMIC ENERGY COMMISSION

PREPARED BY
DESIGN GROUP, MASON & HANGER - SILAS MASON CO., INC.

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MASTER

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EARTH SHOCK STUDY

PANTEX PLANT

GENERAL:

Included in this report are comparisons of various earth shocks experienced at Pantex Water Well No. 16. The following shock comparisons are made:

Alaskan quake of March 28, 1964; 3,400 miles away
Amarillo shock of July 20, 1966; 29 miles away
Ten pounds of high explosives, subsurface; 6,500 feet away
Fifty pounds of high explosives, subsurface; 6,500 feet away
Two hundred pounds of high explosives, subsurface; 6,500 feet away
One man stomping feet; near well
Tractor driving; near well

ALASKAN AND AMARILLO SHOCKS:

Both Alaskan and Amarillo shock data were obtained from the Seismology Group at Texas Technological College, which operates a continuous recording station under contract to the U. S. Geodetic Service. The device used by this group is a mechanical-optical-balance-lever device which records particle displacement at a set magnification. The displacement amplitude recorded at the frequency for the Alaskan shock was 1:1000 and for the Amarillo Shock was 1:25000. Thus, to obtain actual displacement, the amplitude is measured directly from the chart and this value divided by the proper magnification. For frequency, the cycles over a given distance are counted and this value divided by the recorded time elapsed.

The distance from the epicenter of the Alaskan shock to the Lubbock station is approximately 3,500 miles. No correction was applied to the recorded shock intensity since Pantex is not significantly closer to Alaska than is Lubbock.

The distance from the epicenter of the Amarillo shock to the Lubbock station was 149 miles and to Pantex, 29.2 miles. The intensity recorded at Lubbock was corrected to give a more realistic value for the shock experienced at Pantex. This was done by assuming that the energy was attenuated by distance alone, along an ever-enlarging circle. This assumes that all soil particles are perfectly elastic and yield an intensity at Amarillo lower than actually experienced and must be considered an approximation.

PANTEX SEISMIC DATA:

For recording of earth shock resulting from Pantex-induced disturbances, a system of geophones was utilized. For each disturbance, seven sets of recordings were made. Three were recorded from Well No. 16 at a depth of 450 feet (50 feet below water level). These three recorded vertical movements and the two horizontal movements at right angles. One recording was made in a test hole 20 feet deep and the other three recordings were taken at various points on the surface of the ground.

The geophones used were "Geospace Corporation" instruments. Movement of the geophone produces a current which flows by a conductor to a galvanometer. The induced current produces rotation of the core by the galvanometer, which is attached to a mirror. As the core rotates, the mirror also rotates. The mirror focuses a beam of light upon a strip of moving photographic paper, so movement of the mirror produces up and down exposures on the paper and a disturbance curve results. In order to determine the magnitude of the induced current producing the curve, a reference current of known voltage was also recorded on the chart. This reference current provided a chart scale since the known current produced a measurable displacement. The intrinsic voltage sensitivity of the geophones used was 0.6 volts/inch/second. Strip curves resulting from these tests are included in this report.

TECHNIQUE OF ANALYSIS:

From the seismic strip charts amplitudes and frequencies were determined, as shown under "Sample Calculations." From these values, two sets of significant quantities were determined- Energy and Damage Index.

A. Energy:

According to Professor L. Don Leeds of Harvard University, the fundamental property of wave motion that governs effects on structures is the amount of energy which the wave delivers to the structure. Kinetic energy is the energy of motion and is a measure of the capacity of a body to do work as a result of its motion. Thus, a comparison of the amount of Kinetic energy a body absorbs from various seismic disturbances would be a comparison of the damage-causing abilities of the different disturbances. Kinetic energy is:

$$K.E. = \frac{1}{2} \frac{W}{g} V^2 \text{ where: } \begin{array}{ll} K.E. &= \text{Kinetic energy} \\ W &= \text{Weight of structure or soil body} \\ g &= \text{Gravity acceleration} = 386.4 \text{ in./sec.}^2 \\ V &= \text{Velocity of } W \text{ during displacement} \end{array}$$

and

$$V = 2\pi fA \text{ where: } \begin{array}{ll} f &= \text{frequency in cycles/second} \\ A &= \text{maximum displacement, inches} \end{array}$$

Using these relationships, the amount of Kinetic energy delivered to the test point for each disturbance was calculated. The results are shown in graph form in this report.

B. Damage Index:

A system based upon studies and experiments by Thoenen and Windes, and used by the U. S. Bureau of Mines, utilizes a Damage Index. This index is explained in the Science of High Explosives by Professor Melvin A. Cook. The damage index is defined by the following empirical relationships:

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$$1. \quad I = \frac{4\pi f^2 A}{12g} \quad \text{where: } I = \text{Damage Index}$$

$$A = \text{Maximum Displacement, Inches}$$

$$f = \text{Frequency, Cycles/Second}$$

$$g = \text{Gravity Acceleration, 32.2 Ft./Sec.}^2$$

or

$$2. \quad I = \frac{2\pi f A_v}{12gk} \quad \text{where: } A_v = \text{Amplitude of Geophone Output, Volts}$$

$$k = \text{Intrinsic Sensitivity Factor of Geophone}$$

Equating the two relationships yields:

$$A = \frac{A_v}{2fk}$$

According to tests and experiences of Thoenen and Windes and the U. S. Bureau of Mines, damage to the most susceptible structures begins at an index of 0.1. No damage has ever been observed below an index of 0.1 and, according to Professor Cook and the Bureau of Mines, any type structure subjected to a damage index of less than 0.1 will not suffer damage. The literature searched does not define the word structure, but doubtless it refers to man-made objects of reasonable rigidity such as foundations, pipes, plastered walls, etc.. Thus, for example, the roof of a loose sand cavity might slough at a lower index value than the 0.1 established for a structure. For this reason, in this report, more emphasis is placed upon comparisons of Kinetic energies than upon the damage indices.

Since the Damage Index is an empirical relationship developed for high explosives, its use for earthquake shocks by direct application of the above formula is doubtful. Since the formula was developed by using amplitudes, frequency, and durations of the same general magnitude, i.e., generated by high explosives, the damage index for earth shocks is not computed in this report. Such computation would yield an extremely low damage index.

RESULTS:

Using the above techniques, the following results were obtained:

<u>Event</u>	<u>Kinetic Energy at Test Point</u>	<u>Relative Amount of Kinetic Energy</u>	<u>Damage Factor, I</u>
10# H.E., Subsurface @ 6,500 Ft.	$1.6 \times 10^{-11} \text{ W}$	1	0.000007
50# H.E., Subsurface @ 6,500 Ft.	$2.4 \times 10^{-10} \text{ W}$	15	0.000032
Tractor Moving near Well	$2.6 \times 10^{-10} \text{ W}$	16	0.000012

RESULTS: (Continued)

<u>Event</u>	<u>Kinetic Energy at Test Point</u>	<u>Relative Amount of Kinetic Energy</u>	<u>Damage Factor, I</u>
Man Stomping near Well	3.6×10^{-10} W	22	0.000037
200# H.E., Subsurface @ 6,500 Ft.	5.5×10^{-10} W	39	0.000036
Amarillo Quake @ 29 Miles	2.7×10^{-9} W	169	-
Alaskan Quake @ 3,500 Miles	2.8×10^{-8} W	1,750	-
Allowable in Penn- sylvania by Law	4.6×10^{-3} W	23,750,000	-

CONCLUSIONS:

From the above results, no damage could be expected to structures or water wells at a radius of 6,500 feet from the firing of typical Pantex test fires. Further, from the extremely low damage indices, wells could be located much nearer the firing site and still not be expected to suffer damage.

In comparing the Kinetic energy delivered to the test well, it is noted that the Alaskan quake generated about 45 times the amount of energy developed by the 200-pound subsurface shot. It is understood that many wells in the area pumped sand following the Alaskan quake. No distorted casing or well failures have been reported as following this event. Thus, the amount of energy delivered by this quake could be considered as just above the maximum desirable at a well. Using this as a basis, one forty-fifth of this amount of energy must be considered negligible and not capable of causing well damage.

This conclusion agrees qualitatively, though no quantities are given, with published data such as The Science of High Explosives by Professor Cook¹, and Vibrations from Construction Blasting by L. Don Leets². In Blasting Vibration by Harold H. White³, it is noted that for the Hiroshima and Nagasaki nuclear blasts with an equivalent yield of 20,000 tons of TNT exploded 1,800 feet in the air, "very little damage was sustained by underground structures and underground utilities, EVEN AT GROUND ZERO."

- 1. Professor Cook: Director, Explosives Research Group, Univ. of Utah
- 2. Professor L. Don Leets: Prof. of Geology, Seismologist in Charge,
Seismograph Station, Harvard University
- 3. Harold H. White: Consulting Engineer on Explosives, Blasting & Vibration

NOTE:

For all Pantex-recorded strips, the displacement curves are numbered to correspond to the following geophone locations:

- (1) Vertical phone in well, 450 feet deep
- (2) Horizontal phone in well, 450 feet deep
- (3) Horizontal phone in well, 450 feet deep
- (4) Phone in test hole, 20 feet deep
- (5) Phone on ground surface, 220 feet from well
- (6) Phone on ground surface, 440 feet from well
- (7) Phone on ground surface, 660 feet from well
- (8) Reference curve from controlled current

ATTACHMENTS:

Plot Plan of Pantex Plant
Bar Graph of Relative Amounts of Kinetic Energies Produced
Strip Chart of Alaskan Shock Recorded at Lubbock, Texas
Strip Chart of Amarillo Shock Recorded at Lubbock, Texas
Strip Chart of 10# H.E. Shot, 30 Ft. Subsurface
Strip Chart of 50# H.E. Shot, 30 Ft. Subsurface, Uncoupled
Strip Chart of 50# H.E. Shot, 30 Ft. Subsurface, Coupled
Strip Chart of 200# H.E. Shot, 30 Ft. Subsurface
Strip Chart of Tractor Moving in Test Area
Strip Chart of One Man Stomping Around Well

APPENDIXES:

Sample Calculations
Pantex Water Well History
Overpressure from High Explosives Detonation

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Extracts from original strip charts of EARTH SHOCK
Recorded at Texas Tech, Lubbock, Tex. by U.S.C. & G. Survey,
Seismological Lab., Rec'd. from Dr. Desmond H. Shurbet by:

Gray W. Jackson Jr. P.E.
9-2-66.

1 of 10
DESIGN
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3 MARCH 27, 1964 QUARRY BLAST - 10 miles distant 3000 lbs. Dynamite
MARCH 28, 1964 ALASKAN EARTH - 3,500 mi. "

RECORDED 9-4-59

APPENDIX "A"

SAMPLE CALCULATIONS

I. Computing Kinetic Energy for 10# H.E. Shot:

- A. From strip chart, measure amplitude of reference current as 40 units on the "C" scale of an engineer's scale. This current is known to be 25 microvolts.
- B. From strip chart, measure maximum amplitude of disturbance curve as 35 units on the same scale.
- C. Calculate amplitude of disturbance curve as $(35/40)(2.5)(10^{-5})$ volts = 2.19×10^{-5} v.
- D. Count cycles on strip chart over maximum disturbance as 6 in 0.51 seconds.

$$f = 6 \text{ cycles}/0.51 \text{ seconds} = 11.8 \text{ cycles/second}$$

- E. Using $A = Av/2fk$

$$A = (2.19 \times 10^{-5})/(2)(11.8)(0.6) = 1.5 \times 10^{-6} \text{ inches}$$

- F. Calculating particle displacement velocity: $v = 2\pi fA$

$$v = 2\pi(11.8)(1.5 \times 10^{-6}) = 1.11 \times 10^{-4} \text{ inch/second}$$

- G. Kinetic Energy = K.E. = $\frac{WV^2}{2g} = \frac{W(1.11 \times 10^{-4})^2}{(2)(386.4)} = 1.59 \times 10^{-11} \text{ W}$

II. Computing Damage Index for 10# H.E. Shot:

- A. From strip chart, determine $f = 11.8$ cycles/second and $Av = 2.19 \times 10^{-5}$ v

- B. Utilize formula: $I = \frac{2\pi fAv}{12gk}$

$$I = \frac{2\pi(11.8)(2.19 \times 10^{-5})}{(12)(32.2)(0.6)}$$

$$I = 7 \times 10^{-6} \text{ or } 0.000007$$

III. Computing Kinetic Energy and Damage Index for 50# H.E. Shot:

Use strip charts and same technique as for 10# H.E. shot above.

IV. Computing Kinetic Energy and Damage Index for 200# H.E. Shot:

- A. The first 3 seconds of disturbance was missed by the recording machine. To determine an approximate value, the similarity of the 50# disturbance curve after 3 seconds and the 200# disturbance after 3 seconds (at first part of strip chart) was noted. Realizing that amplitude persists at a fairly uniform value for a longer period but that higher

IV. A. (Continued)

frequencies are quickly attenuated, a ratio was established as follows:

1. On 50# strip, determine frequency at maximum disturbance as 12.7 cycles/sec.
2. On 50# strip, determine frequency after 3 seconds as 2 cycles in 0.46 seconds or $2/0.46 = 4.35$ cycles/second.
3. Frequency for 200# shot at maximum will be considered the frequency after 3 seconds multiplied by $\frac{12.7}{4.3} = 3$ times.
4. Frequency of 200# shot after 3 seconds found to be 3.5 cycles/sec. Multiply by 3 to obtain initial frequency of 10.5 cycles/second.
5. Maximum amplitude of disturbance found to be 1.25×10^{-4} volts.
6. Utilizing $A = Av/2fk$

$$A = (1.25 \times 10^{-4}) / (2)(10.5)(0.6)$$

$$A = 9.9 \times 10^{-6}$$

and

$$v = 2\pi fA$$

$$v = 2\pi(10.5)(9.9)(10^{-6})$$

$$v = 6.52 \times 10^{-4}$$

and

$$K.E. = \frac{WV^2}{2g}$$

$$K.E. = \frac{W(6.52 \times 10^{-4})^2}{(2)(386.4)}$$

$$K.E. = 5.5 \times 10^{-10} \text{ W}$$

7. Computing Damage Index $I = \frac{2\pi fAv}{12gk}$

$$I = \frac{2\pi(10.5)(1.25 \times 10^{-4})}{(12)(32.2)(10.6)}$$

$$I = 3.6 \times 10^{-5}$$

V. Computing Kinetic Energy of Amarillo Shock:

- A. From recording, measure maximum amplitude as 1 inch. This has been

V. A. (Continued)

amplified 25,000 times so actual soil displacement was $1/25,000$ or 4×10^{-5} inches.

B. Count cycles over maximum disturbance area and divide by the time element and obtain frequency of 1.13 cycles/second.

C. Calculate particle displacement velocity, $v = 2\pi fA$

$$v = 2\pi (1.13)(4)(10^{-5})$$

$$v = 2.84 \times 10^{-5}$$

D. Calculate Kinetic energy at Lubbock, $K.E. = 1/2 \frac{W}{g} v^2$

$$K.E. = \frac{(W)(2.84 \times 10^{-5})^2}{(2)(386.4)}$$

$$K.E. = 1.04 \times 10^{-10} W \text{ (At Lubbock)}$$

E. Correct to Pantex by assuming energy attenuated by distance alone by spreading along an ever-enlarging sphere. This assumption assumes soil particles and rocks to be perfectly elastic and the value obtained is lower than actually experienced at Pantex:

$$K.E. = (K.E. @ Lubbock)(149/29.2)^2$$

$$= (1.04)(10^{-10}) W \times 26$$

$$= 2.7 \times 10^{-9} W.$$

APPENDIX "B"

HISTORY OF PANTEX WATER WELLS

WELL NO. 2:

Built in 1942. First major overhaul in 1966, consisting of bailing, sonar cleaning, and installation of new pump and drive shaft.

Well No. 2 has been consistently a sand pumper. In 1961, a hole was noted in the ground adjacent to the casing which required fifteen yards of gravel to fill.

WELL NO. 5:

Built in 1942. Well bailed and pump overhauled in 1952 (at reactivation). From 1952 until 1959, pumped a moderate amount of sand at times. From 1959 until 1965, the well was a sand pumper. In 1965, the well was repaired and a leak was found in the well casing. Six hundred and forty-five feet of liner was installed along with a new pump and new bearings. It is now a productive well pumping a moderate amount of sand.

WELL NO. 6:

Built in 1942 and reconditioned in 1952 by bailing and repairing pump. In 1958, a cave-in was found on southwest corner of wellhouse which extended to the surface. Approximately 300 cubic yards of gravel were required to fill the hole. Well has consistently pumped sand-free water since 1952, so cavity must have formed at time of bringing in the well.

WELL NO. 7:

Built in 1942. In 1959, the pump was repaired and the well relined because of a hole in the casing. In 1964, the pump was again repaired. A new pump was installed in 1966. On each of these occasions, the well was bailed to remove sand. This well has pumped an excessive amount of sand throughout its history.

WELL NO. 11:

Built in 1942. New pump was installed in 1952. This well has pumped sand-free water throughout its history and has consistently been the best producing well at Pantex.

APPENDIX "C"

OVERPRESSURE FROM HIGH EXPLOSIVES DETONATION

From Firing Site No. 10 to Public Highway FM 293 is a distance of 2,400 feet. This is the nearest point to the Pantex property line from any of the several firing pads. At that distance, the following table is applicable.

<u>Size of High Explosives Charge</u>	<u>Overpressure at Property Line</u>	<u>Comments</u>
50 Pounds	0.06 PSI	
100 Pounds	0.08 PSI	
200 Pounds	0.1 PSI	
500 Pounds	0.15 PSI	
1,000 Pounds	0.18 PSI	
5,000 Pounds	0.28 PSI	Larger than ever fired.
200,000 Pounds	1.0 PSI	Windows shattered.