AN INVESTIGATION OF GROUND ACCELERATIONS PRODUCED BY MACHINES

Thesis by

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Pasadena Annex

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ABSTRACT

Machines with reciprocating or rotating parts initiate stress waves which propagate through the ground and produce measurable ground motions in the vicinity of the machines. In many respects these ground motions may be objectionable. Consequently it is desirable to have a body of precise information on the ground motion produced by various common machines.

Measurements of the ground acceleration produced by drop hammers, punch presses, railway trains, heavy automotive trucks, a cutting shear, a hydraulic press, and a pneumatic hammer were made. The vertical and two horizontal components of acceleration were measured at various distances from the source. The maximum ground acceleration component observed was 64.4 feet per second per second near a drop hammer. Ground accelerations as great as 1.6 feet per second per second were measured at a distance of one hundred feet from the source.

The influence of ground acceleration on equipment, on machines, and on human beings is largely dependent on the maximum value of the ground acceleration but also may be markedly influenced by the character of the ground motion. The detailed character of the ground acceleration varies widely with the different sources of the motion, with distance from the source, and with the geology of the transmitting medium. To cover this aspect of the problem sixty-two acceleration time records of the ground motion are reproduced in the thesis.

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I. INTRODUCTION

Numerous measurements of the ground accelerations caused by earthquakes have been made (1, 2)*. As a result, a considerable body of knowledge on design factors to reduce the destructive effects of earthquakes is in existence.

By way of contrast, far fewer measurements of ground accelerations caused by man-made equipment and machinery are available. The localized nature of the machine-caused accelerations as contrasted with earthquake accelerations probably accounts to a certain extent for the lack of information on them. There is in addition an extensive variety of situations in which measurements may prove fruitful in solving the particular problem at hand but which may not possess wide generality. Also it has been only recently that instrumentation has been developed which combines the necessary measuring features with the ruggedness and portability required for extensive field work.

In spite of the local nature of the machine-caused accelerations, many problems arise both in industry and the community due to their presence. Typical of these problems is the malfunctioning of one machine due to the operation of another machine, often at considerable distance from the first, which imparts accelerations to the ground. In addition, minor structural damage such as cracks in plaster can be caused by the machine-produced ground accelerations. Still another effect of these ground motions, somewhat difficult to assess quantitatively

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* Numbers in parentheses correspond to the numbered references listed on page 23.

but important nevertheless in the impact on or relation to the community, is that they constitute a nuisance.

With the foregoing several considerations in mind, a series of measurements of machine-caused ground accelerations was made, and the presentation of these measurements forms the body of this thesis.

Significant parameters in the study of ground accelerations are peak acceleration and variation of the acceleration with time. Both of these parameters vary with the nature of the source, distance from the source, physical properties of the soil and geological substructure, and coupling between source and soil. In machine caused ground accelerations the coupling is determined by the machine mount.

Consequently it was originally planned to make a series of measurements near machines of technical importance. Measurements were to be made at explicit distances from each source. It was recognized from the beginning however that very little control could be exercised over soil and geological substructure characteristics. The types of coupling would be that normally found in machine installations and a variety of types would add to the value of the investigation.

The practical application of the plan soon met with difficulties which precluded taking measurements at the same set of distances from each of the sources. These difficulties arose from plant layout and location as well as the necessity to observe industrial safety rules and to cause the least possible interruption to plant operations while the measurements were in progress. It was only through the indulgence and cooperation of the several organizations mentioned in the acknowledgement that the measurements could be made.

II. INSTRUMENTATION

The instruments for recording the ground motion had been previously used for measuring ground accelerations due to a quarry blast (3,4). Of prime importance in the many measurements was the requirement that the measuring system be easily and accurately calibrated. For this reason, an A. C. carrier system with a flat response down to zero signal frequency was chosen. This made possible a direct static gravity acceleration calibration before and after each measurement with a minimum of complication. Relatively low frequencies (less than 80 cps) were expected along with small values of accelerations. This dictated the use of a magnetic accelerometer. The actual accelerometer used was a William Miller Corporation, Type 402-C. It is a variable reluctance, balanced armature, seismic instrument with a natural frequency of approximately 180 cps and fluid damping of approximately 60 per cent of critical damping. The amplifier used was a Brush Development Company, Type BL320, "Universal Analyzer." The "Analyzer" consists of an A. C. bridge circuit, a 2000 cps oscillator, an A. C. amplifier, a demodulator-discriminator circuit, and a D. C. power amplifier. The amplifier output fed into a two Channel Brush, Type BL202, Direct Inking Oscillograph. The amplifier-recorder system has an overall frequency response which is flat from 0 to 100 cycles per second. Serial numbers of all instrumentation are presented in Appendix 2.

For most of the measurements, 110-volt A. C. line voltage was used as the power supply. In addition, a transformer was used to reduce line voltage and the resulting 60 cps signal was fed into one of the oscillograph channels to provide a time signal. In the remaining measurements (those of ground accelerations caused by heavy automotive trucks only) an ATR model 12 HSF Type 12 inverter was used in conjunction with two 6-volt storage batteries for power supply and time signal.

III. PROCEDURE

In use, the accelerometer, measuring 1 by 1-1/2 by 2-1/2 inches, was bolted to a rectangular steel block with dimensions 2 by 2 by 2-1/2 inches. The block was then firmly placed on the ground with the sensitive axis of the accelerometer pointing in the direction of desired acceleration measurement. Horizontal accelerations are those accelerations measured with the sensitive axis of the accelerometer in a horizontal plane and coincidental with a radial line emanating from the source. The alignment was done by eye. Lateral horizontal accelerations are those accelerations in a horizontal plane but perpendicular to a radial line emanating from the source. Here again alignment was done by eye. Vertical accelerations are those accelerations measured with the sensitive axis of the accelerometer parallel to the gravitational field of the earth.

A small spirit level was used on the rectangular steel mounting block during placement of the accelerometer to assure that a precise horizontal or vertical attitude was obtained. After a sufficient warm-up time for the electric and electronic components, the accelerometer was placed in position as described above and the bridge balanced and the oscillograph pen centered. Then with suitable adjustment of amplifier gain and attenuator setting, the sensitive axis of the accelerometer was rotated through ninety degrees in the earth's gravitational field. The ninety-degree rotation was accurately obtained through the use of the spirit level and rectangular mounting block. A calibration signal corresponding to one gravitational unit was thus recorded. The accelerometer was then placed in its original position and the measurement in question was taken. After the measurement, the calibration was repeated.

Careful visual observations were made during the course of the measurements to detect any motion of the accelerometer and block with respect to the ground. It became necessary for certain of the more intense accelerations, when the accelerometer was placed on a concrete surface, to bolt the mounting block to the surface.

Because of the wide range of accelerations encountered, it was found best to adjust amplifier gain and attenuator setting with each measurement to provide optimum signal and calibration signal strengths. Amplifier gain, however, was always well below the highest level available where instability of the system had sometimes been observed.

Special care was taken to provide a good electrical ground which aided in noise suppression and elimination of extraneous pick-up.

In certain of the measurements, it was found necessary to put a layer of sponge rubber between the oscillograph and the earth in order to prevent the ground acceleration from causing the pen to leave the oscillograph paper.

IV. RESULTS

Measurements of ground accelerations produced by the following sources were made:

1. Drop hammers of different sizes and with different types of mounts
2. Railroad trains
3. A 2000-ton hydraulic press
4. A shear
5. Two punch presses - a 50-ton press and a 95-ton press
6. A pneumatic jack hammer
7. Heavy automotive trucks

For the above sources, Tables 1 and 2, pages 8 and 9 list the maximum recorded vertical and horizontal ground accelerations at distances as close to the source as safety and convenience would permit. The measurements close to the source eliminate to some extent the variation in transmissability of the soils when a comparison is to be made of the relative strengths of the sources.

Figures 1 through 26, Appendix I, are reproductions of the actual oscillograph recordings of ground acceleration versus time. Each individual accelerogram is identified by source, distance from source, and direction of acceleration component as well as other information where appropriate.

Tables 3, 4, and 5, pages 10, 12, and 14, list the maximum accelerations for all the accelerograms of figures 1 through 26.

It should be emphasized that maximum acceleration as used here refers only to these particular accelerograms and in no sense should be taken to imply that any of the sources are incapable of producing larger ground accelerations.

TABLE 1

VERTICAL ACCELERATIONS

Source	Distance From Source Feet	Maximum Acceleration "g's"
Medium Hammer Oak Mount	6	2.00
Small Hammer Rubber Mount	6	0.52
Train	6	0.22
Large Hammer Spring Mount	10.5	0.20
Shear	6	0.18
Jack Hammer	6	0.15
50-ton Punch Press	6	0.11
95-ton Punch Press	6	0.087
2000-ton Hydropress	6	0.017
Gravel Truck	6	0.0074

TABLE 2

HORIZONTAL ACCELERATIONS

Source	Distance From Source Feet	Maximum Acceleration "g's"
Medium Hammer Oak Mount	6	0.53
Train	6	0.29
Jack Hammer	6	0.13
95-ton Punch Press	6	0.056
Large Hammer Spring Mount	10.5	0.053
Small Hammer Rubber Mount	6	0.035
50-ton Punch Press	6	0.030
Shear	6	0.030
2000-ton Hydropress	6	0.021
Gravel Truck	6	0.0079

TABLE 3

VERTICAL ACCELERATIONS

Source	Distance From Source Feet	Maximum Acceleration "g's"
Large Hammer Spring Mount	10.5	0.20
Large Hammer Spring Mount	50	0.048
Large Hammer Spring Mount	100	0.018
Medium Hammer Oak Mount	6	2.00
Medium Hammer Oak Mount	50	0.12
Medium Hammer Oak Mount	100	0.058
Small Hammer Oak Mount	51	0.038
Small Hammer Oak Mount	100	0.051
Large Hammer Rubber Mount	25	0.48
Large Hammer Rubber Mount	50	0.19
Small Hammer Rubber Mount	6	0.52
Small Hammer Rubber Mount	25	0.18
Train	6	0.22
2000-ton Hydropress	6	0.017

TABLE 3
(Continued)

VERTICAL ACCELERATIONS

Source	Distance From Source Feet	Maximum Acceleration "g's"
2000-ton Hydropress	25	0.0077
Shear	6	0.18
Shear	50	0.017
50-ton Punch Press	6	0.11
50-ton Punch Press	50	0.014
95-ton Punch Press	6	0.087
95-ton Punch Press	50	0.019
Jack Hammer	6	0.15
Gravel Truck	6	0.0074

TABLE 4

HORIZONTAL ACCELERATIONS

Source	Distance From Source Feet	Maximum Acceleration "g's"
Large Hammer Spring Mount	10.5	0.053
Large Hammer Spring Mount	50	0.010
Large Hammer Spring Mount	100	0.0080
Medium Hammer Oak Mount	6	0.53
Medium Hammer Oak Mount	50	0.063
Medium Hammer Oak Mount	100	0.015
Small Hammer Oak Mount	100	0.022
Large Hammer Rubber Mount	25	0.16
Large Hammer Rubber Mount	50	0.13
Small Hammer Rubber Mount	6	0.035
Small Hammer Rubber Mount	25	0.020
Train	6	0.29
Train	24	0.11
Train	48.3	0.037
2000-ton Hydropress	6	0.021

TABLE 4
(Continued)

HORIZONTAL ACCELERATIONS

Source	Distance From Source Feet	Maximum Acceleration "g's"
2000-ton Hydropress	25	0.0058
Shear	6	0.030
Shear	50	0.0033
50-ton Punch Press	6	0.030
50-ton Punch Press	50	0.0045
95-ton Punch Press	6	0.056
95-ton Punch Press	50	0.0034
Jack Hammer	6	0.13
Gravel Truck	6	0.0079

TABLE 5

LATERAL HORIZONTAL ACCELERATIONS

Source	Distance From Source Feet	Maximum Acceleration "g's"
Large Hammer Spring Mount	10.5	0.027
Large Hammer Spring Mount	50	0.010
Large Hammer Spring Mount	100	0.0035
Medium Hammer Oak Mount	6	0.28
Medium Hammer Oak Mount	50	0.023
Medium Hammer Oak Mount	100	0.014

V. DESCRIPTION OF SOURCES

Drop hammers are rather loosely classified according to the nominal weight of the moving hammer head. The actual moving object in the machine frequently weighs substantially more than the head. In addition, all the hammers measured in this investigation were power driven either by steam or compressed air. It is thus clear that the striking force of the hammer is not directly related to the hammer head weight. For the purpose of this investigation then, three classes of hammer category were arbitrarily established. They are small, medium, and large. Hammers in which the head weighs less than 10,000 pounds are placed in the small category. Hammers in which the head weighs between 10,000 and 20,000 pounds are placed in the medium category, and hammers in which the head weight is greater than 20,000 pounds are placed in the large category. The smallest hammer measured had a head weight of the order of 6000 pounds. The largest hammer measured had a head weight of 30,000 pounds.

As is evident from the figures, the type of drop hammer mount had a significant effect on the strength of the transmitted force and, hence, ground acceleration. The oak timber and concrete mounts consisted of three layers of 12" x 12" oak timbers with the timbers running in alternate perpendicular directions in consecutive layers. Under the timbers was a large base of concrete. The top of the mount was flush with the ground surface. This type of mount evolved from early industry practice and was used in the installations investigated here because they had proved satisfactory in the past.

The rubber mount used on the small drop hammer consisted of squares of rubber approximately 16 inches on a side and 4 inches thick placed directly between the base of the hammer and a concrete foundation. The large hammer rubber mount was a solid layer of rubber approximately 4 inches thick placed between the base of the hammer and a concrete foundation.

The spring mount used on only one hammer in this investigation consisted of a large reinforced concrete inertia block which received the anvil. This inertia block was suspended by means of beams and springs at its edges. Under the inertia block in a pit constructed to receive it was a layer of rubber which was compressed by motion of the inertia block. An undetermined amount of frictional damping produced by snubbers on the inertia block beams was also present.

The accelerations due to railroad trains were measured adjacent to the well kept and maintained right-of-way of a major railroad. The distances from the source are perpendicular distances from the closest rail. The trains in question were a luxury streamlined passenger train with three diesel electric power units. The train in each case had stopped for a grade crossing approximately 1/4 mile from the accelerometer and was in process of accelerating as it passed the accelerometer. The speed of the train as it passed the accelerometer was estimated at from 10 to 25 mph. Not evident in the accelerograms, figures 12, 13, 14, and 15, but present in the original record, is the periodic nature of the ground accelerations as successive cars passed a point opposite the accelerometer. The duration of the ground accelerations caused by the trains was directly comparable to the duration of earthquakes (1, 2). The apparent average frequency of the train caused ground accelerations is substantially higher than for earthquakes, however.

Hydraulic presses are rated by the maximum force they can exert. Consequently, the 2000-ton hydropress investigated could exert a 2000-ton force between dies. The press was vertical and extended two stories above ground level. It required a substantial custom-built, underground-mounting structure. Definite ground accelerations were observed when the dies first came into contact and also when the force was relieved from them. The noise, observable on the hydropress accelerograms, figure 17, apparently came from the numerous electrical fields caused by the plant wiring system. Many components of this system were located in the basement of the building near the hydropress base where the acceleration measurements were made.

The shear was perhaps the most innocuous in appearance of any of the machines investigated. It had a rated cutting capacity of 72 inches of 1/4 inch thick mild steel and was mounted directly on concrete. In spite of its appearance, it had caused considerable trouble through ground accelerations. An adjacent welding-cutting table could not be used for accurate work when the shear was operating.

Punch presses are also rated by the maximum force they can exert. The presses investigated were mounted directly on concrete. Here also two distinct phases of ground acceleration were encountered though in the smaller press the first phase was so small as to be rarely distinguishable.

The jack hammer was of the hand-operated type in common use. Accelerations caused by it were taken as a point of reference since most persons have heard, if not seen, this type of machine in operation. These particular ground accelerations were the most periodic of any obtained in this investigation. The distance from the source was measured from the point of application of the bit.

The trucks which produced ground accelerations measured in this investigation consisted of a tractor with a load box and a trailer. The load was either crushed rock or sand. Different trucks were used to get the horizontal and vertical acceleration components. Distance from the source was taken as the perpendicular distance from the edge of the highway, and accelerations were recorded only for trucks in the outer highway lane. The highway in the vicinity of the accelerometer was relatively smooth. Truck speed was estimated at approximately 35 miles per hour.

VI. DISCUSSION AND CONCLUSIONS

Excellent repeatability of pen deflection for 1g calibration signals both before and after an acceleration was recorded contributed towards accuracy. The smallest scale division on pen deflections is one millimeter. It is estimated that pen deflection can be read accurately within 0.2 millimeters. Over 85 per cent of the lg calibration signals agreed within 0.2 millimeters on the before and after signal. Amplifier gain was set to give 15-millimeters pen deflection on the lg signal for most of the measurements. Thus, the possible calibration error is 1.3 per cent. It will be observed from figures 1 through 26 that the ground acceleration signal is greater than 5 millimeters for most measurements. The attenuator ratios used for increasing system sensitivity were found to be accurate within the reading accuracy of the pen trace. Consequently, for a 5-millimeter pen deflection signal, the combined possible error due to calibration and measurement is 5.2 per cent. For a 15-millimeter pen deflection, the combined possible error is 2.6 per cent.

Several uses for the results are evident. For example, in the isolation of structures from transient or shock loads, it is convenient to know the variation of the forcing function with time. The accelerograms provide the forcing function fed into a structure by the earth.

In assessing the damage-producing capability of machines, the ground acceleration records are valuable. Extensive studies of structural damage caused by quarry blasting (5) have shown that ground accelerations equal to or greater than 10 per cent of gravity are required to initiate plaster cracking. Plaster cracking is usually the first stage of structural damage.

Indirectly, the results can serve as a guide to desired objectives in drop hammer mount design. While specific mount design details are not given and no claim to optimum mount design is made for the spring-mounted hammer reported, it is nevertheless clear from Tables 1 and 2, pages 8 and 9, that a 10 to 1 reduction in intensity of ground acceleration at the source may be expected over the conventional oak timber supported hammer when a mount is efficiently designed to reduce the accelerations. It is felt this conclusion is warranted even though different size hammers and different type forging operations were being conducted.

During the course of the measurements, the accelerometer and block were placed at various times on concrete, asphalt, and soil surfaces. No effects traceable to the type of surface were observed. All measurements were made within Los Angles County, California. The soil may be briefly described as being a sandy loam with some variations. In the area where the punch presses, shear, and oak-mounted and spring-mounted drop hammers were located, the sandy loam tended towards a finer sand with relatively little silt. In the location of the rubber-mounted drop hammers and the hydraulic press, the soil was a typical sandy loam. In the general area near the railroad measurements, the sandy loam was characterized by a heavier sand with silt and some gravel present. None of the soils are homogeneous to any considerable depth. It is clear then that the plasticity of the surface soils is relatively low.

Ground accelerations of the type investigated herein are caused by the unbalanced forces associated with the propagation of a pressure wave in the soil. This wave is characterized by a continuous change of shape and amplitude with distance from the source. These changes are a consequence of the spherical divergence of the wave and the stress-strain relationship of the medium (6). Reflections of the waves from surfaces of different physical properties than the soil, such as underlying rock strata, greatly influence the character of the ground acceleration at any given point. At the surface of the earth the situation is further complicated by reflections from the surface itself. Consequently it becomes difficult to predict the attenuation of the ground acceleration with distance from the source.

In attempting to empirically fit some of the observed attenuations that are evident in tables 3 and 4 one is limited by the lack of measurements at varying distances from the sources of repeatable strength. The drop hammer measurements for instance should not be used in this way since the strength of each individual blow varied somewhat from the next even when the hammer operator tried to strike blows of equal intensities. Only one local measurement could be made for any blow with the equipment available for the investigation.

To aid in putting the results of this test in proper perspective, figure 27, Appendix 1, is an accelerogram of the Vernon, California earthquake of October 2, 1933. The maximum ground acceleration of the earthquake is approximately equal to that occurring at a point 400 yards from a quarry blast in which 375,000 pounds of nitramon explosive was used as a charge (3). This same magnitude of ground acceleration (13% of g) is also approximately equal to that found at a distance of 1 mile from an underground burst of a nominal atomic bomb (6).

VII. REFERENCES

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(2) Alford, J. L., Housner, G. W., and Martel, R. R., "Spectrum Analysis of Strong Motion Earthquakes." First Technical Report, ONR Project Nr-081-095, California Institute of Technology, 1951.

(3) Housner, G. W., Hudson, D. E., and Alford, J. L., "Ground Shock and Building Motions Produced by a Quarry Blast." Proceedings of the Society for Experimental Stress Analysis, Vol. XI, No. 2.

(4) Hudson, D. E., Alford, J. L., and Housner, G. W., "Measured Response of a Structure to an Explosive-Generated Ground Shock." Bulletin of the Seismological Society of America, Vol. 44, No. 3, July 1954.

(5) Throenen, J. R., and Windes, S. L., "Seismic Effects of Quarry Blasts." Bulletin 442, United States Department of the Interior, Bureau of Mines, 1942.

(6) "The Effects of Atomic Weapons." U. S. Government Printing Office, 1950.

VIII. APPENDIX 1

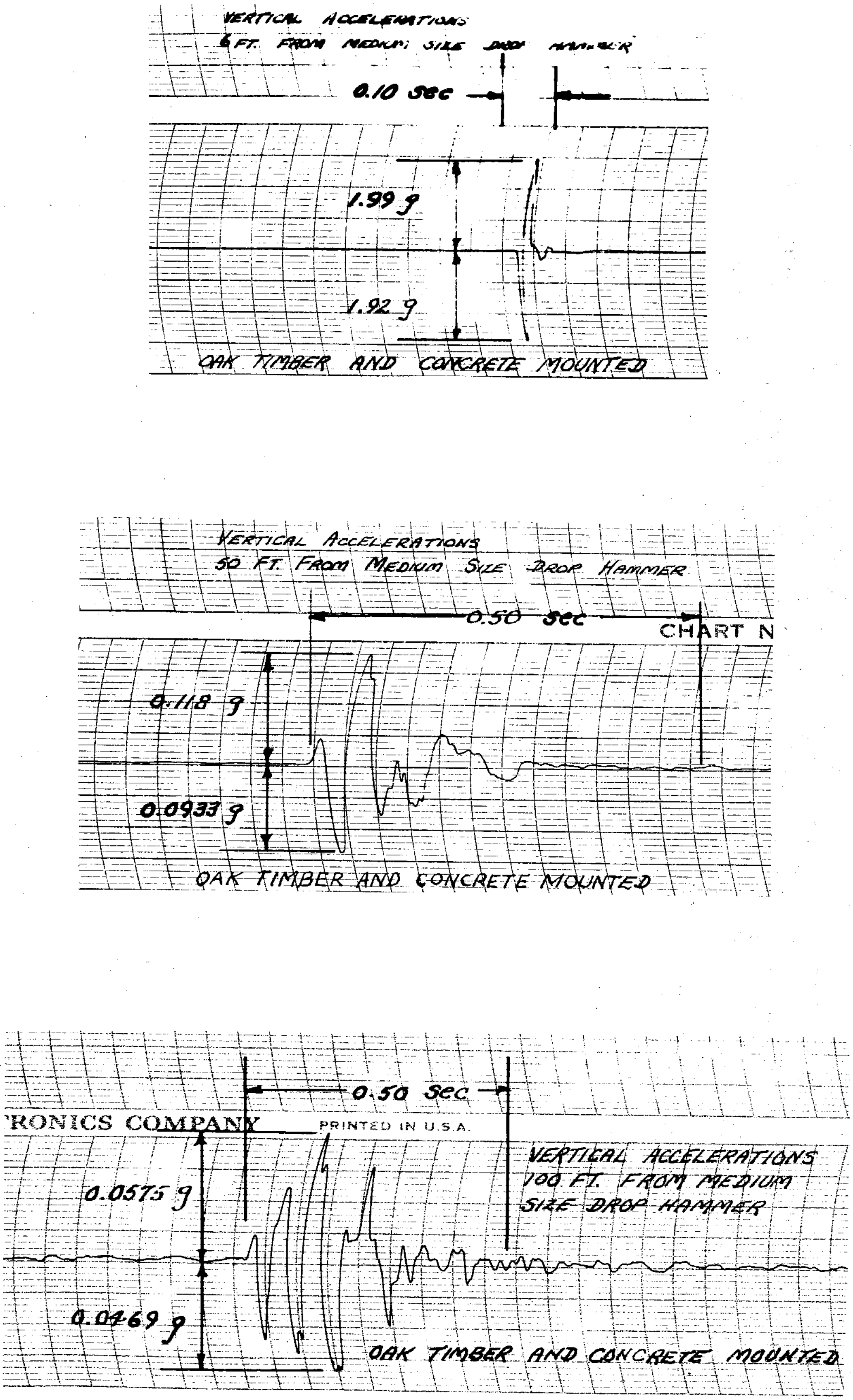

VERTICAL ACCELERATIONS
6 FT. FROM MEDIUM SIZE DROP HAMMER
0.10 sec
1.99 g
1.92 g
OAK TIMBER AND CONCRETE MOUNTED
VERTICAL ACCELERATIONS
50 FT. FROM MEDIUM SIZE DROP HAMMER
0.50 sec
CHART N
0.118 g
0.0933 g
OAK TIMBER AND CONCRETE MOUNTED
0.50 sec
RONICS COMPANY
PRINTED IN U.S.A.
VERTICAL ACCELERATIONS
100 FT. FROM MEDIUM
SIZE DROP HAMMER
0.0575 g
0.0469 g
OAK TIMBER AND CONCRETE MOUNTED

FIG. 1

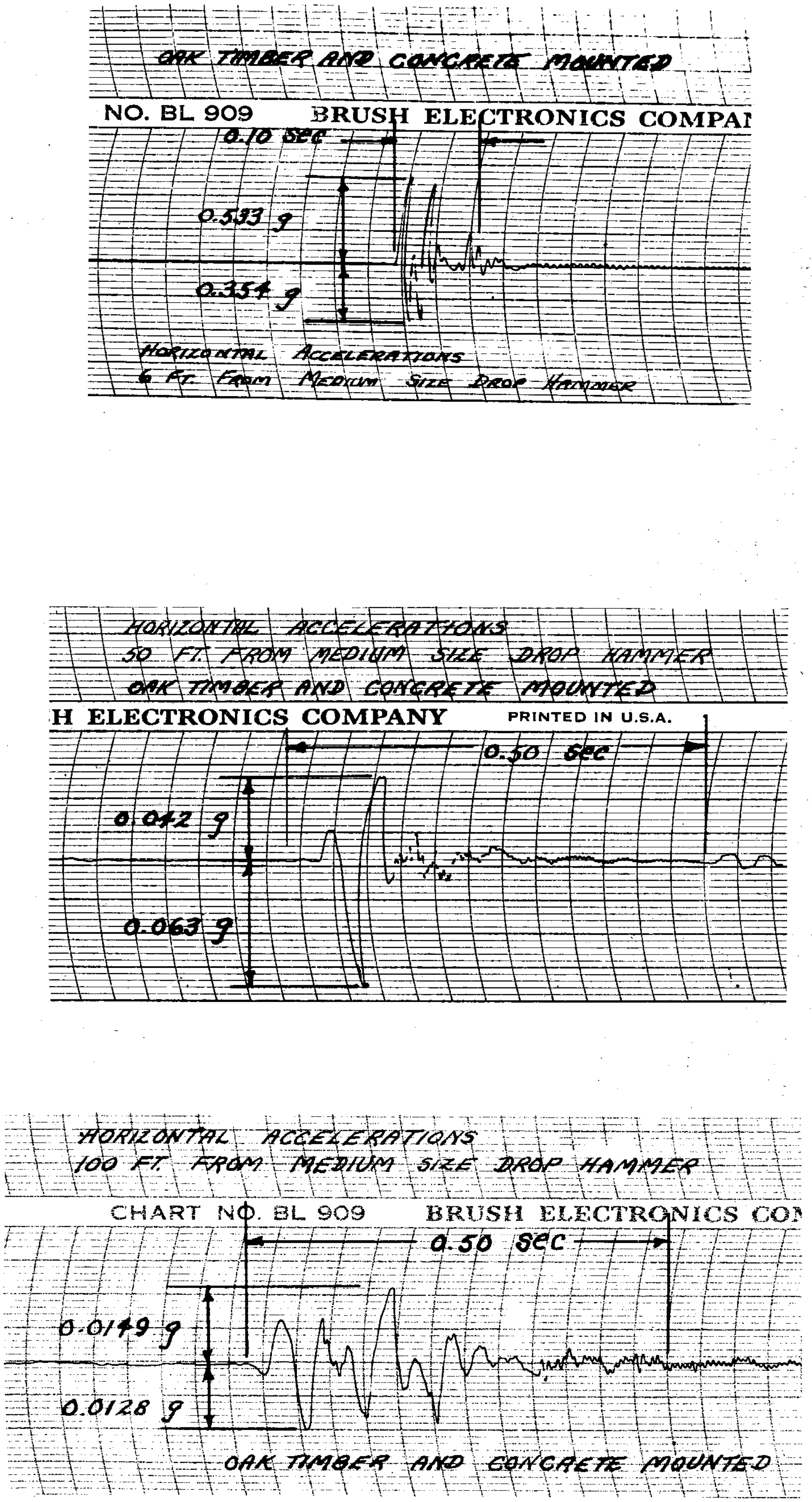

OAK TIMBER AND CONCRETE MOUNTED
NO. BL 909 BRUSH ELECTRONICS COMPA
0.10 SEC
0.533 g
0.354 g
HORIZONTAL ACCELERATIONS
6 FT. FROM MEDIUM SIZE DROP HAMMER
HORIZONTAL ACCELERATIONS
50 FT. FROM MEDIUM SIZE DROP HAMMER
OAK TIMBER AND CONCRETE MOUNTED
H ELECTRONICS COMPANY
PRINTED IN U.S.A.
0.50 SEC
0.042 g
0.063 g
HORIZONTAL ACCELERATIONS
100 FT. FROM MEDIUM SIZE DROP HAMMER
CHART NO. BL 909
BRUSH ELECTRONICS CO
0.50 SEC
0.0149 g
0.0128 g
OAK TIMBER AND CONCRETE MOUNTED

FIG. 2

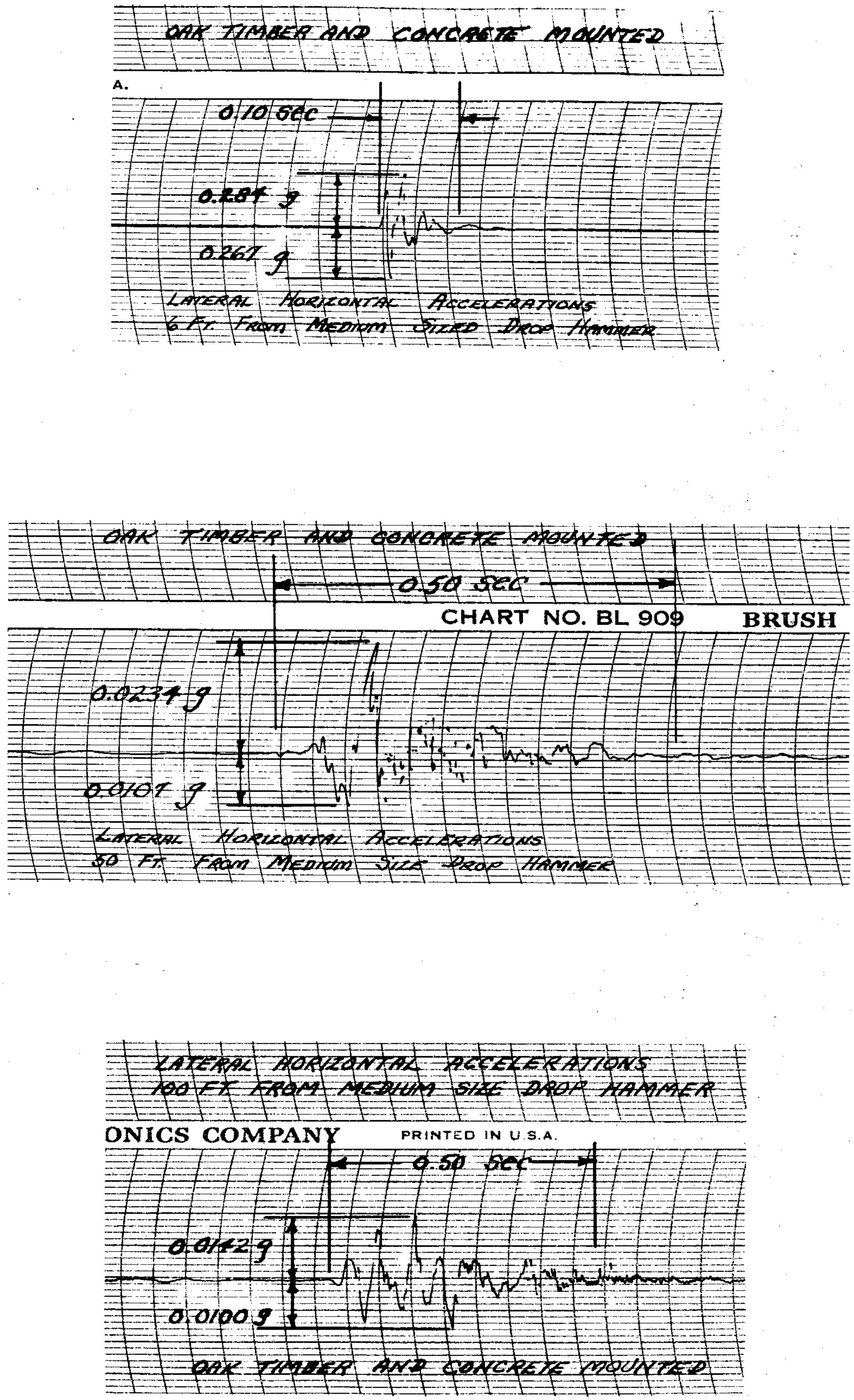

OAK TIMBER AND CONCRETE MOUNTED
A.
0.10 SEC
0.284 g
0.267 g
LATERAL HORIZONTAL ACCELERATIONS
6 FT. FROM MEDIUM SIZED DROP HAMMER
OAK TIMBER AND CONCRETE MOUNTED
0.50 SEC
CHART NO. BL 909
BRUSH
0.0234 g
0.0107 g
LATERAL HORIZONTAL ACCELERATIONS
50 FT. FROM MEDIUM SIZE DROP HAMMER
LATERAL HORIZONTAL ACCELERATIONS
100 FT. FROM MEDIUM SIZE DROP HAMMER
ONICS COMPANY
PRINTED IN U.S.A.
0.50 SEC
0.0142 g
0.0100 g
OAK TIMBER AND CONCRETE MOUNTED

FIG. 3

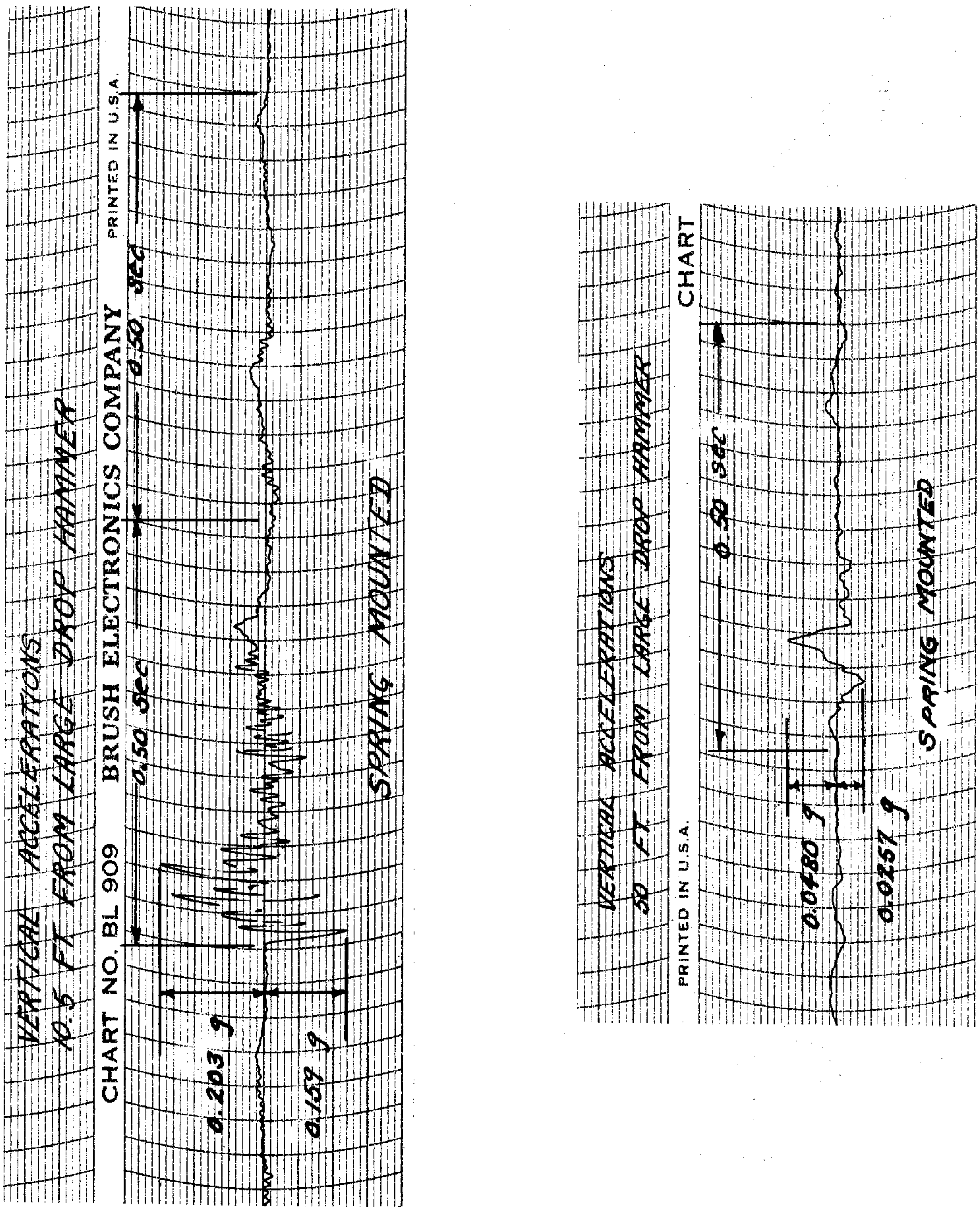

VERTICAL ACCELERATIONS
10.5 FT FROM LARGE DROP HAMMER
CHART NO. BL 909 BRUSH ELECTRONICS COMPANY
PRINTED IN U.S.A.
0.50 sec
0.50 sec
0.203 g
0.159 g
SPRING MOUNTED
VERTICAL ACCELERATIONS
50 FT FROM LARGE DROP HAMMER
PRINTED IN U.S.A.
CHART
0.50 sec
0.0480 g
0.0257 g
SPRING MOUNTED

FIG. 4

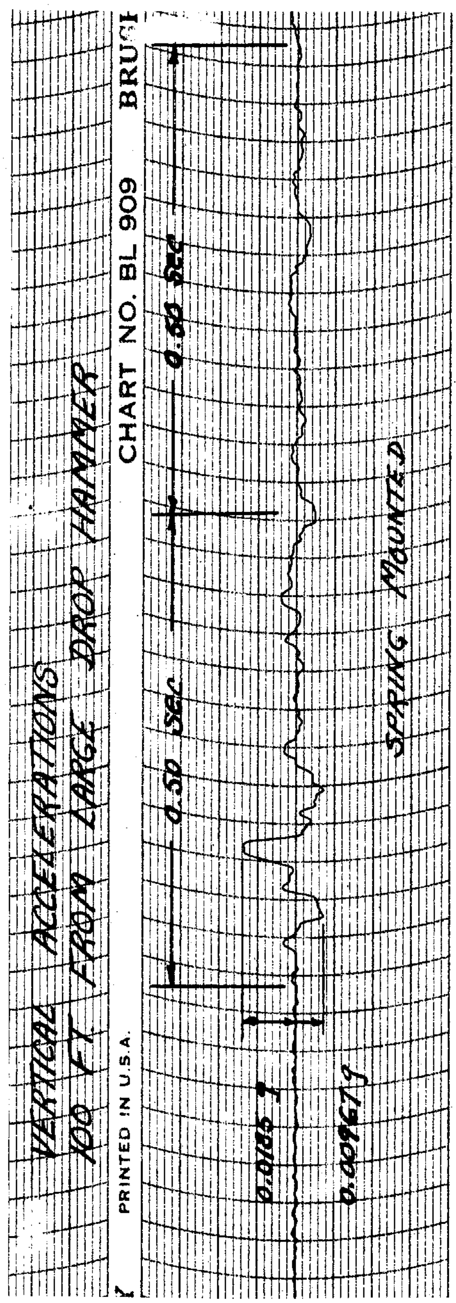
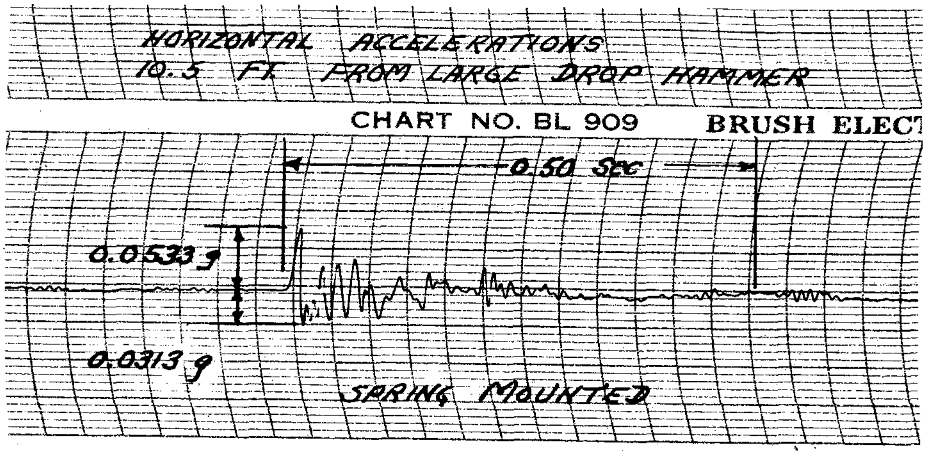
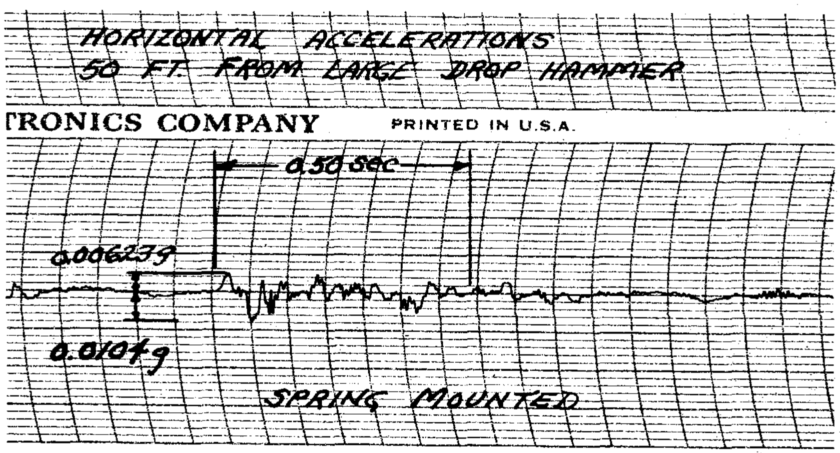

VERTICAL ACCELERATIONS
100 FT FROM LARGE DROP HAMMER
PRINTED IN U.S.A.
CHART NO. BL 909
0.50 SEC
0.50 SEC
SPRING MOUNTED
0.0185
0.00967 g

FIG. 5


HORIZONTAL ACCELERATIONS
10.5 FT. FROM LARGE DROP HAMMER
CHART NO. BL 909
BRUSH ELEC
0.50 SEC
0.0533 g
0.0313 g
SPRING MOUNTED


HORIZONTAL ACCELERATIONS
50 FT. FROM LARGE DROP HAMMER
TRONICS COMPANY
PRINTED IN U.S.A.
0.50 SEC
0.00623 g
0.0104 g
SPRING MOUNTED

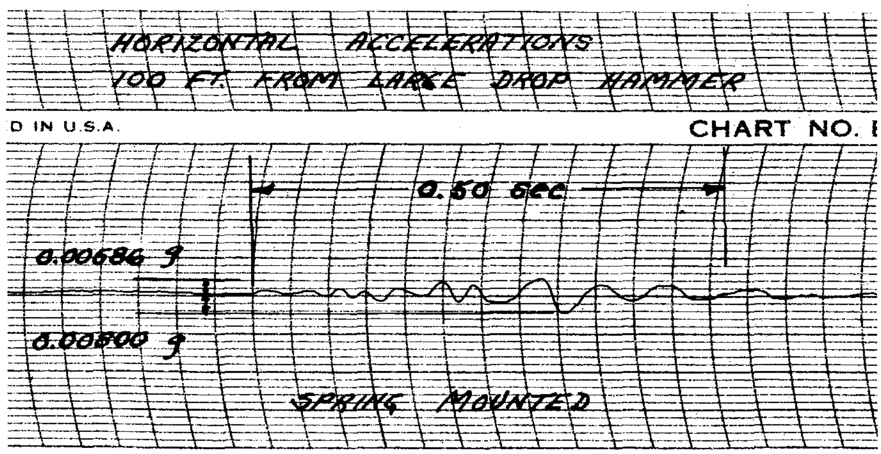

HORIZONTAL ACCELERATIONS
100 FT. FROM LARGE DROP HAMMER
D IN U.S.A.
CHART NO.
0.50 SEC
0.00686 g
0.00800 g
SPRING MOUNTED

FIG. 6

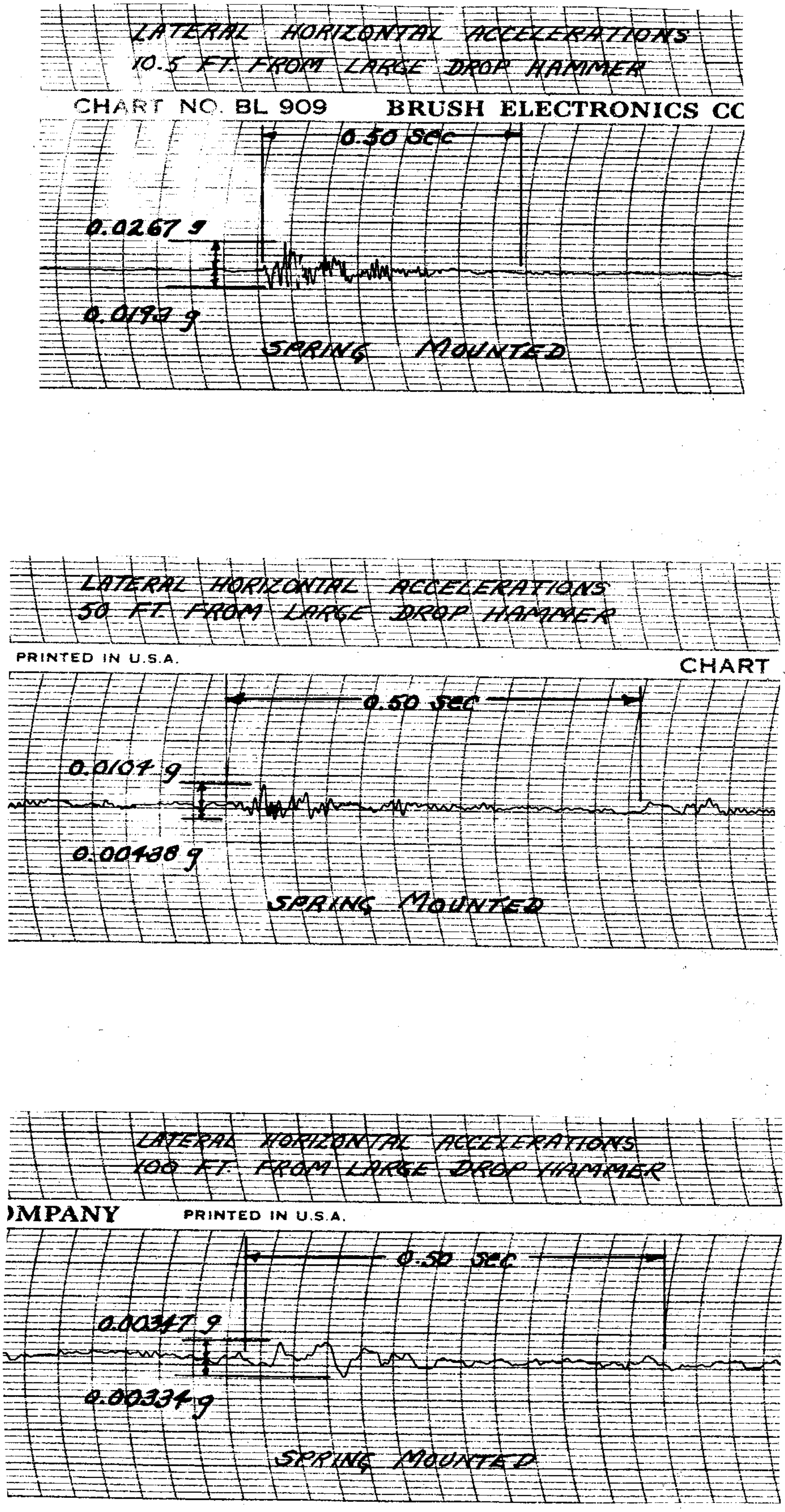
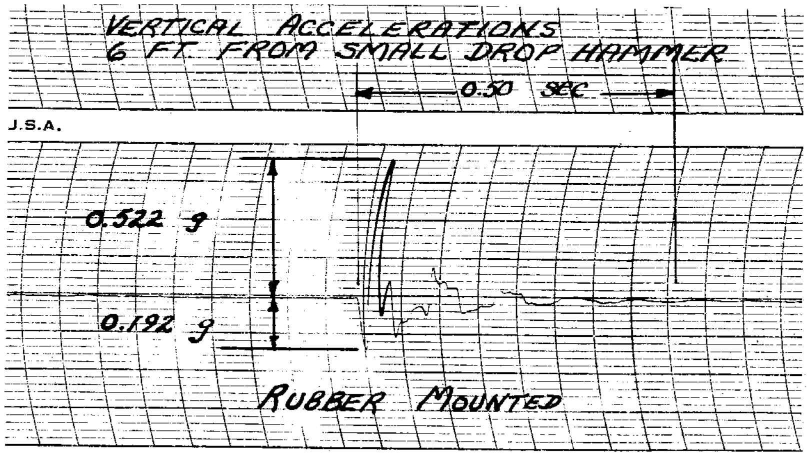

LATERAL HORIZONTAL ACCELERATIONS
10.5 FT. FROM LARGE DROP HAMMER
CHART NO. BL 909
BRUSH ELECTRONICS CC
0.50 SEC
0.0267 g
0.0192 g
SPRING MOUNTED
LATERAL HORIZONTAL ACCELERATIONS
50 FT. FROM LARGE DROP HAMMER
PRINTED IN U.S.A.
CHART
0.50 SEC
0.0107 g
0.00438 g
SPRING MOUNTED
LATERAL HORIZONTAL ACCELERATIONS
100 FT. FROM LARGE DROP HAMMER
MPANY
PRINTED IN U.S.A.
0.50 SEC
0.00347 g
0.00334 g
SPRING MOUNTED

FIG. 7


VERTICAL ACCELERATIONS
6 FT. FROM SMALL DROP HAMMER
0.50 SEC
J.S.A.
0.522 g
0.192 g
RUBBER MOUNTED

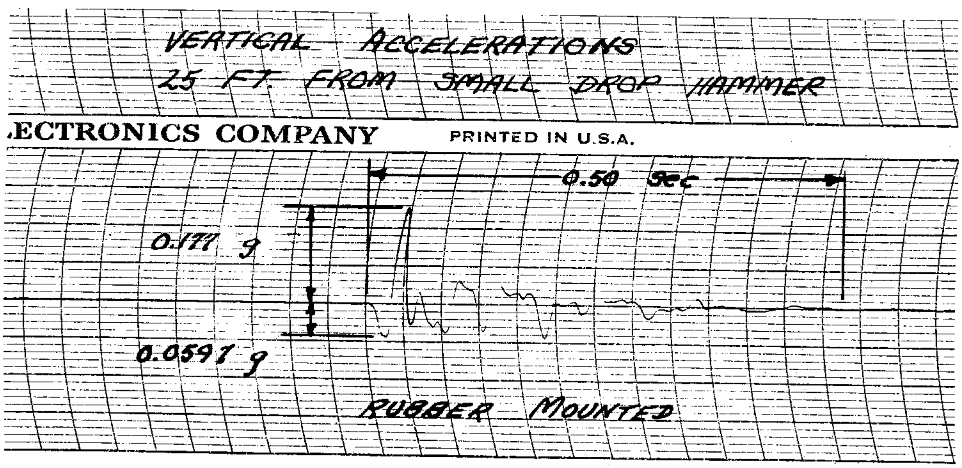
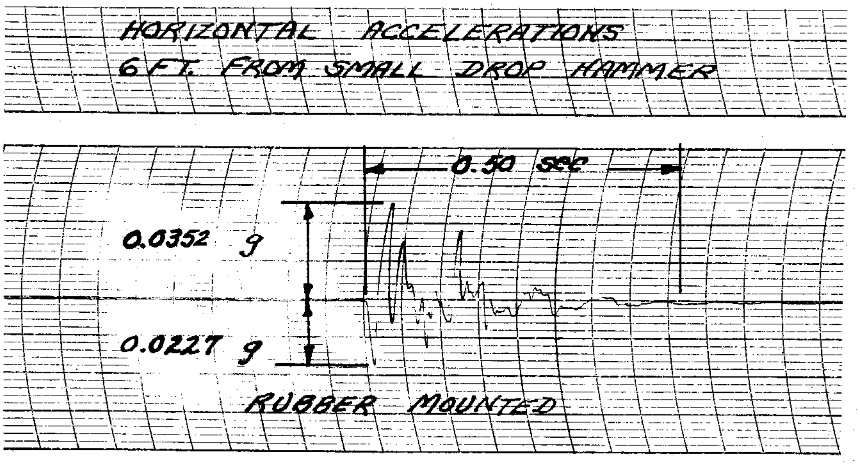

VERTICAL ACCELERATIONS
25 FT. FROM SMALL DROP HAMMER
ECTRONICS COMPANY
PRINTED IN U.S.A.
0.50 SEC
0.177 g
0.0597 g
RUBBER MOUNTED

FIG. 8


HORIZONTAL ACCELERATIONS
6 FT. FROM SMALL DROP HAMMER
0.50 sec
0.0352 g
0.0227 g
RUBBER MOUNTED

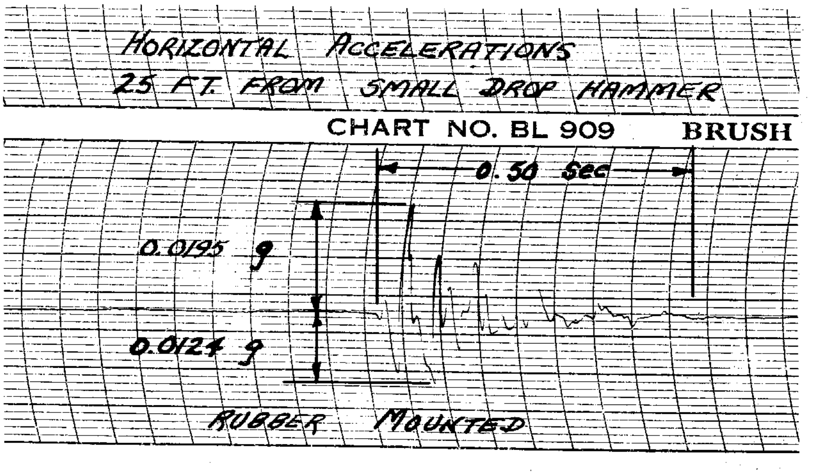

HORIZONTAL ACCELERATIONS
25 FT. FROM SMALL DROP HAMMER
CHART NO. BL 909
BRUSH
0.50 sec
0.0195 g
0.0124 g
RUBBER MOUNTED

FIG. 9

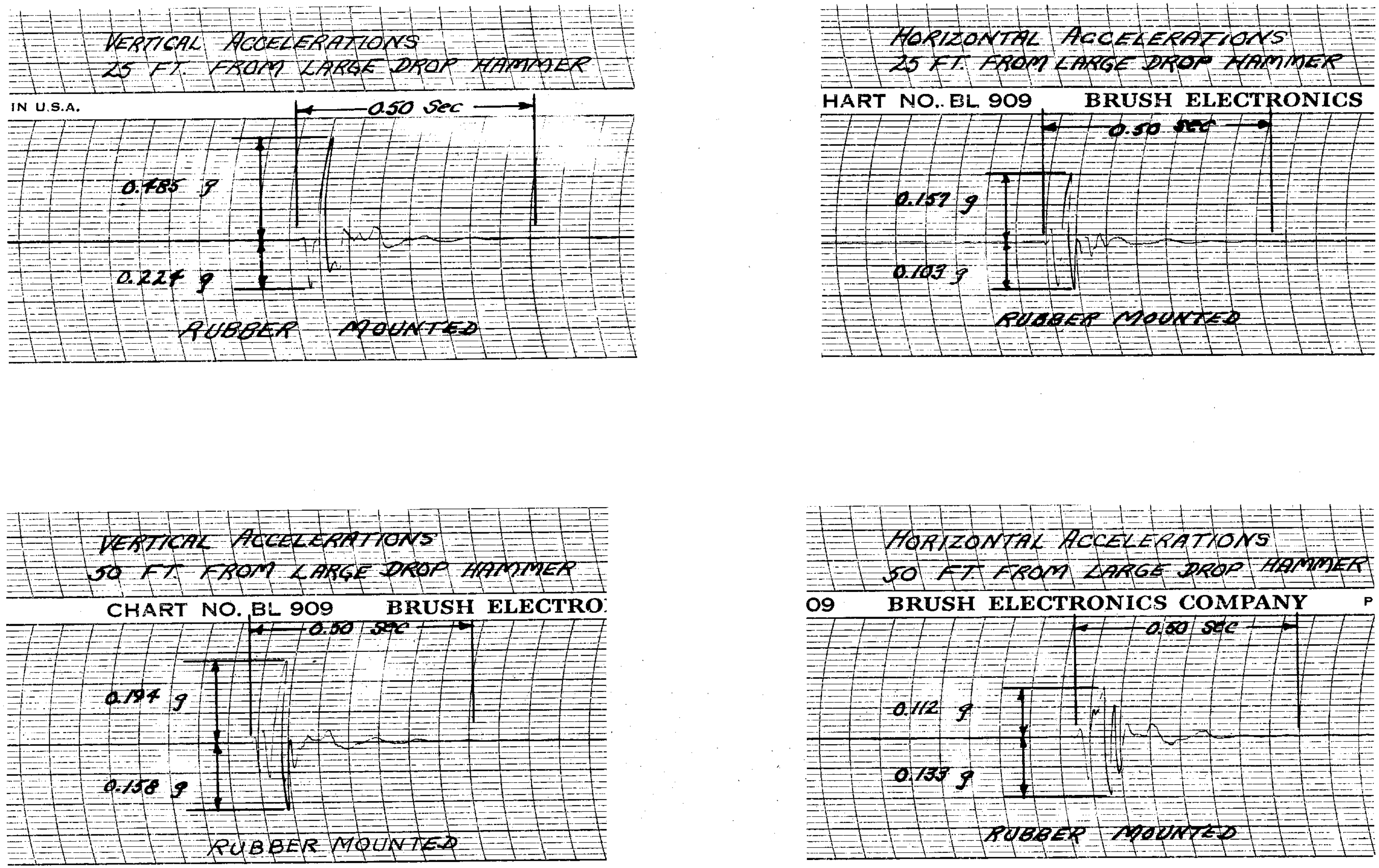
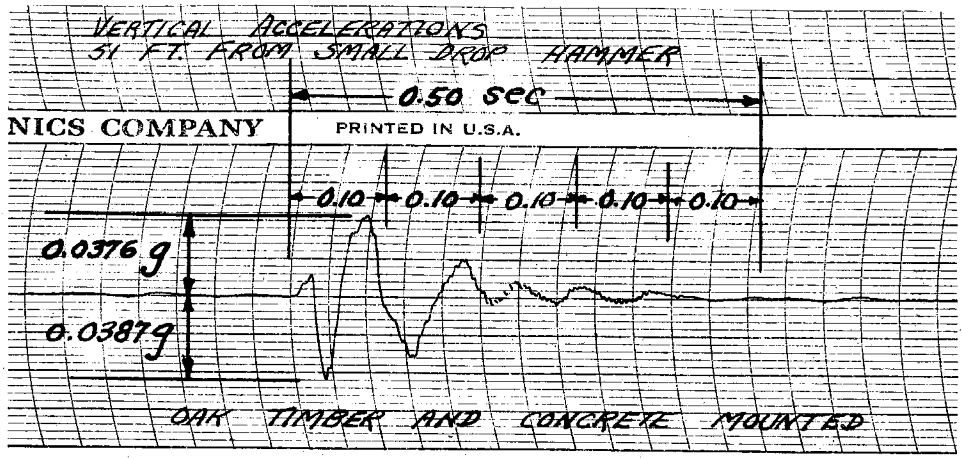
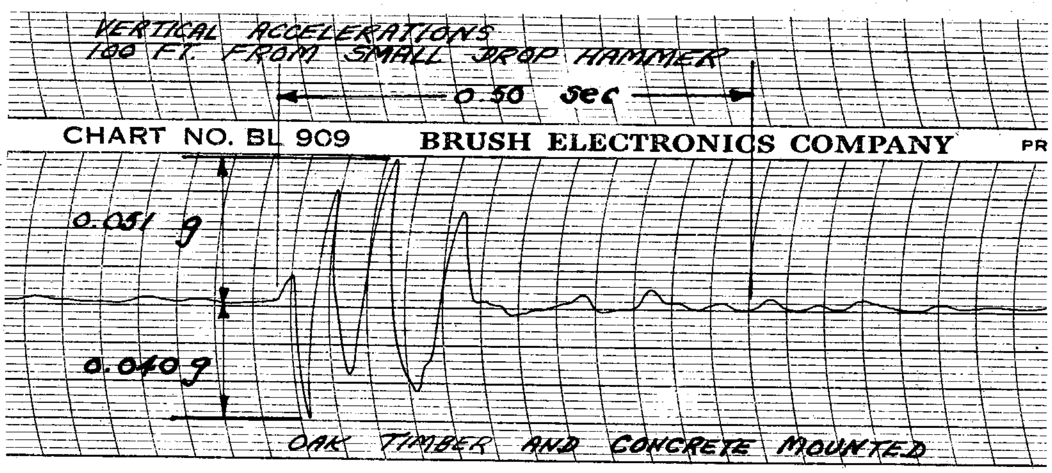

VERTICAL ACCELERATIONS
25 FT. FROM LARGE DROP HAMMER
IN U.S.A.
0.50 Sec
0.485 g
0.224 g
RUBBER MOUNTED
HORIZONTAL ACCELERATIONS
25 FT. FROM LARGE DROP HAMMER
HART NO. BL 909
BRUSH ELECTRONICS
0.50 Sec
0.157 g
0.103 g
RUBBER MOUNTED
VERTICAL ACCELERATIONS
50 FT. FROM LARGE DROP HAMMER
CHART NO. BL 909
BRUSH ELECTRO
0.50 Sec
0.194 g
0.158 g
RUBBER MOUNTED
HORIZONTAL ACCELERATIONS
50 FT. FROM LARGE DROP HAMMER
09
BRUSH ELECTRONICS COMPANY
P
0.50 Sec
0.112 g
0.133 g
RUBBER MOUNTED

FIG. 10


VERTICAL ACCELERATIONS
51 FT. FROM SMALL DROP HAMMER
0.50 sec
NICS COMPANY
PRINTED IN U.S.A.
0.10
0.10
0.10
0.10
0.10
0.0376 g
0.0387 g
OAK TIMBER AND CONCRETE MOUNTED


VERTICAL ACCELERATIONS
100 FT. FROM SMALL DROP HAMMER
0.50 sec
CHART NO. BL 909
BRUSH ELECTRONICS COMPANY
0.051 g
0.040 g
OAK TIMBER AND CONCRETE MOUNTED

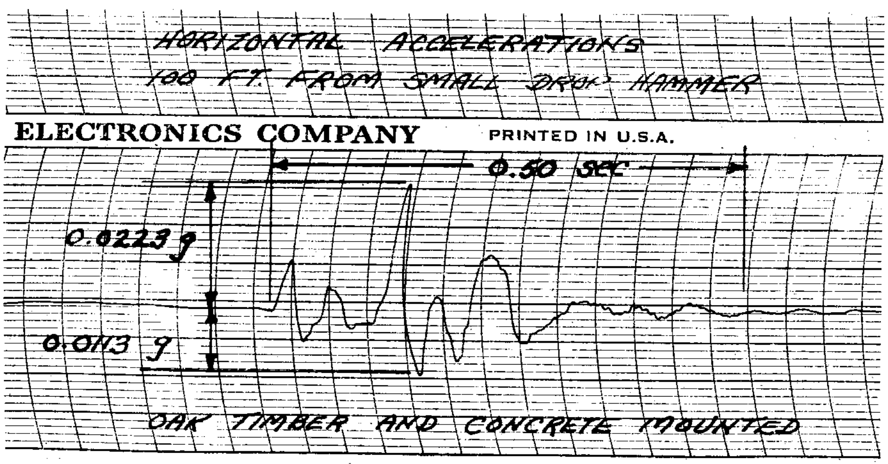

HORIZONTAL ACCELERATIONS
100 FT. FROM SMALL DROP HAMMER
ELECTRONICS COMPANY
PRINTED IN U.S.A.
0.50 sec
0.0223 g
0.0113 g
OAK TIMBER AND CONCRETE MOUNTED

FIG. 11

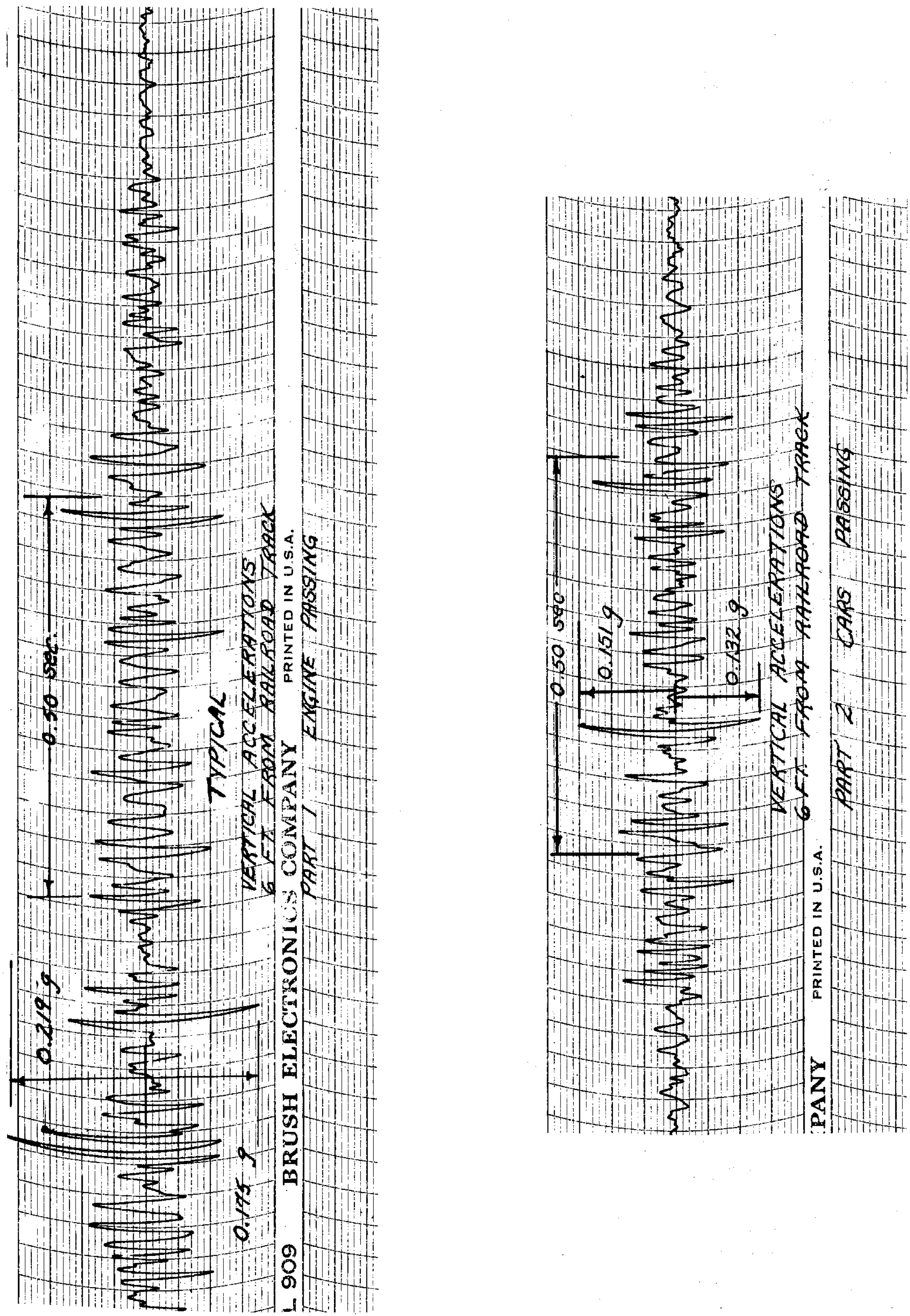

0.219 g
0.50 sec.
0.175 g
TYPICAL
VERTICAL ACCELERATIONS
6 FT. FROM RAILROAD TRACK
PART 1 ENGINE PASSING
BRUSH ELECTRONICS COMPANY
PRINTED IN U.S.A.
0.50 sec
0.151 g
0.132 g
VERTICAL ACCELERATIONS
6 FT. FROM RAILROAD TRACK
PART 2 CARS PASSING
PRINTED IN U.S.A.
PANY

FIG. 12

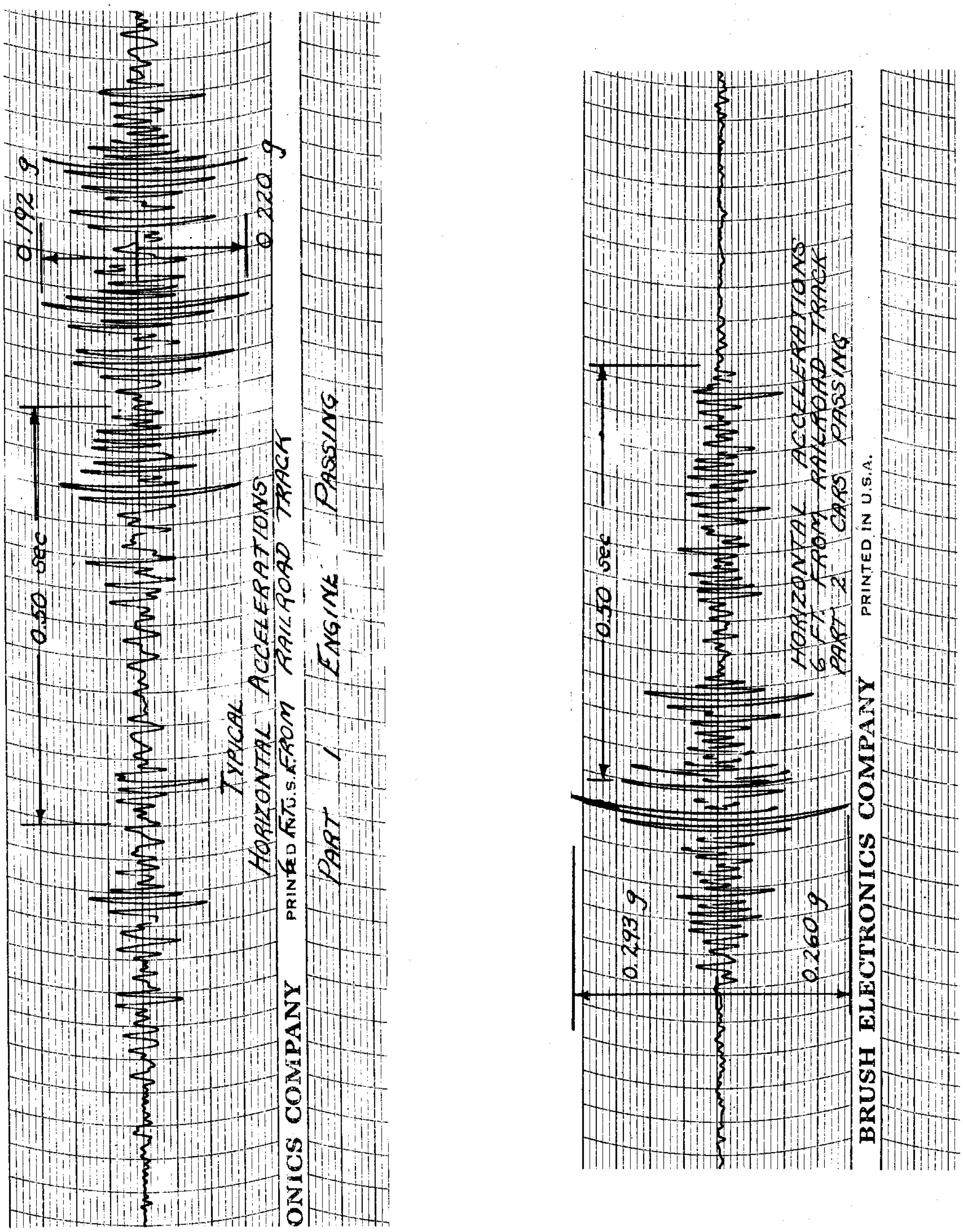
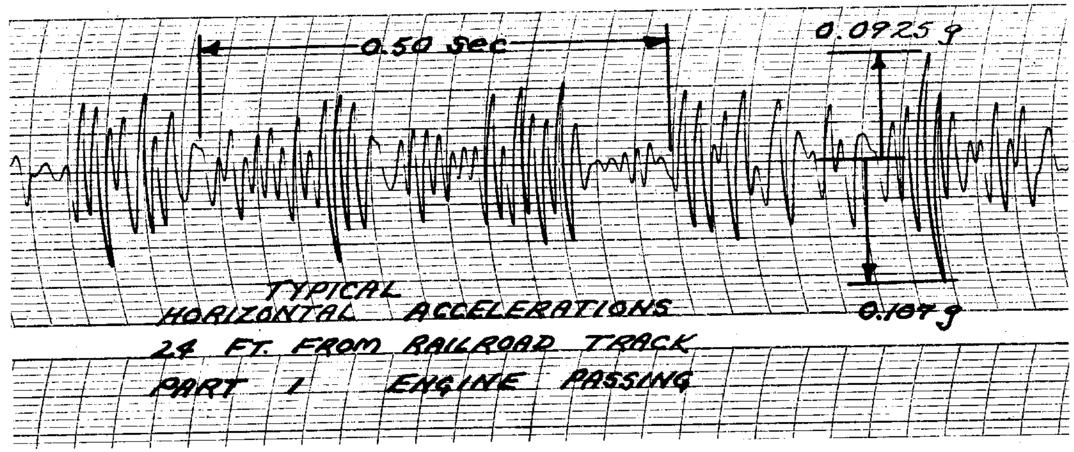

0.192 g
0.220 g
0.50 sec
TYPICAL
HORIZONTAL ACCELERATIONS
6 FT. FROM RAILROAD TRACK
PART 1 ENGINE PASSING
ONICS COMPANY
PRINTED IN U.S.A.
0.293 g
0.260 g
0.50 sec
HORIZONTAL ACCELERATIONS
6 FT. FROM RAILROAD TRACK
PART 2 CARS PASSING
BRUSH ELECTRONICS COMPANY
PRINTED IN U.S.A.

FIG. 13


0.50 sec
0.0925 g
0.107 g
TYPICAL
HORIZONTAL ACCELERATIONS
24 FT. FROM RAILROAD TRACK
PART 1 ENGINE PASSING

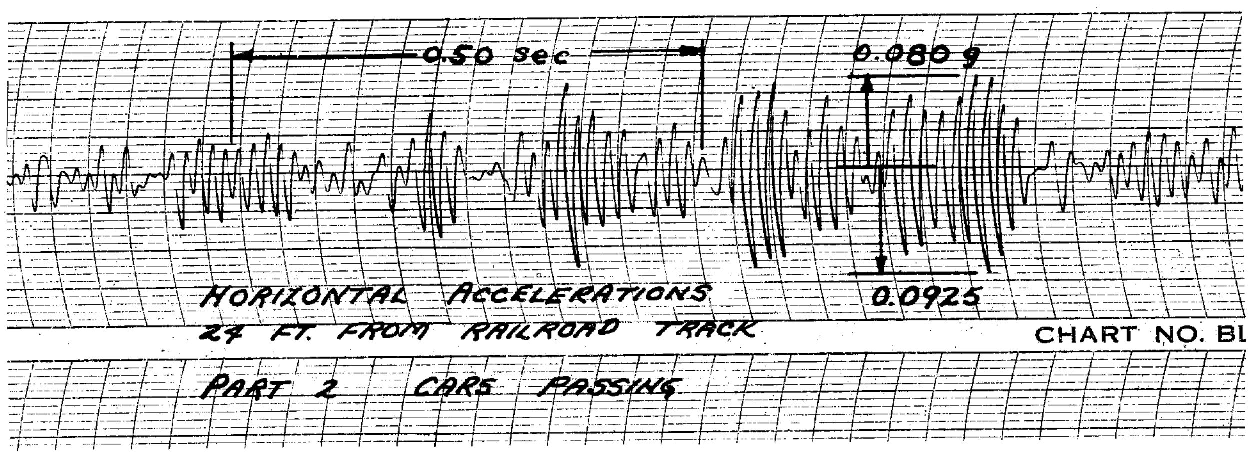

0.50 sec
0.080 g
0.0925
HORIZONTAL ACCELERATIONS
24 FT. FROM RAILROAD TRACK
CHART NO. BL
PART 2 CARS PASSING

FIG. 14

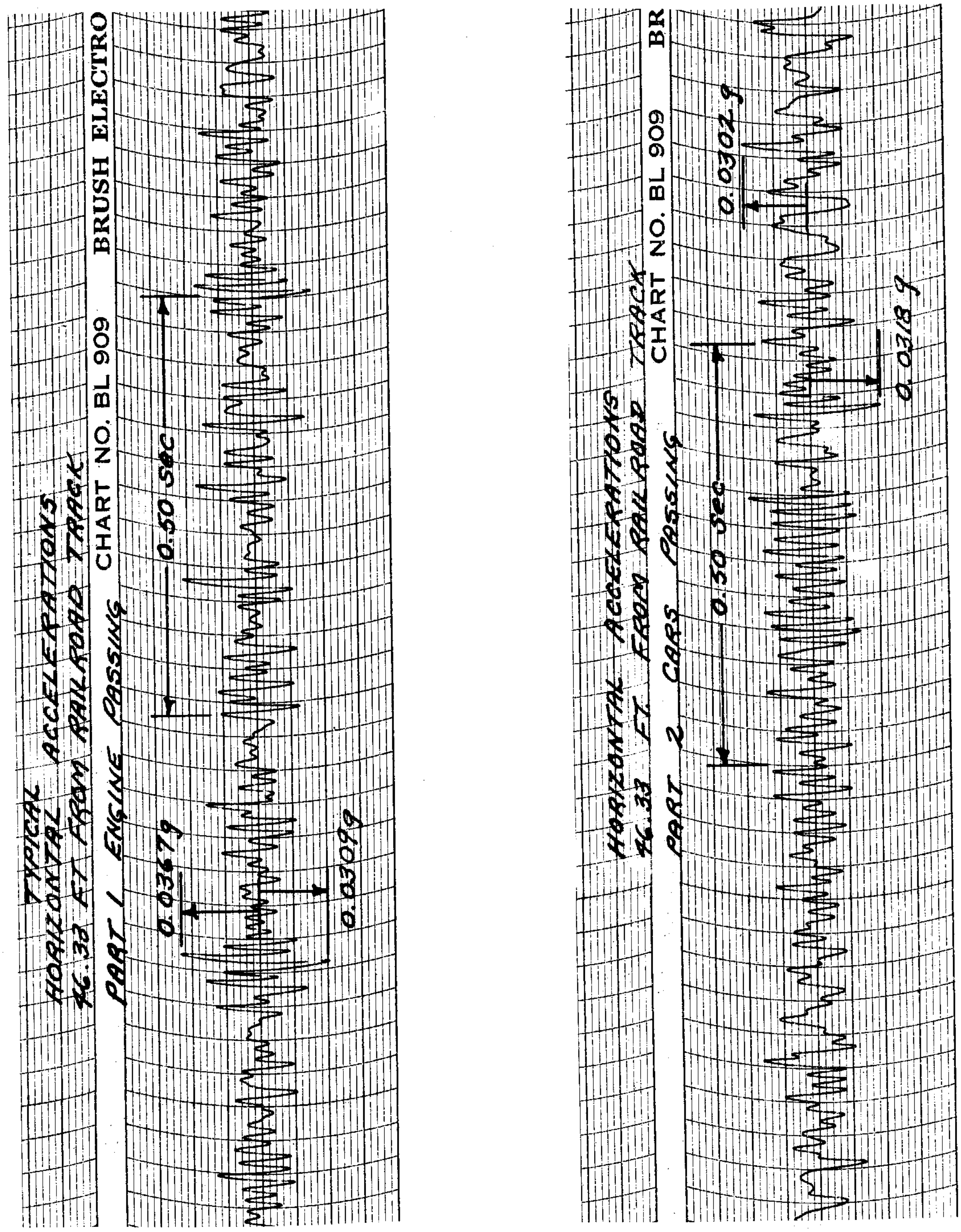

TYPICAL
HORIZONTAL ACCELERATIONS
46.33 FT FROM RAILROAD TRACK
PART 1 ENGINE PASSING
0.50 SEC
0.0367g
0.0309g
CHART NO. BL 909
BRUSH ELECTRO
HORIZONTAL ACCELERATIONS
46.33 FT FROM RAILROAD TRACK
PART 2 CARS PASSING
0.50 Sec
0.0302 g
0.0318 g
CHART NO. BL 909
BR

FIG. 15

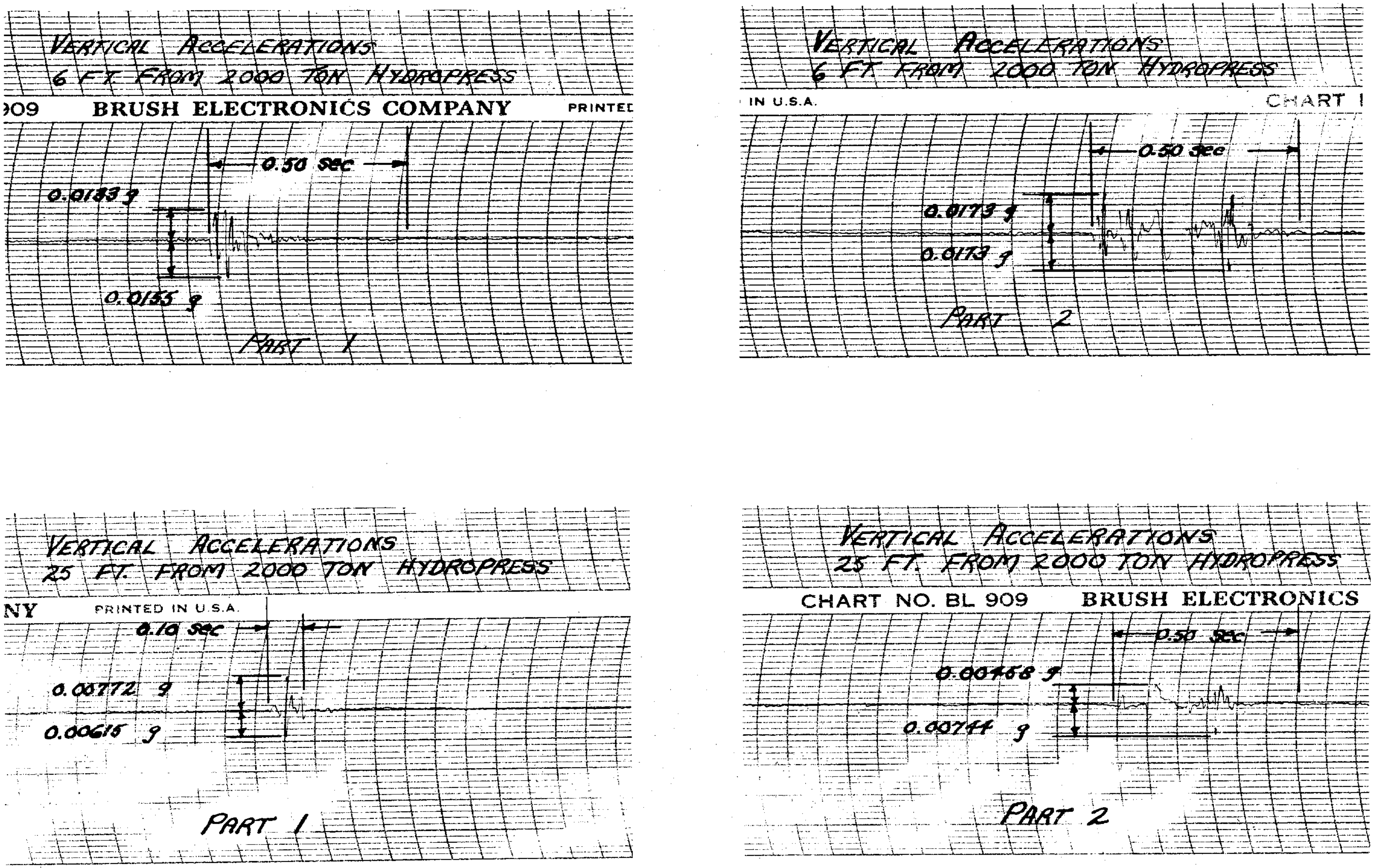

VERTICAL ACCELERATIONS
6 FT. FROM 2000 TON HYDROPRESS
909 BRUSH ELECTRONICS COMPANY
PRINTED
0.50 sec
0.0183 g
0.0155 g
PART 1
VERTICAL ACCELERATIONS
6 FT. FROM 2000 TON HYDROPRESS
IN U.S.A.
CHART
0.50 sec
0.0173 g
0.0173 g
PART 2
VERTICAL ACCELERATIONS
25 FT. FROM 2000 TON HYDROPRESS
NY
PRINTED IN U.S.A.
0.10 sec
0.00772 g
0.00615 g
PART 1
VERTICAL ACCELERATIONS
25 FT. FROM 2000 TON HYDROPRESS
CHART NO. BL 909
BRUSH ELECTRONICS
0.50 sec
0.00744 g
PART 2

FIG. 16

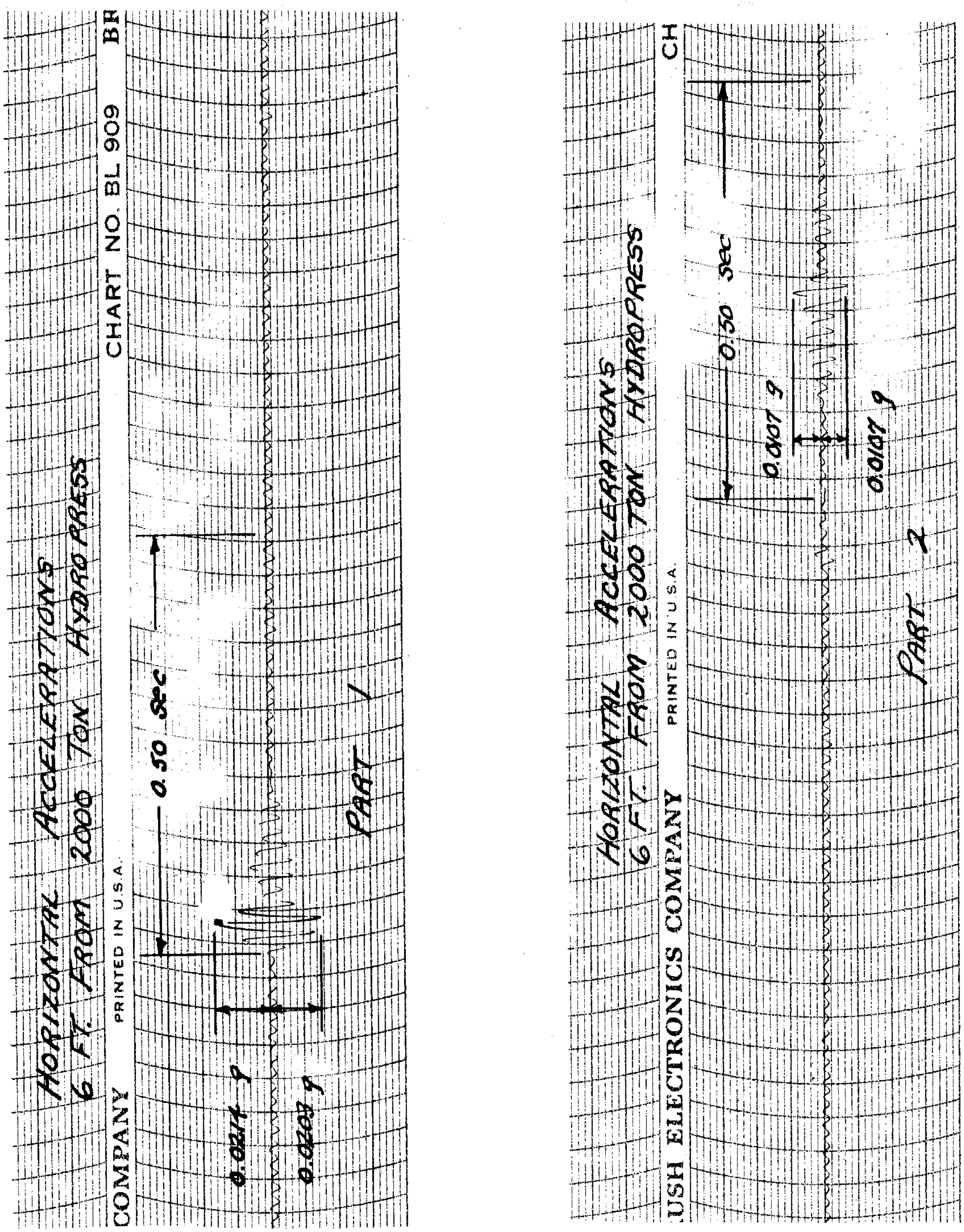

HORIZONTAL ACCELERATIONS
6 FT. FROM 2000 TON HYDROPRESS
COMPANY
PRINTED IN U.S.A.
CHART NO. BL 909
0.50 SEC
0.0214 g
0.0209 g
PART 1
HORIZONTAL ACCELERATIONS
6 FT. FROM 2000 TON HYDROPRESS
USH ELECTRONICS COMPANY
PRINTED IN U.S.A.
0.50 SEC
0.0107 g
0.0107 g
PART 2

FIG. 17

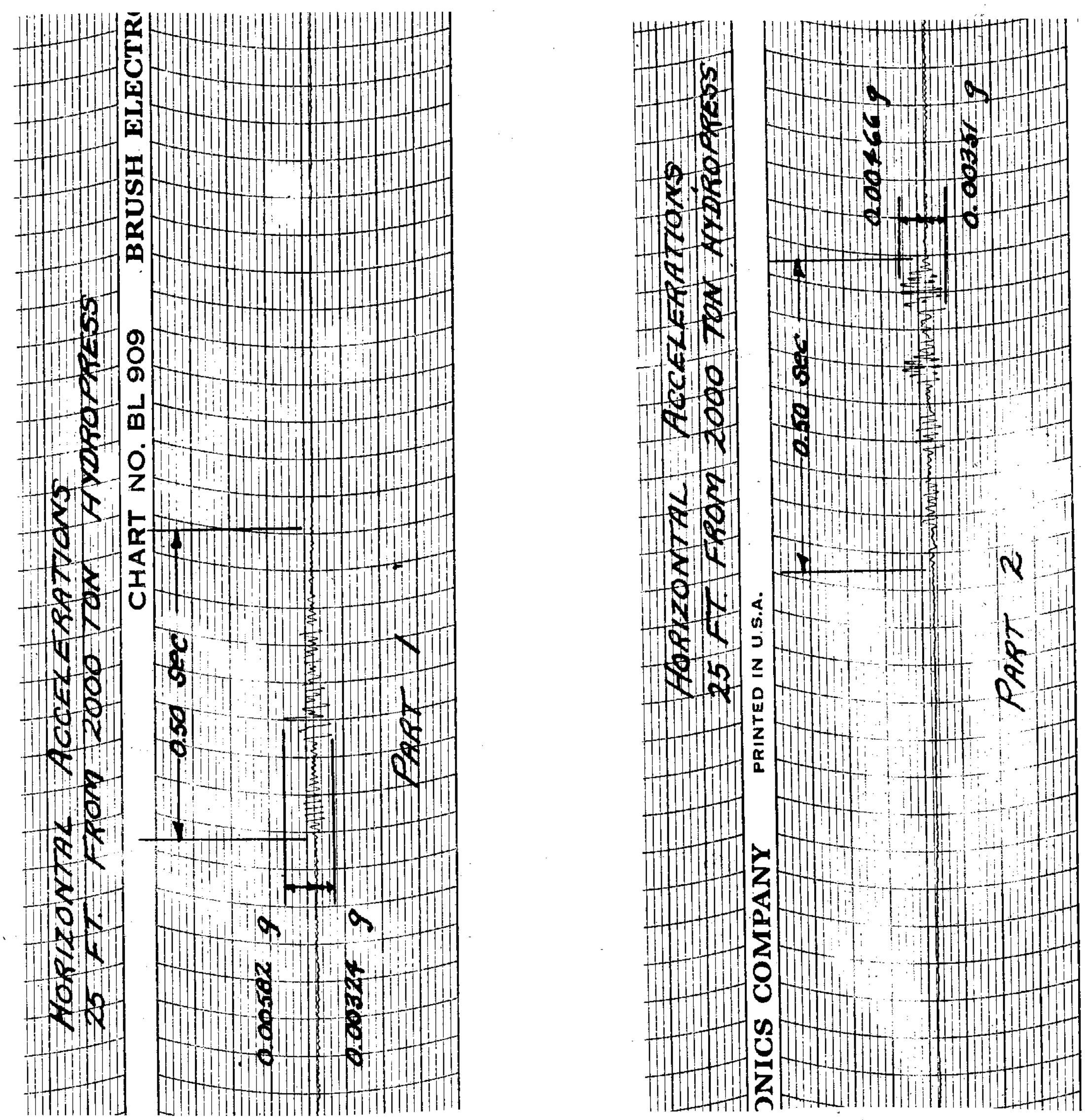
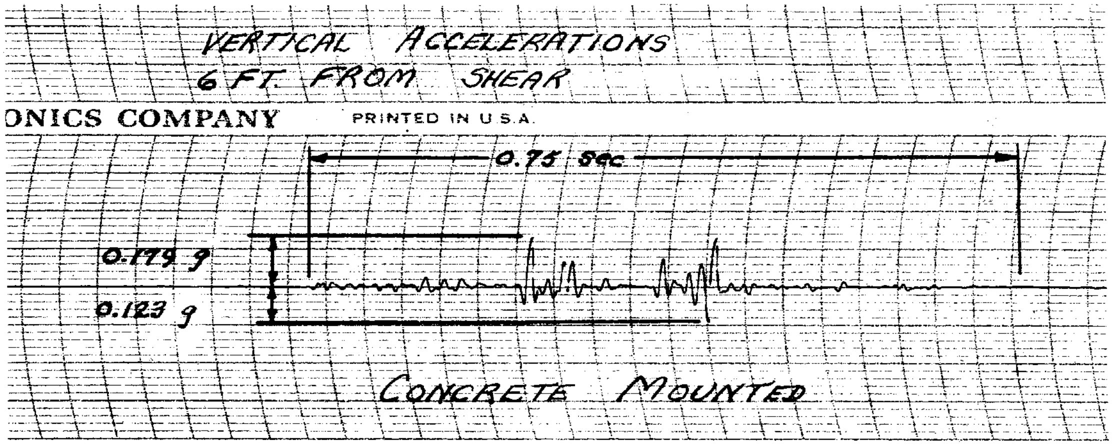

HORIZONTAL ACCELERATIONS
25 FT. FROM 2000 TON HYDROPRESS
CHART NO. BL 909
BRUSH ELECTRONICS COMPANY
PRINTED IN U.S.A.
0.50 SEC
0.00582 g
0.00324 g
PART 1
HORIZONTAL ACCELERATIONS
25 FT. FROM 2000 TON HYDROPRESS
0.50 SEC
0.00466 g
0.00351 g
PART 2

FIG. 18


VERTICAL ACCELERATIONS
6 FT. FROM SHEAR
ONICS COMPANY
PRINTED IN U.S.A.
0.75 sec
0.179 g
0.123 g
CONCRETE MOUNTED

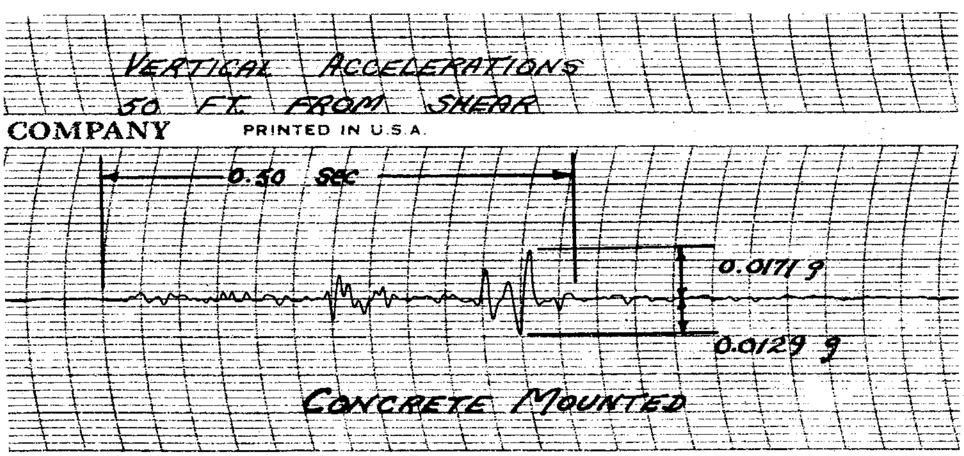
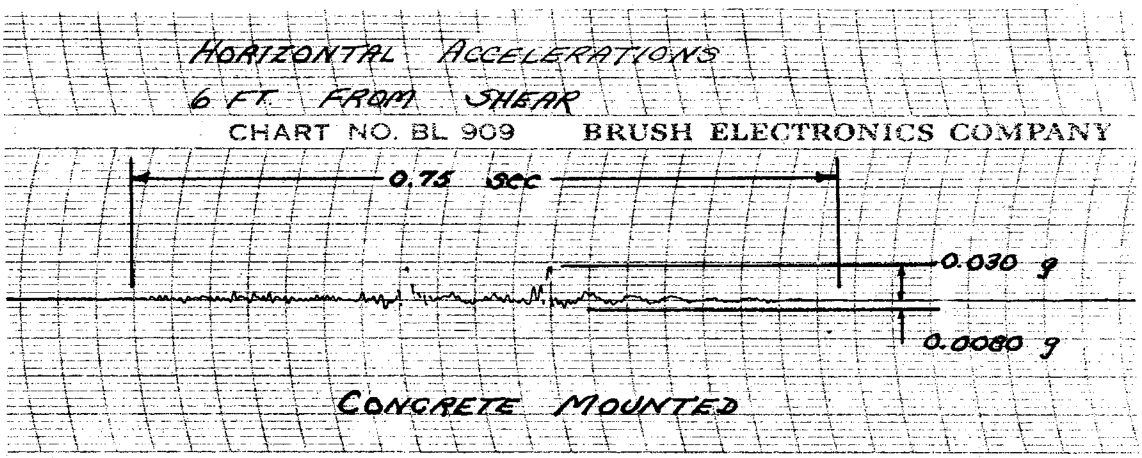

VERTICAL ACCELERATIONS
50 FT. FROM SHEAR
COMPANY
PRINTED IN U.S.A.
0.50 sec
0.0171 g
0.0129 g
CONCRETE MOUNTED

FIG. 19


HORIZONTAL ACCELERATIONS
6 FT. FROM SHEAR
CHART NO. BL 909 BRUSH ELECTRONICS COMPANY
0.75 SEC
0.030 g
0.0080 g
CONCRETE MOUNTED

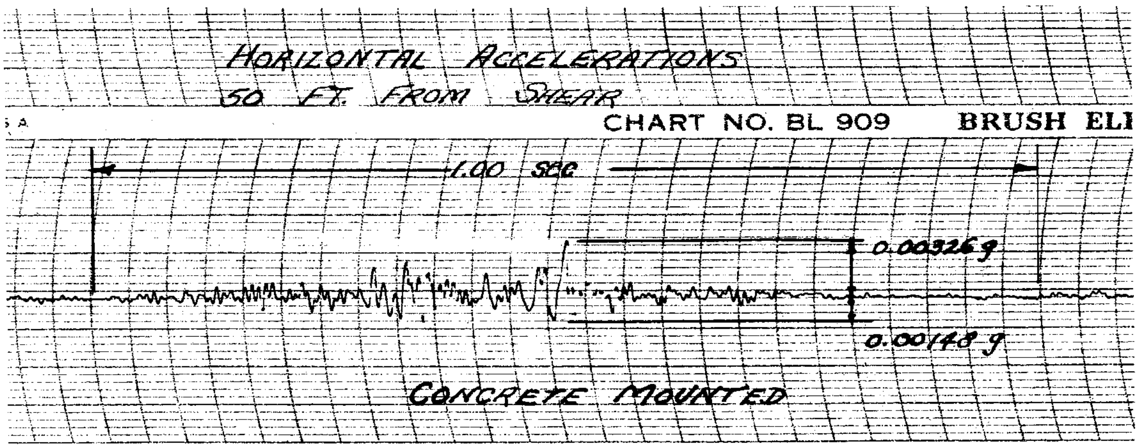
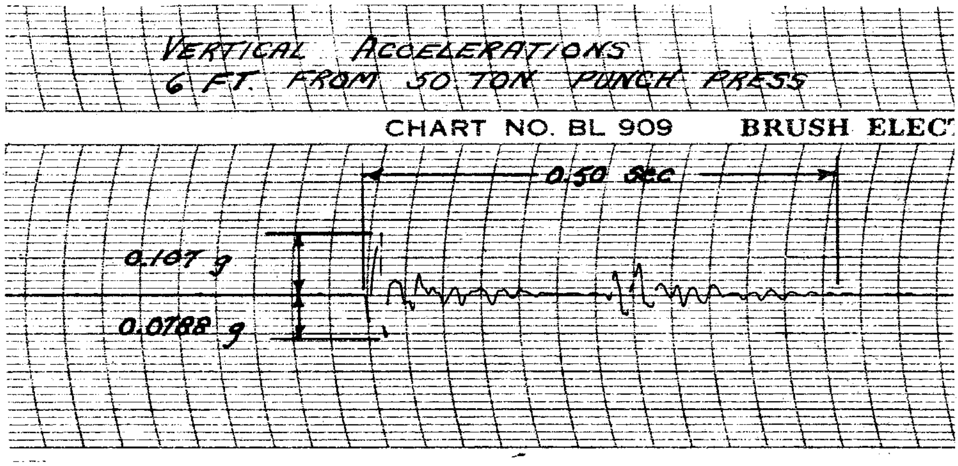

HORIZONTAL ACCELERATIONS
50 FT. FROM SHEAR
CHART NO. BL 909 BRUSH EL
1.00 SEC
0.00326 g
0.00148 g
CONCRETE MOUNTED

FIG. 20


VERTICAL ACCELERATIONS
6 FT. FROM 50 TON PUNCH PRESS
CHART NO. BL 909 BRUSH ELEC
0.50 sec
0.107 g
0.0788 g

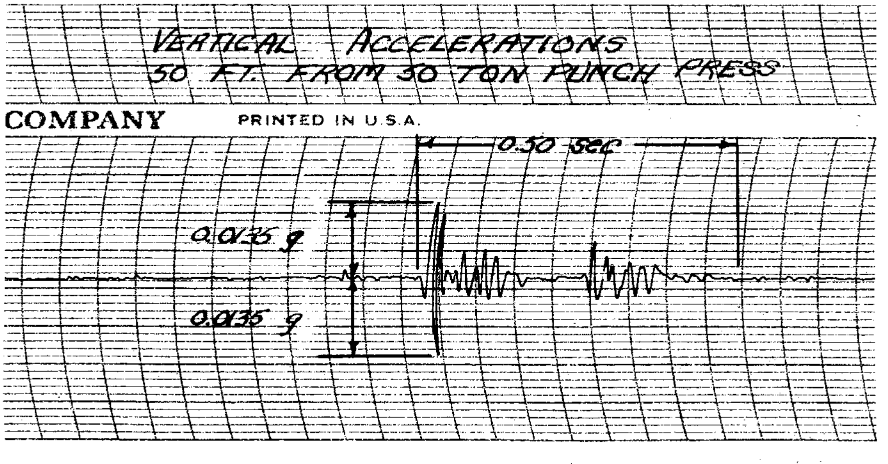
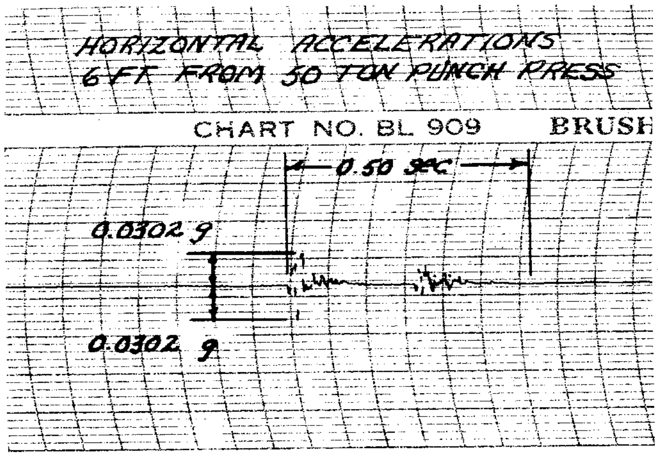

VERTICAL ACCELERATIONS
50 FT. FROM 50 TON PUNCH PRESS
COMPANY
PRINTED IN U.S.A.
0.50 sec
0.0135 g
0.0135 g

FIG. 21


HORIZONTAL ACCELERATIONS
6 FT. FROM 50 TON PUNCH PRESS
CHART NO. BL 909
BRUSH
0.50 SEC
0.0302 g
0.0302 g

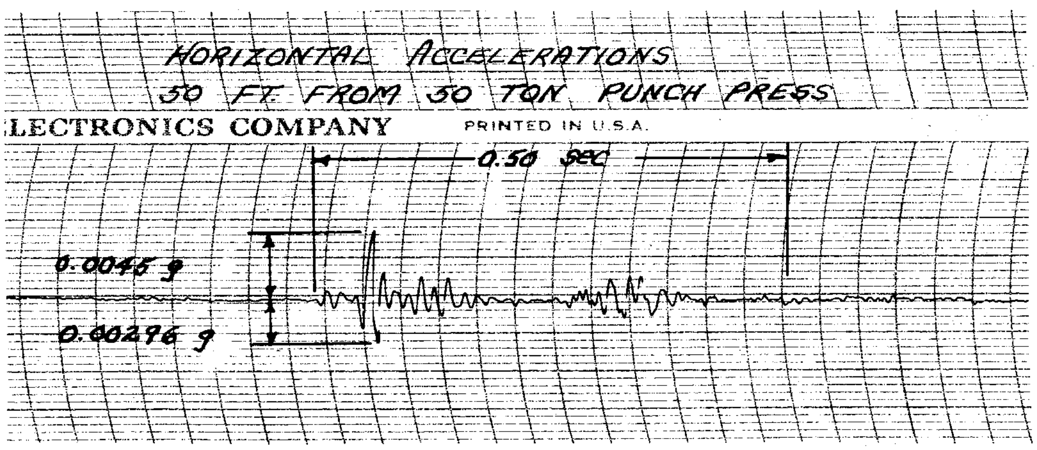

HORIZONTAL ACCELERATIONS
50 FT. FROM 50 TON PUNCH PRESS
LECTRONICS COMPANY
PRINTED IN U.S.A.
0.50 SEC
0.0045 g
0.00296 g

FIG. 22

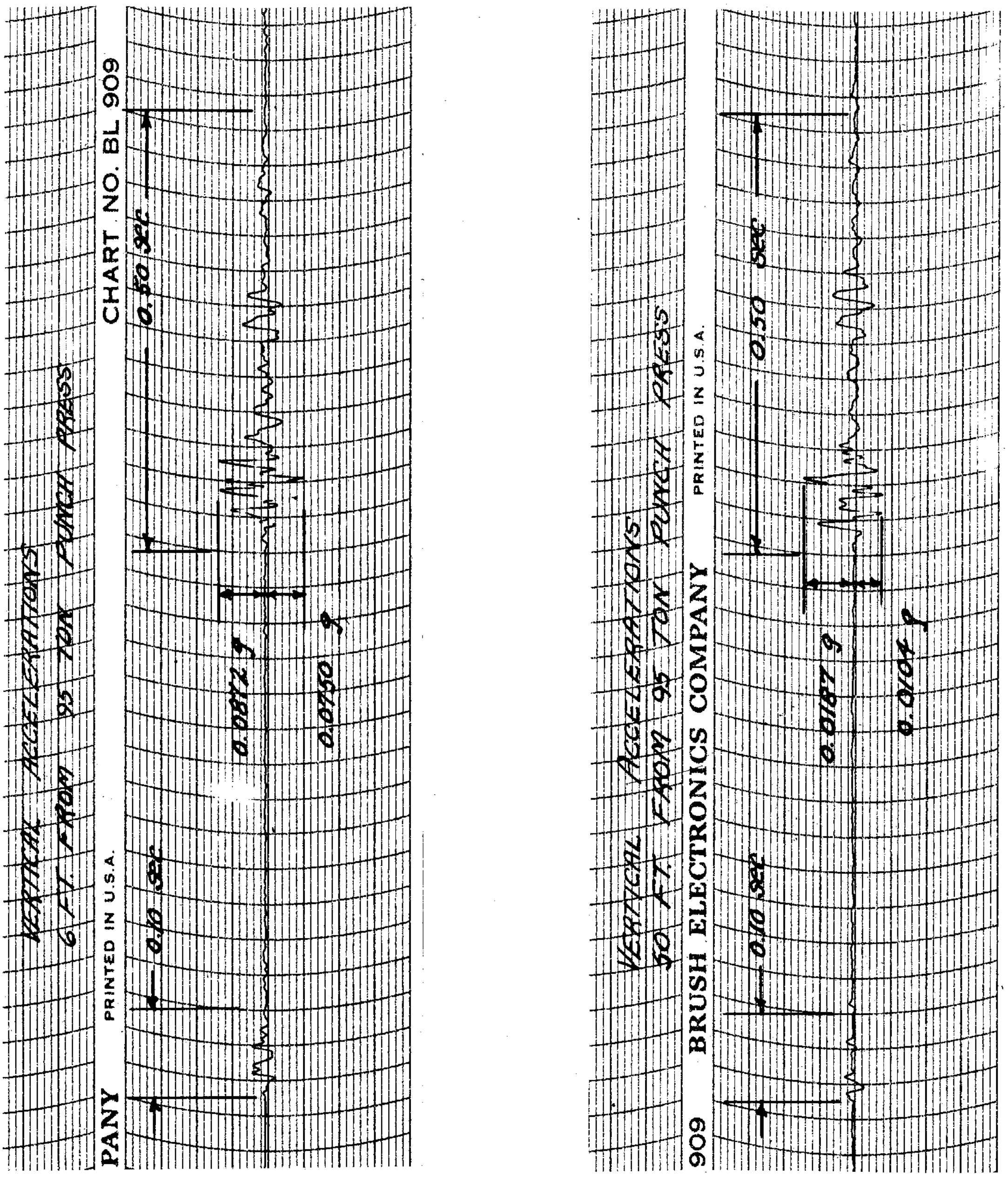
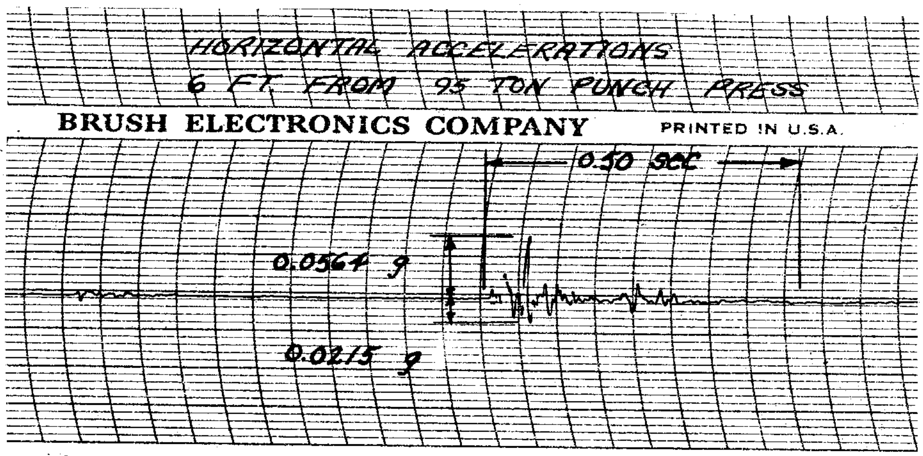

VERTICAL ACCELERATIONS
6 FT. FROM 95 TON PUNCH PRESS
PANY
PRINTED IN U.S.A.
CHART NO. BL 909
0.10 SEC
0.50 SEC
0.0872 g
0.0750 g
VERTICAL ACCELERATIONS
50 FT. FROM 95 TON PUNCH PRESS
909
BRUSH ELECTRONICS COMPANY
PRINTED IN U.S.A.
0.10 SEC
0.50 SEC
0.0187 g
0.0104 g

FIG. 23


HORIZONTAL ACCELERATIONS
6 FT. FROM 95 TON PUNCH PRESS
BRUSH ELECTRONICS COMPANY
PRINTED IN U.S.A.
0.50 SEC
0.0564 g
0.0215 g

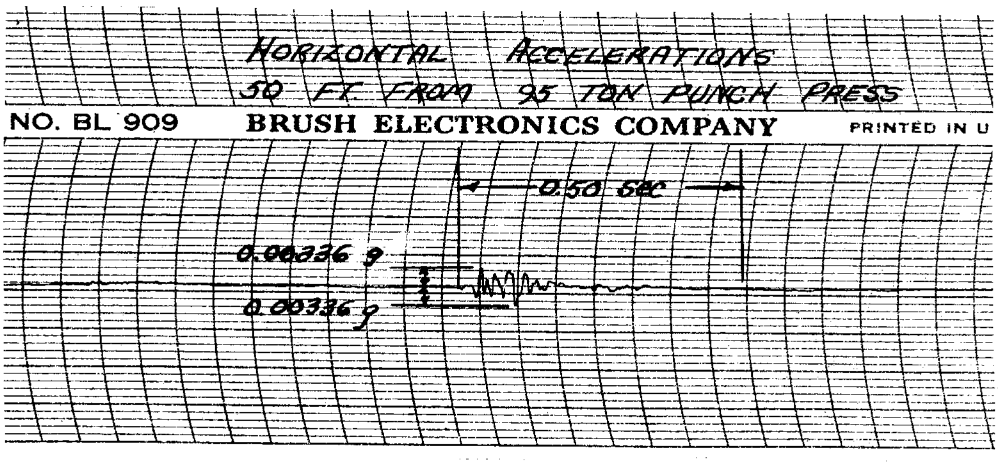

HORIZONTAL ACCELERATIONS
50 FT. FROM 95 TON PUNCH PRESS
NO. BL 909
BRUSH ELECTRONICS COMPANY
PRINTED IN U
0.50 SEC
0.00336 g

FIG. 24

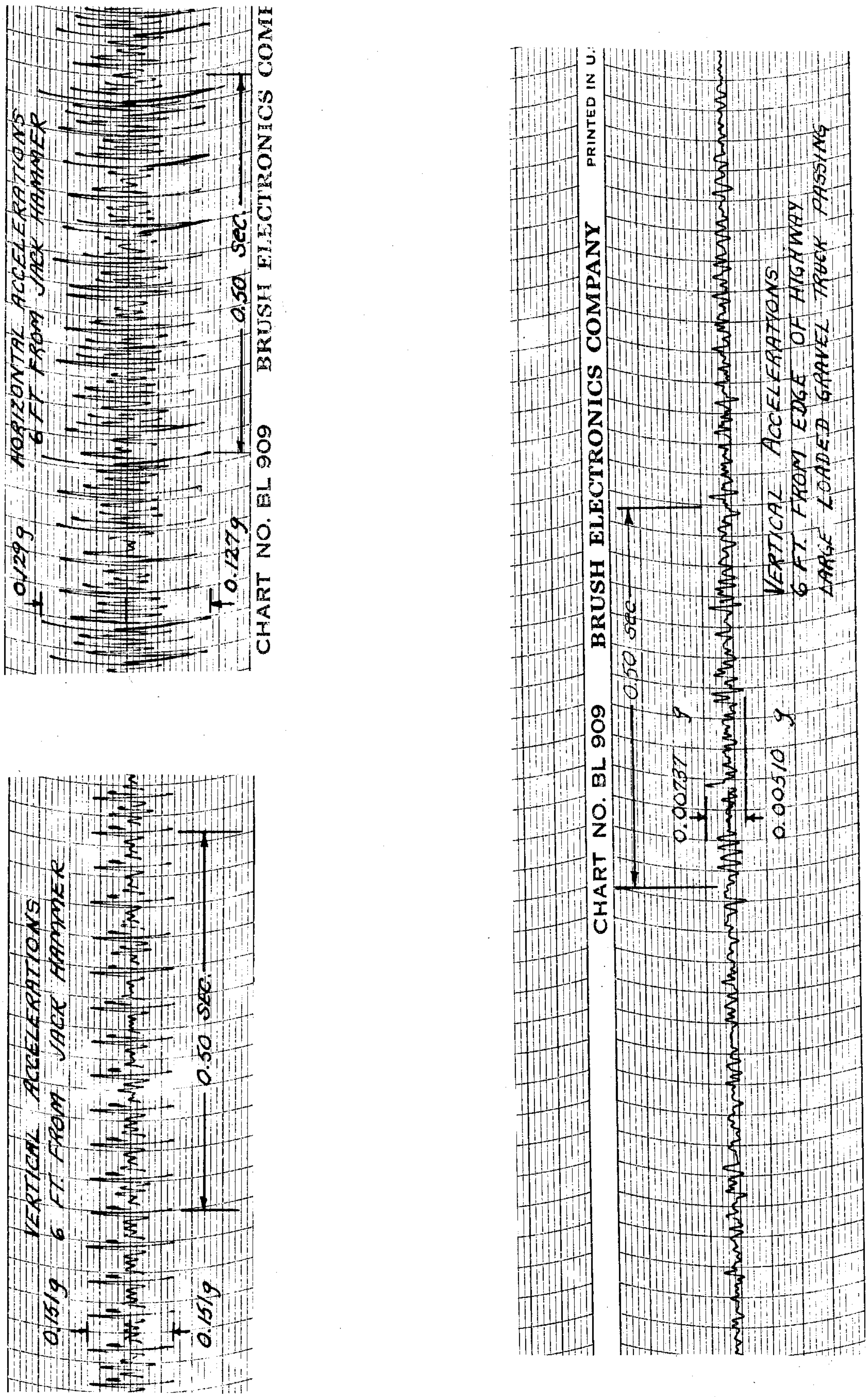

0.129 g
HORIZONTAL ACCELERATIONS
6 FT. FROM JACK HAMMER
0.127 g
0.50 sec.
CHART NO. BL 909
BRUSH ELECTRONICS COMP
0.151 g
VERTICAL ACCELERATIONS
6 FT. FROM JACK HAMMER
0.151 g
0.50 SEC.
CHART NO. BL 909
BRUSH ELECTRONICS COMPANY
PRINTED IN U.
0.50 sec
0.00737 g
0.00510 g
VERTICAL ACCELERATIONS
6 FT. FROM EDGE OF HIGHWAY
LARGE LOADED GRAVEL TRUCK PASSING

FIG. 25

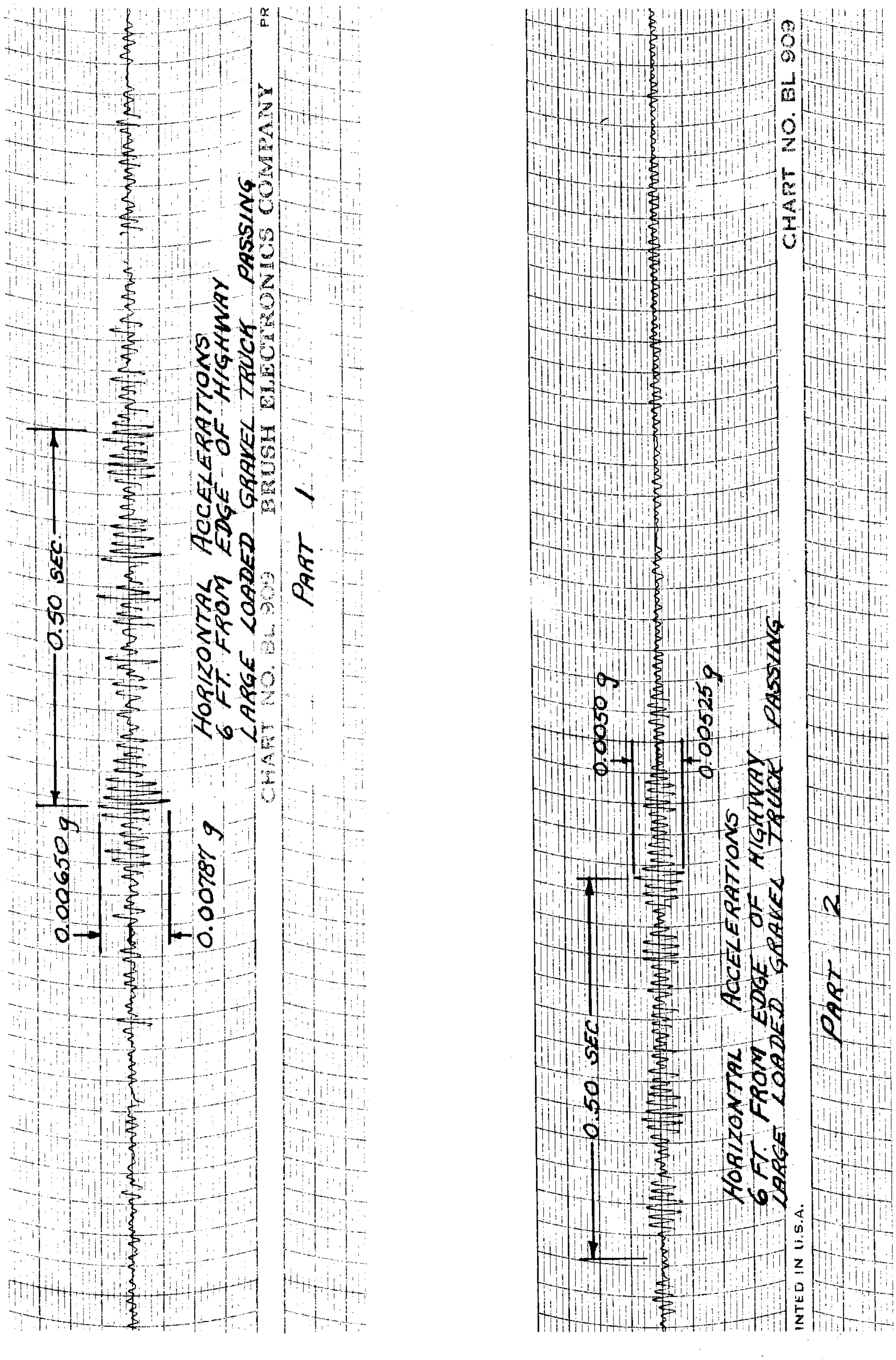

0.00650 g
0.50 SEC.
0.00787 g
HORIZONTAL ACCELERATIONS
6 FT. FROM EDGE OF HIGHWAY
LARGE LOADED GRAVEL TRUCK PASSING
CHART NO. BL 909
BRUSH ELECTRONICS COMPANY
PART 1
0.50 SEC
0.0050 g
0.00525 g
HORIZONTAL ACCELERATIONS
6 FT. FROM EDGE OF HIGHWAY
LARGE LOADED GRAVEL TRUCK PASSING
PART 2
INTED IN U.S.A.
CHART NO. BL 909

FIG. 26

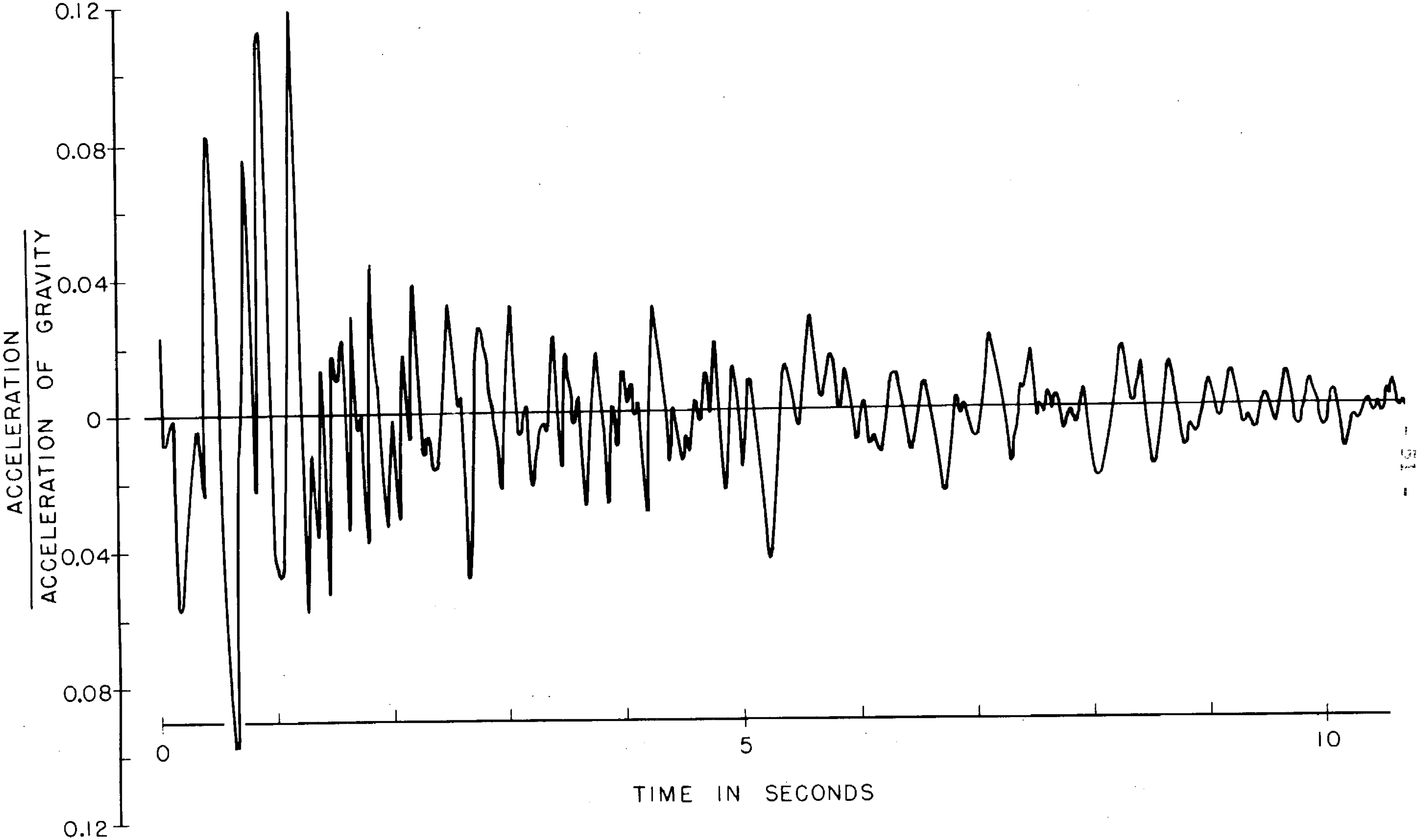


FIG. 27 **Accelerogram for Vernon, California; earthquake of Oct. 2, 1933. Component S 82 E.**

IX. APPENDIX 2

INSTRUMENTS

Number Used	
1	Brush Development Co. Universal Analyzer Model BL320 Serial Number 429
2	Brush Development Co. Two Channel Magnetic Pen Oscillograph Type BL202 Serial Numbers 1129 and 3027
1	William Miller Corp. Accelerometer Model Number 402-C Serial Number 140
1	ATR D.C./A.C. Inverter Model 12HSF Type 12 Serial Number 1152296