

U.S. RIFLE WORKS, HARPERS FERRY, WEST VIRGINIA

Resistivity and Seismic Surveys, and Excavations.

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An archaeological test survey was conducted at the site of the U. S. Rifle Works, Harpers Ferry, West Virginia, during the summer of 1962. The instruments which were used were a resistivity meter and a portable seismograph. The survey was sponsored by Dr. Froelich Rainey, Director of the University Museum, University of Pennsylvania, and Dr. John Cotter, archaeological director of Region 5 of the National Park Service. The tests and the digging which followed were carried out by Hamilton H. Carson of the Applied Science Center for Archaeology, University Museum. The survey was undertaken as part of the archaeological study at Harpers Ferry, now in its third year, under the direction of Edward McM. Larrabee, contracting archaeologist for Region 5 of the National Park Service.

The object of the experiment was twofold:

1. To determine the precise location of the foundation remains which had been approximately located by Mr. Larrabee and,
2. To make a controlled test comparison of the value of the two instruments for archaeological prospecting in this type of site.

### Apparatus and Methods

#### Resistivity Apparatus:

The instrument used was a Geohm resistivity meter manufactured by Gossen and Co., Erlanger, Germany. The meter box weighs 5 pounds, is convenient hand-carrying size, approximately 8"x4"x5", and is powered by a 4.5 volt battery. The meter box includes a vibrator, a galvanometer, and precision resistors. The cost is approximately \$95.00<sup>1</sup>. In addition, the apparatus requires four probes, and an expandable cable for each probe fitted with an alligator clamp. The probes which were used in this survey were steel, 3 feet long and ½ inch in diameter. The cables could expand to 20 feet. The probes and leads with clamps were made and assembled for about \$25.00.

The basis of the resistivity method of surveying is the measurement of the difference in potential across a given volume of earth when a given alternating current is passed through this volume. Four probes are set into the ground with equal spacing between them. An alternating current is attached to the outer two, and the change in potential offered by the earth is measured between the inner two. This change is interpreted as the conductance, or the reciprocal, resistance, of the earth lying between the inner probes to a depth approximating the distance between adjacent probes (see Fig. 1). The Geohm indicated the resistance in ohms of this volume.

The primary conductive component of earth is its water content. Thus we are essentially dealing with the variance of water in the soil, or in effect, the varying abilities of soil phenomena, sand, silt, stone, etc. to hold water. For example, a stone structure, because of the imperviousness of stone to water, should offer more resistance than earth or sand.

It should be noted that in practical field application one should be conscious of the following:

1. Good probe contact with the ground is important. The probes should be pushed firmly into the earth to an equal depth. It was found that an increase of probe depth made a small, though not significant, variation in readings. This was attributed to better probe contact with the ground. The probes were placed consistently to a depth of one foot to eliminate this variable. Ground probe tests are easily made by taking readings with the probes in a fixed position while increasing their penetration upon each reading. After firmness in the ground is achieved, further penetration should yield a diminishing return of change. Furthermore, in actual surveying procedure, each new resistance measurement requires the repositioning of at least one probe, so it should be noted that unnecessary probe depth can be time consuming and wearing to the operator.

2. Probe spacing is critical. They must be equidistant. A test was run to determine the amount of error given by faulty spacing. It was found that the closer the intended spacing the greater the error given by uneven probe spacing. But under field circumstances one cannot measure ground distances with a micrometer, so as a note of reassurance, it may be said that an error of an inch or two at ten foot probe spacing had no effect. Ten foot spacing was one of two space intervals used at Harpers Ferry. The other probe interval,

that of five feet, produced a change as large as 5 ohms with an error of two inches in probe spacing. Thus, probe spacing accuracy is left to the operator's discretion, keeping in mind that the closer the spacing intended, the more critical the error.

#### Resistivity Procedure:

A 100 foot square area overlying the site of the east wing of the 1853 machine shop and the western section of the 1859 tower building was chosen and sectioned by string lines into a grid of ten foot intervals. The north-south traverses were numbered from 0 to 10, with 0 the westernmost, and the east-west traverses lettered from A through K, with A the southernmost. Readings were taken at each ten foot segment along the east-west traverses. Additional readings were taken at five foot intervals in the north-east quadrant of the grid along traverses F through K. The two five foot readings for each ten foot space were averaged to give a single five foot reading for each ten foot interval. Figure 2 shows the grid superimposed upon the proposed foundation locations.

It is possible to conduct a resistivity survey by oneself, but a second person is recommended. The probes are placed at the desired spacing at the beginning of a traverse with the appropriate outside probe exceeding the end of the traverse by this spacing since it is the space between the inside probes to which we assign the resistance value. This is obvious, but easily forgotten once the survey procedure becomes routine. The leads are connected to the probes and plugged into the meter box in the same order as the probes. The operator presses the measuring button which sends the alternating current through the probes. The galvanometer needle is brought back to "0" by adjusting the resistance balancing knob. The reading on the dial of the balancing knob is

the resistance in ohms of the earth between the center probes. The procedure takes only a few seconds and the current is then shut off. It is not necessary to reposition all four probes for the next reading. The easiest method, for example, is to move the left-hand outside probe beyond the previous right-hand outside probe and reassign the plugs in the meter box to their proper order, the new probe pattern. A new measurement is taken and the process is repeated for each interval along the traverse. With two operators, one moving the probes, the other recording readings, the 100' grid was surveyed within a day.

Two methods for plotting the data were used; a horizontal patch plot of the entire grid, and a vertical differential plot of the north-east quadrant.

#### Horizontal Patch Plot:

Horizontal patch plotting, an adaptation of the topographical contour line technique used for elevations, is a rapid method of plotting resistivity values on a ground plan to ascertain the general areas of higher and lower resistivity. Full contour line drawing is unsatisfactory for this purpose, since it assigns values to areas not actually measured, thus yielding partially spurious results. In the patch method, contour lines are drawn around areas which contain only high or low resistivity. (See Figure 3.)

#### Vertical Differential Plot:

The vertical differential technique is dependent upon the fact that the space between the probes defines the limit of depth of the volume which is measured. This method is similar to the Barnes<sup>2</sup> technique, a method by which resistivity changes in a series of stratification may be determined. The center point of the location of the four probes is kept fixed and the probe spacing is changed progressively. A minimum probe spacing of three feet, for example, is chosen, and a resistance reading is taken. The probes are then spaced at twice this interval, six feet, maintaining the same center point, and a second reading is taken.

The next reading is taken at three times the minimum and so on. The increase in probe spacing permits greater depth measurement of the volume of the earth which lies between the center probes in a proportion approximating the increase in the probe spacing. The specific resistance for each measurement is calculated and subtracted from the specific resistance<sup>3</sup> of the previous measurement, yielding the specific resistance of the layer between the depth limits of these measurements. Thus, significant changes at controlled depths may be determined.

At Harper's Ferry the ruins were known to lie 5 feet below the surface. Therefore, in addition to the overall survey at 10 foot, probe spacing, one section, the north-east quadrant was surveyed at 5 foot spacing. The specific resistance at 5 foot and 10 foot depths were determined, and the specific resistance of the second 5 foot layer was obtained by subtraction<sup>4</sup>. Figure 4 shows the contrasting specific resistances at the two levels and the ruins in elevation along the measured traverses.

#### Seismic Apparatus:

The seismic apparatus, purchased at a cost of \$2725.00 from Geophysical Specialties Co., 15409 Robinwood Drive, Hopkins Minnesota, includes the seismograph, an eight lb. sledge hammer with inertia switch and cable, and a geophone. A steel plate, not included, is required; the one used in this survey was 6" square and  $\frac{1}{4}$ " thick.

The seismograph is a battery operated timer which weighs 14 lbs. and is enclosed in an aluminum case 16"x9"x8". The control panel is equipped with a row of ten indicator lights, a reset switch, a gain control knob, a power switch knob, a geophone receptacle, a hammer receptacle, a ground receptacle, and an external power receptacle. The indicator lights show the length of time taken by sound wave travel. They are marked in intervals which are multiples of two beginning with  $\frac{1}{4}$  milliseconds on the right and ending with 128 milliseconds on

the left. The sum of the lights which remain lit after the counting circuits stop is the arrival time of the sound wave. The reset switch clears the counting lights for the next reading. The gain controls the amplification level of the geophone signal. The power switch has three positions: off, internal power, and external power. The internal position is for use with the battery supply within the instrument, the external position for use with an external power source when desired. The receptacles receive the cables from the geophone, hammer, ground connection, and external power source when necessary.

The sledge hammer has an inertia switch taped to the handle near the head end. The switch consists of two electrodes. One electrode is fixed and the other is suspended on a flat spring. A gap of  $1/8''$  separates the electrodes. A cable runs from this switch to the seismograph. When the hammer is struck on the plate, the shock closes the electrodes, allowing the counters to start in the instrument.

The geophone consists of a highly sensitive vibration transducer in a case with a  $2\frac{1}{2}''$  spur to assure firmness in the soil for maximum vibration sensitivity. The geophone unit also actuates a switch to stop the counters in the instrument upon reception of the sound wave.

Refraction seismology is based on the fact that strata which differ in structure or density will transmit sound waves at different velocities. The refraction seismograph measures the time between the initiation and reception of a sound wave.

Consider a site of two strata: the first layer consists of earth having a sound carrying velocity  $V_1$ ; the second layer consists of bedrock having a faster sound carrying velocity  $V_2$ . Bedrock velocities are faster typically than overlying earth. A traverse is laid out along this profile with the geophone at one end and hammer stations placed at regular intervals on the traverse. (See Figure 5).

When the hammer strikes, sound waves are dispersed throughout the ground in all directions. At hammer station A, the first wave to activate the geophone will be the wave travelling through the V1 layer from A to the geophone. The same situation occurs at station B. The time recorded at B would be twice that at A since the distance is doubled. At station C the situation changes. Due to the increased distance between the hammer station and the geophone, there is sufficient time for a sound wave to penetrate through the upper layer, V1, travel through the faster velocity layer, V2, and be refracted back through the V1 layer to the geophone, before the wave travelling directly through the slower velocity layer, V1, reaches the geophone. This will be the case for the stations following C. If a still higher velocity layer, V3, lies beneath the V2 material, the same wave refraction principle will occur once the hammer station is at a sufficient distance from the geophone (See Figure 5, Stations E & F)

The data are plotted as shown in Figure 6. The strata velocities appear as slopes; the greater the velocity, the closer the slope approaches the horizontal. The depth of the surface of the V2 layer may be calculated by the formula:

$$\text{Depth} = \frac{x}{2} \sqrt{\frac{V_2 - V_1}{V_2 + V_1}},$$

where x is the point of intersection of the slopes.

Depth estimation is the fundamental use of the seismograph. Alone, this is not of great value to archaeology. However, anomalous irregularities in the surfaces of these sub-strata are detectable by the seismograph. These irregularities could represent archaeological features lying on the surface of the sub-strata if the potential velocity of the archaeological material is more similar to the velocity of the sub-strata than that of the overlying layer. Rises and dips in a subsurface may appear as points lying not directly on the graphed slope of the velocity of this surface. (See Figures 7 & 8).

When a rise occurs on the surface of the V2 stratum, the seismograph registers a shorter time lapse from hammer to geophone, than it does when the surface is level. This is due to the fact that the rise enables the sound wave to enter the higher speed V2 layer sooner simply because it is closer to the ground surface. When graphed, a rise appears as a point lying beneath the V2 slope, a point of shorter time than the normal points on the slope. In contrast, a dip in the sub-surface will cause the sound wave to enter the higher speed stratum later, since it is farther away from the ground surface. When graphed, a dip appears as a point above the V2 slope, a point of longer time lapse than the normal points on the slope.

Although rises and dips may indicate points of interest to the archaeologist, there can be, unfortunately, other reasons for these anomalous points: irregular surface topography, background noise, lack of discrimination between the arrival of the first and second cycles of the seismic wave.

#### Irregular Surface Topography:

Irregular surface topography may cause sound waves to behave in much the same way as in subsurface rises and dips. Observation of surface contours should suffice to control this possible variable.

#### Background Noise:

Background noise readings will result from pre-existing sound waves in the ground; highway traffic or aircraft, for example. The geophone responds to the first impulse significant enough to affect it. Such sound will cause the geophone to close the counting circuits before the shock wave from the hammer has a chance to arrive. Thus, background noise will produce faster time readings. A good test for background is to activate the switch on the hammer without striking the plate and observe when the counter stops. If it stops within the time range of the

survey, detrimental background noise is present. The test is repeated until the noise subsides, i.e., until the time lapse increase is great enough to be outside the range needed for the survey. The time range of a seismic survey will vary according to the local ground conditions; the significant range of the survey at Harpers Ferry, for example, was between 8 and 64 milliseconds. If noise persists the gain control may be lowered. When the gain is lowered in an effort to make the geophone less sensitive to background noise it likewise reduces sensitivity to the hammer wave. This may be rectified by harder hammer blows, which will add amplitude to the hammer wave. Persistent tests for quieter background by hammer switch activation are important and, since normal seismic surveying requires many hammer blows, unnecessary blows should be avoided in the interest of preserving the hammerer's energy and cooperation.

#### Seismic Wave Cycles:

A seismic wave consists of an initial impulse (first cycle), followed closely by another of greater amplitude (second cycle). In the event that the geophone is not triggered by the first, but is the second, the time recorded will be slower because it will include the time lag between the first and second cycles. Graphically, a second cycle velocity slope will be above and nearly parallel to the velocity slope of the first cycle. Thus, when anomalous readings appear to lie along a straight line it is likely to be an indication of the reception of both cycles rather than subsurface anomalies. Correction may be made by increasing the gain to assure the reception of the lower amplitude first cycle.

Finally, it is advisable to take several readings at each hammer station, not only to account for the variables mentioned above, but because it was rare that any readings occurred within 1 millisecond of each other at any single hammer station.

**Seismograph Procedure:**

The intersecting points of the ten foot segments of the resistivity grid were used as hammer stations for the seismograph. Two surveys were made: one along each north-south traverse with the geophone at the south end of each traverse; the other along each east-west traverse with the geophone at the west end of each traverse.

The instrument is set up initially for proper gain setting. The geophone is placed at the end of a traverse and the hammer and plate are taken to the extremity of the traverse. Care should be taken that the plate be lying firmly on the ground surface to assure good plate-ground contact. While repeated blows are made, the gain is advanced from "0" position until the counters stop in response to the shock. Since this will probably be the reception of the greater amplitude impulse, the second cycle, the gain should be advanced further until counts of less time are observed. This will indicate that the gain is high enough to respond to the earlier but lower amplitude impulse, the first cycle. The gain in this position should be adequate for the local ground conditions confronted by the survey. Occasional adjustment may be necessary to deal with the second cycle and background noise problems discussed above.

The data were plotted, time against distance. The rises and dips, indicated by points which did not lie on the velocity slopes, were transferred to a grid plan of the site according to the positions of the hammer stations which yielded them. (See Figures 9 & 10). These positions must be considered as a maximum distance location from the geophone position since the angle of incidence of the sound wave as it enters the second velocity material is always in a direction towards the geophone. (See 'Y', Figure 7)

Results of the Instruments

The data given by the Resistivity apparatus and the seismograph are shown in Figs. 3, 4, 9 and 10.

Results of the Test Trenches

Trenches were dug across anomalies indicated by both instruments. The depth of the structures was 6 feet, with exceptions ranging from 2 feet to 11 feet. The upper 5 feet were removed by an earth moving machine, a back hoe. The final clearing was finished by hand shovelling. Since, at the level of 3 feet, the profuse iron slag in Trench 4 (see below) offered resistance to the back hoe identical with that of the architectural features found in the other trenches, deeper penetration here was not attempted. Trench location and instrument data locations are shown in Figs. 2, 3, 9 and 10.

The trenches yielded the following:

General Remarks:

The building material used for the flagstones and the foundations was a local sedimentary shale. All architectural features were covered by a loose shale rubble. Some of these pieces measured up to 2½ feet across their widest portion. Some had mortar adhering to them indicating that they had once been part of the foundation structures. A thin layer of charcoal was found on the flagstone surfaces indicative of the conflagration of the Confederates in June 1861. occasional nails, bottle glass and melted glass were found wedged in the flagstone junctures and against the foundation blocks. This distribution is probably a result of the first post-war flood in 1869. All the foundation walls had top surfaces which were rough and broken with mortar adhering to them. No artifacts were found on top of any of these surfaces. This would indicate that the walls of the buildings were standing at the time of the initial post-war flood.

Trench 1: (See Fig. 11)

Trench 1 was cut north to south between traverses 4 and 5 from D to G

through an area of low resistivity and a seismic rise along traverse F<sub>0</sub>. According to the proposed plan of the building locations, the foundation wall which was exposed was that of the south wall of the east wing of the 1852-53 machine shop. Two structures with finished surfaces lay adjacent to the north of it. The first of these was a juncture of two flagstones, and the second was a wall with a single finished stone on top of it. These features may outline an east-bound water channel which is thought to have run through the entire complex of factory buildings. If this is true, the exposure in trench 1 indicates that this channel had a flagstone cover, and that the south wall of the machine shop wing was mounted upon the south wall of the channel. Another foundation wall was found at the extreme south end of the trench. This structure had a top surface which was rougher and at a lower level than the south wall foundation of the shop. Since the nature of its construction is different and its location places it outside the proposed plan of the factory buildings, it is probably not a part of the machine shop. It may be the foundation of one of the buildings belonging to Captain John Hall's Rifle Works which stood at this site from 1819 until 1847 when they were replaced by the U.S. Rifle Works.

Trench 2: (See Fig. 12)

Trench 2 was cut north to south between traverses 5 and 6 from G to K through an area of low resistivity at H, high resistivity at J, seismic rise at I and J, and seismic dip at H-5. A bounty of architectural features were exposed including a turbine pit 9 feet in diameter, 5 feet deep, made of blocks 14 inches thick, and ranging from 2½ feet to 7 feet in length.

The northern portion of the trench exposed a series of structures forming the headrace, the entry channel for the water which drove the turbine.

Beginning with the north end of the trench, the remains of two masonry conduits were found. Enough of one was extant to permit the measurement of its diameter which proved to be 1 foot 6 inches. The interior surface of the pipes was a fine grain mortar. The partially extant entry pipe was the most shallow feature found in all the test trenches as it lay only 2 feet below the ground surface. (See Fig. 12a, Section y-y).

Adjacent to the entry pipes was a rectangular tank to receive the water which poured through them. The surface of the tank was lined with a fine mortar similar to the interior of the conduits. Bits of dried moss were found on the bottom surface of this tank indicative of the presence of water. The western limit of the tank was undetermined due to the limitation of the excavation, as was that of the conduit structure. It is possible that the tank extends some distance to the west and likewise the entry pipe structure, so that the pipes which were exposed are only two of a longer series.

The third and last structure of the headrace was a sluice, 4 feet wide, which cut through the north foundation wall of the building. The bottom consisted of a single finished stone 7 inches thick, which was covered by wide, heavy wood planks in excellent preservation. An iron plate 1½" thick stood at the juncture of the sluice and the receiving tank. (See Fig. 12, Section I-X). It is presumed that the planking was a gate which, when raised vertically against the plate, served to control the flow of water into the sluice. One may only speculate about the reason for the iron stake which was driven into the juncture of the iron plate and the foundation wall. In this position it renders the gate useless. Perhaps it is a token reminder of the Confederate fire of June 1861 which destroyed the factory buildings.

The turbine pit was constructed in five mortared courses of stone blocks 14 inches thick and of irregular lengths measuring from 2½ feet to

7 feet 10 inches across their inside faces. The uppermost course formed a circle 12 feet in diameter which was concentric with the curvature of the pit. This course was incomplete leaving about a 10 foot gap at the south. The other four courses formed a circular pit 9 feet in diameter. The topmost course formed a full circle. Four pairs of holes, roughly circular, were cut into the top face of the masonry. The pairs were situated with two on each side of the pit, 3 feet 8 inches apart and positioned symmetrically in relation to an axis drawn through the center of the tailrace gap. The holes were  $2\frac{1}{2}$  inches in diameter, 7 inches deep, 6 inches from the edge of the pit, and  $4\frac{1}{2}$  inches apart in each pair. Among the artifacts found was a structural cast iron plate with a pair of holes cut into it which conform to the holes in the masonry. (See Fig. 14 ). It is likely this plate is a structural member of the turbine case.

The remaining three courses left a gap 5 feet wide at the south side of the pit which provided the exit for the tailrace, the channel which allowed the water to leave the pit after it had passed through the turbine. The floor of the pit was a single piece of stone upon which the circular pit blocks were mortared.

The pit was filled with shale rubble mixed with brick. The percentage of brick increased towards the bottom of the pit. The floor was littered with artifacts: Iron artifacts included machine parts, gun parts, and hardware; also there were bottle glass, melted glass, and pieces of red and grey slate. Some of these artifacts are illustrated below (Fig. 16 to 29), but a full inventory is not available at this time (See Appendix).

An iron bearing box  $\frac{1}{4}$  inches square was found inserted into the center of the floor. (See Fig. 15). This box was set into a shallow niche

with lead poured around it to insure its stability. The box held the lower bearing of the vertical shaft of the turbine. The lugs in the sides of the box allowed the shaft to be recentered when necessary.

Preliminary research into 19th Century water power technology and information gathered from Mr. George Kellison, a long time resident of Harpers Ferry, led to the following conclusion: the curbing and the inset at the top of the pit held a circular series of gates which would have allowed equal distribution of water at all points around the turbine. This ring of gates, or case, probably made of iron, was anchored by lugs which fitted into the four pairs of holes described above. This would prevent the case from rotating with the turbine drum. The gates could be regulated by a spider control, a series of rods, one for each, which led to a single control wheel. The case would also have contained the upper bearing box with centering lugs.

#### Trench 3: (See Fig. 13)

Trench 3 was cut east to west between traverses H and I from 6 to 10 through an area of high resistivity at 6 and 8, and seismic dip at 8 and 9. This trench bisected the area which was surveyed by the resistance apparatus at both 5 feet and 10 feet intervals.

The westernmost end of trench 3 exposed a foundation wall  $4\frac{1}{2}$  feet wide which had a rough mortared surface resembling that which was found in trench 1. A 6 inch iron pipe ran parallel to the east side of the wall. This foundation wall was bounded on the west by the curbing of the turbine pit and to the east by a flagstone floor which extended eastward to a point midway between lines 8 and 9. Here the flagging stopped abruptly. The final flagstone measured 4 inches in thickness. A trial probing 2 feet deep showed a supporting wall beneath the flagging which extended to an undetermined depth.

A foundation wall running east-west was exposed under the northern banks of the trench with a corner which overlapped the limit of the flagging. This must have been the southwest corner of the tower of the 1859 building. The southeast corner was too far under the trench bank to be exposed. The unsuccessful probing for this corner proved the wall to be at least 12 feet long.

Trench 4:

Trench 4 was cut obliquely from J-9 to K-6 through an area of contradictory seismic rise and dip. This trench was shallower than the others (see above, General Remarks) penetrating only 3 feet. At this level the yield was profuse in iron slag and fused lumps of rusted lathe chips. It was evident from the exposures of the other trenches that this area lay just outside the north wall of the building.

Trench 5:

Trench 5 was cut obliquely from a point 5 feet south of H-2 to a point 3 feet north of J between traverses 2 and 3. This was an area of low resistivity and contradictory seismic rise and dip. The north foundation wall of the machine shop was exposed, according to the proposed building plan, with a flagstone floor extending south. The flagstones were large, only one juncture being exposed by the entire trench.

Trench 6:

Trench 6 was not cut as a result of the survey data. It served only as a ramp for the earth moving machine enabling the tractor to widen trench 2 to expose the entire turbine pit following its initial discovery. As the machine withdrew, a trench was cut to see if the wall complex which was exposed by trench 1 continued running east to meet the south bound tail race of the turbine pit. The structures did in fact extend east, but

extending south and continuing beyond the southern limit of the trench was a covering of large rough flagging over the tailrace channel. The stone sides of the channel could be seen by flashlight through large gaps in the stone covering. This covering was bounded on the east by a foundation wall also running beyond the limit of the trench. This wall was an extension of the wall at the western end of trench 3. South of point F-6, the blocks of this wall became rougher than the foundation blocks which were associated with the 1852-53 machine shop, indicating that an addition had been made to this earlier building to provide a foundation for the 1859-60 building.

### Discussion of the Instruments

#### Seismograph:

The results of the seismograph showed the depth of the higher velocity material, bedrock, to range from 15 to 17 feet. Anomalies were noted in both surveys. All those anomalies which could be interpreted as rises and dips were plotted on two grids, one representing the north-south survey, the other representing the east-west survey with the hammer station which yielded the anomaly being the point of orientation of the rise or dip. As stated above, this position must be considered as the outermost limit the anomaly lies from the geophone due to the angle of incidence of the seismic wave. Some of the rises and dips were at points which agree with structure positions. Others do not agree.<sup>6</sup> With this in mind plus the fact that the depth indicated was 15 to 17 feet, we conclude at this time that most of the seismic surveys sounded below the ruins and that the anomalies shown were rises and dips in the surface of the bedrock.

#### Resistivity:

The resistivity results are separated according to plotting techniques, the horizontal patch plot, and the vertical differential plot.

#### Horizontal Patch Plot: (See Figure 3)

The points of higher resistance at H-7, I-7, and J-6 represented a heavy stone foundation wall impervious to moisture thus behaving as a point of high resistance as anticipated. This structure began at a two foot depth at J-6, was at a depth of six feet at H-7, going to an undetermined depth at all points.

The large area of low resistance yield a bounty of architectural features including the turbine pit. The problem is to explain the reversal of behavior of these stone structures when it has been demonstrated that stone should produce higher resistance. The hypothesis offered here is based on the fact that the water table was very close to the level of the ruins. It is also variable,

having a natural fluctuation of several feet and flood rise of some eighteen feet. The surveys were made during a dry spell when the river level was approaching a mean low water. Thus, the explanation offered for the presence of water indicated by low resistance is that the tail race channels and the turbine pit behaved as moisture traps inhibiting the leeching of the water from the soil during this period of low river level.

The higher resistance patch at G-9, H-9, I-9, and J-9 indicated the tower foundation of the 1859 building and the supporting wall beneath the termination of the flagstone flooring exposed by probing in trench 3. As stated above in the description of trench 3, this latter structure went to an undetermined depth.

#### Vertical Differential Plot. (See Figure 4)

The vertical differential plot is the more conclusive, in this case, of the two plotting techniques although more time consuming. If the operator knows the level at which his quarry lies, this technique is much more discriminating than the generalizations given by the horizontal patch method. This is particularly true for situations involving any depth. This method allows the surveyor to eliminate the resistivity of the overburden and obtain the resistivity variations of the actual level at which he is interested.

Figure 4 shows the different specific resistivity values of the first and second five foot layers along traverses H, I, and J. We may consider that trench 3, exposed both H and I although I actually lay three feet to the north of the trench bank. The illustration shows the resistivity values over the tower foundation. The points of actual resistance measurement are the center points A, B, C, D, and E along three significant traverses, H, I, and J. At H the tower does not appear but the structure underneath the terminal flagstone and the building wall foundation at about point 6 do. Each of these features yielded a higher specific resistance at the second 5 foot level. The values given by the first

five feet were complacent and relatively low as in all instances at this level with the exception of point E on the most westerly point of traverse J where the masonry remains of the headrace entry conduits intruded up into this level some 3 feet. This raised the specific resistance of this point in the upper 5 foot level.

The tower foundation appears at traverse I. Both points A and B of this traverse are higher values. A has increased from its value of traverse H but B has continued high since point B at traverse H was already over a structure. D of traverse I remains high because the wall continues north. The third profile shown, traverse J, is a projection from the differential resistivity data. If we are to assume that the tower foundation is square as indicated by the historic photograph, and the width of the foundation blocks agree with those already exposed which measured from 4' to 4½', then the point B of traverse J would lie over the smaller interior square space which would be outlined by the square tower foundation. Point B offers low resistance at the 5' to 10' depth suggesting a structural void while the point B on traverses H and I was high, indicative of the structures which were subsequently exposed. Therefore, a tentative profile of the interior of the tower foundation may be made by the low specific resistance given by this point on traverse J.

Conclusion

In summation, we make the following evaluations of the seismic and resistivity instruments for use in archaeology:

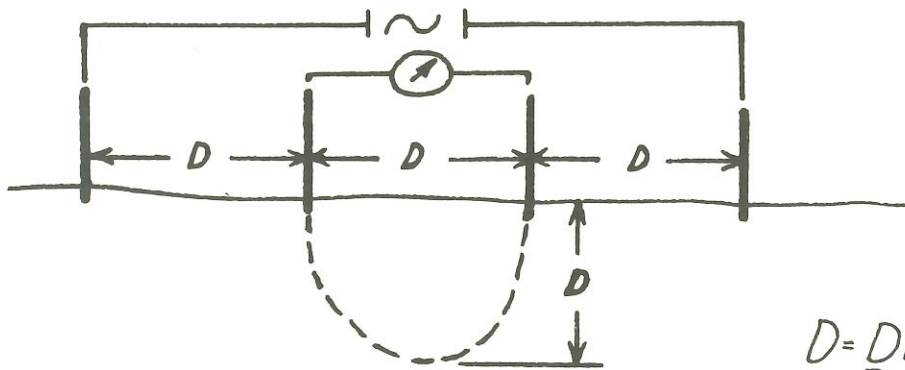
1. Resistivity Apparatus:

Good correspondence with architectural features, especially evident in the vertical differential plotting technique.

2. Seismograph:

Good for depth estimates of geological features. Correspondence with shallower architectural features not certain.





$D$  = Distance between Probes

Fig. 1

Plan of Survey Grid  
 + Test Trenches

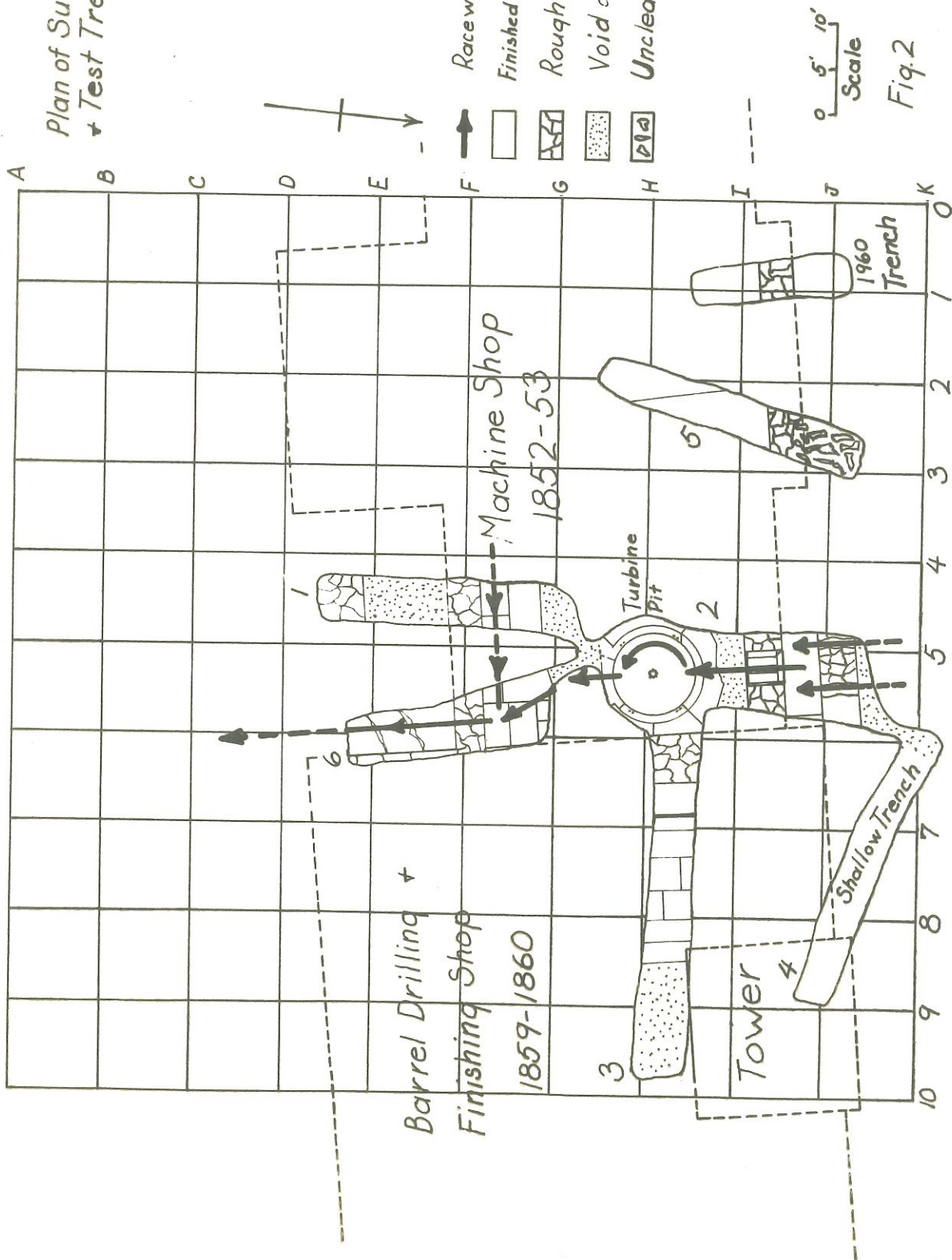


Fig. 2

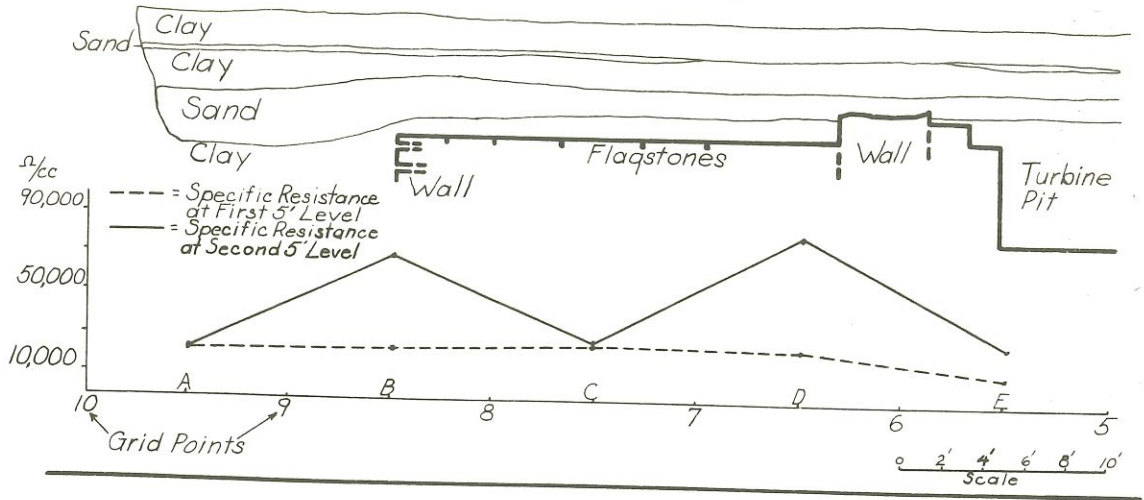
Resistivity Survey:  
Horizontal Patch  
Plot Method



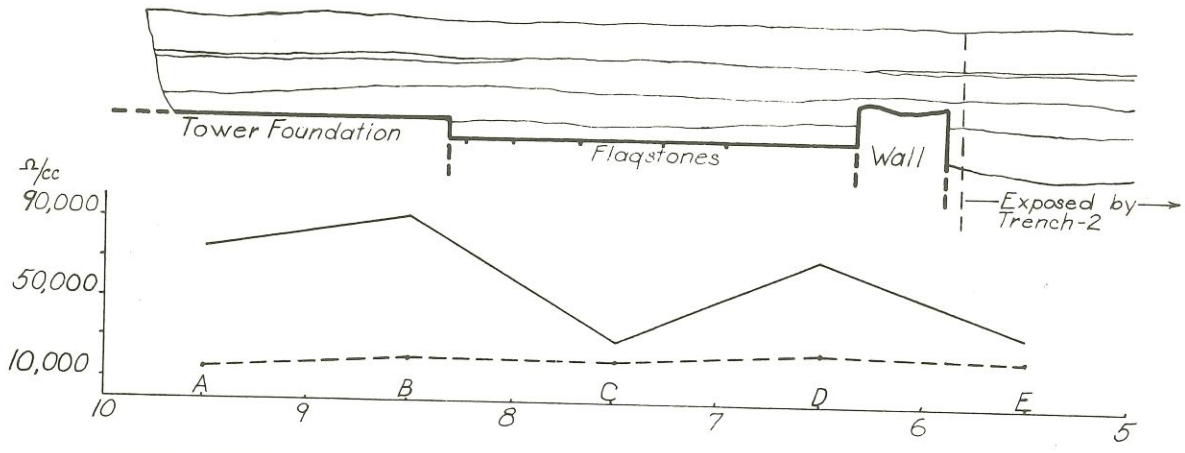
Fig 3



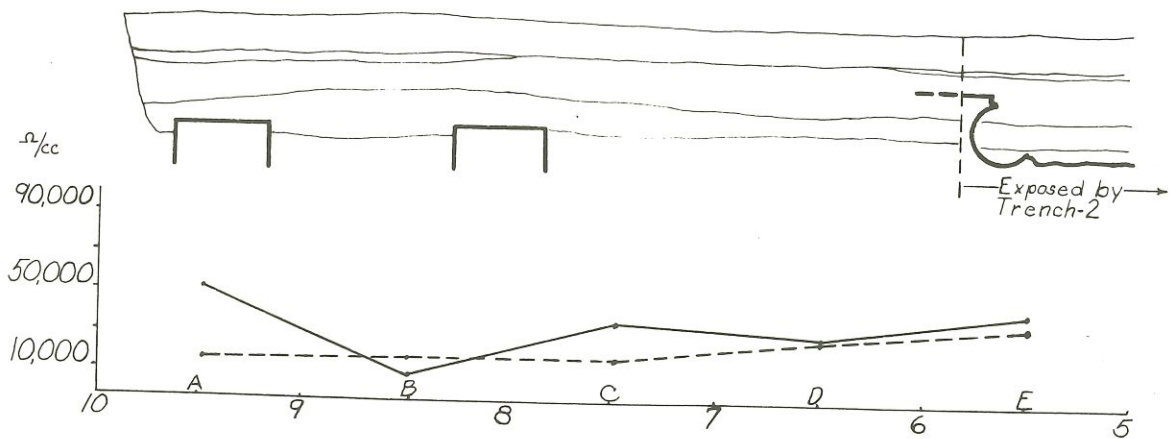
### Traverse H-Profile



### Traverse I-Profile

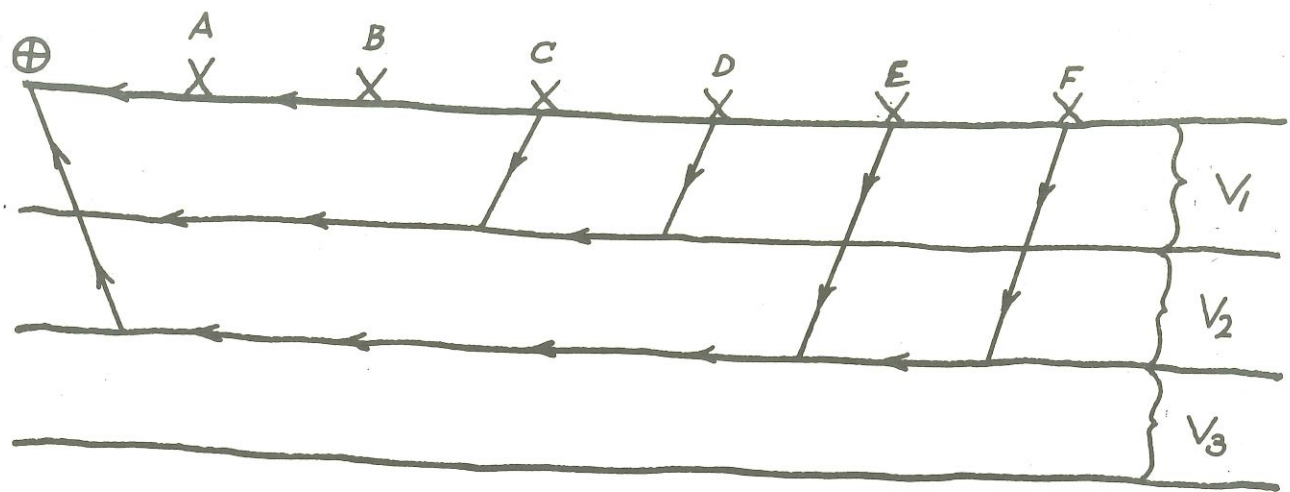


### Traverse J- Possible Profile



Resistivity Survey:  
 Vertical Differential  
 Plot Method

Fig. 4



⊕ = Geophone

X = Hammer Station

Fig. 5

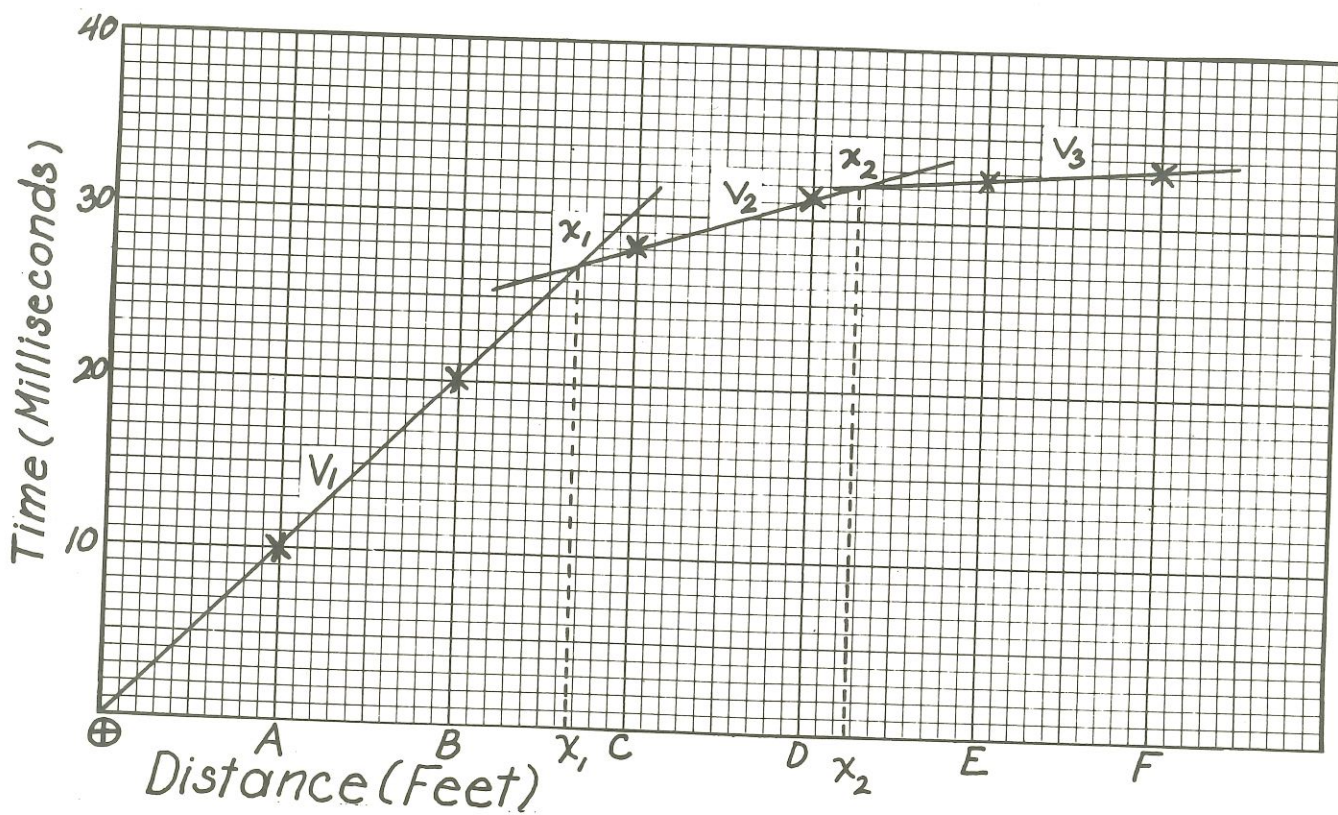


Fig. 6

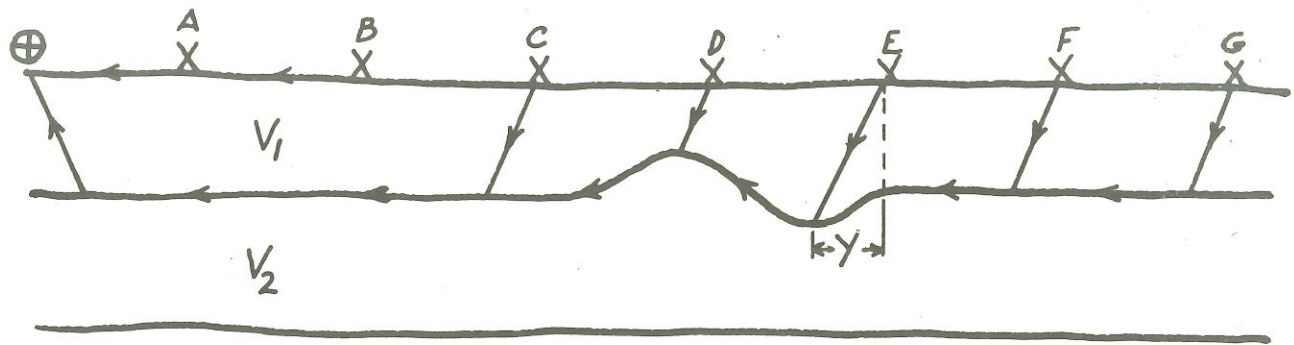


Fig. 7

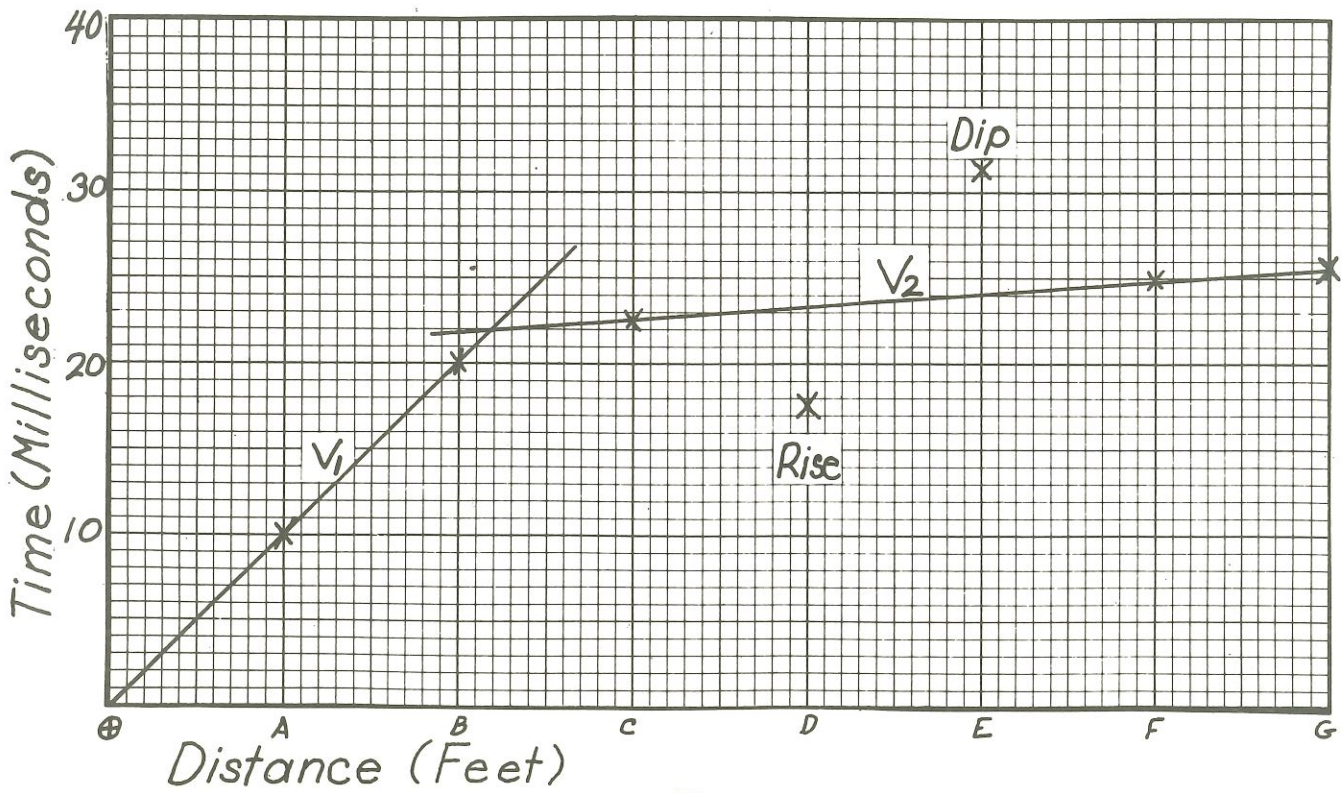
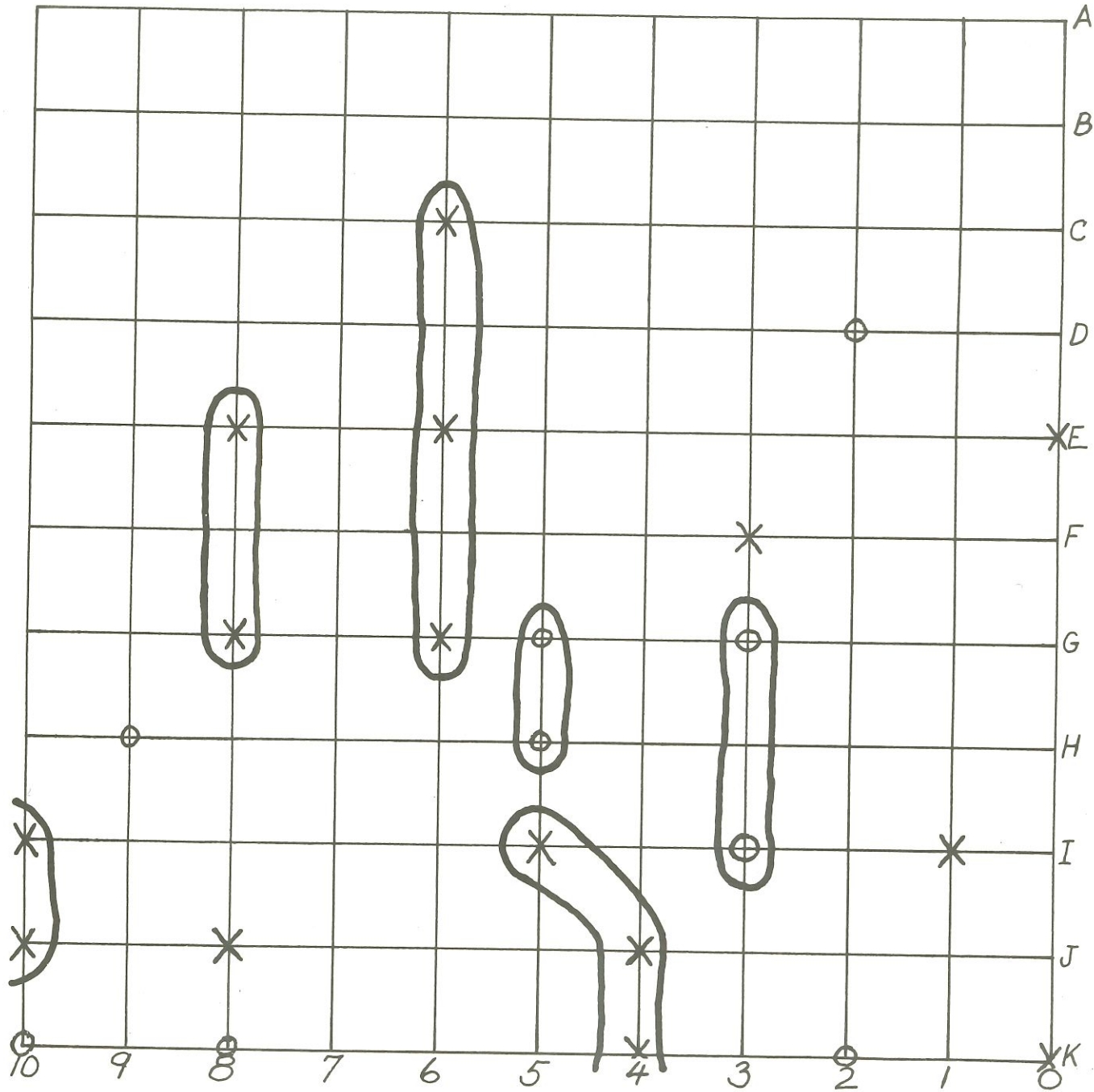


Fig. 8



Seismic Survey:

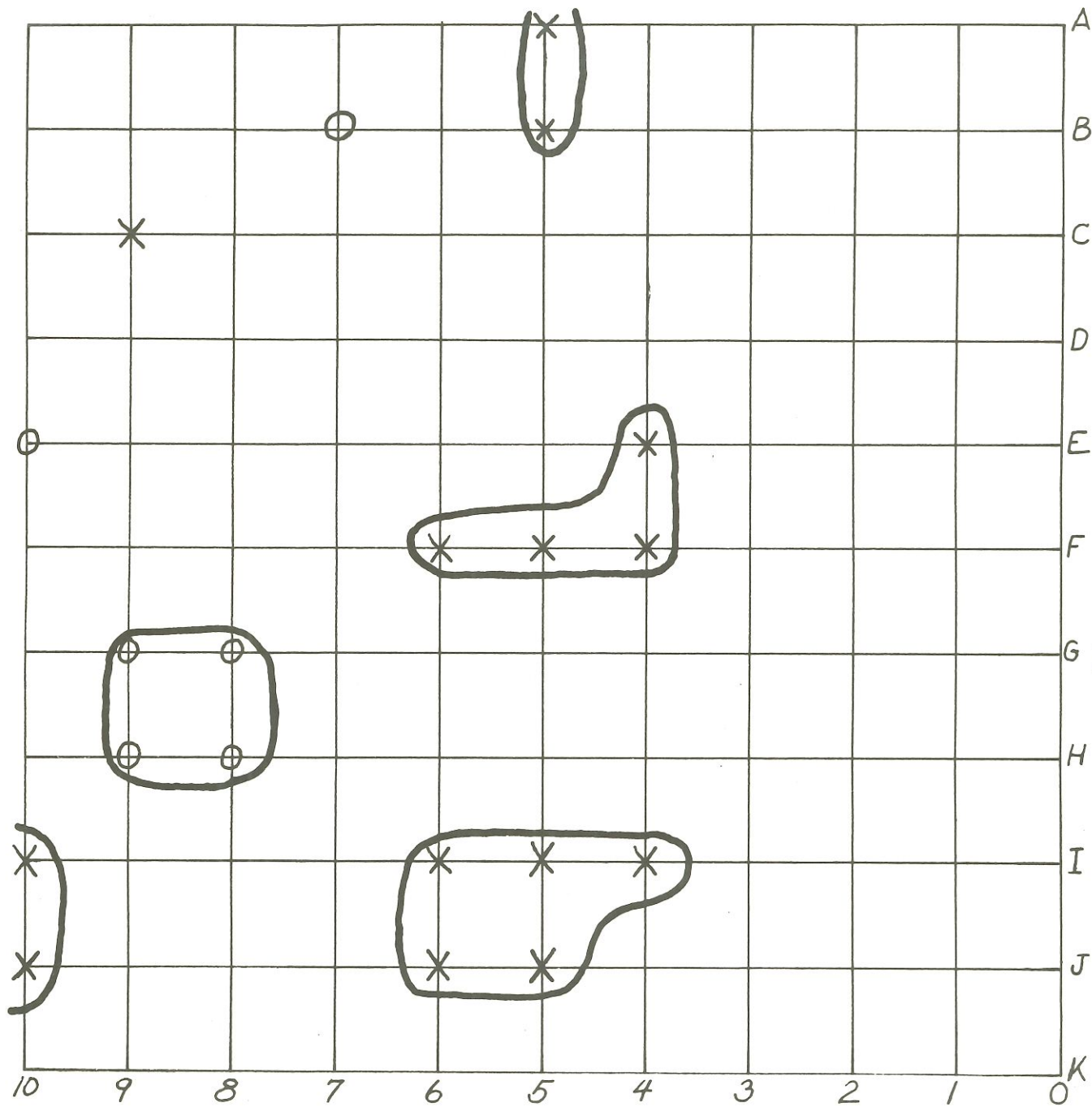


X = Hammer Station which Yielded a Rise

O = Hammer Station which Yielded a Dip

0 5' 10'  
Scale

Fig. 9



Seismic Survey:

Wave Direction

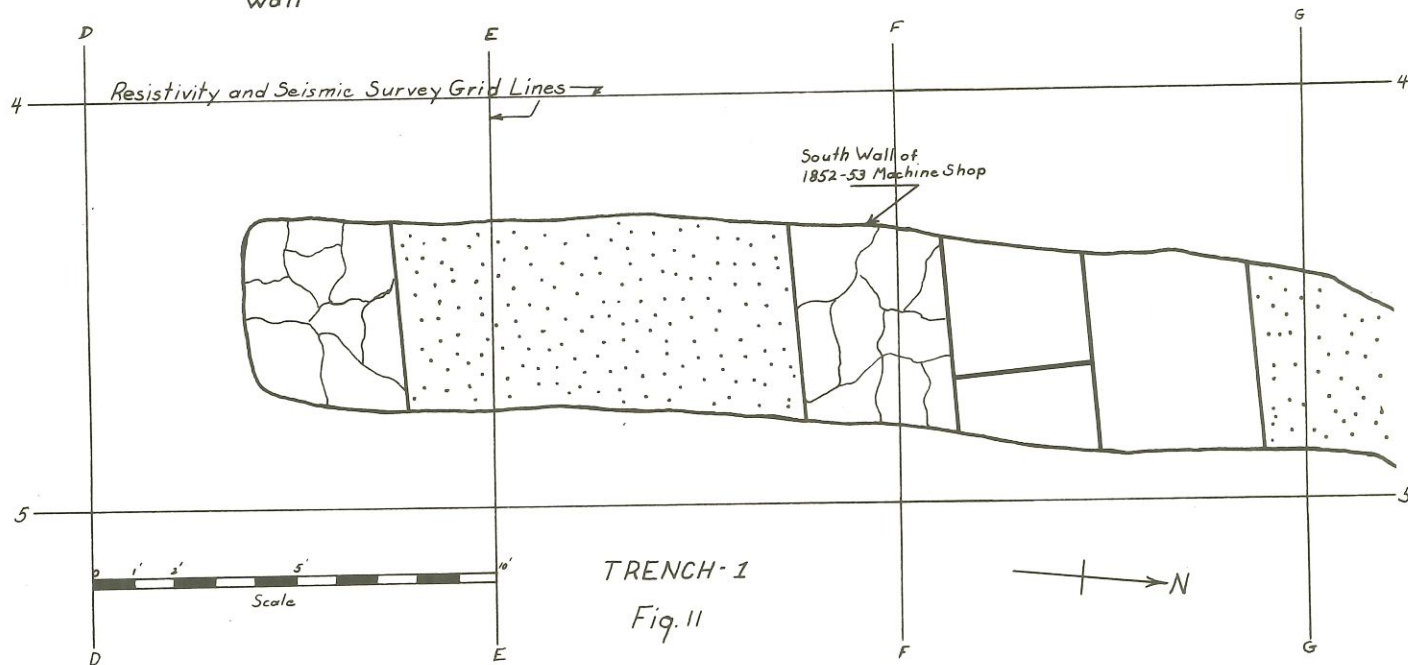
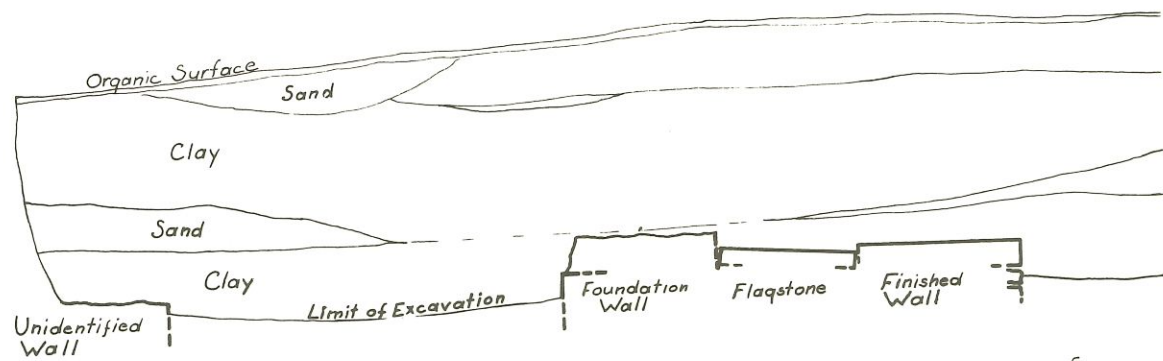


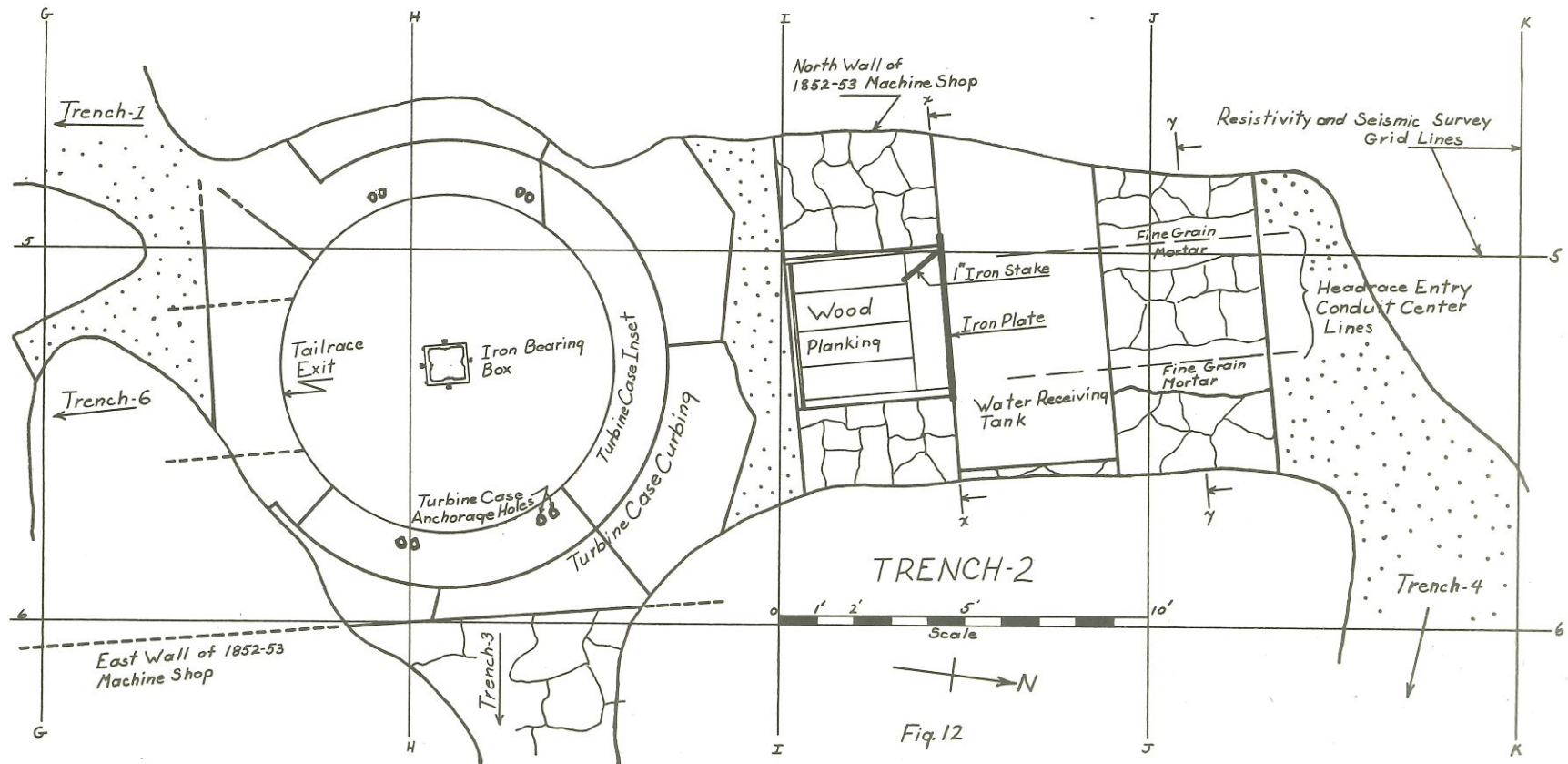
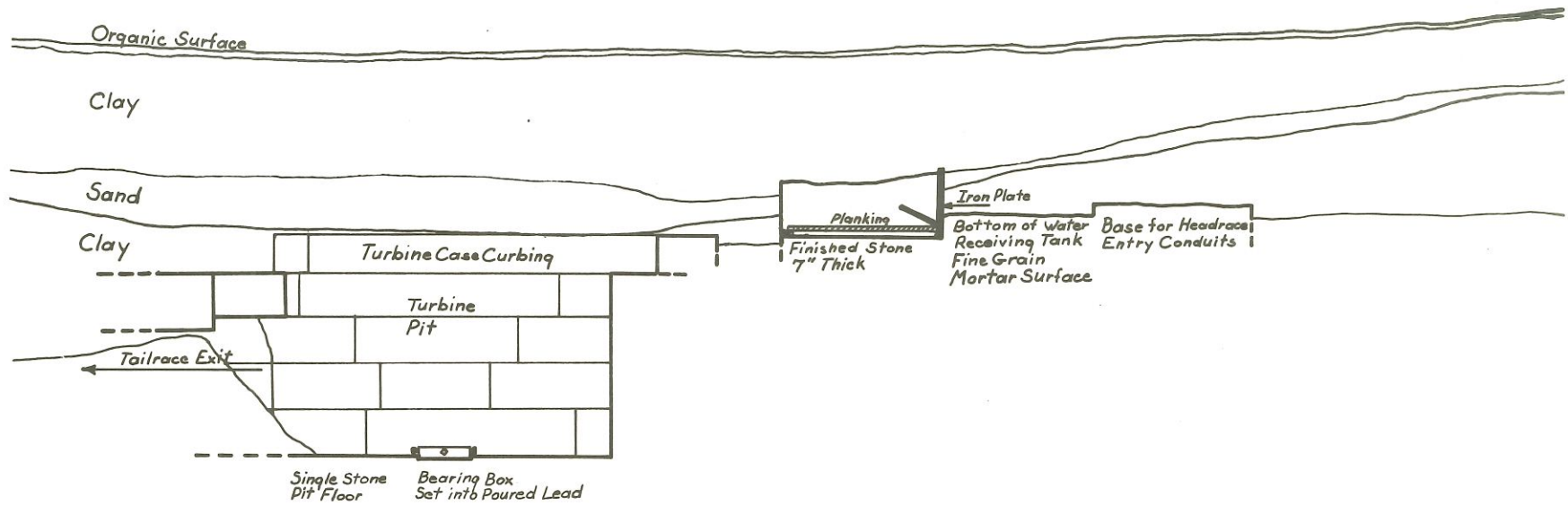
X = Hammer Station  
which Yielded a  
Rise

O = Hammer Station  
which Yielded a  
Dip

0 5' 10'  
Scale

Fig. 10





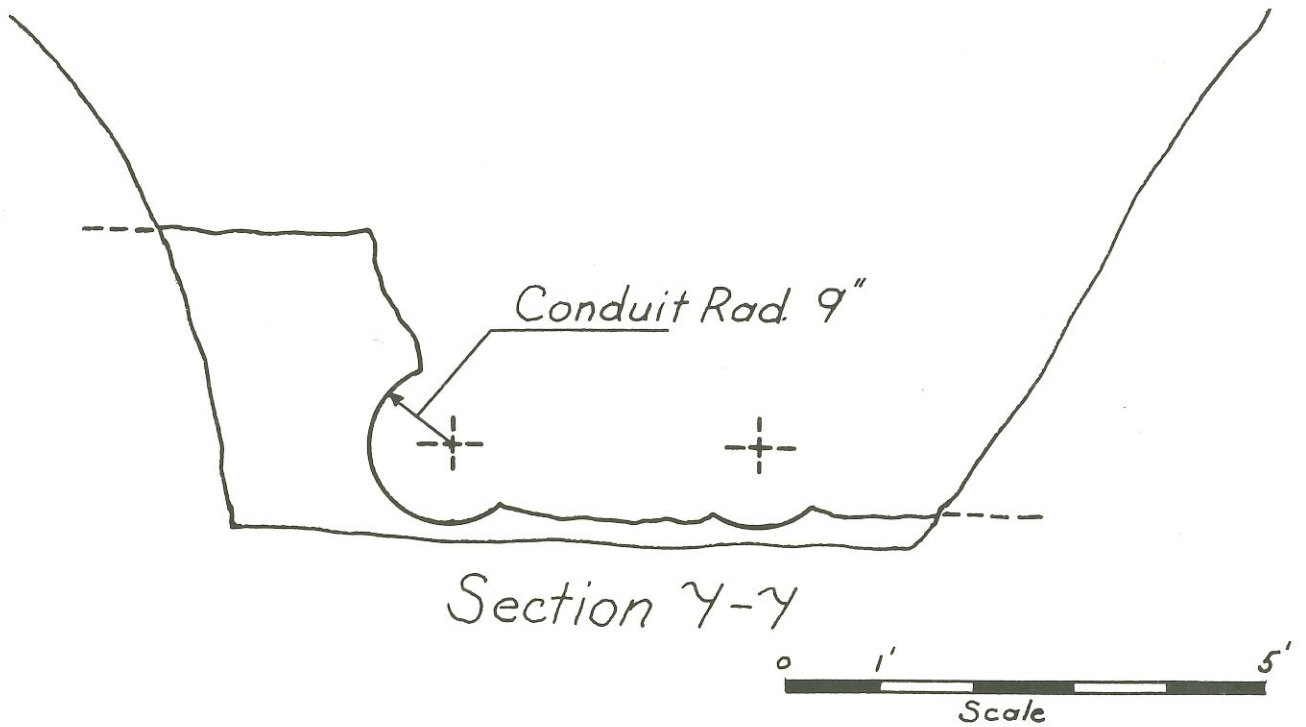
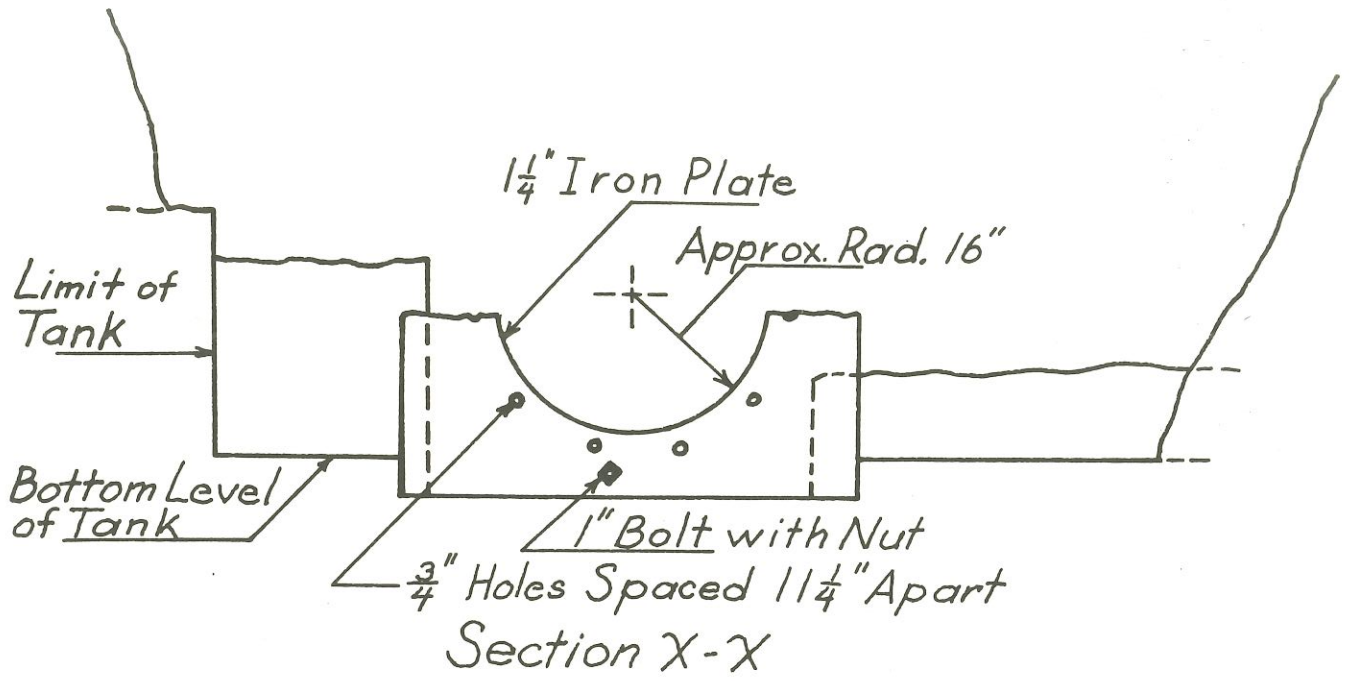


Fig. 12a

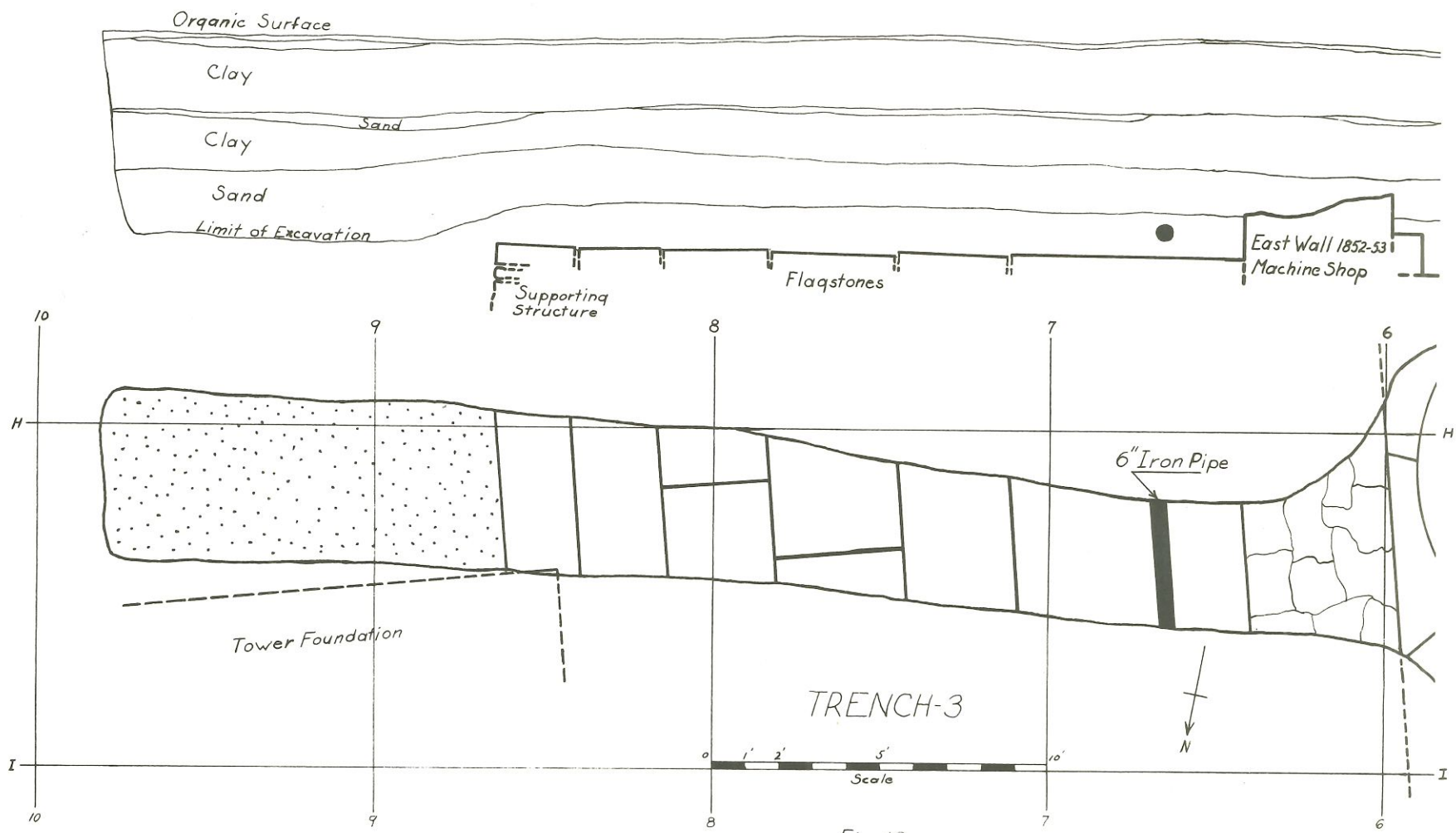
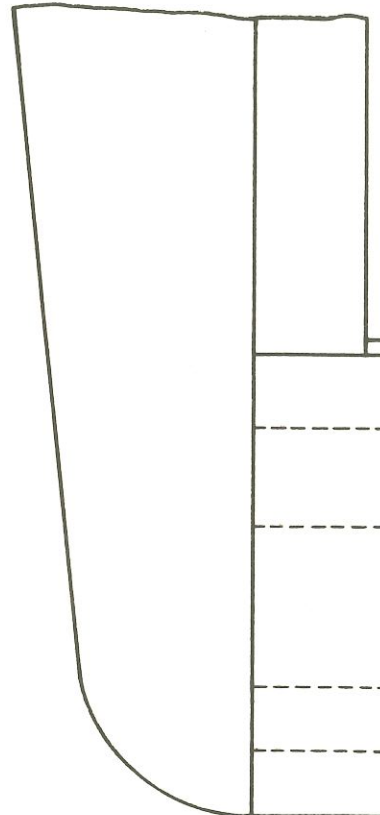
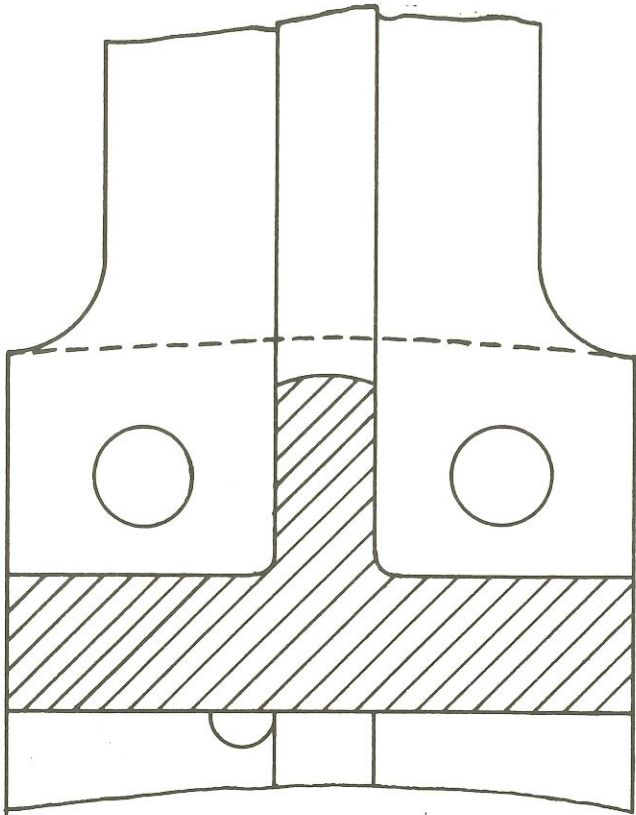


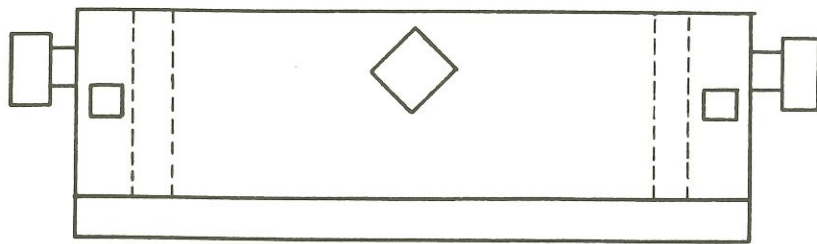
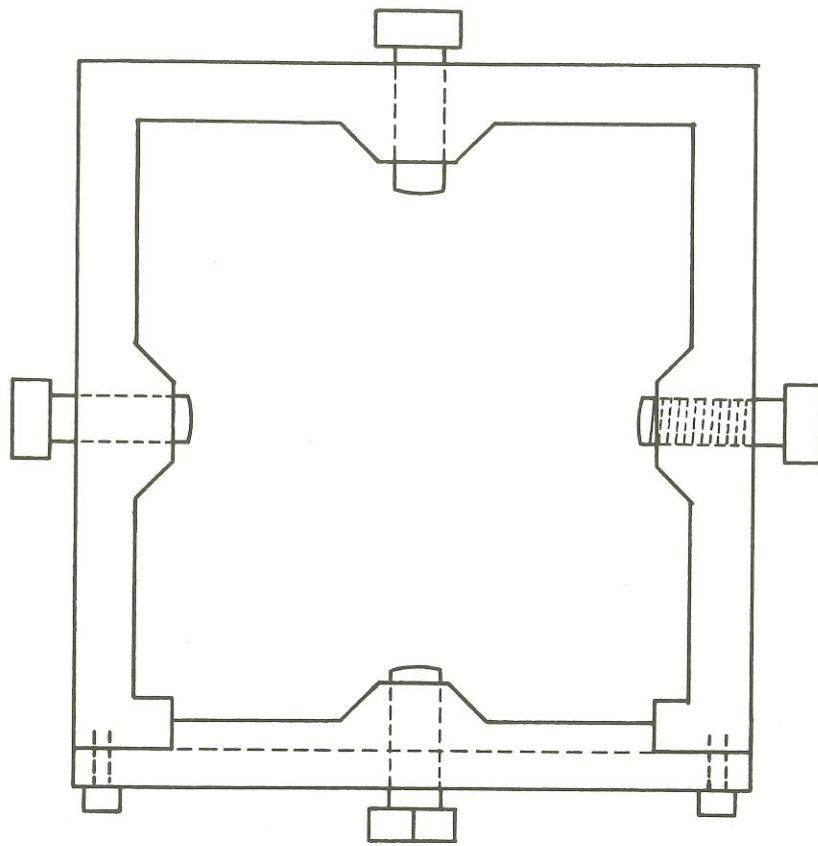
Fig. 13



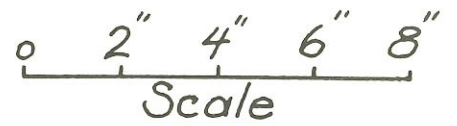
0 1" 2" 3" 4"  
Scale

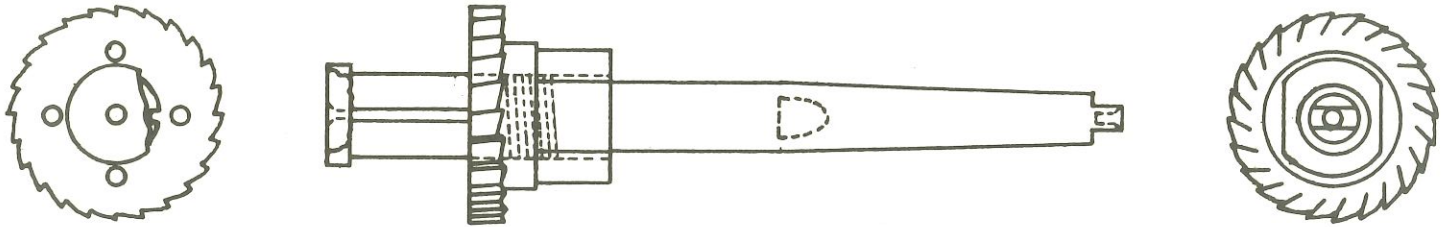
*Turbine Case Member*

*Fig. 14*



Bearing Box  
Fig. 15

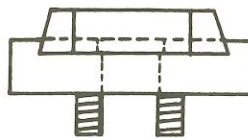
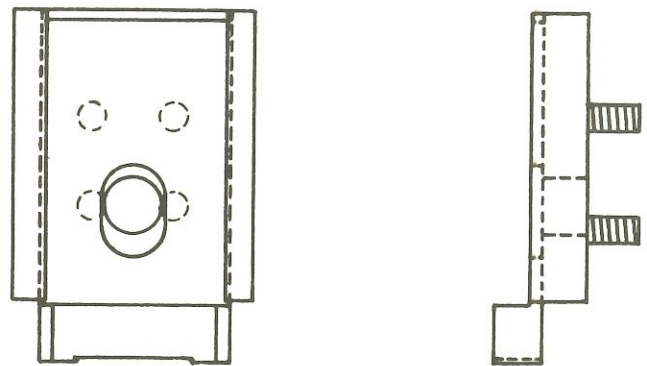




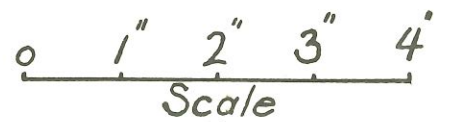
*Milling Gear Assembly*



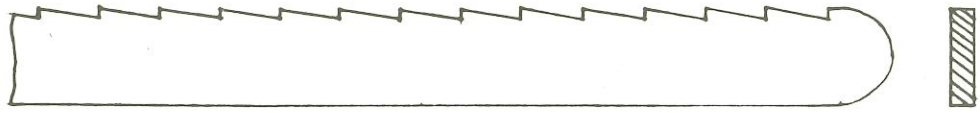
*Fig. 16*



*Slide Rest*



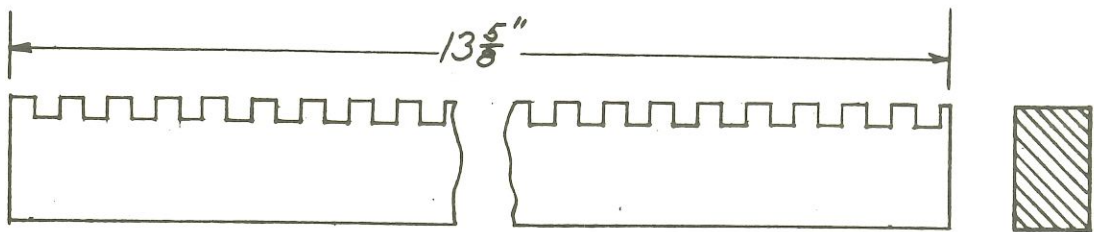
*Fig. 17*



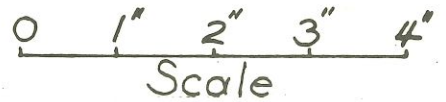
Ratchet Arm  
Fig. 18

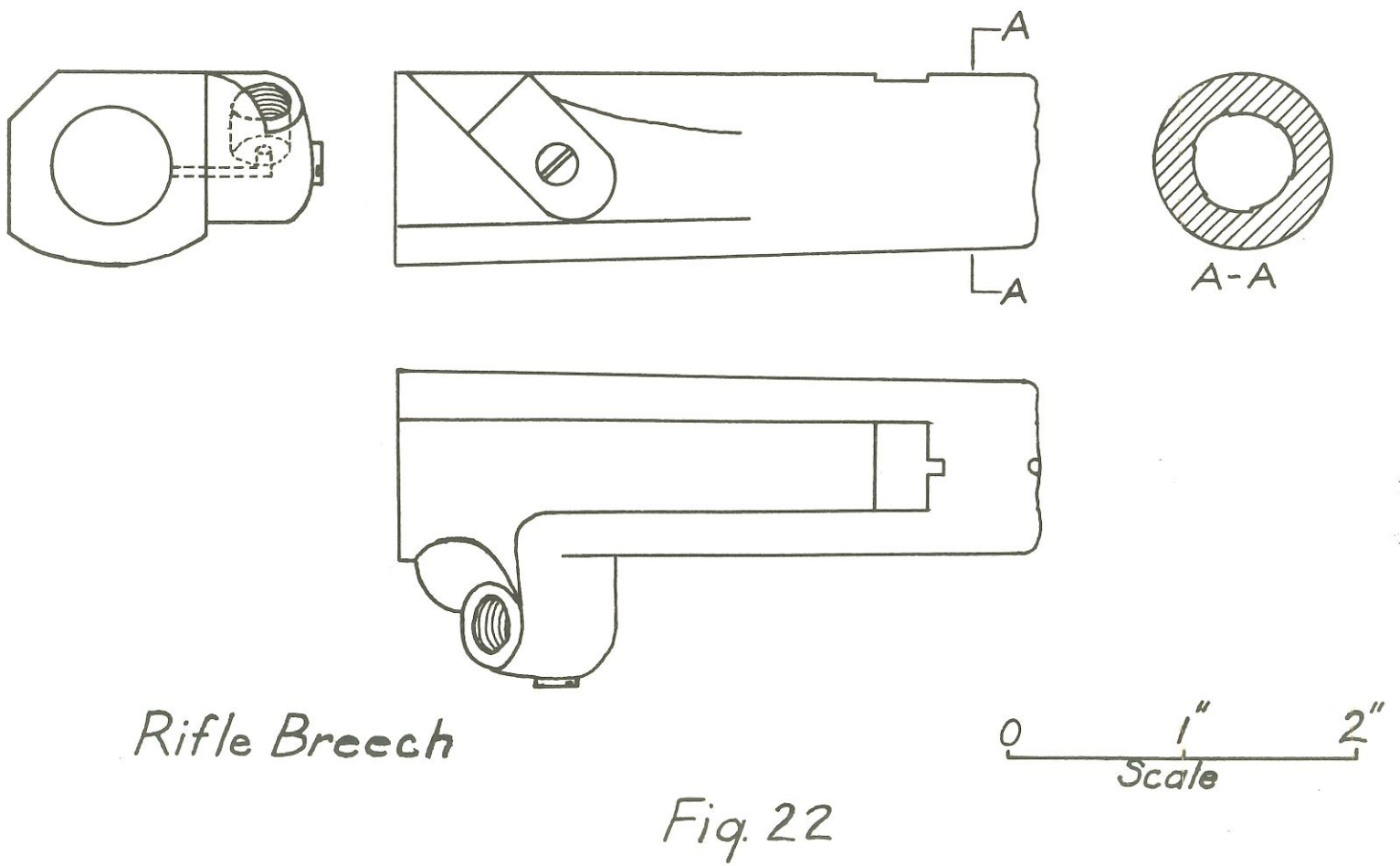
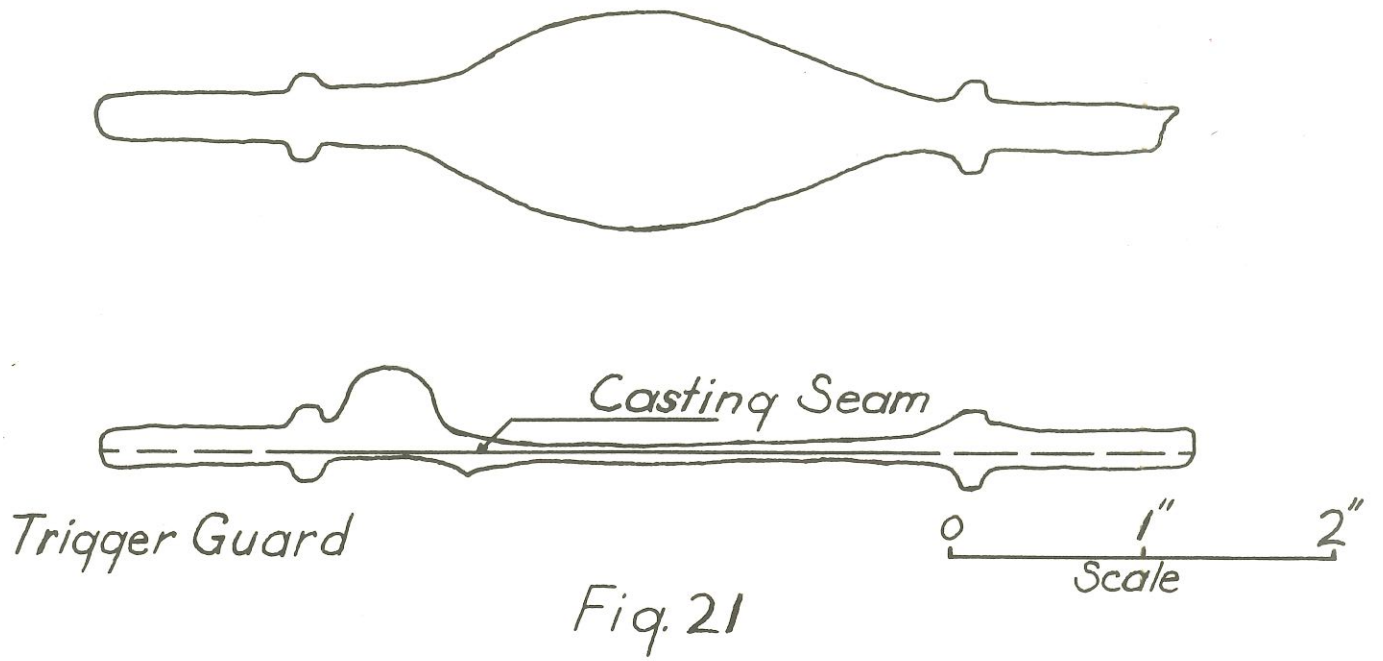


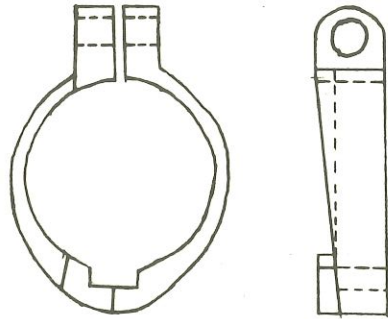
Left Hand End Mill  
Fig. 19



Geared Bar  
Fig. 20



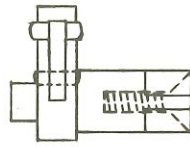
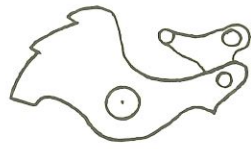




Bayonet Clamp  
Fig. 23



Rejected "Minnie" Bullet  
Fig. 24



Hammer Cam

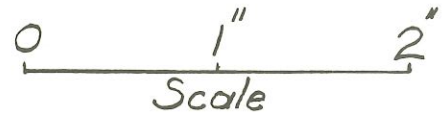
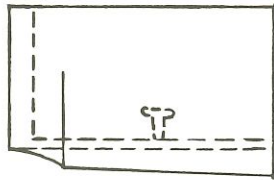


Fig. 25



Brass Stock Fitting

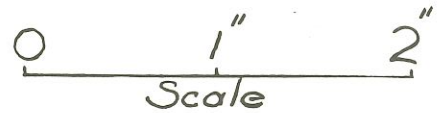
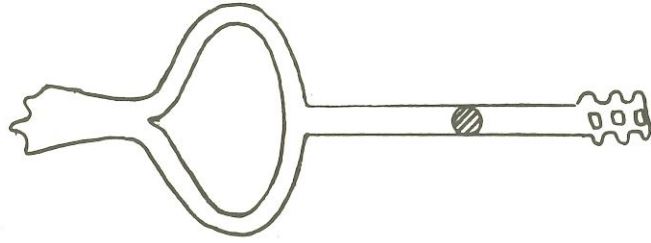


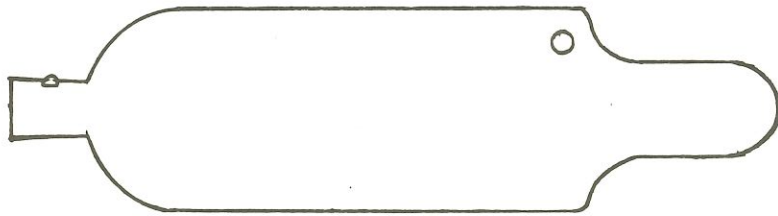
Fig. 26



Key



Fig. 27



Template



Fig. 28

Cast Stove Door

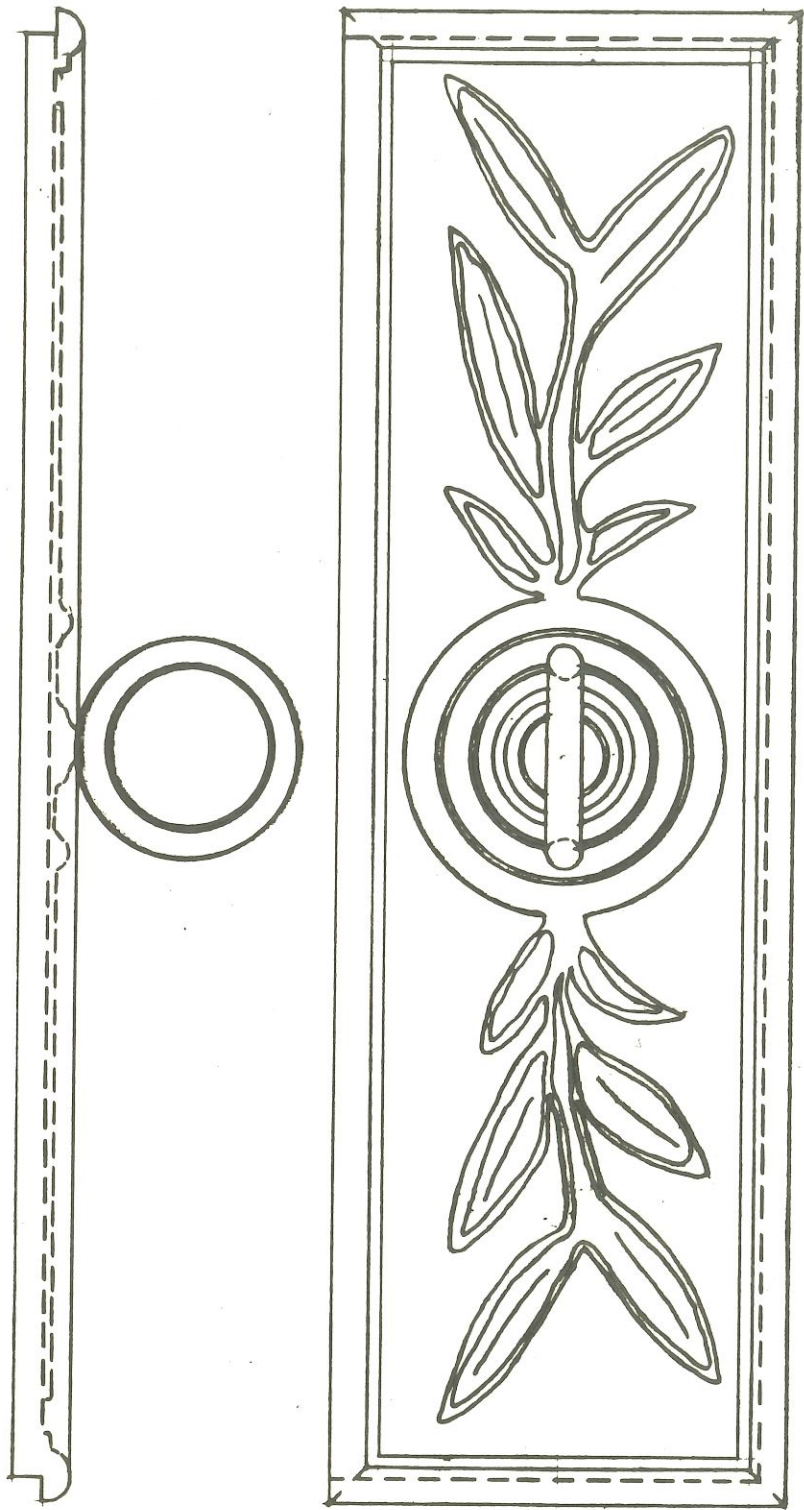


Fig. 29

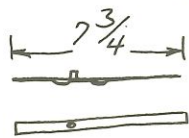
APPENDIX










Artifacts

Over 500 artifacts were found at the bottom of the turbine pit. This does not include the large number of nails, pieces of bottle glass, window glass, and bits of red and gray slate. In addition, all the architectural features yielded a scattering of nails and glass. Trench 4 contained a profuse quantity of forge slag, fused lathe chips, and a 6 foot iron stoker with a loop handle at one end and a right angle bend at the other. Mortared pieces of broken shale and brick, some with glazed or white pigmented surfaces, were found throughout the excavations.

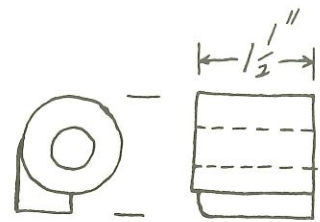
The layer which yielded the artifacts at the bottom of the pit ranged from 2" to 8" in thickness. The even distribution of the material within this layer indicated that the deposition had been made at a single time, sometime prior to the flood of 1869. Furthermore, some of the material was unfinished, Fig. 21; defective, Fig. 24; or broken, Fig. 16, indicating that the deposit was factory refuse. 182 artifacts were selected and sent to the laboratory of the Applied Science Center for Archaeology for processing and identification. A few are shown in Figs. 16 to 29. The following is a list of objects, iron unless otherwise specified, with tentative identifications when possible:

## Artifacts-Rifle Parts and Accessories

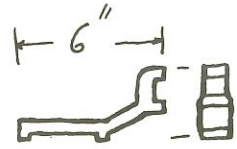
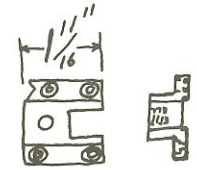
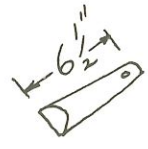
Description	Catalog Number	Outline Sketch
Butt Plate	129	
Hammer Cam	135	See Fig. 25
Breech, 3 1/2" Long	75	See Fig. 22
Unfinished Breech, 2 1/2" Long	110	
Unfinished Trigger Guard	82	See Fig. 21
Ramrod, Flat Head	69	
Ramrod, Concave Head	42	
Rejected "Minnie" Bullet	169	See Fig. 24
Bayonet Clamp	38	See Fig. 23
"	40	
"	146	
Template	113	See Fig. 28
Unfinished Trigger Housing Strip ?	153	
Brass Stock Fitting	148	See Fig. 26

Description	Catalog Number	Outline Sketch
Milling Gear Assembly	80	See Fig. 16
Three Sided Fitting	166	
Unfinished Casting	132	
Circular Fitting	137	
Cast Rectangular Stock	29	
"	90	
"	10	
"	72	
"	28	
Drilled Washer	111	
Machine Part	154	
Geared Bar	104	See Fig. 20
Cast Handle with Forged Bolt	174	
Slide Rest	120	See Fig. 17
Ratchet Arm	105	See Fig. 18
"	34	"
Left Hand End Mill	151	See Fig. 19
Cast Bevelled Stock	172	

Cam	61
"	119
"	101
"	77
"	48
"	143
"	102
Cast Stock, Half Round	55
Round Stock, Drilled	4
Round Stock	44
Machined Fitting	142
Broken 'U' Fitting	164
Flat Stock	109
Machine Part	136
Round Stock	30
Scrap Round Stock	117
Casting	179



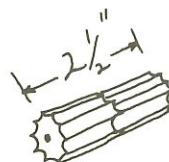
Same as above, only 2" long.



1" Sleeve, 2 3/8" long	87
" 2 1/2" "	116
" 2 3/4" "	79
" " "	70
" " "	96
" " "	54
" 3" "	35
" 3 1/8" "	88
" " "	162
" 3 7/8" "	58
" 4" "	123



Drilling Scrap 127



Wedge Scrap 150

Rod 31

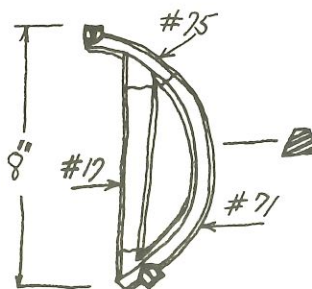
Rod 85





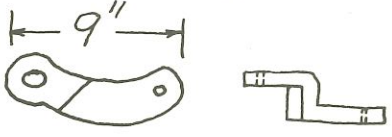
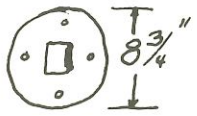

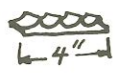
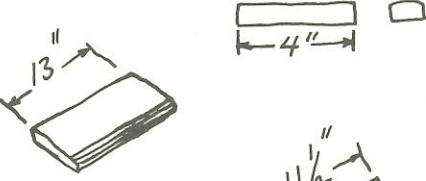


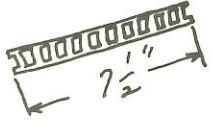
Flat Stock 99

Broken Casting 75



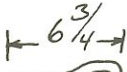


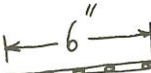

" 71

" 17



Lathed Scrap (Lead)	146	
Rectangular Stock	37	
Machine Part	163	
Round Stock	93	
"	94	
Rod	32	
Turbine Case Member	11	See Fig. 14
Anchorage Clamp	122	
1/2" Plate Scrap	86	
Disc, 3/8" Plate	1	
Casting	53	
Lathed Scrap	155	
Round Stock	27	
Drilling Scrap	54	
Stock with Rounded Side	9	
Plate with Stepped Edge	18	
Drilled Plate	25	
Drilling Scrap	22	
Pressing Scrap	97	
"	125	

## Artifacts-General Hardware and Miscellaneous

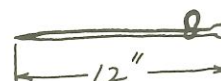
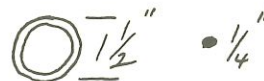
Description	Catalog Number	Outline Sketch
Pickaxe Head	19	
Washer	5	
Heavy Wire Rod	65	
Ceramic Cone	134	
Scrap Brass Sheeting	144	
Rod	21	
Eye	68	
Key	147	See Fig. 27
Washer	171	
Tinned Iron Sheeting Ration Can ?	177	
Tinned Iron Sheeting	158	
Drilled Strap	131	
Lead Plug	7	
"	95	
Block	26	
"	60	
Strip	62	
"	47	

Harness Hook	51
Fitting	49
Hook	36
Hooked Fitting	66
Rod	15
Block	114
Chisled Rod	139
Broken Hinge	16
Drilled Corner Fitting	89
Flat Stock	43
Fitting	175
Door Hook	130
"	128
"	126
Cast Stove(?) Door with Floral Decoration	180
Melted Mass	74
Strip	13
Horse Shoe	23
Bar	52



See Fig. 29

Rod (Screwdriver ?)	45
1/4" Rod, 16" Long	11
"    13"    "	14
3/16" Rod, 20" Long	12
Ring	152
Rt. Angle Fitting	33
Flat Stock	121
Scrap 1/16" Sheet	98
wall Hook	50
"	91
Hinge	92
"	63
Broken Hinge	100
Broken Casting with Floral Decoration	24
Zinc Sheet	176
Bottle with Cork (No Lettering or Decoration) -Found near the top of the tur- bine pit, not in the lower deposit.	181
Hitching Stake	81



File-Rough, Half Round, Complete	138
File Handle	3
File-Rough, Triangular	33
File-Fine, Triangular	84
File-Rough, Half Round -Lead solder clinging to the flat surface.	8
File-Fine, 1/4" Square, Complete	39
File-Fine Finishing, Flat, Complete	159
3/4" Round Rod 13" Long	67
1/2" x 2 3/4" Pin with Bevelled Head, which is Flat on One Side.	141
5/8" x 2 1/2" Machine Set Screw	59
1/4" Machine Screw	2
1 3/4" Screw	157
1 1/2" Wood Screw	149
2 1/2" "	168
2 3/4" "	140
2 3/4" "	156
3" "	170
3 7/8" "	108

4 1/4" Wood Screw	107
4 1/2" Wood Screw	106
3/8" x 7 1/2" Bolt and Nut Assembly	57
"	161
3 1/8" Pin	178
2 3/4" Pin	6
1/4"x 20" Flat Head Screw	20
3/8" x 2 1/2" Bolt	103
"	112
3/4" x 4" Bolt	56
3/4" x 5 1/2" Bolt	78
3/4" Nut	167
1" x 5" Bolt	124
1" Bolt Head	15
1" Bolt Stem	173
<p>#15 and #173 fit together forming a unit identical to #124. These two bolts fit the holes in the turbine case member, Fig. 14, and would have secured the turbine case to the masonry holes on the upper surface of the pit, Fig. 12.</p>	
5/8" Nut	41

5 1/2" Spike	46
"	118
4" Nail	160
3" Nail	165