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BILBY STEEL TOWER FOR TRIANGULATION

BY

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Signalman

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BILBY STEEL TOWER FOR TRIANGULATION

By JASPER S. BILBY, *Signalman, United States Coast and Geodetic Survey*

PURPOSE OF TRIANGULATION TOWERS

In many regions it is not possible to select stations for a scheme of triangulation and have the stations intervisible from the ground, as trees, buildings, and other objects obstruct the line of vision between adjacent points. On geodetic surveys, covering wide expanses of territory, the curvature of the earth must also be taken into account. Towers are, therefore, necessary to elevate above intervening obstructions the observer and his instrument at one station and the signal lamp or object on which he makes his observations at the distant station.

A complete triangulation tower is a combination of an inner and an outer structure mutually independent; that is, the two structures must not touch at any point. The service required of a tower, when two observing parties are working at the same time at different stations in the same figure is, briefly, that the outer structure must support the observer and the tent which protects him and his instrument from the sun and wind and, at the same time and without interference with the observer or his work, support a light keeper and the lamp or heliotrope upon which the other observer is sighting. The inner structure must support the instrument with such stability that, except in very strong winds, its motion in azimuth will never be so rapid nor so great as to affect seriously the accuracy of the measured angles and that its disturbance in level will never be so irregular as to inconvenience the observer by making frequent adjustments necessary.

WOODEN TOWERS

Wooden towers were used exclusively for triangulation towers for a great many years but in recent years the cost of lumber and labor has become so high as almost to prohibit their use. Plans and specifications for the various types of wooden towers and illustrations showing their construction are given in United States Coast and Geodetic Survey Special Publication No. 93, entitled "Reconnaissance and Signal Building," by J. S. Bilby. The type of wooden tower most generally used in recent years is shown in Figure 1.

STEEL TOWERS

During the winter of 1926 preliminary specifications were prepared by the writer for a steel tower that could repeatedly be erected,

taken down, and moved by truck to a new station. Later, he took the preliminary plans to the factory of the Aermotor Co. in Chicago, where, with the aid of their designing engineers and after several tests and modifications, a complete tower was constructed and erected.

Three essential requirements have to be satisfied to make the steel tower a success: First, the tower must have great rigidity and stability against vibration and against twist in azimuth; second, the tower must be so constructed that it can be readily erected and taken down; third, the total weight of a completed tower should preferably be light enough that a single moderate sized truck can transport it from station to station.

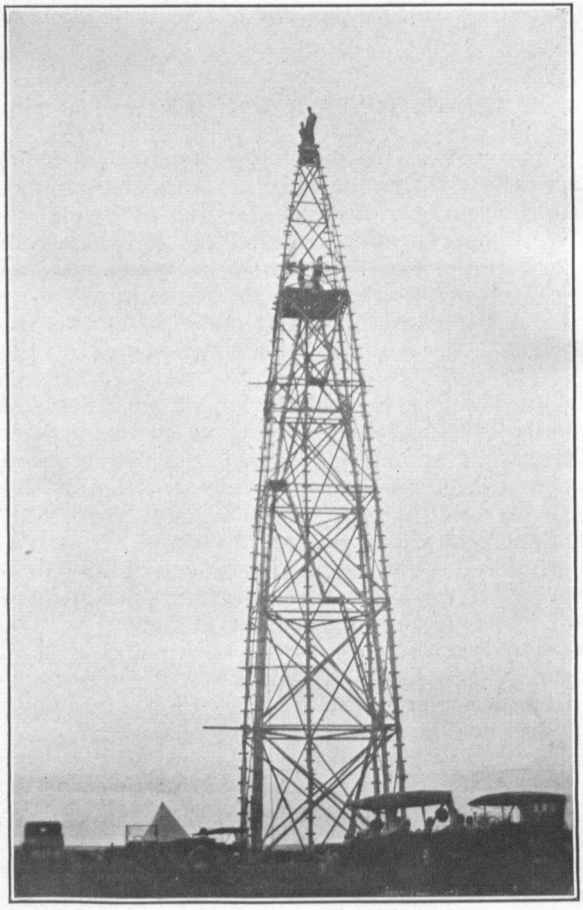


FIGURE 1.—Seventy-five-foot wooden tower at McDowell triangulation station, Texas

After the first tower had been completed and erected at the factory a final test was made which showed clearly the degree of rigidity and elasticity which could be expected in the towers. This test made it clear that the steel tower would satisfy every requirement. The following plans, specifications, and instructions to bidders were drawn for the additional towers and forwarded to the Director of the United States Coast and Geodetic Survey, who gave the structure the official designation of "Bilby Steel Tower."

SPECIFICATIONS FOR BILBY STEEL TOWER

The attached blue print[1] shows a design sketch of the Bilby tower, complete as to detail. It is an exact copy of the plans used in constructing a test tower. Bidders must submit bids only on this design, and the successful

[1] Figure 2 of this publication.

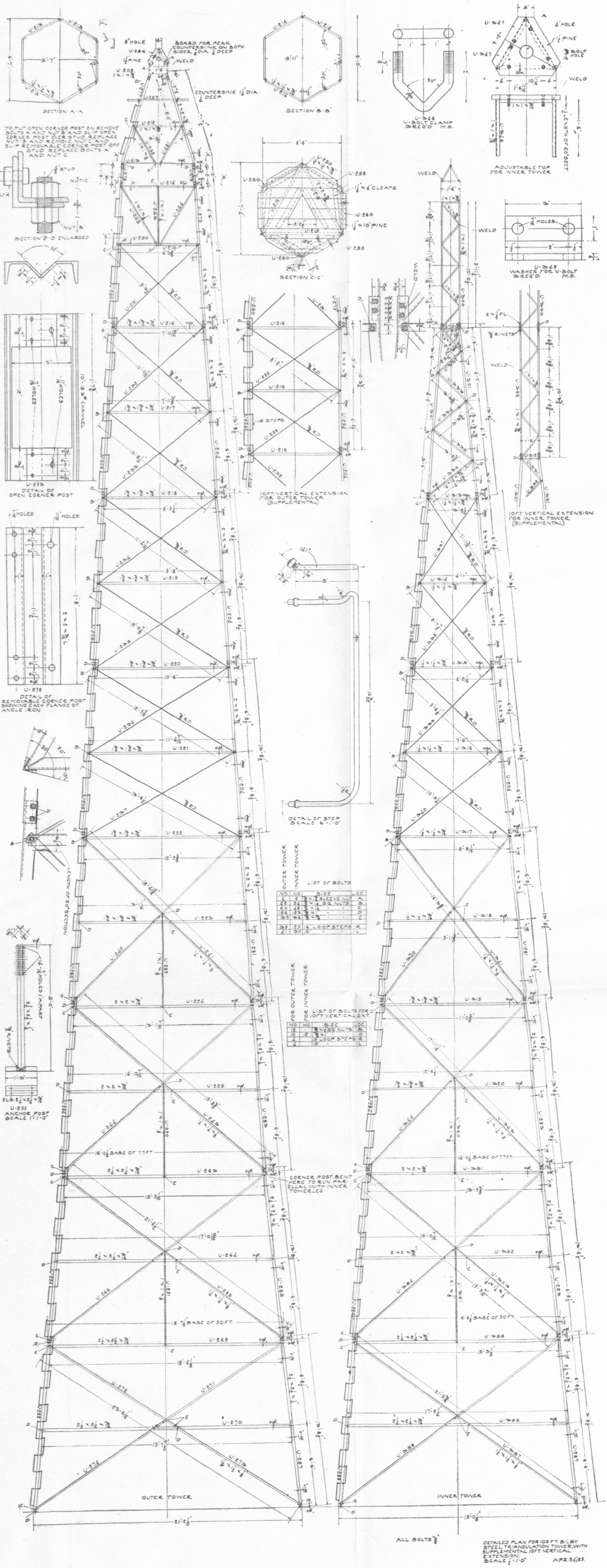
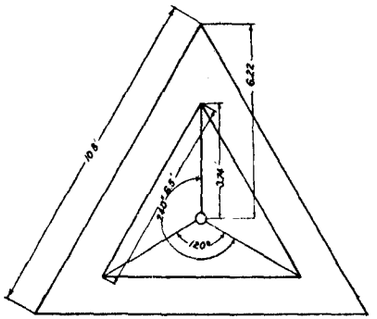
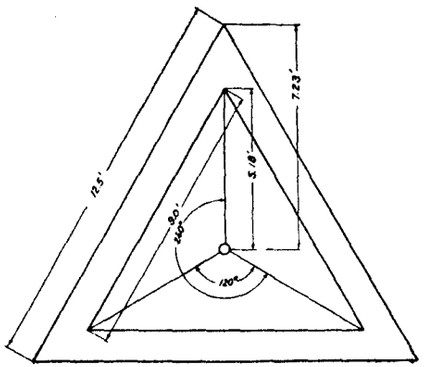


FIGURE 2.—Detailed drawings for 90 to 103 foot inner structure and for outer structure 10 feet higher

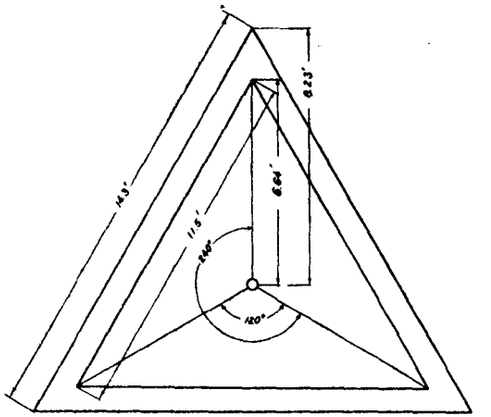
This illustration is about one-third the size of the original tracing. The scales indicated above are therefore correspondingly in error.



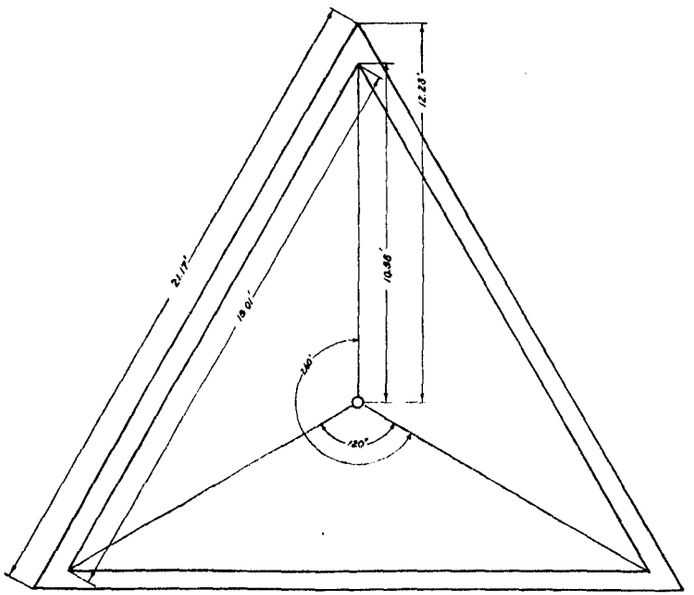
No. 1 37' Tower



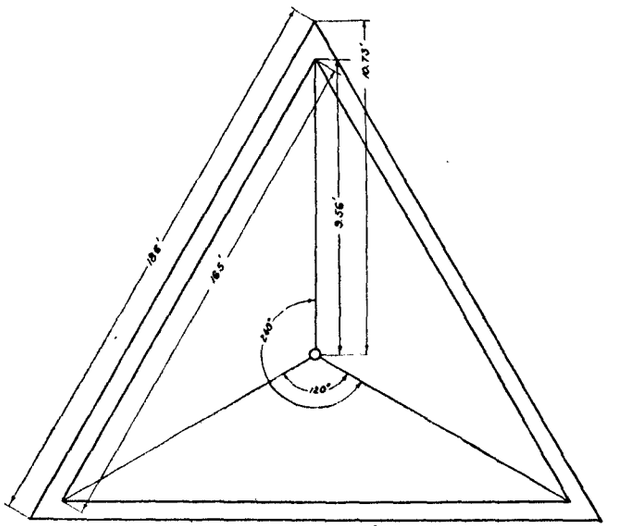
No. 2 50' Tower



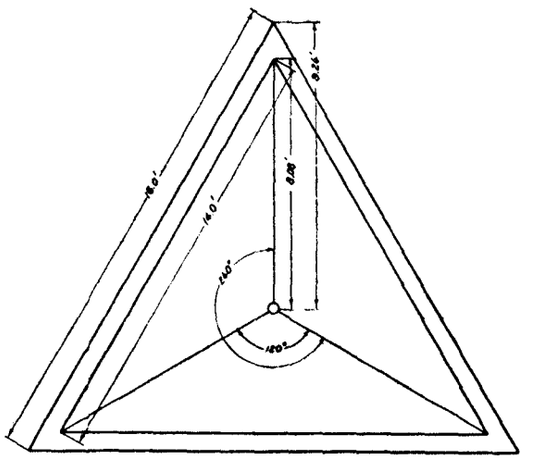
No. 3 64' Tower



No. 6 103' Tower



No. 5 90' Tower



No. 4 77' Tower

Ground Floor Plans of Six Sections of Bilby Triangulation Tower

Note.- Measurements are between lower ends of each 13'6⅛" section

FIGURE 3.—Ground plans for Bilby steel tower

bidder must follow these specifications and the details shown on blue print without any deviation therefrom.

Both inner and outer towers are three-legged, as shown by blue prints[2] showing ground plan of tower at different heights. The outer tripod tower is changed to hexagonal shape at section C–C, as shown by sections A–A, B–B, and C–C.

All material of metal shall be of high-grade structural steel. All steel parts shall be galvanized in accordance with the best practice after all machining and welding is completed, and shall not be subject to flaking.

There must be furnished with each tower a diagram showing the size and the factory number of each of the pieces of the structure, including bolts, anchors, platforms, etc. The parts of the several towers must be interchangeable.

The sectional lengths of the outer and of the inner towers must be the same as shown on the attached blue print.[1] The towers must be so constructed that one or more of the lowest sections can be omitted when the full height is not needed. Holes must be made in the tops of the anchor posts, as indicated in the sketch, in order that the tower may be adjusted in height on the anchor posts.

Ladder steps must be of the same type as shown on the blue print, or of a type equally as strong. The steps will be used on one post of the inner tower and one post on the outer tower, as shown on the blue print.[1]

Bands of paint, 8 to 10 inches in length, must be placed on all upright and diagonal pieces of the outer and inner towers. Blue paint will be used for the outer tower and red for the inner one. This will make it easy to separate the pieces belonging to the inner and outer structures. The bands will be placed at the top ends of the sections of the posts and near the left-hand end of the ties and diagonals, as viewed from outside the tower. The small blue print attached indicates the parts of the members which are to be banded.

There must be furnished, with each tower, extra bolts to the extent of 20 per cent for each size and length of bolt used on the inner and outer structures. A like amount of nuts for these bolts shall also be furnished.

For a lot of 10 or more towers there should be 6 anchors for each tower and 12 extra anchors. The extra anchors are to serve as replacements and also are for use by the forward building parties prior to the arrival at the station of the tower with the regular anchors.

There must be furnished with each lot of towers 12 suitable end wrenches to fit all bolts and nuts and also 3 good spike punches of sufficient length and size to clear holes and to spring parts together.

TESTS TO BE MET BY COMPLETED TOWER

INNER STRUCTURE

Horizontal displacement.—A horizontal pull of 400 pounds at top of inner structure must not displace the top by more than one-half inch.

Angular displacement.—A tangential horizontal pull of 50 pounds applied at the corner of the top of inner structure must not cause an angular displacement of the top of more than 1 minute of arc. This corresponds to a horizontal displacement of the corner of the structure with relation to the center of about two-thousandths of an inch.

A tangential horizontal pull of 50 pounds at the corner of the inner structure 23 feet below the top must not cause an angular displacement of the top of the structure of more than 50 seconds of arc.

Vibration.—A wind velocity of 20 miles per hour averaged over 1 minute intervals shall not cause the top of the inner structure to vibrate in azimuth more than 10 seconds of arc.

Semipermanent change in azimuth.—Gusts of wind of a velocity of 35 miles per hour or less shall not cause a semipermanent angular displacement of the top of the inner structure of more than 2 seconds of arc.

OUTER STRUCTURE

A horizontal pull of 500 pounds at center of side of outer structure at height of floor platform, the pull being applied through a bridle attached to two of the

[1] Figure 2 of this publication. [2] Figure 3 of this publication.

main posts, must not displace the outer structure horizontally by more than 3 inches nor cause the buckling of any member. The same pull applied to a corner post of the outer structure at the height of platform must not displace the top of the structure horizontally by more than 5 inches nor cause buckling of any member.

DETAILED DRAWING FOR BILBY STEEL TOWER[3]

Figure 2 gives detailed drawings for a 103-foot inner structure and a 113-foot outer structure, both of the tripod type. The drawings show one side of each structure and the manner in which the parts are assembled and bolted together. Bolts are used throughout on both structures, except at the top section of the inner one, which is welded and has an adjustable top secured with V-bolt clamps, which can be adjusted to the proper height for the observer. One post of each structure is fitted with steps, as shown in the drawing. Sections A–A, B–B, and C–C show the design of the frame of the outer structure for the observing tent and the observer's platform. Above this is the superstructure on which the lamp is mounted. The seat for the lightkeeper is 2 feet below the top of the superstructure.

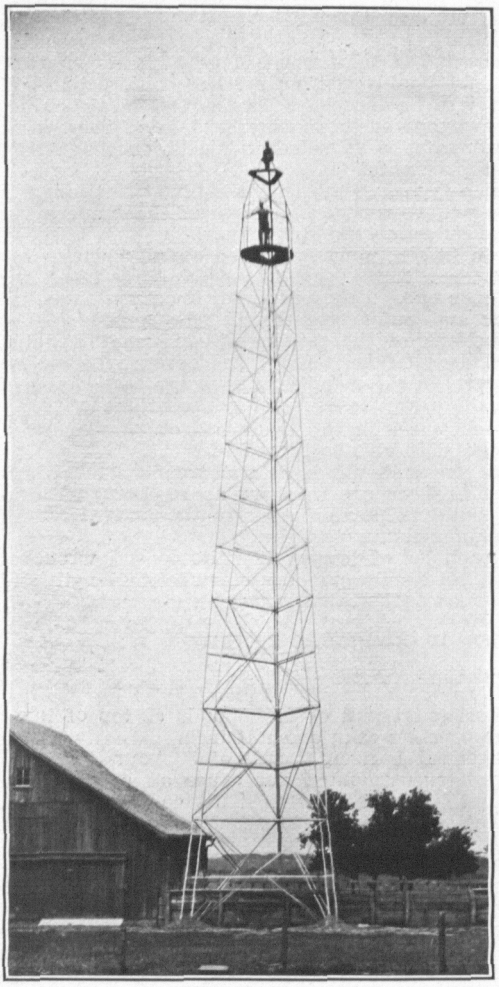


FIGURE 4.—Ninety-foot Bilby steel tower, complete

Figure 4 shows a completed triangulation steel tower, consisting of an inner and outer tripod, each separated from the other so that the inner one may not be affected by the observer's movements. The height of the inner tripod is 90 feet and the outer one is 100 feet. The total weight of the complete tower, including anchors and anchor sills, is 5,000 pounds. The maximum height of tower now in use is 103 feet for the inner structure and 113 feet for the outer one, a tower of this height weighing about 6,400 pounds.

[3] While this publication was in press the height of the Bilby tower was increased by additional sections to 129 feet to the top of the inner structure, and to 139 feet to the top of the outer one.

Figure 3 shows the ground plan for laying out the holes and setting the anchors for towers of different heights. The towers are designed so that from one to five of the lowest sections may be left out where it is not necessary to erect the tower to its full height. The measurements given on the ground plan correspond with sectional measurements on the tower.

ANCHORS

Each anchor post is 5 feet long riveted to a steel footplate in which are four holes for bolting it to a wooden mudsill. The wooden mudsills are not supplied by the factory, but timbers for them can be obtained at any lumberyard. Each mudsill should be 3 inches thick, 8 inches wide, and 3 feet long. The bolts should be put through from the underside with a large washer under the head of the bolt. The wooden mudsills should be made and bolted to the footplates before the towers are sent out to the stations and need not be taken off when the towers are taken down and moved. The six crosspieces 2 by 10 by 36 inches, mentioned on page 7, are also carried from station to station.

ERECTING TOWER

HOLES FOR ANCHORS

The first step is to trace the outlines of the holes for the anchors, as shown on the ground plan, Figure 3. A stake with a nail in the top may be used for a temporary station mark from which to locate the holes. It is convenient to use a small theodolite (fig. 5), and a steel tape for this work. The theodolite should be plumbed over the temporary station mark. The angle readings to the centers of the three holes are 0°, 120°, and 240°, respectively, and the distance from the center stake to each anchor post is given on the ground plan. In setting the anchors the measurements given on the ground plan corresponding to the height of tower to be erected should be used. If possible, the orientation of the tower should be such that no line of sight from the head of the inner tripod will be obstructed by a leg of the outer structure. With the aid of an azimuth compass and the progress sketch the approximate direction of each line can be determined and the holes can be located to give best clearance for the lines. The holes should be about 3 feet square and 5 feet deep. The bottoms of the holes need be only approximately on the same level, as the difference in level can be adjusted by the bolt holes in the tops of the anchor posts.

Care should be taken to get the inner and outer tower anchor posts in alignment with the station mark and to give each anchor post the same slant as the corresponding corner post of the tower.

SETTING ANCHORS

The legs of the inner tower have a different slope from the legs of the outer tower. To set the anchor posts at the correct distance from the center stake and at the proper slope a frame template is used. This consists of a 1 by 4 inch board long enough to reach from the center stake to the outer anchor post for the tallest tower. On one end of the board is nailed a 1 by 3 inch board about 3 feet long, making the same angle with the long board as the outer tower leg makes with the horizontal plane. On the other end of the long board is nailed another 1 by 3 inch piece making the same angle with the

long board as the leg of the inner tower makes with the horizontal. The long board can be marked with the distances from the center stake to the bottom of the lower tower leg for towers of different heights. If the long board is placed on the center stake, made hori-

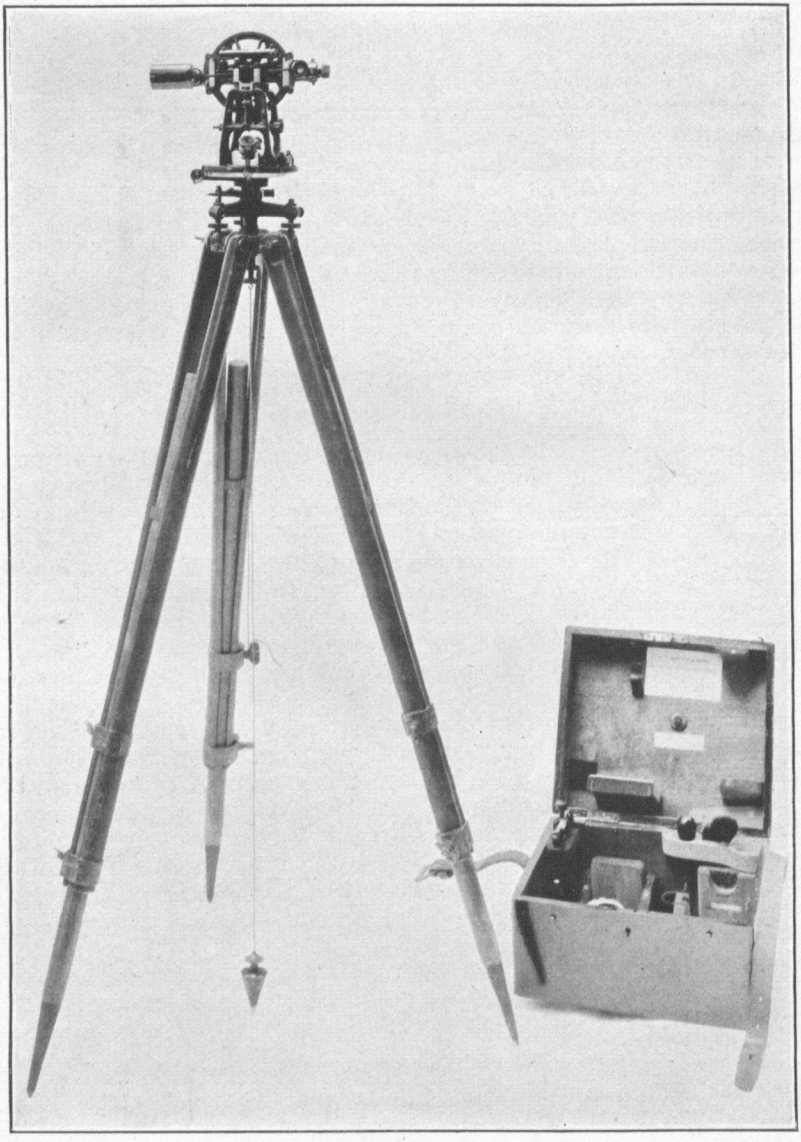


FIGURE 5.—Four-inch theodolite

zontal with a carpenter's level, and held with the slope piece for the outer anchor post against that post at the proper distance from the center for the height of tower which is being erected, then the anchor post can be adjusted for slope and distance at the same time. The same process is used for the anchor post for the inner tower leg, using

the other slope piece and the correct distance from the center for the inner tower as marked on the horizontal piece. The template should be so constructed that the foot of the slope piece will reach to approximately the same point on the anchor post as the bottom of the tower leg. If this is done, it will not be necessary to bend the bottom of the tower leg to fit it onto the anchor post.

If towers of 77 feet, or less, to the top of the inner tripod are built, a second template is required, since the legs of the outer tower have a different slope on the two lower sections of the 103-foot tower from that of the upper sections.

When the anchors are put in place they must be firmly settled by using a heavy ram, then by filling in dirt and tamping well to a depth of about 1 inch above the anchor timber. Then two planks, 2 by 10 by 36 inches, should be placed crosswise on top of the anchor timbers, one on each side of the steel post. The lower half of the hole can then be filled in. The dirt must be well tamped and special care must be taken that no large rock or sod forms a solid connection between the inner and outer anchor posts. A solid substance between the two anchors will transmit movements of the outer tower to the inner one and make accurate observations impossible.

LEVELING TOWER

After the anchors are set and holes are about half filled, a round of levels should be taken to determine the place on each post at which each leg of the lower tower section should be fastened to insure that the tower will be plumb. As shown on the working plans (fig. 2), there are 14 bolt holes 1 inch apart in the upper end of each anchor post. A bolt should be placed in a hole of one anchor post and used for a bench mark. The instrument should then be leveled over the center peg and a leveling rod consisting of a piece of 1 by 4 inch board should be set on the bolt and the height of the instrument marked on it. By holding this rod beside each of the other posts and sliding it up or down until the mark is again at the height of the instrument, the bottom of the rod will show which hole is at the same height as the bolt in the first post and a bolt can be placed in this hole. The lower section of the tower can then be bolted on, care being taken to use the proper hole in each anchor as indicated by the levels.

The small theodolite used for locating the anchor holes can be used as a leveling instrument by setting the vertical circle to the reading corresponding to the horizontal position of the telescope and then bringing the bubble to the center of the tube by means of the vernier slow-motion screw.

Since the holes in the anchor posts are 1 inch apart it may sometimes be impossible to bring the bottoms of the various legs to the same level closer than about one-half inch. If the bottom of one leg of a 90-foot tower is changed in elevation by one-half inch, the top of the tower will be changed in horizontal position by about 3 inches. In order to provide a means for more accurate leveling and centering of the inner and outer towers, clamps are sometimes used instead of bolts to fasten the tower legs to the anchor posts. The clamps are bolts V-shaped at the center, threaded at both ends for nuts, and long enough to permit a crossbar and filler block to be fitted to the inner angle of the leg or anchor post. (See fig. 2.)

The clamps can be made by any blacksmith, if the towers are not already equipped with them. They have the added advantage that they permit a tower to be easily centered over a mark which is already established, or to be recentered if the tower has been slightly pushed over by high winds when the ground under the anchors is soft.

ERECTION OF TRIPODS

Both inner and outer towers are built up in sections of 13 feet 8 inches, which is the length of one piece of each corner post. The members of the inner and outer towers are marked with paint of contrasting colors, as described on page 3. Each section has two sets of horizontal members, and one set of diagonal braces as shown on the working plan. (See fig. 2.) The horizontal members are spaced 6 feet 10 inches apart. Figures 6 and 7 show the first section of the tower completed and the second section under construction. Three men work aloft and one man on the ground sends the pieces up as needed, using a single 6-inch ball-bearing pulley and half-inch rope. The pieces for the corner posts are sent up first, piece by piece, and bolted in place. Then one set of horizontal ties is sent up and bolted on. Next the diagonal braces are sent up. The lower ends are bolted to the corner post and near the intersection of the two diagonals they are bolted to the horizontal tie. This completes the lower part of the section. Then the small platform at each corner of the inner tower on which the workman stands is placed in a corresponding position on the horizontal members above. From there the top set of horizontals and the top ends of the diagonals are bolted to the corner posts and the platform is again raised.

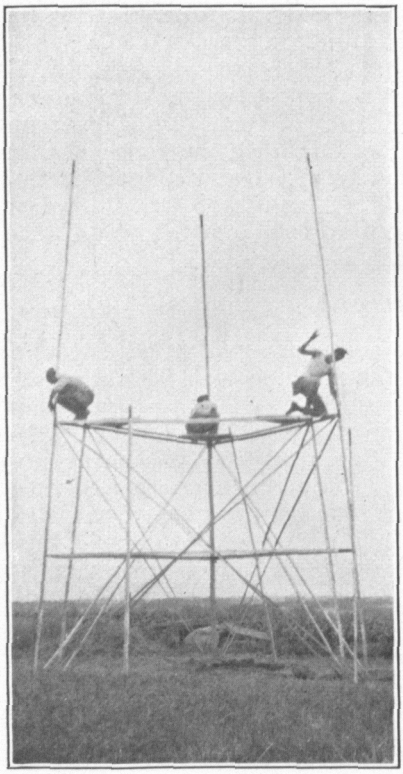


FIGURE 6.—Lower section of tower completed, corner posts being bolted on for second section

The inner and outer towers are built up together to within one and one-half sections of the observer's platform. On a 90-foot tower this is to the top of the fifth section. Then the outer tower is completed, including the observer's platform. The observer's platform is in three sections and the center section is the first to be sent aloft. When the outer tower is completed the hauling line is then dropped down through the center and the block made fast to the top of the outer tower.

The two top sections of the inner tower are then put in place. The welded 10-foot upper section of the inner tower is, of course, always transported and erected as a unit. The next lower section is also usually kept bolted together and is erected as a unit. Each is so designed as to permit being hoisted through the inside of the next lower section.

CONSTRUCTION PLATFORMS

The small platforms mentioned above are of great importance, for upon the proper construction and use of these platforms depends the safety of the men working aloft. Three of these triangular platforms are needed, one for each of the inner corners of the tower. They are about 24 inches on each side, with 2 by 2 inch cleats nailed on the underside to fit closely along the outside of the horizontal ties on which the platform rests. Each workman must be cautioned to make certain that the platform is securely in place before trusting his weight upon it. In a strong wind the platform may be lifted out of position without the workman noticing it. Under conditions of high winds a couple of strong spring clips should be fastened to the underside of each platform in such position that one end of each clip can be slipped under the flange of the horizontal steel piece on which the platform rests to hold the platform securely in position.

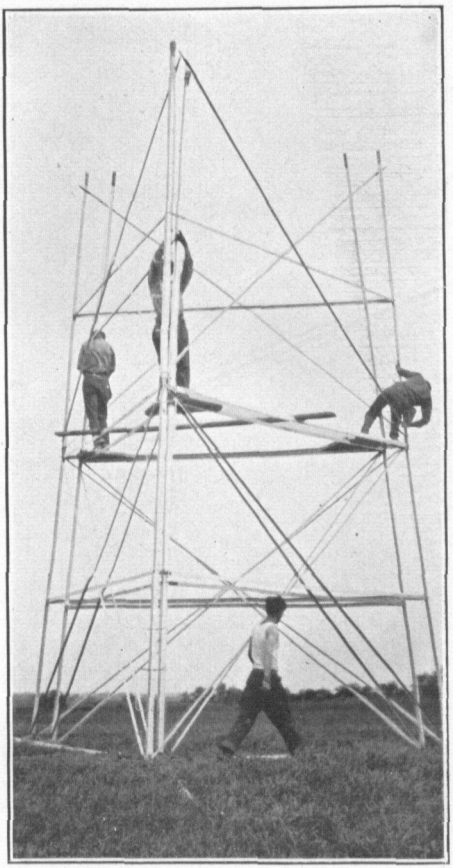


FIGURE 7.—Work on second section of tower

MARKS FOR TRIANGULATION STATIONS

The essential parts of the specifications for station and reference marks now in use are given below:

Metal tablets.—Each station which has been located with first, second, or third order accuracy, should be marked by a standard tablet of copper alloy, so fastened in the rock or concrete as to effectively resist extraction, change of elevation, or rotation. (See fig. 11.) The name of the station and the year established should be stamped upon the mark, preferably before it is set in the rock or concrete.

Setting of tablets.—Stations for horizontal control must often be located where the permanent marking of them is difficult, and for that reason a great variety of settings for the tablets must be permitted. The location of the station, depth of soil, or presence of rock ledges, and the availability of ma-

terials will usually control the choice of the mark to be used. The precautions to be taken in establishing each kind of mark are briefly stated below.

(1) *In rock outcrop.*—Care should be taken that the rock in which a mark is set is hard and is part of the main ledge, not a detached fragment. The tablet should be countersunk and well cemented in.

(2) *In bowlders.*—When a tablet is set in a bowlder, the latter should be of durable material and of cross section, area, and depth below the surface not less than the standard concrete mark as described below.

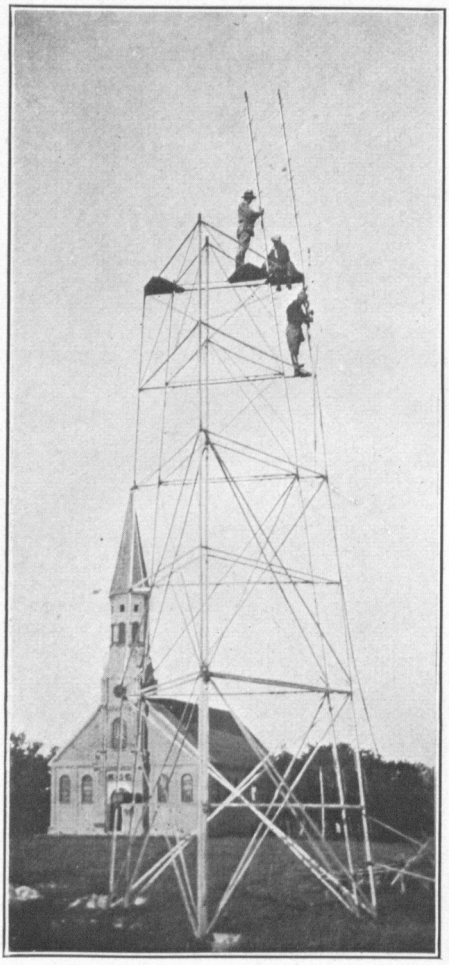


FIGURE 8.—Corner posts being bolted on fourth section of tower

(3) *In rock ledges below surface.*—When the ledge is only slightly below the surface, a tablet set in the usual manner in the ledge will be sufficient, provided two reference marks are established. Where the ledge is so far below the surface that a surface mark is required, a tablet or copper bolt should be set in the ledge, the ledge carefully brushed or washed off for a space at least 18 inches in diameter, and a concrete surface mark placed above the subsurface mark. A tablet should be set in the surface mark directly over the subsurface tablet or bolt. If the rock ledge in which the subsurface mark is set is very smooth, it should be furrowed with a chisel to afford better anchorage for the concrete.

(4) *In concrete.*—(*a*) *Shape.*—The mark should be either a frustum of a cone or of a pyramid, or have the form of a post with an enlarged base. If of pyramidal or conical form, the sides should have a batter of at least 1 inch to 1 foot. When a post with an enlarged base is used the bottom of the base should be 4 inches larger in least horizontal dimension than the post proper and should have a vertical thickness of at least 6 inches. If the concrete is cast in place the enlarged base can easily be provided for by enlarging the bottom of the hole at the sides with the digger. Extreme care should be used to avoid making the mark with a mushroom top or with projecting corners near the surface, which would provide leverage points for frost action and would make easier the malicious destruction of the mark.

(*b*) *Size and depth.*—The concrete post should extend to a depth of from 30 to 36 inches, depending upon the kind of soil. It should be not less than 14 inches in diameter, except that the upper 12 inches may be in the shape of a frustum of a cone or pyramid with the upper surface not less than 12 inches in diameter. Where the mark is not in the path of traffic or in soil subject to cultivation, it should extend from 2 to 4 inches above the surface. When located where traffic passes over it the top of the mark should be slightly below the surface.

Before sending the towers out at the beginning of a season a set of forms should be made for the station and reference marks and sent out with each tower. When the tower is taken down and moved, the concrete in the marks

will be set and the forms can be taken off and sent forward with the tower so as to be ready for use at the next station. If care is taken in removing the forms, they can be used during an entire season's work. The lumber for a set of forms costs $1.75, and it requires one hour for one man to make one set of forms. While this is a small item, it will amount to about $60 per month, aside from the time saved in going after lumber, and is well worth considering.

The procedure in making the standard concrete mark is as follows: A hole is dug to a depth of 3½ feet or more. It should be 16 inches in diameter for the top 2½ feet and 10 inches in diameter at the lower end. Concrete made of good cement, sand, and gravel or broken rock is placed in the lower part of the hole to a depth of 6 inches. A standard tablet station mark (fig. 11) is then set in the concrete, with the top of the tablet slightly depressed. This completes the underground mark. A layer of 4 to 6 inches of sand or dirt is then put into the hole. The hole is then enlarged about 2 inches in radius near the bottom in order that the lower end of the block of concrete for the surface mark will be mushroomed, and then the hole is filled with concrete to within 9 inches of the surface of the ground. Next a mold or frame 12 inches on a side at the top, 13 inches at the bottom, and 12 inches in depth is set in the hole on top of the concrete and filled in around the outside with dirt tamped firmly. The frame is then filled with concrete level with its top and a standard tablet station mark (fig. 11) is set in the center of the concrete, with the top of the tablet slightly depressed. The tablet must be centered exactly over the underground mark. The top of the concrete should be smoothed with a trowel and the frame should be left in place to protect the concrete until it becomes firmly set.

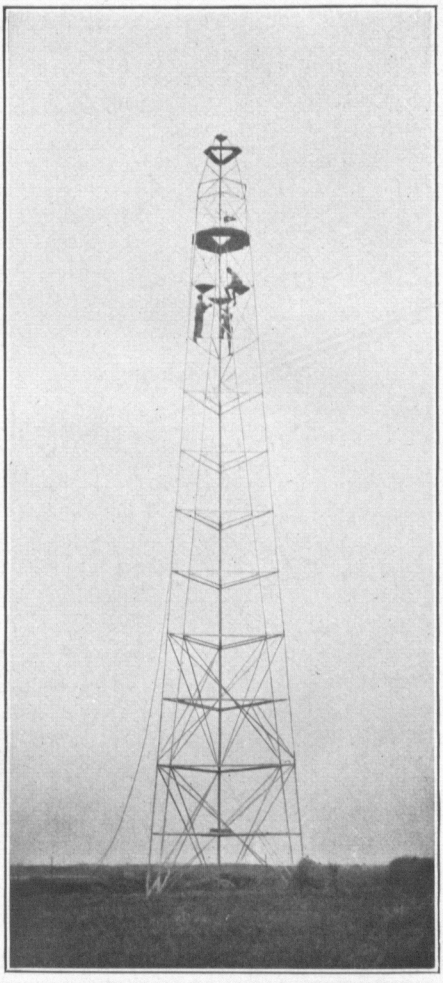


FIGURE 9.—Outer structure complete; top section being bolted on inner structure

Care must be taken not to disturb the position of the tablet in the underground mark when placing the layer of sand or dirt and when pouring the concrete for the surface mark. A piece of thin board should be placed over the lower mark or other suitable means used to insure against any horizontal movement of the tablet due to the impact or pressure of the material above.

SPECIAL CONDITIONS

Under certain conditions special marks will often be required, and these should conform in size and durability to the marks described above.

(1) Sand.—In sand, which if used as a mold would spoil the concrete by absorbing the water from it, sewer tiles 8 inches in diameter and 30 inches long may be used, set with the bell end down, filled with concrete and with the base end set in concrete. A sheet-iron mold of the same dimensions filled with concrete may also be used. A metal tablet should be set in the center of the top.

(2) Marsh.—Where the surface of the ground is too soft to hold a mark of the usual type, a post of durable wood should be forced down vertically as far as it will go, its top cut off flush with the surface, and a sewer tile at least 6 inches in diameter set into the marsh around the top of the post. The tile should then be filled with concrete and a tablet set in the top. Where the marsh is very soft but dries out at certain seasons of the year, successive tiles can be forced down around the post, the post then can be withdrawn and the mud worked out from within the tiles, and the tiles then filled with a hydraulic cement mixture.

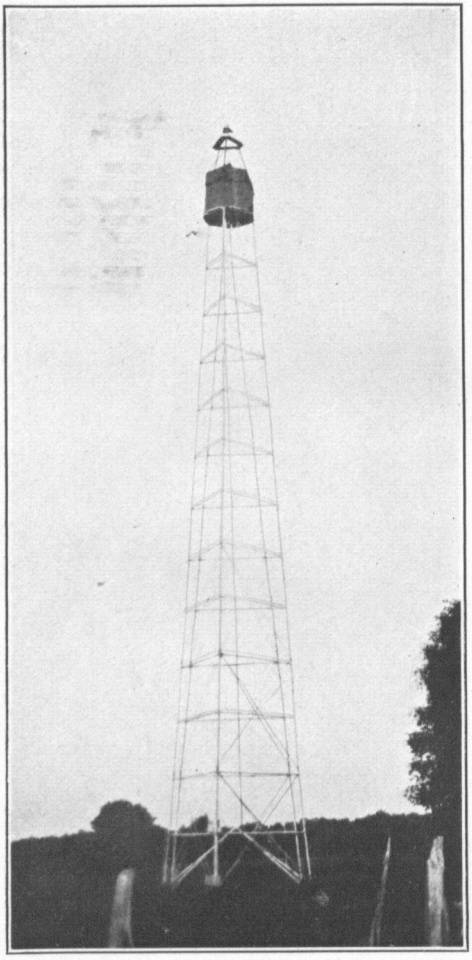


FIGURE 10.—Ninety-foot Bilby steel tower, complete, showing observing tent

(3) Land subject to cultivation.—The subsurface or lower mark should be a tablet in a block of concrete 10 inches square or 10 inches in diameter and 6 inches thick, set with its top 3 feet below the surface. The upper mark should be a tablet set in a block of concrete 15 inches in least horizontal cross-section dimension and 20 inches high, with its top 12 inches below the surface of the ground. About 3 inches of dirt should be placed between the concrete blocks bearing the upper and lower marks.

All stations so marked should be referenced by two standard reference marks placed on property boundary lines, preferably along a well-established highway or quarter-section line, in a location where there is little likelihood of their being disturbed. The directions to the reference marks should be such as to give a good angle of intersection at the station. The reference marks may be as much as a half mile from the station, if necessary, provided they can be seen from the station. The distance to each reference mark should be carefully measured. Other distances, such as those to the center of a highway, the corner of a building, or the center of a well, should be measured if feasible. Two or more such measurements will intersect so near the station that the concrete block will be easily found with a small prodding rod. When measurements are made to buildings or other objects the directions must also be given. If measurements of this kind are made the station may usually be easily recovered, though the reference marks may both be destroyed. The measurements to a road should always be to the center of the road and not to the fence line. All distances must be carefully measured and not estimated. Care should be taken in placing reference marks along highways, for nearly all States are widening the highways.

REFERENCE MARKS

Each reference mark should consist of a metal tablet similar in material and shape to the station mark, but bearing an arrow which points to the station. A reference mark should be stamped with the same designation as its station mark, and where there is more than one reference mark they should be numbered

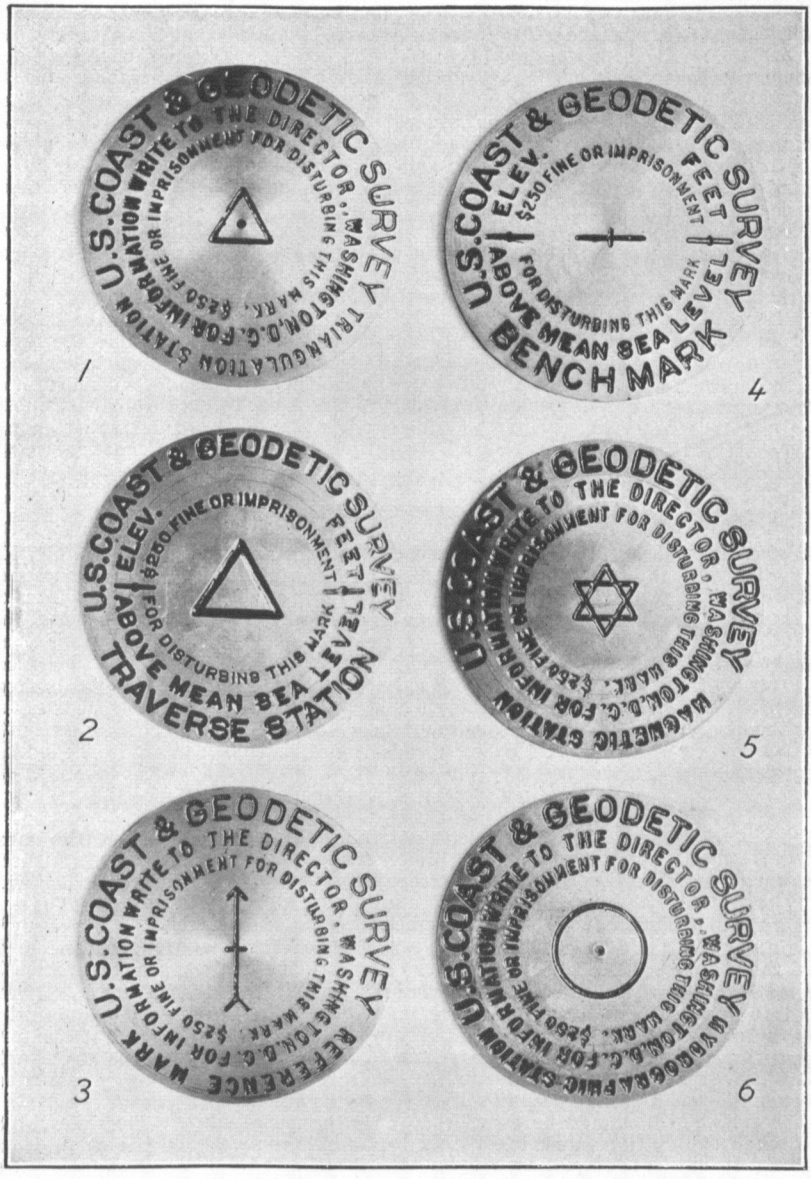


FIGURE 11.—Station marks of the United States Coast and Geodetic Survey

1. Triangulation station mark
2. Traverse station mark
3. Reference mark
4. Bench mark
5. Magnetic station mark
6. Hydrographic station mark

serially in a clockwise direction, the number to be stamped upon each one. Each should be set under the same conditions as specified for the station mark, except that the concrete post in which it is set may be 2 inches smaller in diameter and 6 inches shorter than for the station mark.

Each station mark must have at least one reference mark and should preferably have two. If the station mark, due to surface conditions, is entirely beneath the surface, there should be two reference marks, unless there are permanent witness marks, such as road crossings, etc., which will serve to locate the station without an excessive amount of digging. If the station mark is on ground liable to be disturbed or washed away, two reference marks should invariably be established. These should be so located as to avoid the probability of both being disturbed by the same cause. They should also preferably be so located as to give a good angle of intersection at the station, or else be placed in range with the station.

Material.—The main considerations in making concrete are to have clean materials, mix them well before adding water, have the mixture not too wet, and tamp well into the form. Each streak of dirt in concrete means a line of cleavage. Where rough aggregate is available the proportions may very well vary from 1–2–4 to 1–3–5, but the top 12 inches of the mark should be of considerably richer mixture. Where only cement and sand are available the lower part of the mark should be proportioned 1 part of cement to 3 parts of sand, and the upper part should be 1 part of cement to 2 parts of sand. With a mark of the proper size it will not be necessary to reinforce the concrete with metal rods or wire. To avoid cracking of the concrete, due to rapid drying, it should be covered with paper or cloth and then with earth or other material for a period of at least 48 hours.

AZIMUTH REFERENCE MARK

At stations where a tall tower is used to render adjacent stations visible, the observing party is instructed to measure the direction to some near-by permanent object which is visible from the ground at the station, in order that surveyors using the station after the tower is removed may be able to obtain an azimuth, or direction, as well as a geographic position. If no permanent sharply defined object, such as a church steeple or water tank, is visible from the ground, then a reference mark must be established at least 100 yards from the station and in a location where it will be visible through an instrument mounted over the mark on an ordinary surveyor's tripod. When an azimuth reference mark is established only one additional reference mark is needed.

TRAVERSE STATIONS

The size and character of the mark at traverse stations should be the same as for triangulation stations, except that certain stations may be left without permanent marks when several are close together. The following rules will apply to the distribution of permanent marks on first-order traverse.

In general, there should be a permanently marked station at least every 3 miles along the traverse, except when a section of traverse along a tangent is more than 3 miles in length. A traverse station should always be permanently marked if either of the lines leading from it is a mile or more in length. When a station is marked in a permanent manner, one of the adjacent stations must be permanently marked in order that a line of known length and direction may be recoverable. Traverse stations which are not marked permanently should be marked by stakes of some durable wood in order that they may be recoverable for at least a few years.

Reference marks should be established only in special cases. They should be used when the station mark is entirely beneath the surface of the ground and there are no permanent witness marks near it such as road crossings, etc. Reference marks should be set if the station is at a railroad crossing or junction point or if both of the adjacent stations are 4 or 5 miles distant. In cases where reference marks are required, two should invariably be established for each station. They should be so located as to avoid the probability of both being disturbed by the same cause. Along a railroad track they should usually be placed in the fence lines of the right of way and on opposite sides of the track. They should be so located as to give a good angle of intersection at the station or else be in range with the station. Traverse stations along a beach which

are subject to loss by the erosion of the shore line should have two reference marks placed as far back from the shore line as practicable.

Whenever a horizontal control mark is to serve also as a bench mark it should correspond in depth below the surface to the requirements for bench marks. (See Spec. Pub. No. 140, p. 31.)

VERTICAL COLLIMATOR

An instrument called a vertical collimator is used for centering a tower over the mark of a previously established station, for placing a mark under a new tower, or for centering the theodolite or lamp over the station mark. There should be an opening in the

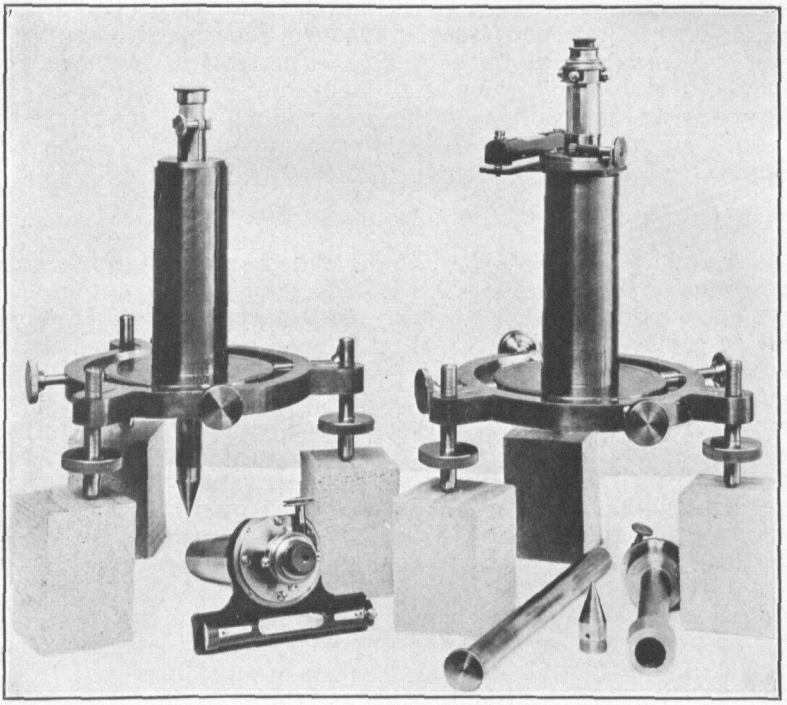


FIGURE 12.—Vertical collimator, old type

center of the cap block of the inner tower about 4 inches in diameter and one in the cap block of the outer tower about 6 inches in diameter to permit the instrument to be used.

OLD TYPE OF COLLIMATOR

Two different types of vertical collimators are shown in Figures 12 and 13. The one shown in Figure 12 will be described first. In principle the instrument consists of a telescope fitted with a diaphragm bearing cross wires, a tribrach with three leveling screws and a long vertical collar, into which the telescope is placed with the eye end uppermost. Near the eye end of the telescope and eccentrically placed is a level at right angles to the axis of the telescope.

To adjust the collimator place the cross wires in the focus of the eyepiece by pulling out or pushing in the eyepiece until the wires are as sharply defined as possible, then focus the telescope on the object beneath so that there is no shifting of the intersection of the wires over the object as the eye is moved across the eyepiece. Next the level is adjusted in the usual manner until there is no movement of the bubble when the telescope is rotated. Finally the cross wires are adjusted by means of the diaphragm screws until the intersection of the wires remains on a point in the field of view when the telescope is rotated. When so adjusted the point covered by the intersection of the cross hairs in the field of view is in the vertical line passing through the center of the telescope.

In actual use it is not essential that the instrument should be in perfect adjustment, for if the bubble is brought to the same reading in each of four positions of the telescope, about 90° apart, four points may be determined on the ground, and the intersection of the lines joining the diagonally opposite points will be the point sought.

PLUMBING IN A NEW STATION MARK USING OLD TYPE OF COLLIMATOR

Ordinarily the tower is built first, and then the station mark is put in place. A small stake is used for the central point in laying out the ground plan of the tower. In this case no special effort is made to center the cap block on the inner or outer structure over the stake, but after the tower has been completed the vertical collimator is used in centering the mark. With the vertical collimator shown in Figure 12 this is done most conveniently by first plumbing in a point on a bench a few inches above the ground. A bench can be made by driving two stakes about 4 feet apart, one on each side and in line with the center stake. Place a 1 by 4 inch board across the top of the stakes, then nail to this board another piece about 12 inches square directly over the center stake. Drive a nail through one end of the 1 by 4 inch board into the stake at that end, and at the other end drive a nail about one-half inch into the stake. The latter end can then be moved to one side when necessary, and can be replaced exactly in its original position at any time.

With the bench in position proceed as follows to plumb down from the cap block on the outer tower, on which the lamp or heliotrope is to be posted. Place approximately in position on the cap block a board about 12 inches square with a ¼-inch hole in the center. Set the vertical collimator on the board directly over the hole and after leveling the instrument withdraw the telescope and insert the plunger, move the instrument until the point of the plunger is in the center of the hole in the board, then withdraw the plunger and insert the telescope and move the board horizontally until the vertical line defined by the line of sight of the telescope passes through the center of the opening in the cap block on the inner tower, correcting the leveling of the collimator as the board is shifted. Then fasten the board securely to the cap block with screws, and plumb down and locate a mark on the bench as follows: Have a man hold a square on the bench and shift its position until the line of sight of the vertical collimator coincides with one edge of the square. A line should then be drawn on the board along this edge of the square. Next

turn the telescope of the collimator 180° and repeat the operation, keeping the square parallel to its first position. Then turn the telescope of the collimator 90° and 270° from its original position and locate two more lines on the board at right angles to the first two lines. This program gives a direct and reverse pointing in each of two directions approximately at right angles to each other and the intersection of the two diagonals of the resulting rectangle on the bench is in the vertical line through the telescope of the collimator. The point on the bench can then be used for setting the station mark by drilling a small hole through the board and using a plummet.

NEW TYPE OF COLLIMATOR

The new type of collimator shown in Figure 13 consists of a right-angled telescope, the objective end of which is mounted vertically in a bracket collar which is supported by a tribrach with three leveling screws. The vertical element of the telescope can be rotated in its collar through an angle of somewhat more than 270°, which permits the cross hairs mounted on the diaphragm of the right-angled eyepiece to be adjusted to the optical axis of the telescope. A level bubble is attached normal to the vertical element of the telescope and revolves with it. The bubble and the cross hairs are tested and adjusted in the usual manner.

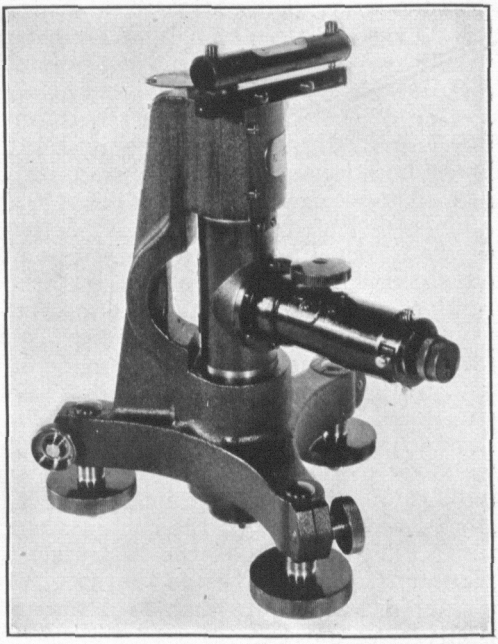


FIGURE 13.—Vertical collimator, new type

The collimator is so constructed that it can be mounted on an ordinary theodolite tripod. The tripod should have an adjustable head which will permit of some horizontal motion of the instrument on the tripod head to facilitate plumbing the instrument over or under a definite point.

To determine a point on the ground directly beneath the hole in the cap block of the light stand set up the collimator on its tripod approximately in its correct location, adjust and level the collimator, and attach the plumb bob. By sighting upward at the hole in the cap block a close estimate can be made of the distance the tripod must be moved to place the collimator directly beneath the hole in the cap block. A piece of board may be placed on the ground beneath the plumb bob and the point for the new trial centering of the collimator marked on the board. The tripod is then shifted and centered roughly by the plumb bob over the new trial point and

the instrument accurately leveled. Usually the final adjustment into the vertical line through the hole in the cap block can now be made by shifting the adjustable tripod head. The bench described on page 16 for the old-type collimator is now built, without disturbing the collimator, and the exact point on the bench is determined by means of the plumb bob attached to the collimator.

To center the hole in the cap block of the light stand directly over the station mark set up the collimator directly over the mark, adjust and level it. Mark on the under side of the cap block the point where the vertical line of sight strikes it, and bore a hole in the cap block at that point. The eccentricity of the old hole can then be measured directly and the old hole plugged up, the new hole being used as a lamp mounting for all future pointings.

USE OF THEODOLITE IN PLACE OF COLLIMATOR

If a vertical collimator is not available, the centering can be done with a theodolite or transit. The instrument should first be put in as nearly perfect adjustment as possible. The objective should be focused until there is no parallax or apparent movement of the intersection of the wires over an object on which it is pointed when the eye is moved back and forth in front of the eyepiece. The stride level should be carefully adjusted. The instrument should be set up at a distance from the tower about equal to the height of the tower and leveled up by using the stride level. Of course, if a transit is used, the leveling must depend upon the plate levels. A pointing should be made upon the center of the tripod head, using the slow-motion screw, and then the telescope should be plunged down to point to a piece of horizontal board placed on the ground under the tripod. Two marks should be made on this board, one near the side toward the instrument and one near the far side, both coinciding with the line of sight of the instrument. The telescope should then be reversed, the instrument rotated 180° around its vertical axis, a pointing made on the center of the tripod head, and the telescope again plunged down to point to the board. If the line of sight is now slightly to one side of the two marks on the board, due to a lack of perfect adjustment of the instrument, two more marks should be made on the board beside the first two to define the second line of sight. A line should then be drawn on the board to give the mean position of the two lines of sight. The theodolite should then be moved to a point about 90° around the tower and the whole process repeated. The intersection of the two lines will be the point sought. If the mark is already established, a similar process can be used to plumb up to the tripod head.

TEARING DOWN TOWERS

The towers are taken down by reversing the order of the operations used in their erection. Each part of the inner structure is marked with a band of red paint and each part of the outer structure with a band of blue, thus making it easy to separate the parts for each structure. As the tower is taken down the rods and crossbars of each section are wired together with No. 14 stovepipe wire. The

upper two sections of the inner tower are lowered, then the work starts at the top of the outer tower and continues downward. The lower sections of the inner and outer structure are taken down, section by section. After the anchors have been taken out, the holes must be filled, well tamped, and rounded up to allow for settling, in order that the ground may be left in good condition.

ORGANIZATION OF PARTY

The organization of parties and the manner in which the work is carried on are as follows:

One chief of party may have charge of the tower-construction party and another chief of party have charge of the observing party, or one chief of party may have charge of both the tower-building and the observing parties and have a signalman or foreman hand to superintend the building. In either case the construction party should consist of 3 subparties—2 advance parties of 4 men each and 1 rear party of 4 men. One man of each subparty acts as foreman. Attached to the construction party are two men, each with a 2½ ton truck, or a truck and trailer, with which to move the towers forward. Each subparty must be provided with a truck as a means of transportation, and with necessary tents, tools, instruments, and equipment. The signalman or foreman hand in charge of the construction must also be provided with a truck, lamps, heliotropes, and other equipment for testing lines.

As soon as the observations on one or more of the rear towers are finished, the chief of the observing party will notify the rear construction subparty which take the towers down. Usually the notification will be made through the rear light keeper, by code signals. With two observers, one on each side of the scheme, usually two towers are ready to be taken down on the same day. Therefore as soon as the rear construction subparty has taken down one tower it moves across the scheme to the second tower and takes it down also. Then the material of each complete tower is loaded on one of the 2½-ton trucks (or truck and trailer) and moved forward to the site of a new station, where one of the advance subparties will reerect it. Each forward subparty carries an extra set of anchors and as soon as it reaches the site of a new station the men dig the holes and set the anchors, so usually everything is in readiness to begin erecting the tower as soon as it arrives.

For a double observing party there should ordinarily be 12 towers, 8 of which will usually be standing while 2 towers at the rear are being taken down and 2 at the forward end are being erected at new stations.

Under certain conditions it is necessary that the two advance subparties should have one or more additional men to assist in digging holes. In localities where extra labor can be employed the chief of the construction party can go ahead, mark out positions for the holes, and employ the necessary men to dig the holes and have them ready for the anchors when the construction party arrives.

A party organized as described in the preceding paragraphs can take down, move, and erect an average of 30 towers per month if the observing party is not seriously delayed by bad weather.

Care should be taken in selecting for the building party men specially fitted for the work. Men working aloft should be from 5 feet 10 inches to 6 feet in height, should weigh not more than 170 pounds, and should not be more than 35 years of age. They should be of the athletic type and not given to talking while at work, except when they have something important to say. The two men for the trucks used in moving the towers must be careful drivers and good mechanics who can keep their trucks in good order. They must be men who can find their way through new country and who will cooperate with the building parties. Usually the truck driver is at the rear when a tower is being taken down and should assist in that work. In return, the forward and rear subparties should assist the truck driver in loading and unloading. It is teamwork that makes the work move along smoothly. When any member of a party becomes grouchy and does not show a proper disposition to cooperate with other members of the party, it is advisable to displace him.

As it is often necessary for the parties to move at night, each truck should be provided with a good lighting system.

COOPERATION OF THE BUILDING AND OBSERVING PARTIES

The officer in charge of building should camp in some large town about 75 miles ahead of the observing parties, where he can visit his two forward subparties and also be in touch with his truck drivers who are hauling the steel towers up from the rear. The chief of party, who is with the main observing party most of the time, can then be familiar at all times with the location of the officer in charge of building and can reach him by telephone or telegraph, in case obstructed lines or other troubles are encountered when the stations are occupied. On a combined building and observing party it is quite necessary that the foreman or officer in charge of all building operations shall return each day to his temporary headquarters, and he should arrange for someone to receive all messages and phone calls in order that the chief of party as well as each of his foremen and truck drivers may communicate with him.

LOCATION OF STATION

The station is often located on or near the fence line on the side of a public highway. Often a telephone line is along the same side of the highway. In building the tower the telephone wires can pass through or along the side of the tower but they should not touch the inner tower. If the wires come near or touch any part of the outer tower, a few layers of old inner tire tube should be placed between the wire and the tower. In this way the telephone wire can be made fast to the outer tower if necessary to prevent it from touching the inner tower. The towers are also easily put up among trees without any clearing or cutting of limbs.

SECURING AUTHORITY TO ESTABLISH STATIONS

It shall be the duty of the officer in charge of the building to obtain the permission of the property owners before a mark is set and tower erected. The regulations state that settlement may be made for damages incurred in cutting trees or destroying crops, provided a

written agreement is made with the landowner before the damage is done. It will usually be found to be the case that, if the purpose of the survey is explained to the property owner beforehand, permission will be granted and no damages will be claimed. If damages are claimed, the amount must be determined beforehand on a basis of the value per acre of actual damages to crops or the unit value of injuries to trees. If crops are damaged, the area involved should be measured and the damages computed, using the value per acre agreed upon. Usually the amount is so small that the property owner does not insist on payment. If trees are cut it is very essential that the amount of damages be agreed upon beforehand. Under no condition should a station be established without interviewing the property owner and arriving at a basis of settlement. Much trouble has been caused in the past by carelessness in this respect.

The chief of party should instruct all employees that, if any property owner discusses the matter of damages, they should tell him that actual damages only can be paid and that payment can only be made in the event of a prior agreement.

EQUIPMENT FOR BUILDING PARTY

The following is a list of articles required for the different units of the party.

OUTFIT FOR FORWARD BUILDING SUBPARTY OF FOUR MEN

Anchors, extra for tower, set	1
Axe, small	1
Axes, large	2
Bedding	(3)
Bits, assorted	5
Block, 6-inch single	1
Board, scaffold, 2 by 10 inches by 12 feet	1
Boards, scaffold, special triangular	3
Box, concrete mixing	1
Brace, carpenter's	1
Buckets	2
Cans, 10-gallon, water	4
Can, oil	1
Canteens	2
Chisel, cold	1
Collimator, vertical	1
Compass, azimuth	1
Cots	4
Dies, stamping, set of letters and figures	1
Digger, post-hole	1
Drills, stone	6
Emery wheel, large	1
Hammers, claw	2
Hammer, blacksmith's	1
Hatchet	1
Heliotrope	1
Lanterns, oil	3
Lamp, signal	1
Level, carpenter's	1
Line, hauling, ½-inch rope 230 feet long with stray line 8 feet long spliced to main line	1
Mattock	1
Mess outfit, including all cooking utensils	1
Picks	3
Pliers, wire	3
Plummet	1
Pockets, canvas, with belts for nuts, bolts, and wrenches	4
Punches, special tower	4
Saws, hand	2
Saw, keyhole	1
Shovels	3
Spades, regular	2
Spades, tile	2
Square, 2-foot	1
Strap, leather, 18-inch with rings to serve as bridle between the two parts of the hauling line just above the stray line	1
Strap, rope	1
Stove, 3-burner Kamp Kook	1
Table, camp-made	1
Tape, steel, 30-meter	1
Tarps, bed	4
Telescope, draw	1
Tents, 9 by 9 foot center pole	2
Tent, 7 by 7 foot center pole	1
Template for setting anchors	1
Theodolite	1
Towels, etc	(3)
Trowel	1
Truck, 1 to 1½ ton, complete with tools and tarpaulin	1
Washbasins	(3)
Wrenches, open end for tower	4

[3] As needed.

OUTFIT FOR REAR DISMANTLING SUBPARTY OF FOUR MEN

Axe, small	1	Mess outfit, complete, including all cooking utensils	1
Axes, large	2	Pick	1
Bedding	(4)	Pliers, wire	3
Bits, assorted	5	Pockets, canvas, with belts for bolts, nuts, and wrenches	4
Block, 6-inch single	1	Punches, special tower	2
Board scaffold, 2 by 10 inches by 12 feet	1	Saw, hand	1
Boards, scaffold, special triangular	3	Shovels	3
Brace, carpenter's	1	Spades, regular	2
Buckets	2	Stove, 3-burner Kamp Kook	1
Can, 10-gallon, water	1	Strap, leather, 18-inch with rings to serve as bridle between the two parts of the hauling line just above the stray line	1
Can, oil	1	Table, camp-made	1
Canteens	2	Tarps, bed	4
Chisel, cold	1	Telescope, draw	1
Cots	4	Tents, 9 by 9 foot, center pole	2
Dies, stamping, set of letters and figures	1	Tent, 7 by 7 foot, center pole	1
Drills, stone	2	Towels, etc	(4)
Emery wheel, large	1	Truck, 1 to 1½ ton, complete with tools and tarpaulin	1
Hammer, claw	1	Washbasins	(4)
Hammer, heavy	1	Wire, No. 14 gauge, soft stovepipe, bundle	1
Hatchet	1	Wrenches, open end for tower	4
Lanterns, oil	2		
Line, hauling, one-half inch rope 230 feet long with stray line 8 feet long spliced to main line	1		

OUTFIT FOR TRUCK DRIVER MOVING TOWERS[5]

Axe	1	Rope, tow	1
Bucket, gasoline	1	Shovel	1
Bucket, water	1	Tarp	1
Can, oil	1	Tarp, bed	1
Cot	1	Tent, 7 by 7 foot, center pole	1
Hammer	1	Truck, 2½-ton, with tools and equipment complete	1
Lantern, oil	1		
Rope, lash	1		

TRUCK FOR TRANSPORTING TOWERS

Figure 14 shows the type of truck used for transporting the steel towers. The body is 14½ feet long and has a slide door opening in the front end, at each side of the cab. The long members of the tower can project forward along the side of the cab. The truck's rated capacity is 2½ tons which is the total weight of a 90-foot tower. The total weight of a 103-foot tower is about 6,400 pounds, which is about 25 per cent overload. The truck has ample power and will carry a 103-foot tower over ordinary roads. However, in regions that require the frequent use of a 103-foot tower, it is advisable to use a two-wheeled trailer in connection with the 2½-ton truck.

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[4] As needed.

[5] This truck driver is either on the road or with the forward or rear building parties, and therefore he does not need a camp outfit other than as mentioned in this list.

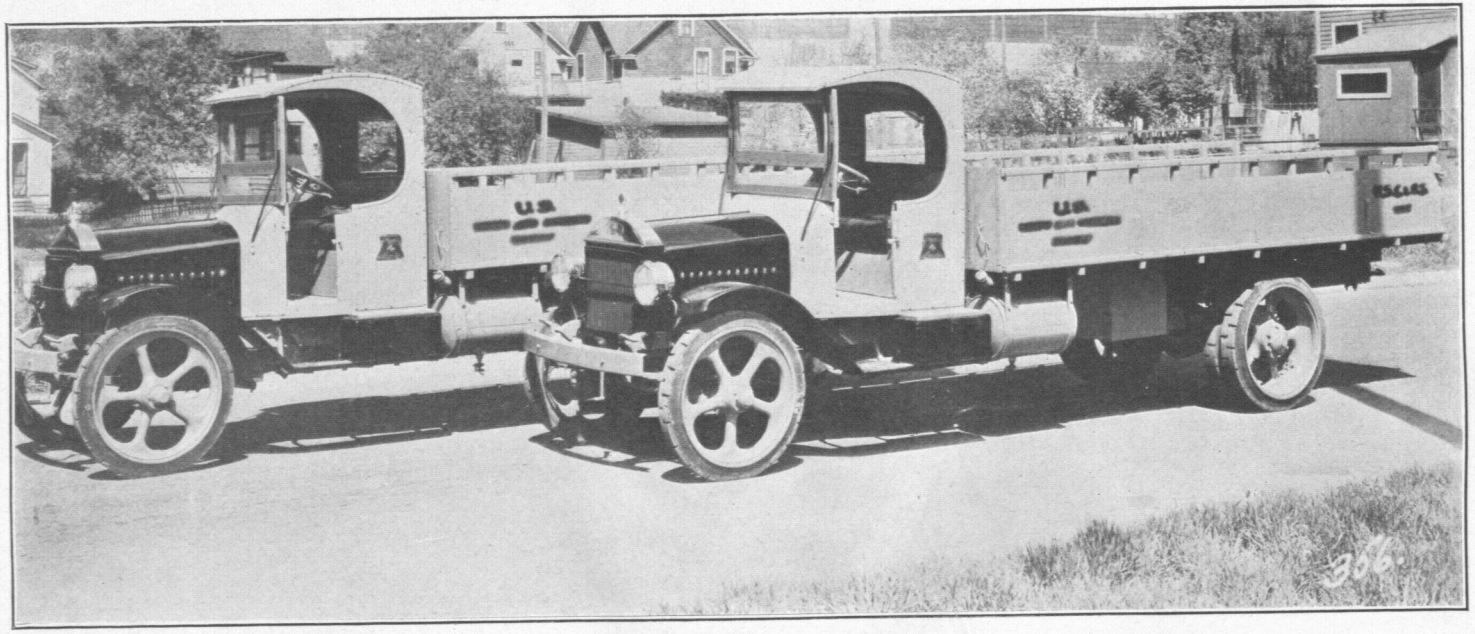

FIGURE 14.—Two-and-a-half-ton trucks for use in transporting towers