BILBY STEEL TOWER FOR TRIANGULATION.

(The following are extracted from U. S. Coast and Geodetic Survey Special Publication No 158, *Bilby Steel Tower for Triangulation,* by JASPER S. BILBY, Washington, D. C., 1929, pp. 1-9.)

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.

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.

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.

Specifications. — Both inner and outer towers are three-legged, as shown by Fig. 3 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* on Fig. 2.

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.

The steps will be used on one post of the inner tower and one post on the outer tower, as shown on Fig. 2.

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. There should be 6 anchors for each tower.

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 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 A BILBY STEEL TOWER.

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 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 below, 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 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

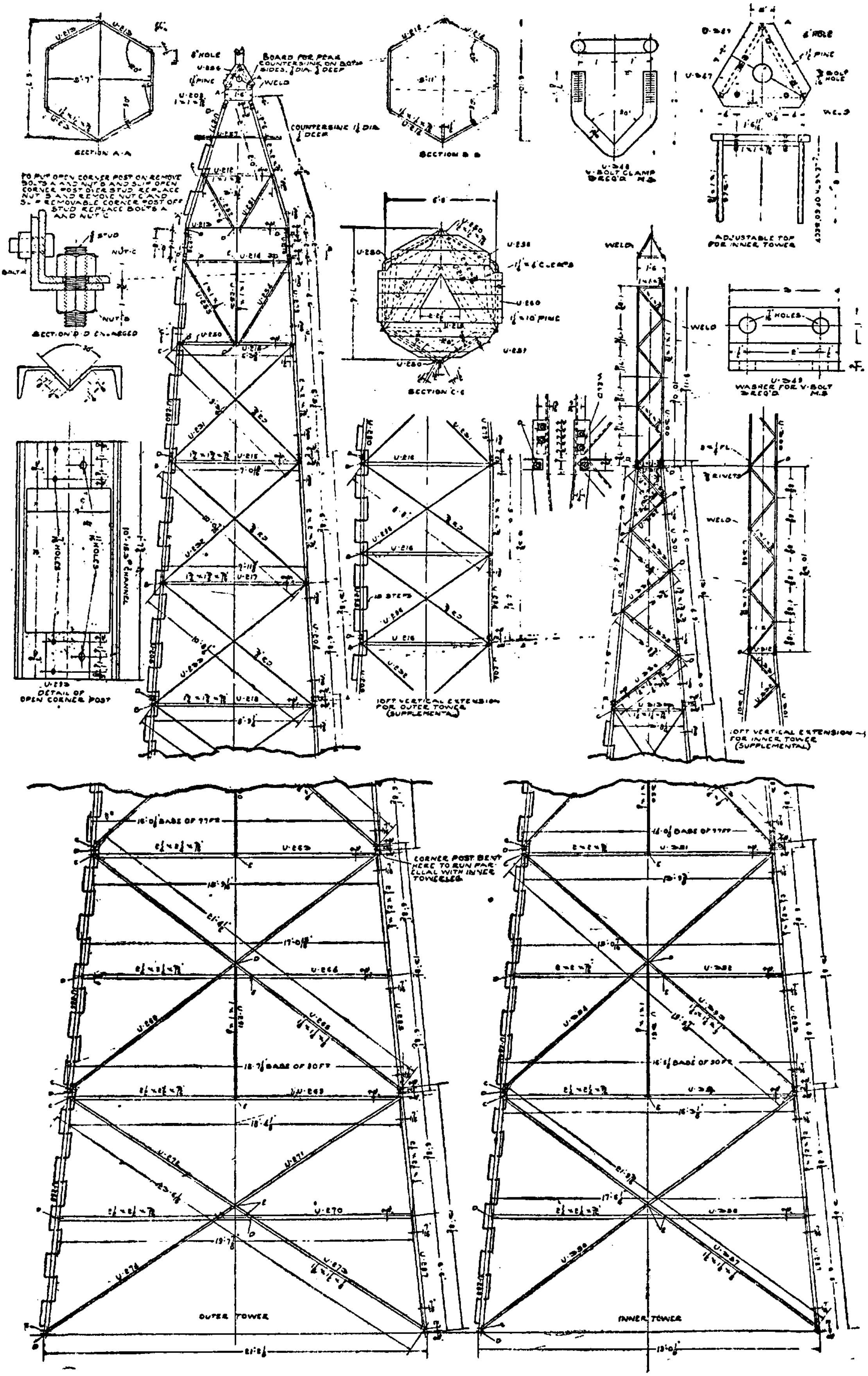

SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D ENLARGED
DETAIL OF OPEN CORNER POST
ADJUSTABLE TOP FOR INNER TOWER
10FT VERTICAL EXTENSION FOR OUTER TOWER (SUPPLEMENTAL)
10FT VERTICAL EXTENSION FOR INNER TOWER (SUPPLEMENTAL)
CORNER POST BENT HERE TO RUN PARALLEL WITH INNER TOWER LEG
OUTER TOWER
INNER TOWER

FIG. 2.

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 horizontal 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 on to 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.

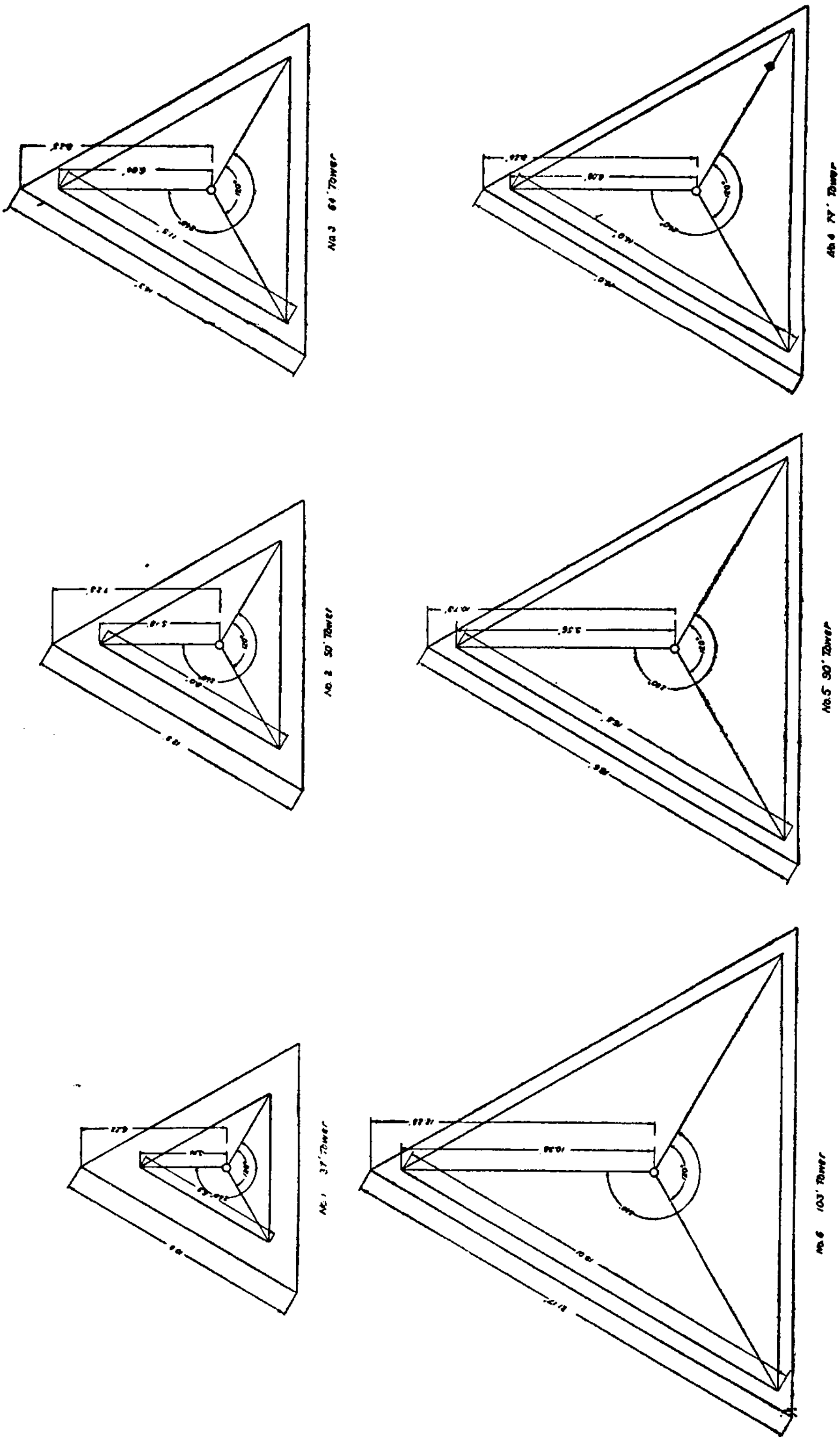
After the anchors are set and holes are about half filled, a round of levels should be taken to determine the place on each post at which each leg of the lower tower section should be fastened to insure that the tower will be plumb. As shown on the working plans (Fig. 2) there are 14 bolt holes 1 inch 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



Ground Floor Plans of Six Sections of Bilby Triangulation Tower

Note:- Measurements are between lower ends of each 13'6½" section towers are marked with paint of contrasting colors, as described above. 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 4 and 5 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.

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.