TRIANGULATION

In the preceding articles the methods used in laying out or expanding parallel and tapering forms were fully illustrated and described. The surfaces that the boiler maker encounters cannot always be expanded by the use of the two methods mentioned above. This is due to the fact that these surfaces do not conform to any particular law, that is, they are not cylindrical in form or conical, etc. Consequently some method must be devised whereby those forms can be laid out accurately and quickly. The method most commonly used is that of triangulation. Most young layersout seem to experience difficulty in grasping the principles involved in this method and in consequence are always experiencing difficulty in laying out forms by triangulation. This trouble is largely caused by the fact that the layerout has failed to grasp the elementary or underlying principles involved. We shall undertake to present these principles in such a manner that they will be readily understood. Once the boiler maker has these principles thoroughly mastered he should experience little or no difficulty in applying them to any problem that may arise in the practice of his profession.

The definition of the word triangulation is simply the measurement by triangles. In surveying, it is the series of triangles with which the face of a country is covered in a trigonometrical survey and the operation of measuring the elements necessary to determine the triangles into which the country to be surveyed is supposed to be divided. In boiler making, triangulation simply means the division of the surface of any irregular object into triangles, determining the lengths of their sides from the drawing and transforming them in regular order in the pattern. In constructing these triangles the lengths of three sides are known, and as it is obvious that from any three given dimensions only one triangle can be formed, this method furnishes an absolutely correct method of measurement. In all articles whose sides do not lie in a vertical plane, the length of a line running parallel with the form cannot be determined from the elevation above nor from the plan. The elevation gives us the distance from one end of the line vertically to the other as it appears

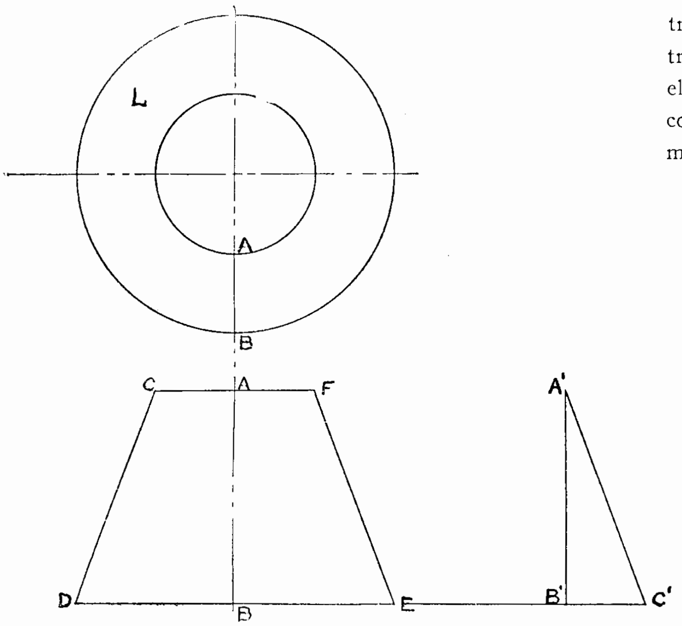

FIG. 1.

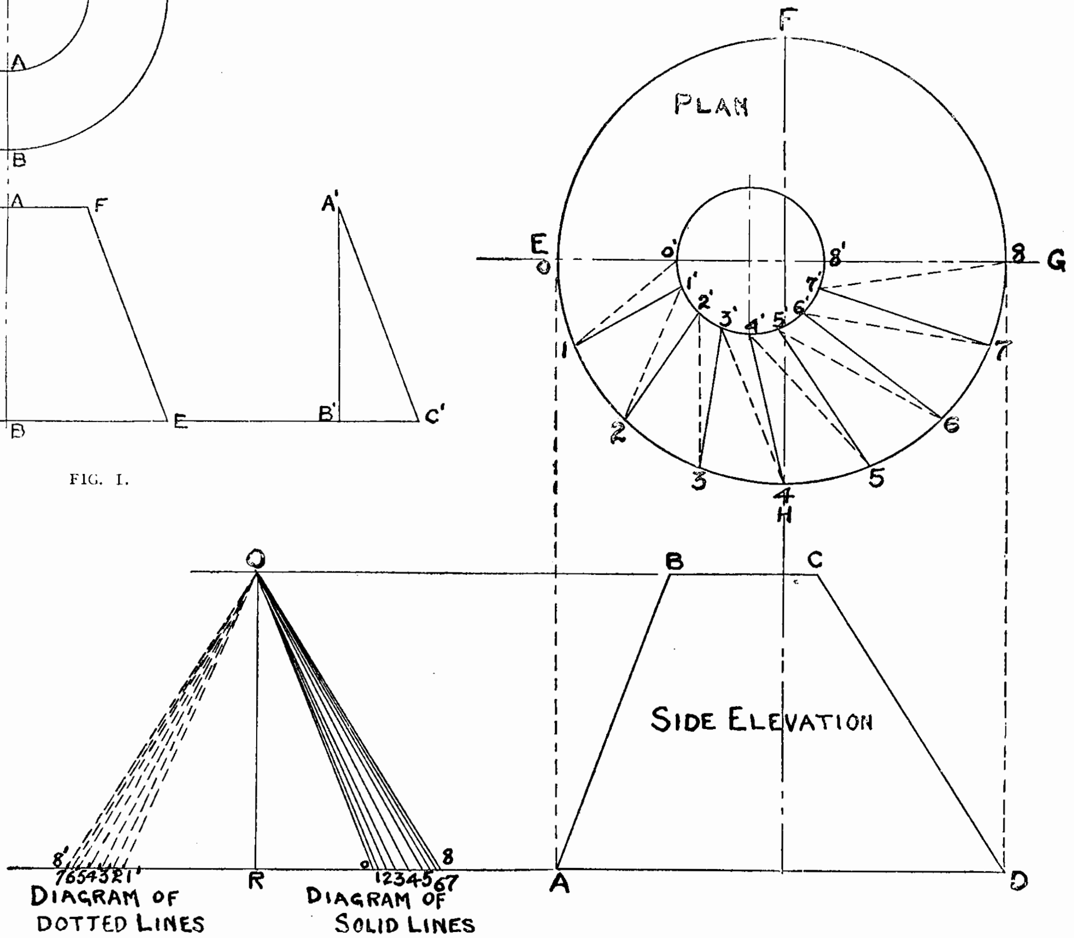

FIG. 2.

to the eye. To get the distance forward or back from one end of the line to the other we must go to the plan. From the foregoing we can readily see that the true length of a straight line lying in the surface of an irregular form can be found only by constructing a right-angled triangle whose base is the horizontal distance between the points and whose altitude is the vertical distance of one point above the other. The hypothenuse of this triangle is the true distance between the points, or the required length of the line. To illustrate this, let *C D E F*, Fig. 1, be the elevation of a conical article, and *L* its corresponding plan view. It is required to find the true length of the line *AB*. It is evident that the distance *AB* in the elevation is the actual vertical height of the line, and that the distance *AB* in the plan is the actual horizontal length of the line. We will consequently proceed to construct a right-angle triangle whose height *A'B'* corresponds to the height *AB* in the elevation, and whose base *B'C* corresponds to the distance *AB* in the plan view. Draw *A'C'* and it is evident that the distance *A'C'* is the true length of the line *AB*. This is the principle upon which triangulation is based.

In Fig. 2, *A B C D* is the side elevation of a truncated scalene or oblique cone. We will assume that this truncated cone is a transition piece connecting two round pipes. It is also somewhat similar, though greatly exaggerated, to the throat sheet of a locomotive boiler. The idea of the article is simply to explain the method of triangulation, any other irregular piece would serve our purpose as well. *E F G H* is the corresponding plan view of the truncated cone. We will simply expand one-half of the article, the other half being the exact duplicate of it. Divide the large half circle *E H G* into any number of equal parts. Eight parts were taken in this case, though as a rule, the larger number of parts taken the more accurate will be the work. Divide the small semi-circle into the same number of parts; number the divisions on the large semi-circle 0 to 8, and on the small semi-circle 0'-8'. Join the points 0-0', 1-1', 2-2', 3-3', etc., with full lines; also join the points 0'-1, 1'-2, 2'-3, 3'-4, etc., with dotted lines.

We are now ready to construct our triangles to find the true lengths of the lines 0-0', 1-1', etc., and the lines 0'-1, 1'-2, etc. Erect the vertical line *OR* and at right angles to *OR* draw a horizontal line. The line *OR* is equal to the vertical height from the line *BC* to the line *AD* or the actual vertical height of the cone. This line is evidently one leg of our triangles. The other legs are the distances 0-0', 1-1', 2-2', etc., as explained in Fig. 1. Transfer the distance 0-0' to *R*-0, the distance 1-1' to *R*-1, the distance 2-2', to *R*-2 on our diagram for triangles. Join *O*-0, *O*-1, *O*-2, *O*-3, etc., these lines give us the true lengths of the solid lines. In a similar way we find the true lengths of the dotted lines, laying the distances out to the left of *R* and joining these points with *O*. We now have the true lengths of all the solid and dotted lines and are ready to proceed with the actual expansion.

In Fig. 3 lay out the horizontal line 0-0' equal in length to the full line *O*-0 in Fig. 2. Set a pair of dividers to the spacing 0'-1', 1'-2', etc., on the small semi-circle and set another pair of dividers to suit the spacing of the large semi-circle. The setting of these dividers should be very carefully done as any little inaccuracy here will throw the whole work out. Now, with 0 as a center, with the dividers set to the large spacing, strike an arc. With 0' as a center, and the distance 0-1', Fig. 2, as a radius, strike an arc cutting the previous arc at 1. With 1 as a center, and the distance 0-1, Fig. 2, as a radius, strike an arc. Now, with 0' as a center, with the dividers set to the small spacing, strike an arc cutting the previous arc at 1'. Continue this operation until the points 8 and 8' are reached. Join the points 0, 1, 2, 3, 4, 5, 6, 7 and 8 with a smooth curve, and similarly with the points 0', 1', 2', 3', 4', 5', 6', 7' and 8'. This then is the true expansion of half of the truncated cone shown in Fig. 2.

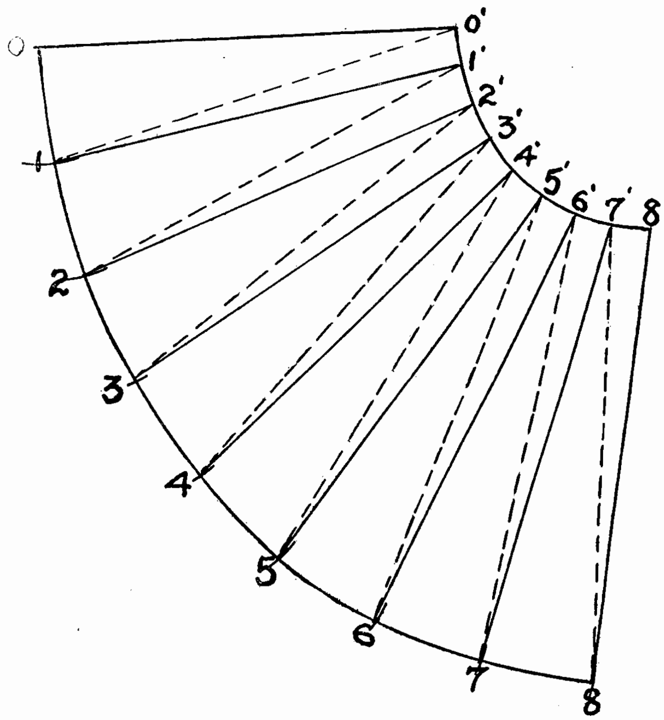

FIG. 3.

The above illustrates in a simple manner the method of developing irregular surfaces by triangulation. It will be readily seen that it is not an absolutely accurate method of laying out, due to the fact that a curved surface is divided into a small number of parts and these parts are assumed to be straight lines. However, with a sufficient sub-division and with great care on the part of the layerout, no great inaccuracy will result. It is not advisable to lay out surfaces by triangulation, except as a source of last resort, that is, if there is any other feasible method for expanding the article, use it. However, there are a great many irregular-shaped forms that can only be expanded by adopting this method, and every layerout should understand it thoroughly. The frustrum of an oblique cone, which we have just expanded, can be laid out by applying the principles of laying out tapering forms. It was chosen as an easy example, illustrating the fundamental principles of triangulation. In a later chapter we will apply the principles of triangulation to more intricate forms.

LAYING OUT A CIRCULAR HOOD FOR A SMOKESTACK.

In this article we will consider the development by triangulation of a circular hood for a stack which projects through an inclined roof. In Fig. 4 is shown the elevation of the stack; *ABCD* is the elevation of the circular hood. *A'B'* is the plan view of the stack and the circle *C'D'* the plan view of the outer edge of the flange. This shows as a circle in the plan view, as it is required that the flange be equal on all sides.

Fig. 6 shows an elevation *ABCD* of the hood similar to *ABCD,* Fig. 4. Above this elevation is a half plan of the top *AEB.* This half plan is divided into ten equal parts. From the points on the larger semi-circle *EHG* from 0 to 10. Connect the points 0-0', 1-1', 2-2', 3-3', etc., with full lines, and the points 0'-1, 1'-2, 2'-3, 3'-4, etc., with dotted lines. These solid and dotted lines form the bases of a series of right-angled triangles, whose altitudes are obtained from the elevation, Fig. 6. The hypothenuse of these triangles will give us the correct lengths of the lines on the pattern.

Returning to Fig. 6, connect the points on *AB* with the correspondingly numbered points on the line *CD.* Also extend the lines *AB* and *DS* indefinitely to the right. Do the same with the points on the line *CD.* At *S* erect a perpendicular line between the lines *BR* and *DS.* At *S* set off the

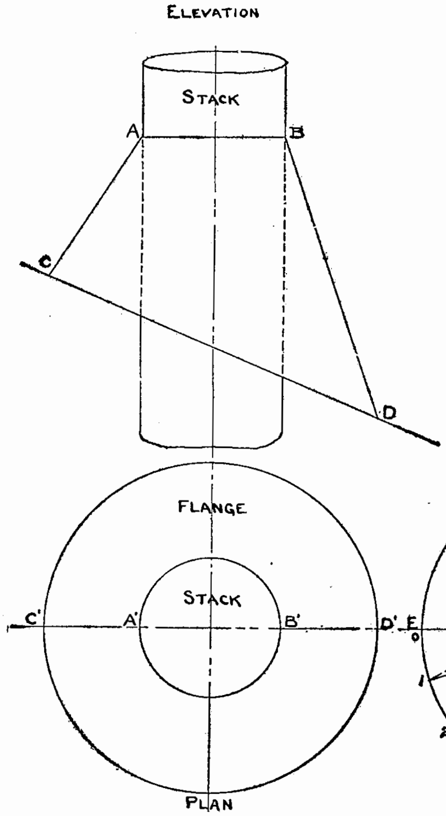

FIG. 4.

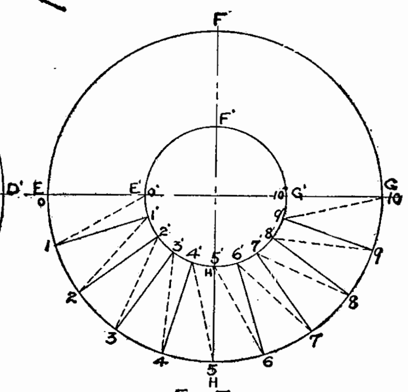

FIG. 5.

these points drop perpendiculars to *AB.* We must now obtain the actual shape of the section as it passes through the roof. To do this, construct the half plan of the base *GHK* and divide this semi-circle into the same number of equal parts as the semi-circle *AEB.* From these points erect perpendiculars cutting the line *GK.* Extend these lines to cut the line *CD.* From these points drop lines perpendicular to *CD.* On these lines lay out distances equal to the similarly numbered perpendicular lines on the half plan view *GHK.* Through these points draw a smooth curve. This gives us the true shape of the section as it passes through the roof and furnishes us with the stretchout of the base used in obtaining the pattern.

We are now ready to prepare for constructing the triangles for developing the pattern. In Fig. 5 construct a plan view of the hood similar to that shown in Fig. 4. Divide these semi-circles similarly to the semi-circles in Fig. 6 and number the points on the smaller semi-circle, *E'H'G',* from 0' to 10' and distance *SQ* equal to the distances 0'-1, 1'-2, 2'-3, etc., Fig. 5. At *Q* erect a perpendicular cutting the line *BR* at *P.* Join *P* with the points, 0, 1, 2, 3, etc., on the line *RS.* This gives us the true lengths of the dotted lines on the pattern. Now at *O* on line *DS* erect a perpendicular line cutting the line *BR* at *N.* Now set off the distance *OM* equal to the lengths of the full lines in Fig. 5, 0-0', 1-1', 2-2', etc., which are all equal. Erect the perpendicular *ML* and join *L* with the various points on the line *NO.* This gives us the lengths of the solid lines on the pattern.

We are now ready to lay out our pattern. The stretchout of top end of the flange is obtained from the semi-circle *AEB,* Fig. 6, and that of the lower part, or where the flange strikes the roof, is obtained from the section *CFD,* Fig. 6. Draw the line *A'C',* Fig. 9, equal in length to *AC,* Fig. 6. Set a pair of dividers to the distance 0-1 on *CFD* and another pair to the distances 0'-1', 1'-2', etc., on *AED.* These distances are all equal. With 0 as a center and 0-1 on *CFD* as a radius strike the arc o-1. With o′ as a center and the distance *P*-1, Fig. 8, as a radius, strike an arc cutting the previously constructed arc at 1. With 1 as a center and the distance *L*-1, Fig. 7, as a radius, strike an arc, and with o′ as a center and the distance o′-1′, Fig. 6, as a radius, strike an arc cutting this arc at 1′. Continue this process until the points 10 and 10′ are reached. Draw a smooth curve through these points and join 10 and 10′. The resulting surface *A′B′C′D′* gives us the development of one half of the hood. The other half is exactly similar.

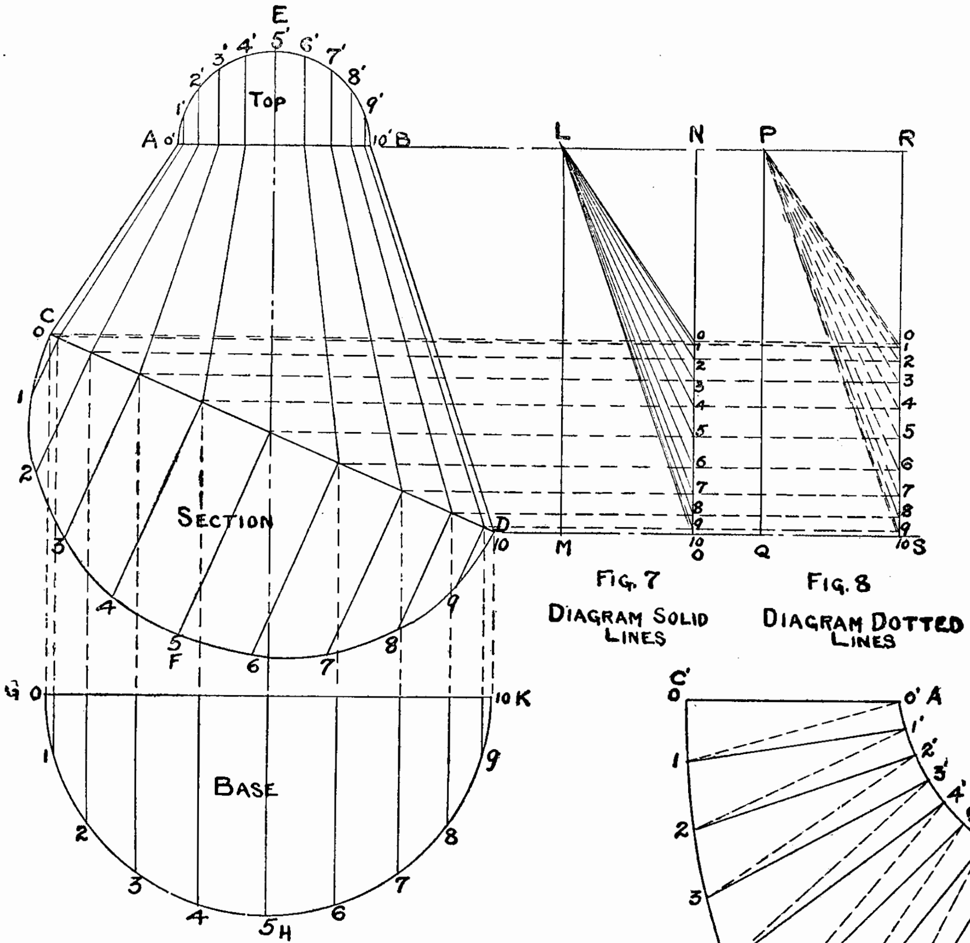

Fig. 6.

Fig. 7

Fig. 8

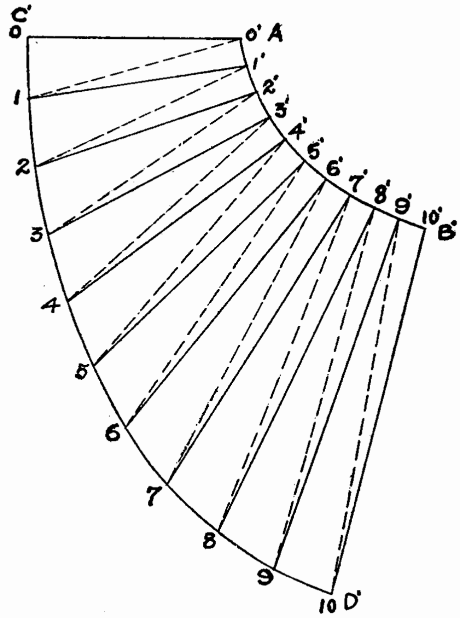

Fig. 9.

THE LAYOUT OF A "Y" CONNECTION.

The plan and elevation of a "Y" connection, such as it is frequently necessary to construct for the uptakes of boilers or in branch pipe work, is shown in Fig. 10. The main pipe is circular and the two branch pipes are oval in shape, the diameter of the large pipe and major diameter of the small pipes being the same. It will be seen that not only would the connection from the large pipe to one of the smaller ones be an irregular and difficult piece to lay out, but that the interesection of two of these irregular pieces make the problem still more complicated. The fact that the connections to each of the branch pipes are exactly similar brings their intersection in a vertical plane, as shown by the line *A*4. Divide the half plans of the large pipe and one of the small pipes into the same number of equal spaces. Number the points on the large pipe 1, 2, 3, 4, 5, 6 and 7, and on the small pipe 8, 9, 10, 11, 12, 13 and 14. Now divide the surface of the connection into triangles by connecting points 1-8, 2-9, 3-10, etc., by solid lines and the points 2-8, 3-9, 4-10, etc., by dotted lines, as shown in Fig. 10.

It is necessary to find the true length of each of these lines of which we have just drawn the plan and elevation, in order to obtain the shape of the connection when stretched out flat.

Draw the line *BA*, Fig. 11, and at any point, as *Y*, square up the line *XY*. It will be seen from the elevation, Fig. 10, that the vertical distance between the upper and lower ends of each of the lines of which we wish to get the true length is the same; that is, it is the perpendicular distance between the lines 1-7 and 8-14. Therefore, lay off this distance in Fig. 11 from X to Y and then set the trams to the distance 1-8 in the plan, Fig. 10, with Y as a center, Fig. 11, lay off the distance $Y8$ to the right of the line YX. Again, set the trams to the distance 2-8 in the plan, Fig. 10, and with Y as a center lay off the distance $Y8$, Fig. 11, to the left of the line XY. Draw the solid line $X8$, and also the dotted line, $X8$. These lines will then be on the half plan of the branch pipe), strike an arc intersecting the arc previously drawn at point 13. Again set the trams to the solid line X-13. Fig. 11, and with 13, Fig. 12, as a center, strike an arc at point 6. With 7 as a center and with dividers set to the distance 7-6, Fig. 10 (the length of the equal spaces

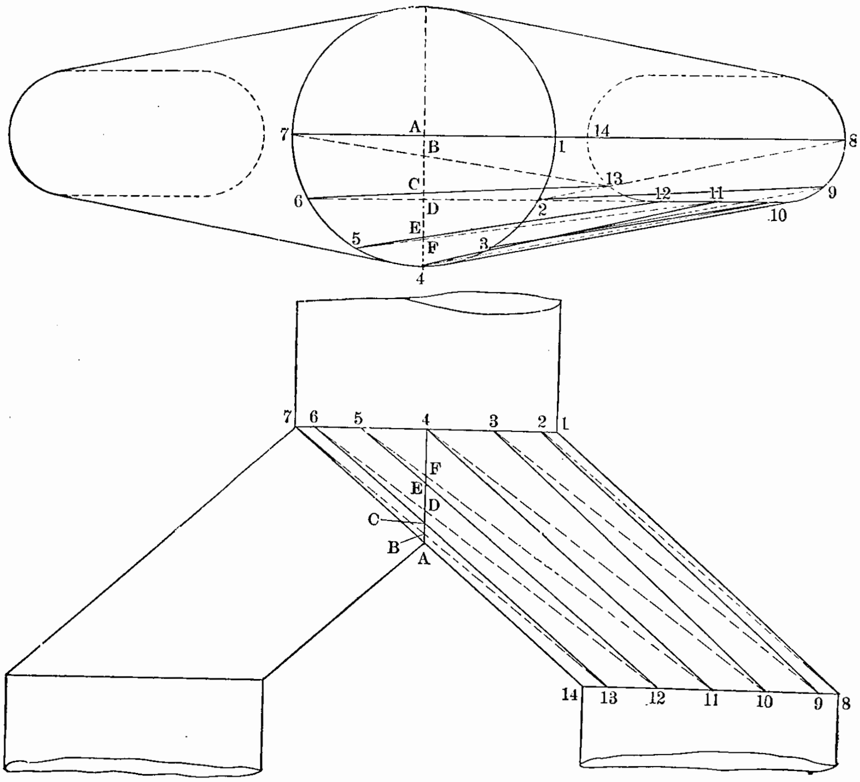

FIG. 10.

the true lengths of the solid line 1-8 and the dotted line 2-8, shown in Fig. 10.

Perform the same operation for each of the solid and dotted lines in Fig. 10, obtaining the lines $X9$, $X10$, $X12$, $X13$ and $X14$, Fig. 11. In order to avoid confusing the figure, since all of the lines are of nearly the same length, draw the solid lines at the right of the figure, and the dotted lines at the left.

in the half plan of the large pipe), strike an arc intersecting the arc previously drawn at point 6. Proceed in a similar manner, locating the points 5, 4, 3, 2 and 1 on the long edge of the sheet, and the points 12, 11, 10, 9 and 8 on the short edge of the sheet.

Having obtained the pattern for the entire connection from the large pipe to one of the small ones, it is now an easy mat-

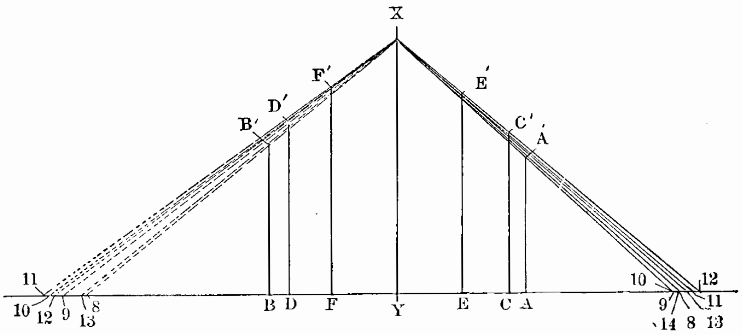

FIG. 11.

Having obtained the true length of all the lines which form the triangles into which the connection is divided, we are now ready to lay out the sheet as it will be before it is rolled up. Draw the line 7-14, Fig. 12, equal in length to the line 7-14, shown in the elevation, Fig. 10. Now set the trams to the dotted line X-13, Fig. 11, and with 7, Fig. 12, as a center draw an arc at the point 13. With 14 as a center and the dividers set to the distance 14-13 (the length of one of the equal spaces

ter to locate the line of intersection between the two intersecting connections. Set the trams to the distance $7B$ in the plan Fig. 10, and with Y, Fig 11, as a center lay off the distance YB. At the point B square up the line $B\ B'$ until it intersects the line X 13; then set the trams to the distance $X\ B'$, and with the point 7, Fig. 12, as a center, lay off the distance $7B$ along the line 7-13. Again set the trams to the distance $6C$ on the plan, Fig. 10, and with Y, Fig. 11, as a center lay off the distance

$Y C$; at C square up the line $C C'$ until it intersects the line $X13$ at the point C'; then set the trams to the distance $X C'$; and with point 6, Fig. 12, as a center lay off the distance $6C$ along the line 6-13. In a similar manner locate the point D on the line 6-12; E on the line 5-12, and F on the line 5-11. Draw a smooth curve through these points, and then the figure A, 4, 1, 8, 14 represents a half pattern of the connecting pipe.

This problem shows how the principles of triangulation make possible the solution of problems which require the development of surfaces of which there is no regular form or taper. The only inaccuracies or errors which creep into this, as well as any other problem which is solved by triangulation, are those due to the fact that the lines forming the triangles into which the surfaces are divided are considered as straight lines when, as a matter of fact, they are slightly curved. Unless there is a very great curvature to the surface, however, this error is very small and the patterns developed by this method will be found to fit nicely into the required positions.

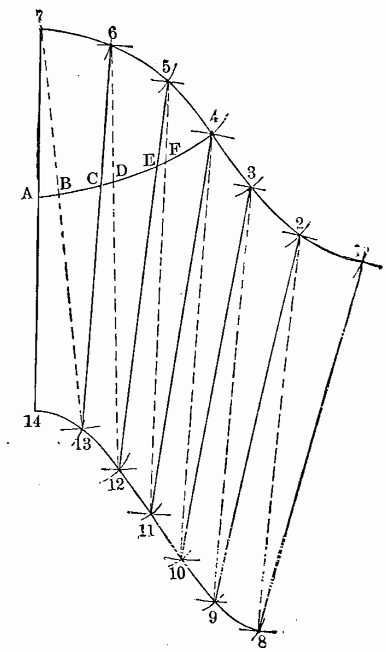

FIG. 12.