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DESIGN AND CONSTRUCTION TABLE FOR EGG-SHAPED SEWERS.

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The design for the cross-section of the first brick-sewers constructed in Cleveland (except for steep grades) was substantially the usual egg-shaped section common in England and in this country. The arch is a semicircle, consequently the greatest breadth of the section is at the spring-line. The vertical diameter is one and one-half times the transverse diameter; hence the spring-line of the arch is two-thirds of the vertical diameter above the base of the section. The *radii* of the side arcs are equal to the vertical diameter, and the radius of the lower arc is one-fourth of the transverse diameter of the section. The curvature of the side arcs is, therefore, slight.

In the construction of brick-sewers in Cleveland, in accordance with this design, great difficulty was experienced in holding the invert and side walls in proper shape until the arch could be completed and loaded, and failures had occurred in completed work by buckling in of the side

walls immediately below the spring line of the arch from the lateral pressure of the quicksand and water which underlie the city, and are constantly met with at the depth the sewers are built. These failures occurred in sewers of the dimensions of 6x4 feet, with 8-inch walls of brick, laid in hydraulic cement, and without headers, except one course at the spring-line of the arch, in cuttings, from 12 to 15 feet in depth. The brick invert was laid in a plank invert held in shape by curved ribs cut from plank and planed inside.

Taking these facts, and estimates made at the time, as a basis, it was deemed impracticable to construct brick sewers larger than 4½x3 feet with this form of section through material of the character met with in Cleveland without a specially prepared foundation, or a thickness of walls disproportionate to the size of the sewer when in comparatively dry cuttings, and consequent disproportionate increase of cost.

The difficulties in construction, referred to above, were obviated, and the stability of the completed work insured, without materially decreasing the carrying qualities of the sewers, subject to an intermittent flow, by the adoption of the form of section shown on Plate V., Fig. I.\* The construction is as follows: Describe the circle  $C B D$  and make the arcs  $B E$  and  $D E$  each equal to one-sixth of the circumference, and the arcs  $B C$  and  $D C$  each equal to two-sixths of the circumference. Through the points  $B$  and  $C$ ,  $D$  and  $C$ ,  $B$  and  $E$ ,  $D$  and  $E$ , draw the indefinite straight lines  $B F$ ,  $D G$ ,  $D H$ , and  $B K$ , respectively, and with the point  $C$  as centre, and a radius equal to the radius of the circle, describe the arc  $F G$ , and with the points  $B$ ,  $D$  and  $E$  as centres, and the radii  $B F$ ,  $D G$ , and  $E H$ , describe the arcs  $F K$ ,  $G H$ , and  $H K$ , respectively.

It will be observed that in this cross-section the spring-line of the arch is nearly identical with a horizontal line passing through the middle point of the vertical diameter; therefore, in the construction of sewers with this form as compared with the usual egg-shaped section in which the spring-line is two-thirds of the height above the base, the amount of brickwork laid upon the centering is proportionately larger, and the more expensive, and usually most neglected portion of the work, is proportionately less, and at the same time the *height* of the side walls to be held in position until the arch can be loaded, referred to above, is very

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\* Designed by the writer.

materially decreased, a matter of considerable moment in the construction of large sewers through bad ground.

As to the necessary thickness of walls for this design, the practice is to have for sewers not larger than 6 x 4½ feet, 8-inch walls, in cuttings from 14 to 18 feet in depth, and 12-inch walls, for sewers from 6 x 4½ feet to 7½ x 6 feet, in cuttings from 16 to 22 feet in depth, using a plank invert only for a foundation, thus showing the expediency of the adoption of a form of cross-section more nearly approaching a circle, as compared with the usual egg-shaped section for sewers with ordinarily imposed conditions, in localities where the material through which they are to be constructed is, or is liable to be, surcharged with water.

Fig. II, Plate V., shows the same design as Fig. I, and will assist in the analysis of the calculations and the application of the following :

Let  $R$  = Radius of lower arc of 60°.

“  $A$  = Area of section.

“  $C$  = Circumference.

$\pi$  = 3.1416.

Then  $A = R^2 [ \pi (3.1666.. + \sqrt{3}) - \sqrt{3} ]$

$$C = \frac{\pi R}{3} (4 + 5 \sqrt{3})$$

Vertical diameter =  $R (3 + \sqrt{3})$

Transverse “ =  $R (2 + \sqrt{3})$

Taking  $R = 1$  in the above formulæ.

Then  $A = \pi (3.1666.. + \sqrt{3}) - \sqrt{3} = 13.6577.$

$$C = \frac{\pi}{3} (4 + 5 \sqrt{3}) = 13.2581.$$

Vertical diameter =  $3 + \sqrt{3} = 4.7321.$

Transverse “ =  $2 + \sqrt{3} = 3.7321.$

And the area of *any* section =  $13.6577.. R^2.$

The following table shows a series of sizes for brick sewers, No. 1\* to No. 16 inclusive, adopted by the City of Cleveland, and is here given as an illustration of a convenient method of notation in connection with a series of areas which in practice fulfills the requirements of ordinary city and town sewerage, taking a “ foot ” as the unit of area.

The areas  $A$ , in the second column, are derived from assumed con-

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\* Not used.



secutive numbers  $N$ , in first column, and are equal to  $\sqrt[3]{N^4}$ ,  $N$  denoting size as, size No. 1, &c.

The vertical and transverse diameters are given in units corresponding to the unit of area.

Assumed consecutive number denoting size. = $N$ .	Sectional Area. $\sqrt[3]{N^4}$ = $A$ .	Radius of lower Arc of $60^\circ$ = $R$ .	Vertical Diameter.	Transverse Diameter.
1.....	1.0000	0.2706	1.2805	1.0098
2.....	2.5198	0.4295	2.0326	1.6031
3.....	4.3268	0.5629	2.6634	2.1006
4.....	6.3496	0.6818	3.2265	2.5447
5.....	8.5499	0.7912	3.7441	2.9528
6.....	10.9027	0.8935	4.2279	3.3345
7.....	13.3905	0.9902	4.6855	3.6953
8.....	16.0000	1.0824	5.1218	4.0394
9.....	18.7208	1.1708	5.5402	4.3694
10.....	21.5443	1.2560	5.9433	4.6873
11.....	24.4638	1.3384	6.3332	4.9948
12.....	27.4731	1.4183	6.7114	5.2931
13.....	30.5674	1.4960	7.0793	5.5833
14.....	33.7420	1.5718	7.4378	5.8660
15.....	36.9932	1.6458	7.7879	6.1421
16.....	40.3175	1.7181	8.1303	6.4122

The areas  $A$  in the second column are based upon assumed consecutive numbers  $N$ , denoting size, in the first column, and are  $A = \sqrt[3]{N^4}$