GASHOLDER CONSTRUCTION.

PAPER.

GAS HOLDER CONSTRUCTION.
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PREFACE:

Gasholder design is an important branch of structural engineering; though the design and construction of modern gasholders and their tanks does not usually enter into the province of the structural engineer. It is the work for a specialist, and to fully appreciate the many details that are essential to the successful working of large gasholders requires both a knowledge of their manufacture and an acquaintance with their behaviour under working conditions.

The limitations of this paper preclude the writer from dealing with the subject exhaustively; therefore, to give the trained engineer a reasonably complete precis of the principles and practice involved, the design of a typical guide framed gasholder of about 2½ million cubic feet capacity, together with its tank, will, it is hoped, be adequately dealt with.

HISTORICAL:

Previous to the year 1781 the only means of retaining gases were bladders, but in that year the great French chemist, Lavoisier, invented the Gasholder, substantially as now applied in all gasworks. The earliest gasholders were made in the form of cubes or other rectangular figures, and were built with timber framing covered with sheet iron and working in wooden tanks, the whole being enclosed in a building. So little was known regarding gas and gasholders in the early days of the industry, that in 1814 Sir Joseph Banks headed a deputation from the Royal Society, which after visiting the gasworks of the Chartered Company in Westminster, England, strongly recommended the Government to restrict the Company from constructing gasholders exceeding 6,000 cubic feet in capacity, which were, moreover, to be confined in very strong buildings.

GENERAL NOTES.

A gasholder consists of essentially two parts, first the tank containing the water which forms a seal preventing the escape of gas, and which also acts as the point of resistance to the
gas causing the holder to rise. The other part is the floating bell, which is a hollow cylinder open at the bottom where it enters the tank and enclosed at its top or crown. The floating bell rises and falls within the tank according to the amount of gas that is being made or going out into the distributing mains.

The bell supported by the gas and floating in the water of the tank is in unstable equilibrium due to the fact that the weight of the crown is at the highest point, and it is therefore necessary to provide some form of lateral support to keep the lower edge of the bell level with the water line of the tank and to resist the overturning moment of the wind.

The form of lateral support employed consists of a number of vertical columns spaced equidistantly round the edge of the tank, each column being provided on its inner face with a guide member extending to the bottom of the tank. Rollers fixed to the top and bottom of the bell travel up and down these guides, preserving the verticality of the bell and transmitting the wind loads to the columns.

In the early designs of gasholders the floating bell consisted of a single lift only, the depth of the lift being slightly less than the depth of its tank, the lift, when deflated, being supported on rest stones which kept it clear of the tank floor. In order to obtain a big capacity holder it was necessary to excavate a large diameter tank having a depth of not less than one-fifth of the diameter; this was found to be not only an uneconomical method of construction, but also the limit of the capacity was very quickly reached. The introduction of the multiple lift or telescopic gasholder about the year 1824, solved the problem of economical tank construction and allowed gasholders of greater capacity to be built, occupying very much smaller areas of ground.

A multiple lift gasholder consists of a number of concentric rings or lifts, rarely exceeding four in number and, up to the present, never more than six. These lifts are hollow cylinders open at each end, excepting the inner lift, which has a spheric segmental roof or crown; the lower end of each lift is provided with an annular ring or cup on its outside face, the cup being about 12in. wide and 18in. deep. Each subsequent lift has a similar cup at its lower end and has an inverted counterpart
of the cup, in this case called the dip, provided on its inside face of the upper end, except the outer lift from which the cup is omitted.

In action, after the tank has been filled with water, gas is admitted into the crown of the inner lift causing it to rise. When it is about to leave the tank its cup engages with the dip of the next lift and raises it out of the tank, each lift follows in succession until the full capacity of the holder is reached, and the floating bell is several times the depth of the tank in height. No gas is lost between the cups and dips, as when a

Fig. 1.—Section Through Cup and Dip.

cup is leaving the tank it fills itself with water, and the dip projecting into the water forms a gastight seal as shown in Figure 1.
GENERAL DESIGN:

For the purpose of this paper it will be assumed that storage requirements demand a new holder of from 2½ to 3 million cubic feet capacity, and that the site available is restricted; it being further assumed that it is situated at an existing manufacturing station, and that due allowance must be made for storage of materials and working space for erection purposes without interfering with the ordinary daily manufacturing operations of the station. Test borings are assumed to have shown that the ground is favourable to excavation for about 21 feet deep, but below that depth very hard dense rock would be met with.

Careful investigations are assumed to have shown that the largest tank that could be accommodated on the site would be 163 feet diameter. The depth of the lifts of a holder should not be less than one-fifth of the diameter; this would indicate that 35 feet would be a suitable lift depth, and that the tank should be 36ft. 3in. deep.

It would be possible to accommodate a five lift holder in such a tank, but the great height of such a holder, in relation to its diameter, does not commend itself. A four lift holder would appear to be a more suitable proposition, and this size will be assumed.

The proposal is therefore to describe the design of a four lift gasholder with steel guide framing complete, working in a tank 163ft. diameter by 36ft. 3in. deep.

TYPES OF GASHOLDER TANKS:

The two main types of tanks usually employed are:—(1) Those built below ground, of brick with clay puddle behind; or of concrete, rendered.
(2) Those built wholly, or mostly above ground; of steel plates or reinforced concrete.

For the very largest holders, i.e., those over 240 feet diameter, the use of steel tanks, is, at present, prohibited by reason of the plate thickness which would be essential but practically impossible. For sizes under 240 feet diameter it may be taken for granted that a steel tank is more economical in construction than brick or concrete. It can be designed with a degree of accuracy lacking in other types.

Brick or plain concrete tanks can be built economically
when constructed in clay or hard pan, and where but little pumping during construction is required. In such a case the tank would be constructed with a comparatively thin wall, the space between the back of the wall and the excavation being thoroughly and firmly filled in, preferably with puddled clay, thus transferring the hydrostatic pressure to the face of the excavation beyond.

A third kind of tank is the composite brick and steel tank. This is built of brick or concrete below ground level, with a steel plate extension above. This type deserves consideration, as its application may in certain cases, such as are indicated by our assumed test borings, result in a saving of construction costs. This method of tank construction is very rarely practiced, probably on account of its comparative novelty. For that reason and from the fact that the principles of both brick and steel tank design and construction are dealt with, a composite tank will be selected for the purpose of this paper.

**Tank Design:**

The first consideration would be to decide the proportions and construction of the brick and steel tank, and to arrange the form of joint between the steel plates and the brickwork. We have an assumed depth of 21 feet, which is in solid clay, with no water present.

It is proposed to extend the brick walls 4ft. 9in. above the ground level in order to get a wide surface between the steel plates and the brickwork for the purpose of forming the watertight joint. This extended portion of the brick wall will not be required to withstand any of the hydrostatic pressure of the water in the tank, as the steel plates are proposed to be carried 2ft. 3in. below the ground level.

It being assumed that the excavation is in stiff clay, a comparatively thin wall only is required round the tank. It would be quite within the bounds of good practice to build this wall in five equal stages, the lowest being 4ft. thick, then 3ft. 6in., 3ft., 2ft. 6in., and finishing 2ft. at the top.

Incorporated into this wall would be sixteen piers for supporting the columns in the guide framing. The heads of these piers require to be 5ft. wide by 6ft. long to carry the base-
plates of the columns; as the wall is thinner than this it is quite sufficient to keep the piers of uniform section throughout.

Both walls and piers should be constructed with hard burned bricks and cement mortar, composed of one part Portland cement and three parts sand. The brickwork should be built in equal stages all round, and the back of the walls and the face of the excavation should be firmly packed and rammed with puddled clay, obtained from the excavation as the work proceeds.

The whole area of the tank does not require excavating, an annular ring of sufficient width to receive the wall and the four lifts of the holder is all that is necessary to take out. The inner face of this annular ring should be cut back at a slope of 40° with the horizontal, leaving in the centre a "dumpling" shaped like the frustum of a cone.

Portion of the spoil excavated, especially the surface loam, can be used to form an embankment round the brick wall above ground level.

On completion of the brickwork the whole of the floor of the tank and the surface of the dumpling should be paved either with brick in cement set on edge, or else given a covering of 6in. of concrete.

**Joint (Between Steel and Brick).**

The joint between the steel plates and the brick tank may be a very troublesome matter, as at least $\frac{3}{8}$in. clearance must be left between the back of the plate and the wall to allow the plating to be lowered into its final position. It will be understood that the possibility of leakage through this clearance due to a head of 17ft. 6in. and a circumference of 312ft. is enormous. In cases where composite steel and brick tanks have been built, serious trouble has been experienced due to the joint leaking, and constant pumping has had to be resorted to in order to keep the water in the tank at its proper level. After careful study the form of joint as shown in Figure 2 has been developed. This consists of a Z shaped continuous cast iron bracket bolted through the lower flange to the tank wall. After the steel plates have been lowered down on to this bracket the spaces between the inside of the plate and the upper flange
of the bracket and between the back of the plate and the wall to within about 1 in. from the top of the brick tank, should be carefully rammed and packed with a semi-dry mixture consisting of one part Portland cement and two parts sand, the remaining 1 in. being run with lead and caulked. The steel plates bearing on the bracket with the space contained within the C.I. bracket carefully packed should prevent the hydrostatic pressure due to the head of the water acting on the remainder
of the joint, but should any weeping or small dribbles show through the joint at any time, a few blows with hammer and caulking tool on the lead joint will readily end them. It is not expected that any trouble will occur with this joint from contraction or expansion of the steel plating due to temperature changes, as the huge quantity of water in the tank, approximately 3,350,000 gallons, (more than two-thirds being below ground level and the whole being shielded from the sun's rays by the gasholder) will not vary greatly in temperature, and will keep the plates at or very near the temperature of the tank water.

**TANK PLATES:**

The tank plates would be arranged in three rings, the upper ring being made about half the extended height in depth. The horizontal seam of rivets between the top and second tier of plates being the only one visible above ground it gives a symmetrical effect by placing it midway. The middle and bottom tiers divide up the remainder of the space equally.

To find the hydrostatic pressure on each tier of plates, the head of water is taken as extending from the top of the tank to a point two-thirds down the depth of the plate in question. The formula for the hydrostatic pressure exerted upon the sides of a cylinder is

\[
\frac{D \times H \times 62.5}{2}
\]

Where \(D\) = Diameter of cylinder.

\(H\) = its height in feet.

and the weight of a cubic foot of water being 62.5 lbs.

For the bottom tier this is:

\[
\frac{15.5 \times 163 \times 62.5}{2} = 78,953 \text{ lbs., or about 35 tons pressure per lineal foot on the vertical section.}
\]

Adopting 16,000 lbs. per square inch as the safe tensile strength for steel plates, then \(78,953 \div 16,000 = 4.9345\) sq. in. of metal is required. The vertical seam in this tier will be butt-jointed with double butt- straps and rivetted with \(\frac{3}{6}\) in. rivets spaced 3 in. pitch. To obtain the net section of plate required, four rivet holes will be deducted and the diameter
of holes taken as \( \frac{3}{8} \) in. Then \( 12 \text{in.} - 4 \times \frac{3}{8} \text{in.} = 8\frac{1}{2} \text{in.} \) net.

\[
\text{length of plate per foot, and} \quad \frac{4.9345}{8.5} = 0.58 \text{o.in. or } \frac{9}{16} \text{in.} = \text{thickness of plate.}
\]

The eight \( \frac{3}{8} \) in. rivets (adopting a shearing value of six tons per square inch) have a double shear value of 4.64 tons each, therefore \( 8 \times 4.64 = 37.12 \) tons = safe double shear per lineal foot. The safe tensile strength being taken at 16,000 lbs., or 7.12 tons per square inch, the safe load on the net section of the plate = \( 8.5 \times 0.5625 \times 7.12 = 34.04 \) tons, as against 35 tons actually required, this is quite near enough.

The double butt-straips will each be formed of \( \frac{3}{8} \) in. x \( \frac{3}{8} \) in. steel flat straps, the width being determined by the lap required for the rivets, and the thickness by the bearing value of the rivets.

The second tier has a head of ten feet; then:
\[
\frac{10 \times 163 \times 62.5}{2} = 50,937 \text{ lbs. or } 22\frac{3}{4} \text{ tons pressure per lineal foot on vertical section} = 50,937 \div 16,000 = 3.183 \text{ sq. in. required} = \frac{3.183}{8.5} = 0.374 = \frac{3}{8} \text{ in. thick steel plate. Eight}
\]

\( \frac{3}{8} \) in. diameter rivets with a safe shear value of 2.65 tons each will have a total safe shear of 21.2 tons, giving an approximation sufficiently near for all practical purposes.

The upper tier of plates will be kept the same thickness as the second tier, viz., \( \frac{3}{8} \) in. thick. There would be but little, if any, advantage in reducing the thickness of this tier, as the factor to be considered is not the pressure of the water in the tank, but rather that the top of the tank should have a certain inherent stiffness in itself to resist the distortion due to the wind forces transmitted from the outer lift of the holder by the intermediate tank guides. The upper edge of this tier is further stiffened on its outer face by a \( 3\frac{3}{4} \) in. x 3 in. x \( \frac{3}{8} \) in. steel angle curb which also carries the inner edge of a steel chequer plate balcony which is constructed right round the tank. The balcony is 2 ft. 6 in. wide and is carried by an outer steel angle ring on four steel angle-brackets per bay. These brackets are extended to form handrail standards, and carry two lines
of the 3⁄4 in. gas-tubing forming the handrail. In one bay the balcony is extended to form a landing which has a staircase at each end to give access from the ground. The balcony has a further value, inasmuch as it forms a stiff horizontal plate girder round the top of the tank, making the upper portion of the tank very rigid and capable of resisting without deformation the wind loads transmitted from the bottom half of the outer lift.

A gasholder tank is always provided with vertical guide-members attached to its sides, and the number employed is usually twice the number of columns in the external guide framing, so arranged that half the number are fixed in line with the columns and the remainder spaced between. These guides provide paths for the bottom rollers on the outer lift to travel on. In this case they serve a double purpose, first as guides, and secondly, as means of attachment for the plated extension to the brick tank. The guides are formed of 12 in. x 3 in. steel channels, this section being dictated by the size of the front members of the columns in the guide framing. These channels would be concreted 12 in. into the tank bottom, and anchored by means of 15 in. x 6 in. R.S.J. wall ties 12 in. long rivetted to the backs of the channels and concreted into the walls. The upper portion of the channels would be rivetted to the steel plates, and those channels at the columns would be further secured to the columns themselves.

The tank plating should have four cast-iron overflow boxes bolted on at equidistant points, the upper edge of the boxes being 1 in. below the edge of the tank to allow any excess water in the tank, due to rain, to run cleanly away instead of overflowing across the tank balcony.

Sixty-four rest blocks formed of 15 in. x 5 in. R.S.J.’s 5 ft. 3 in. long, bolted to the tank bottom, are required. These blocks provide a level seating for the lifts, when at rest, keeping the cups 15 in. above the tank floor, which allows clearance for the rollers fixed underneath the cups.

**INLET AND OUTLET PIPES:**

The gas is admitted to and withdrawn from the holder through inlet and outlet pipes. These pipes which connect with the works’ mains are carried down vertically outside the
tank below the foundations and are then taken horizontally below the walls and under the floor to the required distance in the tank, this portion of the work being carried out before the foundations are put in; they then rise vertically till their upper ends finish at the level of the tank top. The pipes outside and under the tank floor should preferably be of cast iron. The vertical lengths inside the tank are of cast iron or rivetted steel as desired, and require to be stayed with diagonal stays anchored to the tank floor. The diameters of these pipes should not be less than 24 in.

CROWN FRAMING:

The crown-sheeting of the inner lift during erection, and afterwards whenever the holder is landed on to the rest blocks, requires to be supported upon a framework, the upper curved surface of which must correspond to the shape of the crown. In holders—say up to about 100 ft. in diameter—this framing is of steel built into the inner lift, and from its shape is sometimes referred to as "umbrella" framing. In this holder the modern practice of providing fixed timber framing in the tank for holders which are over 100 ft. in diameter would be suggested. This framing consists of a number of vertical timber posts cross-braced together and securely anchored to the tank bottom. Radiating from the centre of the tank will be a number of main beams carried by the vertical posts, the beams being so fixed and shaped that the form of their upper surface will exactly conform to the shape of the crown. Between the beams, rings of purlins will be fixed and spaced so that each ring of crown sheeting will be supported by its own ring of purlins.

GASHOLDER.

DIMENSIONS:

The brick tank is 163 ft. diameter, but this diameter would be reduced by the insertion of the steel tank plates within the masonry tank; and further, as the steel tank guide channels are secured directly to the steel plating, the diameter between the inside faces of their webs, which is 162 ft. 3 9/32 in., must be considered as the working diameter. Given the diameter of the tank and the number of lifts it is
desired to place therein, there is no rule to determine the lift diameters. That is a matter of judgment, or rather experience in the working of gasholders, especially of large size. It is a fact that a number of gasholders have been, and are being constructed without enough clearance between the various lifts. This is generally not apparent during the first few years of working, but as the holder gets older the racking or wedge action of the lifts begins to show its effects, the heads beginning to be pulled slightly inwards, and the cups correspondingly drawn out (especially is this the tendency where undue economy is enforced by competitive conditions). This causes them to foul on the adjacent lifts, and to wear or tear off rivets in the side sheeting and cups and dips, causing leakage of gas, and what is infinitely a more serious matter is the danger of breaking the seal in the cup due to loss of water, with a possibility of wrecking the holder. In gasholder design a full sized drawing of the proposed cup and dip should be laid down first, showing the attachment of the vertical stays, and from a study of this drawing the final lift clearance can be determined.

In the holder described the difference in the diameters of lifts is fixed at 2ft. 10in., giving a clearance between the lifts of 1ft. 5in. A clearance of 12 41/64in. remains between the face of the web of the guides and the face of the outer lift.

The main dimensions of the various lifts would be:

- Outer Lift 160ft. 2in. diameter by 35ft. deep.
- Third " 157ft. 4in.
- Second,, 154ft. 6in.
- Inner ,, 151ft. 8in.

The crown of the inner lift is a spherical segment having a rise in the centre of 7ft. 1 15/16in. above the top curb. The curve of the crown is struck with a radius of 405ft. This latter figure is used by one of the largest gasholder builders in England, and the writer, during his past connection with that firm, has found that it gives a crown of good appearance and satisfactory design.

With these figures the next step in sequence would be to ascertain the pressure that the completed holder would be
assumed to give, and then estimate its weight from that pressure. The following table gives the calculated capacity, weight and pressure of each lift.

<table>
<thead>
<tr>
<th>Capacity Cub. Ft.</th>
<th>WEIGHT OF</th>
<th>PRESSURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crown ...</td>
<td>Steel Tons</td>
<td>Water Tons</td>
</tr>
<tr>
<td>64,870</td>
<td>220</td>
<td>-</td>
</tr>
<tr>
<td>Inner Lift</td>
<td>632,324</td>
<td>119</td>
</tr>
<tr>
<td>Second</td>
<td>626,566</td>
<td>116.5</td>
</tr>
<tr>
<td>Third</td>
<td>649,750</td>
<td>115</td>
</tr>
<tr>
<td>Outer</td>
<td>673,354</td>
<td>570.5</td>
</tr>
<tr>
<td>Combined2,648,864</td>
<td>570.5</td>
<td>60</td>
</tr>
</tbody>
</table>

This completes most of the data required to enable the design of the holder to be proceeded with.

CONSTRUCTION OF LIFTS:

The structure of a lift may be defined simply as a frame on which is secured a skin of metal sheeting. This frame consists of vertical posts, commonly called "vertical stays," spaced round the circumference of a lift and tied together at their heads and feet by strong plate rings, the space between being filled in with sheeting. The technical terms for the strong rings are:

- Inner Lift: Top Ring Curb, Bottom Ring Cup
- Intermediate Lifts: Dip, Cup
- Outer Lift: Dip, Bottom Curb

As structural members the curbs, cups and dips preserve the shape of the holder, the cups and dips in addition forming hydraulic seals between the lifts when the holder rises from the tank. The vertical stays provide a rigid connection between the rings, acting as columns when the holder is at rest in the tank, and as tension members when the holder is inflated, transmitting the weight of the lifts to the crown; they also serve in the intermediate and outer lifts, as guide paths for the rollers fixed under the cups. The sheeting in the sides of the lifts has no other duty than retaining the gas, but the
crown sheeting has, in addition, to lift the whole weight of the holder during inflation.

**Top Curb:**

The first step in the design is to proportion the top curb, and it may be first stated that the top curb is that portion of the inner lift at the junction of the crown and the sides, and is generally assumed to include the top row of side plates and the two outer rings of crown plates, together with the curb angles. The top curb thus forms a circle of large diameter and of angular section. It is acted on by four forces varying in magnitude and direction, as follows:

- **First:** The pull of the top sheets acting at the curb, tangential to the sheeting at its junction with the curb, due to the pressure of the gas lifting the holder, \( = S \).
- **Second:** The pressure of the wind on the sides acting horizontally. The wind load is taken at 32lbs. per square foot, or 16lbs. per square foot on the cylindrical surface, \( = W \).
- **Third:** The weight of the side sheeting, etc., acting downwards in a vertical direction, \( = D \).
- **Fourth:** The pressure of the gas from within upon the side sheets, \( = G \).

The curb is shown in Figure 3, together with the direction of the four forces acting on it, and it will be seen that it presents several features not met with in ordinary general struc-

![Fig. 3.—Section of Top Curb](image-url)
spacing of the guide columns and enclosed within the ring of guide framing which is designed to take care of all the forces acting on the holder and transmitted to the individual guide columns through the carriages on the lifts. These carriages have radial and tangential rollers, thus bringing into action any thirteen standards according to the wind direction. As will be explained when the guide framing is under review, the relative effective resistance offered by any standard is proportional to the square of the cosine of its respective angle.
with the wind direction. With the wind blowing from any direction one half the holder will be loaded, but four of the eight loaded bays, together with the eight leeward bays, will be fully supported by the guide framing, leaving four bays only to be considered, and if it is assumed that these four bays are an elastic arch it will be seen that if it starts to deform, one or two of the three remaining unloaded columns will be brought into action, and the arch would be immediately restrained from further deforming. Thus with the sixteen columns round the holder, thirteen will always be in action, the sides and crown being further stiffened by the thirty-two vertical stays extending the full depths of the sides of the lift and rigidly secured to the crown plating, it will be quite enough to design the curb to resist the direct compression due to the four forces acting on it. This agrees with F. Southwell Cripps in his “Investigation into the strains upon the top curb of the gasholder,” and the method adopted by him to calculate the requirements of the curb will be followed here, thus:

Data:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius of Crown</td>
<td>405 feet</td>
</tr>
<tr>
<td>Rise of Crown</td>
<td>7.1615 feet</td>
</tr>
<tr>
<td>Diam. of Inner Lift</td>
<td>length of chord of arc of crown</td>
</tr>
<tr>
<td></td>
<td>151.6667 feet</td>
</tr>
<tr>
<td>Weight of Crown</td>
<td>191,225 lbs</td>
</tr>
<tr>
<td>Area of Inner Lift</td>
<td>18,066 square feet</td>
</tr>
</tbody>
</table>

\[ p = \text{effective pressure of gas.} \]
\[ = \frac{\text{total floating weight of holder} - \text{weight of crown}}{\text{area of outer lift in sq. ft.}} = \frac{60.55 \text{lbs. per square foot.}}{\text{area of outer lift in sq. ft.}} \]

\[ p_1 = \text{actual pressure of gas.} \]
\[ = \frac{\text{total floating weight of holder}}{\text{area of bottom lift in sq. ft.}} = \frac{70.3 \text{lbs. per sq. ft.}}{\text{area of bottom lift in sq. ft.}} \]

The weight in lbs. per foot run hanging on curb
\[ = P = \frac{20,148 \times 60.53}{476.476} = 2,560 \text{lbs.} \]

Half the angle included between the two radii at extremities of the chord of arc of crown = 10° 47' 30"

The stress in the crown sheeting due to the vertical pull of
the holder is tangential to the arc of the crown at the curb and will amount to:—

\[
P = \frac{2560}{\sin 10^\circ 47' 30''} = 13,672 \text{ lbs. per lineal foot.}
\]

and \( S = \frac{13,672 \times \text{diam. of lift}}{2} = \frac{13,672 \times 151.667}{2} \)

\[= 1,036,795 \text{ lbs. stress in one side due to weight of holder.} \]

2. To obtain wind pressure \( W \). The wind pressure is assumed to be 32 lbs. per square foot or 16 lbs. per square foot on the diametrical projection of the lift. The surface acted upon is the diameter of the lift by the upper half of its exposed surface (the pressure on the lower half being transmitted through the cup and dip to the guide framing). The exposed surface will not be the full depth of the lift, as the dip of the next lift will protect the lower 18 in. of the inner lift from the wind pressure. To provide for the wind in the carriages, hand-railing, and other projections on the lift, the exposed surface is assumed to be 17.5 feet deep or half the depth of the lift.

then \( W = 151.667 \times 17.5 \times 16 = 42,466 \text{ lbs.} \)

This figure must be divided between the two sides of the curb diametrically opposite, then \( 42,466 \div 2 = 21,233 \text{ lbs.} \)

3. To obtain weight of sides, \( D \).

\[P = \frac{2,560 \times 151.667}{2} = 194,133 \text{ lbs.} \]

4. To obtain the pressure of the gas, \( G \), on the sides. This is a force that should be taken into account, but what portion of the total amount to allow for is purely a matter for conjecture. F. S. Cripps states “that perhaps one-fifth of the total tension, on the side sheets of the inner lift only, would do for stays rivetted up the sides, and one-eighth for stays rivetted only at top and bottom, certainly not more than this. For if we take a thin cylinder and subject it to the external forces acting only at the top and bottom edges, we find that the upper and lower portions of the cylinder may suffer great deformation without making a very appreciable difference in the body or centre part.”
The total tension on the sides =
\[ \pi \text{ as previously found} \times \text{diam. of lift} \times \text{depth} \]
divided by the constant (in this case 8),
multiplied by 2 (for the two sides).

\[ G = \frac{70.3 \times 151.6667 \times 35}{2 \times 8} = 23,323 \text{lbs.} \]

Tabulating the magnitude and direction of the four forces we have:

1 = S = 1,036,793 lbs. acting upwards at 10° 47' 30"
with the horizontal.

2 = W = 21,233 lbs. acting horizontally inwards.

3 = D = 194,133, ,, ,, vertically downwards.

4 = G = 23,323 ,, ,, horizontally outward.

The forces W and G are horizontal, but the resultant of the two forces S and D must be found, this resultant solved graphically in Fig. 5 is also shown to be horizontal. The vertical equivalent of S is P = 2,560 lbs. weight per lineal foot on the curb. Then the resultant of S and D = Q = D \times \cot. 10° 47' 30''', then Q + W - G equals 1,018,464 + 21,233 - 23,323 = 1,016,374 lbs., or 454 tons total compression in the top curb on one side, which agrees with the graphic solution.

It is very difficult to determine how much of the gasholder sheeting should be included with the top curb in apportioning
the sectional area. F. S. Cripps says, "Perhaps a fair allowance to make is to assume the two outer rows of the top, and the top row of sides as forming part of the curb in the strong plate curbs of large holders of good design." This is undoubtedly a safe allowance, and experience has shown that the curbs designed on this assumption have proved quite adequate for the work they have to do.

The selected sections are:

Two 6in. x 6in. x \(\frac{1}{6}\)in. angles.
One 4ft. 4\(\frac{2}{3}\)in. x \(\frac{1}{4}\)in. plate with butt joints in outer ring of crown.
One 2ft. 8\(\frac{7}{16}\)in. x \(\frac{1}{2}\)in. plate with \(\frac{1}{4}\)in. double rivetted lap in second row of crown.
One 2ft. 9\(\frac{3}{8}\)in. x \(\frac{1}{8}\)in. plate with \(\frac{1}{8}\)in. double rivetted lap in top row of sides.

Gross sectional area of

Two 6in. x 6in. x \(\frac{1}{6}\)in. angles = 14.22 square inches.
One 5\(\frac{2}{3}\)in. x \(\frac{1}{4}\)in. plate = 26.31

Total = 40.53

In the two \(\frac{1}{8}\)in. plates there will be forty-four \(\frac{3}{8}\)in. diameter rivets in single shear, allowing a safe shear per rivet of 2.65 tons we get 2.65 \times 44 = 116.6 tons taken up by the rivets. The compression in curb is 454 tons, and 454 - 116.6 = 337.4 tons to be resisted by the sectional area of the two angles and \(\frac{1}{8}\)in. plate = 337.4 \div 40.53 = 8.3 tons compressive stress per square inch.

CROWN SHEETING:

The stress in the crown sheeting was found to be 13,672lbs., or 6.1 tons per lineal foot; assuming \(\frac{3}{8}\)in. diameter rivetting at \(1\frac{2}{3}\)in. pitch, there will be 8.72 rivets per lineal foot, and considering the rivet holes as \(\frac{1}{8}\)in. diameter, the net length of solid plate will be 12in. - 8.72in. \times \(\frac{1}{4}\)in. = 7.64in. Assuming 7.5 tons per square inch as the safe tensile strength, then 6.1 \div 7.5 = .8 square inches of steel required. This implies a sheet 3/32in. thick, but to be on the safe side, especially as regards corrosion, a sheet of No. 10 B.G. \(\frac{1}{8}\)in. thickness will be adopted. The safe shear for a \(\frac{3}{8}\)in. diameter rivet is .66
tons, therefore $8.72 \times .66 = 5.72$ tons safe shear per lineal foot in the rivets.

The sheets will be arranged radially in nine rings, the width of each ring being 7ft. 6in., the sizes of the sheets being such as can be conveniently handled, at the same time reducing the rivetting as much as possible. The circular sheet in the centre of the crown will be $3/16$in. thick, and the ring adjoining the curb plates will be $\frac{1}{4}$in. thick.

**VERTICAL STAYS:**

Much of the successful working of a gasholder is due to the correct design of the vertical stays and their ability, especially those in the inner lift, to resist the tendency of the heads of the lifts to pull inwards when the holder is inflated. These stays are commonly made very light, and indeed some engineers have condemned the aiming of great stiffness in their design. It is certain that for the first ten years or so of their life holders of very light construction do, in fact, work satisfactorily, but the real test comes at the time when the holder should be considered as being in its prime, and then too often they are found to be in a state of general decrepitude. The writer is of the opinion that no economy can result by reducing material from the vertical stays.

The inner lift stays require more rigid construction than those in the other lifts, because they act as brackets between the crown and the sides, and when made of a lattice box type of section, the loading is transferred down the four corner angles, imparting to the stay itself a tendency to resist the pulling in of the crown as the weight comes on to it, the resistance increasing as each successive lift comes into play. It is not during their working life that the stays are most severely stressed, but during the period of erection when they may receive such severe accidental stresses as to nearly cripple them, though this may be unnoticeable at the time. Frequently a track is laid on the dips and curb to carry the sheer legs used in erecting the guide framing, and the weight of these legs together with the piece they are lifting may be anything up to ten tons. These stays are "long columns," in this case 35ft. long, and though they are rigidly secured to the top and bottom strong rings, can be by no means considered as fixed or square ended columns. The inner lift stays are (being the
GAS HOLDER CONSTRUCTION.

most important) always made the heaviest, there being no space restrictions regarding their section.

The usual practice of providing twice as many stays as there are columns in the external guide framing requires that thirty-two stays to each lift should be provided, so arranged that sixteen are placed opposite the columns, the remaining sixteen being spaced between. This arrangement places the stays at the points of attachment of the whole of the guide carriages and rollers, ensuring rigidity. In the inner lift, tapered box section lattice stays are suggested, formed of 3in. x 3in. x ½in. corner angles, with 3in. x 3½in. flat lattice bars. The heads of the stays are rivetted to the ½in. crown plate, to the 6in. x 6in. x ½in. curb angles and to the two upper rows of side plates, the feet being rivetted to the lower ring of side plates, the whole of the rivetting at the points of attachment of the stays being sufficient to carry the whole weight of the holder. It will be seen that these stays, considered as columns, have a great reserve of strength over and above any possible loading that may be brought on to them.

The stays in the outer lifts also provide guide paths for the rollers fixed to the underside of the cups in addition to acting as columns; further, their section is limited by the fact that there is only 6in. between the cup skirting plates and the sides of the adjoining lifts, and of this 6in., at least 2½in. must be left for clearance. The stays selected are a compound section composed of a 9in. x 5½in. x 25.39lbs. channel with a 3½in. x 2in. x 6.75lbs. channel rivetted to each flange. They will be considered as round ended columns having a length equal to the distance between the top and bottom rings of plates, which is 29ft. 6in. or 354in. A factor of safety of six will be used. Then from Rankine Gordon's formula:

\[
p = \frac{5}{l^2} + \frac{8000r^2}{1 + \frac{8000r^2}{1^2}}
\]

where \( p \) = safe load in tons per square inch,
\( l \) = length of column in inches,
\( r \) = least radius of gyration of section, in this case 1.2.
Then:

\[ p = \frac{5}{1 + \frac{354}{8000 \times 1.2^2}} = 0.42 \text{ tons safe load per sq. in.} \]

The area of the section is 11.2 square inches, so that each stay will safely carry 5 tons, which is ample for all purposes of erection.

The 9in. x 3\(\frac{1}{2}\)in. channels acting as guides for the cup carriages are extended 12in. below the cup, the smaller channels being stopped at the bottom of the lift.

**CUPS AND DIPS:**

The cups and dips on any lift perform three duties:

First: As an attachment whereby each inner lift picks up the next outer lift.

Second: As structural members resisting the wind forces and carrying the weight of the lifts greater in diameter to itself.

Third: As a hydraulic seal deep enough to provide a depth of water in excess of the greatest pressure thrown by the holder.

Dealing with the cup and dip first as a structural member it is found that there are three forces acting on it:

First: The weight of the outer lifts —
Second: The wind pressure —
Third: The pressure of the gas within.

The cup of the inner and the dip of the second lift only will be analysed, as their sections will be adopted for each lift.

The wind pressure on the lower half of the inner lift and the upper half of the second lift = 82,052lbs., and it is resisted by the cup and dip. The pressure of the gas within acting on the surface of the cup and dip = 26,144lbs., then 82,052 - 26,144 = 55,908lbs. = 25 tons or 12\(\frac{1}{2}\) tons per side. This is very small, requiring only two square inches of metal, to take care of the compression, and may be well neglected, as for prac-
tical purposes the cups and dips are made of such size that their sectional area will provide an excess of metal over all requirements.

The selected sections of the cup and dip will be considered before dealing with the effect of the weight of the sides. The distance between the sides of the adjacent lifts being 1 ft. 5 in., the cup is formed of a 10 in. x 3\(\frac{1}{4}\) in. x 28.21 lbs. channel, and the inverted channel at the head of the dip is 11 in. x 3\(\frac{1}{2}\) in. x 29.82 lbs. channel. On the projecting flanges of these channels is rivetted 5/16 in. skirting plates 18 in. deep, having 2\(\frac{1}{4}\) in. x 3\(\frac{1}{4}\) in. flat beading rivetted round their projecting edges. This arrangement ensures that there is at least 2\(\frac{1}{4}\) in. clearance everywhere.

The cups and dips transmit the loading from lift to lift, the channels acting as cantilevers; the most severe bending stresses occurring at the attachment of the channels to the side plating where they are rivetted to the 5/16 in. plates through a single row of 3\(\frac{1}{4}\) in. diam. rivets 2\(\frac{1}{4}\) in. pitch.

Investigation shows that the webs of the channels will be stressed to about ten (10) tons per square inch (when all four lifts are cupped) considering the channels as cantilevers and neglecting the bending in the side plating.

To ascertain the bending stresses in the side plates is a complex problem, though it is obvious that the amount will be much more than that in the cup and dip channels. It is therefore arranged to reduce the bending stresses as much as possible by rigidly attaching both cup and dip channels to the vertical stays.

In the case of the cup channels the attachment is made through the cheek plates of the cup rollers, which are rivetted to the underside of the cup and to the backs of the vertical stays; the dip channel is connected to the vertical stays through cleats which are attached to the front flanges of the stays. In this manner the amount of bending in the channels between the stays is very much reduced, and at the stays themselves, there will be little, if any, bending stresses, provision only being made for the shearing stresses.

The ring of side plates at the head of a lift to which the dip channel is attached, and the bottom ring of plates to which the cup channel is rivetted, is considered as being portion of
the cup and dip. These rings in this holder are uniformly 5/16in. thick.

The dip skirting plate besides projecting downwards 18in. into the cup, is also extended upwards 10in. above the lift, its upper edge being reinforced with a 2½in. x ½in. flat bead. This extension provides a deeper seal and acts as a wind guard to the water in the cup.

SIDE SHEETING:

The side sheeting of each lift is made of uniform section, and the lines of the sheeting are so arranged that when the holder is fully inflated they present continuous vertical lines. The sheets are made as large as possible, compatible with ease of manufacture, in order to reduce the amount of riveting. The average size of sheet suggested is 3ft. 3in. wide by 7ft. 8in. long over rivet centres.

In the inner lift the two top rings are ½in. and ⅛in. thick respectively, the bottom ring being 5/16in. thick. In the second and third lifts the top and bottom rings are 5/16in. thick, and in the outer lift the top ring is 5/16in. thick and the two bottom rings ¾in. and ⅛in. thick respectively. The whole of the remainder of the sheeting is No. 10 B.G. ¼in. thick. As stated before this sheeting has no duty to perform beyond retaining the gas, and a thinner sheet would have done for that purpose, but in view of the possible corrosion the use of heavy sheeting saves trouble and loss due to a multitude of small leaks, of which from the huge surface area of the holder, there is always an ever present possibility.

BOTTOM CURB:

The lower edge of the outer lift, not being provided with a cup, needs a stiffening ring or curb. This curb will consist of a pair of 6in. x 4in. x ½in. angles spaced apart 15in. over their backs and rivetted to the ½in. ring of plates through their 4in. leg. The wind pressure acting on this curb will be 44,800lbs., the pressure of the gas within being 33,600lbs., leaving about 5 tons excess wind pressure to be provided for on the two sides. This requires, theoretically, only about one-half square inch of metal each side, but in practice the curb is made with an excess of metal, the amount of excess metal depending on
the judgment of the designer, who has certain forces of unknown magnitude to guard against—such as racking or wedge action of the lifts, etc.

GUIDE CARRIAGES:

Knowing the design of the various lifts and the tank, and the main working dimensions of the structure, the guide carriages will be taken next in order, and their design will, to a large extent or perhaps wholly, determine the construction of the external guide framing. Each lift is provided with guide carriages at both its upper and lower ends. In the three inner lifts the top carriages are external and the bottom carriages internal, the whole of the carriages on the outer lift being external.

The tank guides and vertical stays in the three outer lifts have been referred to as providing roller paths for the bottom carriages; of these the construction and fixing will be considered first. The depth of the tank exceeds that of the lifts, there being a space of 15in. between the underside of the cups and the tank bottom. As the bottom carriages on the three inner lifts are fixed directly to the under side of the cups, they must not be more than 12in. over all, thus allowing a clearance of 3in. between them and the tank bottom. Very often a clearance of only 1in. is allowed between the bottom carriage roller and the tank bottom, but this is too little in many cases, for in the course of time sediment collects in the bottom of the tank, especially in exposed dusty situations, and at times an unexpected collection of debris is met with. It will be readily seen that when, as usually happens, the sediment, etc., tends to collect on one side only, a severe strain is put upon the holder when landing on the rest blocks, and the breaking of the rollers on that side may result. The requirements then are, a fair working clearance, and sturdy construction of the roller carriages.

The carriages are composed of two 3in. flanged plates rivetted directly to the cup channels and to the extended portion of the 9in. x 3¼in. channel in the vertical stays. These plates are slotted to carry a 1½in. diameter turned steel axle on which is mounted a 12in. diameter cast iron roller, and the axle is provided with an adjusting screw at each end. These adjusting screws, of course, cannot be attended to when the
holder is in action, as the carriages are inside the holder, but they are used during the testing of the holder with air, and men on rafts inspect each carriage as each lift rises from the water, making any necessary adjustment. The outer lift bottom carriages are mounted outside the lift and on top of the top angle in the curb. The usual position for these carriages is between the bottom curb angles, with the centre of the axles about 6in. or 7in. above the bottom of the lift.

The highest position of the bottom curb of the outer lift is governed by the maximum holder pressure. In this case with a pressure of 13½in., the bottom of the lift will never rise nearer the surface than 13½in., so that the axles of the carriages, were they placed between the curb angles, would in the most favourable conditions be 7in. below the water level, and would further be rendered virtually inaccessible by the projection of the flange of the curb angle above them. In the case under review the bottom carriages are placed on the top angle in the curb, which is 15in. deep, thus ensuring that the whole of the carriage is out of the water when the holder is fully inflated, and that the axle is 6½in. above the water level, thus permitting of inspection and adjustment. The cheek plates of these carriages are ¾in. thick, flanged and rivetted to the curb angle and to the vertical stay at the back. The axles are 1½in. diameter working in slots, the inner end of the slot being enlarged to permit of the withdrawal of the axle and render the replacement of a roller an easy matter. The cast iron rollers themselves are 10in. diameter.

**Top Carriages:**

Though all the carriages throughout the holder are of equal importance and require the same care and attention to detail, those on the tops of the lifts, from their size and the fact that they determine to a great extent the character of the guide framing, require extreme care in study. The top carriages are not, within certain limits, restricted to size as are the bottom rollers, as they are situated outside the holder, but, on the other hand, sixteen top carriages have to do the same amount of work that 32 bottom carriages have to perform. There must be the same number of top carriages on each lift as there are columns in the external guide framing; in this case, therefore, there will be four top carriages at every column, so de-
signed that when the lifts are down on the rest blocks the sixteen sets of carriages will nest within each other. The outer lift carriages, though having the heaviest individual roller loads, are the smallest, while the inner lift carriages are, considering the work they have to do, comparatively large affairs. Each carriage will be provided with three cast iron rollers, one being fixed radially and working directly against the front face of the guide, the other two being fixed one each side of the radial roller and at right angles to it, tangential to the lift, and working against the side flanges of the guide. This arrangement ensures that thirteen of the carriages will be in action, whatever the direction of the wind, as against four if the radial rollers only were used, thus resulting in a marked economy in the materials in the guide framing.

All the tangential rollers in each lift will be 15in. diameter, working on 2\(\frac{1}{4}\)in. diameter turned axles, contained in 5in. square cast iron bearings 12in. long. These bearings are held in position in boxes formed of a steel plate and channel rivetted to the sides of the carriages. There is ample allowance for adjustment left in these boxes, effected by an adjusting screw at one end. The bearings are locked in position by means of four 1\(\frac{1}{4}\)in. diameter tap bolts.

The radial rollers on the inner lift are 20in. diameter, and on all other lifts 15in. diameter. These rollers work on 2in. diameter axles held in slotted holes in the cheek plates of the carriages, and each axle is provided with two 1\(\frac{1}{4}\)in. diameter adjusting screws for adjusting the roller to its correct position. One little point which is worth attention is that all slotted holes for roller axles throughout this holder have their inner ends enlarged \(\frac{1}{4}\)in. beyond the diameter of the roller axle, so that the carriages may be rivetted up complete and the rollers added afterwards, or, when the holder is working if it is ever necessary to replace a roller or an axle, this may be done with perfect ease.

The outer lift carriages are placed on the top of the dip instead of being fixed at the sides as is often done. There is an objection to the latter position with tangential—or for the matter of that—for any guiding, as the space is so restricted.

The outer lift carriages merely consist of a pair of 3in.
shaped cheek plates with their lower edges flanged for riveting to the dip channel.

The carriages on the three inner lifts are box section, formed of 3/16in. plates and 3in. x 3in. x 3/8in. corner angles. The carriages on the two inner lifts have diagonal stays secured to their heads and extending back to the lifts. This is a necessity due to the overhang. The inner lift carriage is provided with steps up the back to give easy access to the rollers. To give an idea of the size the carriages on the inner lift run to on a multiple lift holder, it is pointed out that the centre line of the axles of the inner lift rollers in this holder in their normal position is 4ft. 5 19/32 in. out from the face of the lift and 5ft. 3 1/2in. above it, the carriage complete weighing 20 4/8 cwt.

All the rollers throughout the holder should have their faces machined and have solid webs, and the top carriage rollers are all provided with grease cup lubricators.

LANDINGS:

In this holder landings are provided on the three inner lifts so arranged that access to each of these lifts can be obtained at any position of the holder. The provision of landings on any lift but the inner lift is unusual, but when it is considered that the successful operation of any piece of plant depends upon the careful inspection and the attention bestowed upon it, there is no reason why the roller carriages, upon which the successful working of the holder depends, should be inaccessible. It may be said that if the inner lift is provided for, the other lifts can be attended to when they land in the tank. That may be so, but it can be taken for granted that when the inspection and lubricating of the rollers is not carried out at definite stated times, but depends upon the lifts being landed on the rest blocks, and the inner lift but partially full, then they will never get attention. The man whose duty it is to attend to them will probably be engaged elsewhere at the time, and be ignorant of the fact that the holder is down. The three landings are arranged to telescope within each other as each lift comes down. The dip of the outer lift is not provided with a landing as, even when it is in its highest position, it can be easily reached from the guide framing. In conjunction with the landings there is provided round the head of each lift a
double line of handrailing, formed of \( \frac{3}{4} \) in. diameter gas-tubing, carried by steel angle standards.

**Manholes:**

Two manholes should be provided in the crown and two in each of the sides for erection and inspection purposes.

Over the inlet and outlet pipes should be fixed a Livesey manlid (so named after its inventor, Sir Geo. Livesey), for the purpose of giving attention to the inlet and outlet pipes during the working of the holder without clearing the crown of gas. This manlid consists of a rectangular box rivetted to the underside of the crown, having an open bottom, and large enough to enclose the heads of the pipes, a luted seal is provided on one side of this box with a connection for flooding it and pumping it out. The important point in connection with this manlid is that the box should be made deep enough to project into the tank at least 2 ft. 6 in. when the lift is down. This is necessary because the crown contains a large quantity of gas, and apart from the monetary loss, the trouble and risk in cleaning the crown from gas, and afterwards from air, requires that the gas be left in the crown if possible.

To use the manlid the inner lift is lowered to about 12 in. from the rest blocks, and the lute on the side of the manlid filled with water. The lute being sealed and the lower edge of the manlid projecting into the water of the tank, the covers can be safely taken off and access made to the pipes.

With the gas in the crown the bottom of the lift should not be allowed to get nearer than 12 in. to the rest blocks. If less than this, a sudden drop in the temperature will contract the gas and lower the lift on to the rest blocks, and a partial vacuum may be formed, wrecking the crown. With the holder 12 in. from the bottom there should be a seal of 18 in. left to provide against a sudden rise of temperature expanding the gas and raising the holder, and the danger of asphyxiating any workmen who might be engaged in cleaning out the pipes.

**Blow-off Valve:**

A 6 in. gas valve should be placed in the centre of the crown to allow the air to be expelled when the holder is put into action.
Joints (Rivetted):

The rivetting in the holder and tank, through plates 3/16in. thick and upwards, and in the attachment of the structural members varies according to requirements from ½in. to ¾in. diameter. These rivets are driven hot with power hammers. All joints between plates, and between plates and sections, where required to be gas and watertight, are made metal to metal and caulked. The joints between the No. 10 B.G. sheets are made with a strip of tape the full width of the lap, inserted between the sheets, the tape being previously soaked in boiled linseed oil and red lead. The rivetting in the crown sheeting is $\frac{3}{16}$in. diam. $\frac{1}{8}$in. pitch, $\frac{1}{2}$in. lap, and in the side sheeting it is 5/16in. diam. $\frac{3}{8}$in. pitch, $\frac{1}{4}$in. lap. These rivets are knocked down cold by hand.

Curved Work:

All curved work in the gasholder such as the top and bottom angle curbs, cup and dip channels, etc., should be curved by first heating in a furnace and then placed on a plate floor and brought to its proper shape against the template by hammering with wooden mauls.

Testing of Holder.

On completion the holder should be tested by inflating it to its full height with air, at least three times, the holder being left standing for a minimum period of three days after each inflation before lowering it again. To be passed for soundness it should stand without showing any appreciable drop, due allowance being made for changes of temperature. During each inflation every joint and rivet would be washed with a soap and water solution for the purpose of detecting leaks.

An air lock should be fixed, preferably on the crown, to enable access to be made to the interior, and men on rafts should carefully examine the cup rollers as they emerge from the water in the tank, making any adjustments that may be necessary. This latter examination is not always carried out, but there can be no doubt as to the wisdom of this course, as this is the only time in the working life of a gasholder when the cup rollers can be observed under actual working conditions.
GUIDE FRAMING.

GENERAL:

Though the three main components of the completed structure, i.e., the tank, gasholder and guide framing, are of equal importance; the latter on account of its greater prominence generally has the most attraction for the engineer. It presents, when standing alone, a light and often graceful appearance, changing to an imposing mass when the holder is fully inflated. The untrained casual observer probably stigmatises a gasholder as being a blot on the landscape, but the trained engineer, looking further than for mere decorative effect in a structure that it is impossible to apply decoration to, will see in a well-proportioned holder a certain dignity of purpose. The guide framing alone offers the designer any scope to relieve the mass of the holder itself, and the structure formed entirely of lattice members has a good appearance under all conditions.

The number of standards, sixteen, suggested for this holder would appear, at first sight, to be on the low side. The most important point is to take care that the horizontal struts are so situated that they allow sufficient room for the lifts to pass them freely. The usually accepted rule in proportioning the number of standards is to keep the length of the horizontal struts from about 22 to 25 ft. This condition would require twenty standards in the framing.

Box section horizontal struts are suggested, having an average length of about 31 feet when sixteen standards are provided. As will be shown later in this paper the sections composing these struts are the minimum consistent with practical working conditions, and reducing their length to 25 feet would not mean any saving in material. The introduction of four extra standards in the framing would effect little, if any, saving in the weight of the standards. On the other hand the provision of four extra piers in the tank walls, the erection costs of four additional standards, twenty extra struts and four bays of bracing, would amount to a large sum. Again 32 extra carriages and 32 extra vertical stays would be required in the holder without giving any commensurate advantage.

This proves that the accepted rule quoted above requires to be used with a certain amount of caution, and that careful
trial should be made before deciding the general proportion of the framing. Probably the best rule is to find the polygon having the least number of sides that will safely contain the proposed holder, without any side fouling the lift.

**NOMENCLATURE OF MEMBERS:**

The outline diagram, Fig. 6, shows the main members of the framing with their positions and designation.

- **A** = The standards (These have been referred to as columns, but from now on their correct term will be employed).
- **B** = The horizontal struts.
- **C** = The diagonal bracing.
- **D** = The horizontal system of wind bracing round the heads of the standards.

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Fig. 6.—Diagram of Guide Framing.
GAS HOLDER CONSTRUCTION.

CALCULATION OF LOADS ON THE GUIDE FRAMING:

There are several methods in vogue for apportioning the loading on, and calculating the stresses in a guide frame; but probably the most rational as well as the most direct method was presented by E. F. Miller in a paper entitled "Guide Framing of a Gasholder," appearing in the "Engineering News" of the 30th November, 1911. Following the method described in that article the writer had the pleasure of designing a holder of about 1½ million cubic feet capacity for West Melbourne Works some three years ago, and the economical construction as well as the good appearance of that holder resulting from following generally the use of E. F. Miller's methods referred to, leads him to believe that few, if any other, methods are superior to it.

Of course the combination of radial and tangential guide rollers on the holder are the most important factor in the economical design of the framing, though the use of tangential rollers still seems to be a contentious point among some engineers to-day. Had radial guiding only been adopted in this holder, there could never be more than five standards in action at any one time resisting the wind forces, but with a combination of radial and tangential guiding thirteen of the sixteen standards are brought into action. With carefully designed roller carriages such as are designed for this holder, the extra cost of providing for the tangential rollers is small, while it is obvious that a very appreciable saving can be effected in the weight of a system of framing, employing 13/16 of the available standards as against a similar framing employing 5/16 of its total number to do the same work under the same conditions.

It is not the usual British practice to provide tangential rollers on any except the largest holders, but the writer is of the opinion that tangential guiding can be profitably employed on small holders, say from 100ft. diameter upwards, especially where more than two lifts are provided.

When the two systems of rollers are used together, the holder can be levelled and adjusted at any time with a certainty and precision lacking in any other system, with a corresponding good effect on its subsequent working life.

The forces which a guide framing must resist are those due to the pressure and impulses of the wind, together with the
unbalanced weight of the bell. This latter force is usually neglected, as the gasholder is designed, as shown in the preceding pages, to be of uniform weight and section throughout its circumference, and any unbalanced condition is purely accidental and impossible of calculation, its effect being considered as fully covered by the factor of safety employed. A third force obtaining in colder latitudes is that of the unbalanced snow load; here fortunately we are able to disregard it. The wind is the only powerful distorting force to be considered, and we have to study its effects on the framing with reference to the varying degrees of inflation of the holder. Where the latter is standing from three-quarters to its full height, there is little danger of distortion of the guide framing, provided that the members are correctly designed and are strong enough to resist the direct load, because the wind does not act with positive continuous equal pressure over the whole of a large surface, such as is presented by a gasholder, but rather its effect is that of a number of rapid impulses of short and varying duration from several directions. It is improbable that these impulses would strike the same spot from the same direction with any regular periodicity, and therefore they cannot quickly overcome the inertia of a large holder which would, as it were, store up the accumulation of loads and transmit them to the guide framing as a fairly continuous force. It is when the guide framing is standing alone that there is a great danger of accumulation of loads due to the vibration caused by the impulses of the wind, and a succession of blows may have a cumulative effect, short period vibrations setting up local stresses in excess of the static calculations. When repeated or prolonged, these local excessive stresses are more destructive to details than the maximum calculated stresses. An efficient design of wind ties at the heads of the standards will largely promote the preservation of its figure and reduce the amplitude of the vibrations.

A guide frame may be considered as a thin cylinder anchored at its base and kept in shape at its top, but in the middle its tendency to buckle or change its shape is resisted only by the rings of horizontal struts and by the standards considered as beams. The struts in this holder are 30in. square in the central rings, while the depth of the standard
radially at the critical point is nearly 4 ft., so that the wind-tie system at the top must be deep and efficient.

E. F. Miller says: "Many guide frames are built without wind ties, but a sufficient rigidity of the top of the frame can be ensured more economically by the use of wind ties than in any other manner. Here it must be remembered that it is impossible to load and test a gasholder frame as a bridge or floor may be tested, and it is not probable that one in a thousand frames is ever subjected to a load as severe as is assumed in the calculations. For this reason guide frames of defective design may have a long and useful life and be repeated, having the approval of experience."

The wind loads have been calculated on a horizontal wind pressure of 32 lbs. per square foot on a normal plane surface, or 16 lbs. per square foot on the diametrical projection of a cylindrical surface. The pressure would, of course, be subject to local conditions. The Melbourne Building Regulations, for instance, call for provision for a 25 lb. to the square foot wind pressure.

**Calculations of Load and Stresses.**

**Main Dimensions:**

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<tr>
<th></th>
<th>Diameter.</th>
<th>Depth.</th>
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<tbody>
<tr>
<td>Inner lift</td>
<td>15 ft. 8 in.</td>
<td>35 ft.</td>
</tr>
<tr>
<td>Second lift</td>
<td>15 ft. 4 in.</td>
<td>35 ft.</td>
</tr>
<tr>
<td>Third lift</td>
<td>15 ft. 4 in.</td>
<td>35 ft.</td>
</tr>
<tr>
<td>Outer lift</td>
<td>16 ft. 2 in.</td>
<td>35 ft.</td>
</tr>
<tr>
<td>Tank</td>
<td>16 ft. 0 in.</td>
<td>36 ft. 3 in.</td>
</tr>
</tbody>
</table>

**Guide Frame:** 16 standards, 152 ft. 1 in. high with five rings of horizontal struts. Each lift is guided on the standards by sixteen carriages, each carrying one radial and two tangential rollers. To determine the general loads on the guide frame, it is sufficient to calculate the total load at the top of each lift; but to design the section of standards, the maximum load on the individual rollers must be ascertained. This is figured as below.

All the rollers standing at an angle of less than 60° with the direction of the wind, and so located that any horizontal movement caused by the wind will be towards the guide, are assumed to be effective, and to carry loads proportional to the
cosines of their respective angles with the wind direction. The effective resistance of these rollers to horizontal translation (due to their reaction against the guide frame) is also proportional to the cosines of the angles. Therefore, the relative effective resistance offered is proportional to the squares of the cosines of the respective angles with the wind direction. It is evident that the radial roller directly in line with the wind and the tangential rollers at right angles will carry the greatest loads.

Fig. 7.—Diagram Showing Guide-rollers in Action.

Radial Rollers

<table>
<thead>
<tr>
<th>cosines² 0 degrees</th>
<th>Radial Rollers</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>2 * 0.92387²</td>
<td>1.707</td>
</tr>
<tr>
<td>2 * 0.707106²</td>
<td>2.000</td>
</tr>
</tbody>
</table>

Tangential Rollers

<table>
<thead>
<tr>
<th>cosines² 22½ degrees</th>
<th>Tangential Rollers</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 * 0.92387²</td>
<td>3.414</td>
</tr>
<tr>
<td>4 * 0.707106²</td>
<td>2.000</td>
</tr>
</tbody>
</table>

Fig. 7.—Diagram Showing Guide-rollers in Action.
It is thus seen that the total horizontal load at any ring of carriages divided by 11.121 will be the maximum roller load, which is also the maximum central load a standard must carry either radially or tangentially.

The roller pressures are as follows:

The horizontal load on the carriages on top of inner lift is:

Diameter of inner lift by half depth of lift by 16.

\[ = 151.6667 \times 16.75 \times 16 = 40,647 \text{lbs. total load.} \]

The maximum load on individual rollers at top of inner lift is:

\[ 40,647 \div 11.121 = 3,655 \text{lbs.} \]

The horizontal load on carriages on top of second lift is:

\[ 40,647 + 154.5 \times 16.75 \times 16 = 40,647 + 41,405 = 82,052 \text{lbs.} \]

The maximum load on individual rollers at top of second lift is:

\[ 82,052 \div 11.121 = 7,378 \text{lbs.} \]

The horizontal load on carriages on top of third lift is:

\[ 41,405 + 157.3334 \times 16.75 \times 16 = 41,405 + 42,165 = 83,570 \text{lbs.} \]

The maximum load on individual rollers at top of third lift is:

\[ 83,570 \div 11.121 = 7,515 \text{lbs.} \]

The horizontal load on carriages on top of fourth lift is:

\[ 42,165 + 160.1667 \times 16.875 \times 16 = 42,165 + 43,245 = 85,410 \text{lbs.} \]

The maximum load on individual rollers at top of fourth lift is:

\[ 85,410 \div 11.121 = 7,680 \text{lbs.} \]

In transferring the figured loads from the carriages to the guide frame, the front flange of the standard is considered as carrying the maximum tangential roller load as a beam loaded in the centre. The maximum individual load = 7,680lbs. from the fourth lift top carriage.

Acting in centre of bay:

\[
\frac{7,680 \times 30 \times 12}{2240 \times 4} = 308.55 \text{ maximum B.M. inch tons.}
\]

Assuming a safe fibre stress of \(7\frac{1}{2}\) tons per square inch requires a Sec. Mod. = \(308.55 \div 7.5 = 41.14\). A 10in. x 6in. x 42lbs. R.S.J., with a Sec. Mod. of 42.3 satisfies the conditions; but a 12in. x 6in. x 44lbs. R.S.J. with a Sec. Mod. of 52.55 is so little heavier that it should be used, as it will, under the worst con-
ditions, be only stressed to 5.87 tons per square inch. This section will be adopted for the front flanges.

The figured deflection for this beam appears to be about \( \frac{1}{6} \) in., but as the beams are really continuous beams over the several lines of horizontal struts, and further as each beam is stiffened up on its web by the two lines of \( 3 \frac{1}{2} \) in. x 3 in. x \( \frac{3}{8} \) in. angles, and the figured wind loads are never likely to be realised, it is pretty certain that the actual deflection under the most severe conditions will not be much more than about \( \frac{1}{8} \) in. This would only be a momentary deflection, and as there is \( \frac{1}{8} \) in. clearance allowed between the tangential rollers and the R.S.J. = to \( \frac{1}{4} \) in. on one side, the guiding of the holder is not likely to suffer. The section of the standard is shown on Fig. 8.

![Section of Standard](image)

The 12 in. x 6 in. x 44 lbs. R.S.J. will be connected to the back flange of the standard by means of a continuous pair of \( 3 \frac{1}{2} \) in. x 3 in. x \( \frac{3}{8} \) in. steel angles rivetted to the back of its web.

**Calculations for Maximum Stresses in Back Flanges of Standards, Diagonal Ties and Horizontal Struts.**

In order to ascertain the maximum stresses in the back flanges of standards, diagonal ties and horizontal struts, the carriage loads must be distributed to the panel points, by considering each section of the standard as a beam (supported by the horizontal struts) upon which the loads act.

In addition to the loads from the carriages there are further small loads due to the wind pressure against the standards standing normal to the wind.

*The width of the surface of the standards acted on will be assumed as 4 ft. wide.*
Fig. 9.—Stress Diagram of Guide Framing and Holder Lifts.
Load distributed to top of first bay.
  Horizontal load from carriages = 40,647 lbs.
  " " " wind on standards =
  \(2 \times 4 \times 30 \times 32\)
  = 3,840 "
  Total max. horizontal shear = 44,487 "

Load distributed to top of second bay.
  Horizontal load from standards = 7,680 lbs.
  Max. horizontal shear from above = 44,487 "
  Horizontal load from carriages
  \(\frac{82,052 \times 65}{361}\) = 14,774
  Then 82,052 - 14,774 = 67,278 "
  Total maximum horizontal shear = 119,445 "

Load distributed to top of third bay.
  Max. horizontal shear from above = 119,445 + 14,774 = 134,219 lbs.
  Horizontal loads on standards = 7,680 "
  Horizontal load from carriages
  \(\frac{83,570 \times 124}{361}\) = 28,705
  Then 83,570 - 28,705 = 54,865 "
  Total max. horizontal shear = 196,764 "

Load distributed to top of fourth bay.
  Max. horizontal shear from above = 196,764 + 28,705 = 225,469 lbs.
  Horizontal load from standards = 7,680 "
  Horizontal load from carriages
  \(\frac{85,140 \times 183}{361}\) = 43,159
  Then 85,140 - 43,159 = 41,981 "
  Total max. horizontal shear = 275,130 "

Load distributed to top of fifth bay.
  Max. horizontal shear from above = 275,130 + 43,159 = 318,289 lbs.
  Horizontal loads from standards = 7,680 "
  Total max. horizontal shear = 325,969 "
GAS HOLDER CONSTRUCTION.

The guide framing acts as a whole, similarly to a hollow cylinder fixed at its lower end and loaded as a cantilever beam. One diagonal tie in each bay (except those bays that happen to stand in planes normal to the wind) is active as a tension member.

The horizontal component of the load which each diagonal tie receives is proportional to the cosine of the angle of its plane with the direction of the wind, but its resistance in a direction parallel to the wind is also proportional to the cosine of the angle. Therefore the relative effective resistance of the diagonal tie to the horizontal shear is proportional to the square of the cosine of the horizontal angle.

It is evident that the diagonal ties that stand in the planes parallel to the wind will receive the greatest loads. See Fig. 10.

![Diagram of Bracing Panels](image-url)
VICTORIAN INSTITUTE OF ENGINEERS.

\[
\begin{align*}
2 \cos \theta & = 2 \times 1^\circ = 2.000 \\
4 \cos \theta & = 4 \times .92387^\circ = 3.414 \\
4 \cos \theta & = 4 \times .707106^\circ = 2.000 \\
4 \cos \theta & = 4 \times .38268^\circ = .586
\end{align*}
\]

Total = 8.000 = \frac{1}{2}N.

Where \( N \) = total number of standards. Therefore the total maximum horizontal shear divided by 8, will give the horizontal component of the greatest load on any diagonal tie.

<table>
<thead>
<tr>
<th>Bay</th>
<th>Max. Horizontal Shear lbs.</th>
<th>Divide by 8</th>
<th>Horizontal component lbs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>44,487</td>
<td>8</td>
<td>5,560</td>
</tr>
<tr>
<td>2.</td>
<td>119,445</td>
<td>8</td>
<td>14,930</td>
</tr>
<tr>
<td>3.</td>
<td>196,764</td>
<td>8</td>
<td>24,595</td>
</tr>
<tr>
<td>4.</td>
<td>275,130</td>
<td>8</td>
<td>34,391</td>
</tr>
<tr>
<td>5.</td>
<td>326,969</td>
<td>8</td>
<td>40,871</td>
</tr>
</tbody>
</table>

The direct load thrown on each diagonal tie is the resultant of the horizontal and vertical components as determined by its vertical angle. These resultants are ascertained from Figure 9, and are shown to be as follows:

<table>
<thead>
<tr>
<th>Bay</th>
<th>Diagonal Component lbs.</th>
<th>Vertical Component lbs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>7,250</td>
<td>5,000</td>
</tr>
<tr>
<td>2.</td>
<td>20,000</td>
<td>13,000</td>
</tr>
<tr>
<td>3.</td>
<td>32,500</td>
<td>21,000</td>
</tr>
<tr>
<td>4.</td>
<td>45,000</td>
<td>29,000</td>
</tr>
<tr>
<td>5.</td>
<td>54,000</td>
<td>36,000</td>
</tr>
</tbody>
</table>

DIAGONAL TIES:

Allowing a safe tensile working stress of 12,000 lbs. per square inch, then the diagonals in

No. 1 Bay require \( .6 \) sq. in. net area = 3 in. x \( \frac{3}{4} \) in. flat

No. 2 Bay require \( 1.66 \) do. do. = 4 in. x \( \frac{3}{4} \) in. do.

No. 3 Bay require \( 2.70 \) do. do. = 7 in. x \( \frac{3}{4} \) in. do.

No. 4 Bay require \( 3.83 \) do. do. = 10 in. x \( \frac{3}{4} \) in. do.

No. 5 Bay require \( 4.50 \) do. do. = 10 in. x \( \frac{3}{4} \) in. do.
GAS HOLDER CONSTRUCTION.

HORIZONTAL STRUTS:
The struts will be about 31 ft. long, and will be box section, consisting of four corner angles, each side being laced with a single triangulation of bracing. The bottom tier of struts will be 3 ft. square, the remainder 2 ft. 6 in. square. The least radius of gyration of the strut will be that of the combined section, though the load will be considered as being distributed over the back angles only.

Top Bay. Assume 2 1/4 in. x 2 1/4 in. x 5/16 in. corner angles. Then the moment of inertia of the combined section is calculated from the formula

\[ I_s = \sum (1 + a x^2) \]

Where \( I_s \) = moment of inertia of combined section.
\( I \) = \( " \), the element.
\( a \) = area of element.
\( x \) = distance from neutral axis of element to neutral axis of combined section.

Then \( I_s = 4(0.822 + 1.464 \times 14.272^2) = 1196.096 \)

\[ r = \sqrt{\frac{1196.096}{5.856}} = 14.291; \quad \frac{l}{r} = \frac{372}{14.291} = 26; \]

then from the tables the crippling load per square inch when \( \frac{l}{r} = 26 \), is 23.44 tons per square inch and the safe load say 5 tons per square inch. Assuming the two back angles to carry the whole of the stress, their area = 2.928 sq. in. at 5 tons per sq. in. = 15 tons. This is more than ample, as we have only about 2 1/2 tons to carry, but we cannot reduce the section of the angles as they are about the smallest that it is practicable to work with.

The horizontal component in the second bay is 6 tons, and in the third bay 11 tons, therefore the sections as found for the top bay will be used.

Fourth Bay. In the fourth bay the horizontal component is 15 tons. Assume 3 in. x 3 in. x 5/8 in. angles.

Then \( I_s = 4(1.72 + 2.11 \times 14.12^2) = 1689.56 \)

\[ r = \sqrt{\frac{1689.56}{8.44}} = 14; \quad \frac{l}{r} = \frac{372}{14} = 27; \]
This figure gives a crippling load of 23.4 tons per sq. in., or about 5 tons safe load per sq. in.
Area of two 3in. x 3in. x 5/8 in. angles = 4.22 sq. in. at 5 tons per sq. in. = 21 tons safe load. These sections will be adopted:

The fifth bay has a horizontal component of 18 tons, therefore the same sections as the fourth bay will be adopted.

**LATTICE BARS:**

The lattice bars in the horizontal struts will be designed for a shear equal to 4 per cent. of the stress due to the load. The stress in the lattice bars is determined by multiplying this shear by the secant of the angle which the bars make with a line normal to the axis of the strut. The lowest tier of struts has the maximum load which is equal to 40,871 lbs. or 18 tons.

\[ 4 \text{ per cent. of } 40,871 \text{ lbs.} = 1,634 \text{ lbs;} \quad 1634 \times \text{secant 45°} = 1634 \times 1.41421 = 2,311 \text{ lbs.} \]

Assuming a 2 3/4in. x 2in. x 5/16in. angle with an area of 1.309 sq. in., its least radius of gyration is .42, length of lattice bar = 3ft. 9in.; then \( \frac{1}{r} = \frac{45}{.42} = 107 \), the crippling load = 16\( \frac{1}{2} \) tons per square inch, therefore this section is quite ample, one 3/4in. rivet at each end with a safe shear of 2.21 tons is also ample. For the sake of stiffness and to eliminate a multiplicity of sections, this section of lattice bar will be used throughout the whole five lines of struts.

**STANDARDS:**

When considering the standards as non-continuous beams loaded radially, the maximum stresses per square inch will occur in the fourth section of the standard, farthest from the centre on the lee side, due to the maximum radial roller load.

The maximum B.M. is \( \frac{361 \times 7680}{4} = 693,120 \text{ in. lbs.} \)

the front flange consists of a 12in. x 6in. x 44lbs. R.S.J. and two 3 1/2in. x 3in. x 5/8in. angles. The back flange consists of two 4in. x 3in. x 1/2in. angles and a 10in. x 1/2in. flange plate.

Calculating for the C of G. of section and assuming the standard as 3ft. 9in. wide at this point;
**GAS HOLDER CONSTRUCTION.**

$$12\text{in.} \times 6\text{in. R.S.J} = 12.94 \times 45\text{in.} = 582.3$$

$$3\frac{1}{2}\text{in.} \times 3\text{in.} \times \frac{3}{8}\text{in. angle} = 2 \times 2.29 \times 43.9\text{in.} = 201.06$$

$$4\text{in.} \times 3\text{in.} \times \frac{1}{2}\text{in.}, = 2 \times 3.25 \times 1.319\text{in.} = 8.57$$

$$10\text{in.} \times \frac{1}{4}\text{in. plate} = .5 \times .25\text{in.} = 1.25$$

\[ \frac{793.18}{29.02} = 27.33 \text{in.;} \]

Then C. of G. of the combined section is 17.67 ins. from front face of standard.

Then \(11.5 \times 27.33 \times C + 17.52 \times 17.67 \times T = 693,120\text{in. lbs.} \)

\[ C = \frac{17.67}{27.33} \times T = .6465T; \]

\[ 11.5 \times 27.33 \times .6465 = 693,120\text{in. lbs.;} \]

\[ 309.578T + 203.19 = 693,120\text{in. lbs.;} \]

\[ 512.768T = 693,120\text{in. lbs.} T = 1352\text{lbs. on the gross area, but for the net section this must be increased by the ratio} \]

\[ \frac{17.82}{16.17} = 1,264\text{lbs. C = 874 lbs.} \]

The greatest stresses due to loads from the tangential rollers will occur in the standard at right angles to the direction of the wind, which fibre stresses have previously shown to be 5.8 tons per square inch.

The greatest direct compression in a standard is due to the vertical component of the maximum load on the diagonal tie in the same bay, plus the weight of the metal in the structure above. The compression will take place in the same standard where the maximum load from the tangential rollers occurs, but the compression due to the load from the diagonal tie is considered as taken by the back flange only, while the load from the tangential roller is considered as taken by the front flange only.

The stress computation for the back flanges is as follows:

\[ \frac{\text{Vertical Component} + \text{weight of metal above}}{\text{Area of Back Flange}} = \text{Compression per square inch.} \]

\[ \frac{5000 + 7230}{5000} = 1530\text{lbs. per sq.in.} \]

\[ \frac{8}{8} \]

\[ \frac{13000 + 13197}{13000} = 3275\text{lbs.} \]

\[ \frac{8}{8} \]
The least radius of gyration for the combined section of the back flange is found next, in order to obtain the values of \( \frac{1}{r} \).

**FOURTH BAY OF STANDARD:**

The bottom length of the standard is not considered with respect to the value of \( \frac{1}{r} \), as this length is stiffened by the tank balcony which is riveted to the standard 10ft. 6in. up, reducing the critical length to 10ft. 7in. The fourth bay with an overall length of 30ft. 1in. will therefore present the most severe condition, and the section selected for the back flange will be continued into the fifth bay.

Two 4in. x 3in. x \( \frac{3}{4} \)in. angles and one 10in. x \( \frac{3}{4} \)in. plate.

\[ \text{Is} = 2(4.98 + 3.25 \times 1.5^2) + 41.05 = 66.235 \]

\[ r = \sqrt{\frac{66.235}{11.5}} = \sqrt{5.76} = 2.4; \quad \frac{1}{r} = \frac{361}{2.4} = 150; \]

which gives a crippling load of 11.29 tons per square inch, or 2.26 tons safe load = 5,062 lbs. per square inch which exceeds the compression shown above.

**THIRD BAY:**

Two 4in. x 3in. x \( \frac{3}{4} \)in. angles and one 10in. x \( \frac{3}{4} \)in. plate.

\[ \text{Is} = 2(3.89 + 2.49 \times 1.46^2) + 31.25 = 50.63 \]

\[ r = \sqrt{\frac{50.63}{8.75}} = 2.4; \quad \frac{1}{r} = \frac{361}{2.4} = 150, \]

which gives a crippling load of 11.29 tons per square inch, or 2.258 tons safe load = 5,062 lbs. per square inch, which exceeds the figure just found.

**SECOND AND TOP BAY:**

In the two top bays, the back flange will be kept to the section found for the second bay. It is not considered that
any marked economy would result from further reducing the members, which of course depend upon the values of $\frac{1}{r}$.

Two 3 in. x 3 in. x $\frac{3}{8}$ in. angles and one 10 in. x $\frac{3}{8}$ in. plate.

$I_s = 2(1.72 + 2.11 \times 1.07^2) + 31.25 = 39.53$

$r = \sqrt{\frac{39.53}{7.8}} = 2.25; \frac{1}{r} = \frac{361}{2.25} = 160$, which gives a crippling load of 10.37 tons per square inch, or 2.08 tons safe load = 4,660 lbs. which is more than required. It is pointed out that 5 was used as a factor of safety in the preceding calculations.

**WIND TIES.**

It is not possible to accurately calculate the stresses in the wind ties. From experience it is proposed to use rods 1½ in. diameter, having upset ends for 2 in. turnbuckles, for adjustment. The bars will be arranged to give an effective depth of about 12 ft. gin. from the face of the standard.

**OVERTURNING MOMENT.**

![Diagram for calculating Overturning Moment](image-url)
In determining the loads at the bases of the standards due to the overturning moment caused by the wind pressure, the guide frame is considered as a cylinder having a diameter equal to the diameter of the tank, plus twice half the width of one standard, and with a height of 152 ft. uniformly loaded at 16 lbs. per square foot on the diametral projection.

The total wind moment will be:

\[
167.5 \times 152 \times 16 \times 83.75 = 34,116,400 \text{ ft. lbs.}
\]

The loads at the bases of the various standards are proportional to their distance from the neutral axis.

The effect of the resistance of each standard to the wind moment is also proportional to its distance from the neutral axis. Therefore the effective relative resistance offered to the wind moment is proportional to the square of its distance from the neutral axis.

\[
2 \cos^2 0 \text{ degrees} = 2.000
\]

\[
4 \cos^2 22\frac{1}{2} \text{ degrees} = 3.414
\]

\[
4 \cos^2 45 \text{ degrees} = 2.000
\]

\[
4 \cos^2 67\frac{1}{2} \text{ degrees} = 0.586
\]

\[
8.000
\]

which is equal to the number of standards in action. Then the total wind moment, divided by the product of half the number of standards into the radius to the centre of the standard, will give the maximum load at the base of any standard. \(34,116,400 \div (8 \times 83.75) = 50,920 \text{ lbs.}\) Load on lee side is compression. \(50,920 + 37,300 \text{ weight of standard} = 88,220 \text{ lbs.}\) Load on windward side is tension, \(50,920 - 37,300 = 13,620 \text{ lbs.}\) Four bolts per base = \(13,620 \div 4 = 3,405 \text{ lbs. per bolt, say 1 \frac{1}{2} tons per bolt.}\) The bolts should be 2 in. diameter over threads = 2.311 square inches area at root of thread, and allowing for subsequent corrosion, etc., only 3 tons per square inch, each bolt is equal to a 7 tons safe pull, or more than four times the amount required. No allowance has been made for the resistance offered by the attachment of the standards to the tank guides, which are built into the tank walls, nor for the weight of the tank plates, which are rivetted to the standards. It is evident that the holding down bolts
are not really required in this case, though they are valuable in preventing any accidental displacement of the heel of the standard.

**JOINTS AND STRENGTH OF MATERIAL.**

To secure rigidity of the frame, the whole of the joints in the standards, together with the attachments of the horizontal struts and diagonal ties to the standards, should be made with rivets. All joints and attachments are provided with an excess of rivets in case some may be loosened by the rackings and vibrations due to the impulses of the wind. Eccentric loading has practically been avoided, but where it does occur it is of such a small amount that it will be fully covered by the low working stresses adopted.

Following the practice in the design of high-grade framing, the tension in the diagonal ties is kept down to 12,000 lbs. per square inch, and the compression in the back flanges of the standards and horizontal struts does not anywhere exceed 7,000 lbs. per square inch, except in the lower length of the standard, where it does not exceed 7,500 lbs. per square inch; in this case the critical length of the standard is reduced from 30ft. 1in. to 10ft. 7in. by the attachment of the tank balcony. The rivetting throughout the framing is \(
\frac{3}{8}\) in. diameter—power driven—with an allowable safe single shear of 5,000 lbs. per rivet, or 11,200 lbs. per square inch, the shear value of rivet is practically the determining factor throughout, but where the bearing value determines the rivetting, the load stresses are so small that the rivets have been arranged in accordance with good practice rather than theoretical requirements.

The steel in the plates, sheets, sections, and rivets should be specified to comply with all the requirements of the “British Standard Specification for Steel in Bridges and for General Building Construction,” etc. It is apparent that, with the low working stresses adopted, and the use of steel of the quality indicated by the Standard Specification, that the framing will be of high structural grade.

**CONSTRUCTION OF FRAMING AND GENERAL REMARKS:**—

At each of the panel points a web plate \(\frac{3}{8}\) in. thick and 6in. deeper than the horizontal strut is fixed between the front and back flanges of the standard. The lower length of the
standard immediately joining the tank, is termed the tank pier, and is 10ft. 6in. high. This pier has a continuous web plate. The length immediately adjoining the tank pier has 6in. web plate at its lower end 8ft. high over all, with an opening in it to allow of a passage through the standards round the tank balcony. Between this web plate and the web plate of No. 5 strut are two sets of web stiffeners, each formed of two 5in. x 3in. x 6in. steel tees back to back, dividing the space into three equal bays, which are filled in with a double triangulation of 3in. x 2in. flat lattice bars. Between the web plates at the remaining panel points the space is divided up into four bays by three sets of web stiffeners, each bay containing two bays of lattice bars.

At the panel points, both flanges of the standards are supported by the box-shaped horizontal struts, the front angles of which are secured to the web plate as closely as possible to the front of the standard, the back angles being rivetted to the gusset plates at the backs of the standards. With this arrangement the diagonal bracing is situated at the back of the standards, and rivetted to the gusset plates, and any tension in the back flanges produced by the radial roller loads will be wholly or partly neutralised by the compression resulting from the pull of the diagonals.

With diagonals and back flanges of the struts secured to the standard through a single gusset plate, the whole of the rivets are in direct shear. All the loads transmitted through the rollers are thus finally carried through the gusset plates at the panel points and are there directly distributed to the various members that resist these loads. As the loads which must be resisted by the guide framing may be applied from any direction, it follows that all members of the same kind which are situated in the same section of the frame should be of identical design. For this reason, only those calculations are made which are necessary to determine maximum stresses.

Reversal of stresses will occur in some members of the guide framing because the loads may be applied from any direction. But as in the most approved practice, the stresses are kept within 6 tons per square inch—say 13,000 lbs.—when resisting a wind pressure of 32 lbs. per square foot, and as storms likely to produce such a pressure will probably never
occur but once in a lifetime, it is obvious that such a reversal is of so little importance that it may be disregarded, and considered as being covered by the factor of safety. The various eccentricities of wind pressure, such as the entanglement of the wind passing between the standards and the holder, the impulses of the wind acting from two or more directions at the same time, and the negative pressure acting on the lee side of the holder, etc., have been totally disregarded. It is impossible to even approximately calculate their effect, and they are assumed to be fully covered by the liberal factor of safety employed.

For erection purposes the diagonal bars should be drilled (in the shop) at one end only, the lower end being drilled at erection after the standards have been plumbed and lined up vertical. This ensures that the bars will fit properly, and present a true appearance. The usual practice is to provide round bars in the diagonal bracing, each bar being in two lengths, with a forged eye or jaw at one end and upset and screwed at the other end, the two bars forming one length being secured together by means of a turnbuckle. This method introduces a great deal of expensive smithing work. The greatest objection to the use of round bars of this description is the utter impossibility of tightening all the rods uniformly by means of the turnbuckles; the erectors prefer this type of bracing, as it presents a ready means of truing up the framing on completion, and some erectors rely on this method solely for that purpose, but this introduces initial stresses of unknown magnitude into the bars, which, when added to the live load stresses, will greatly exceed the amounts figured on by the designer.

The use of box-shaped horizontal struts rather than I-shaped girders, is advisable in large frames as weight for weight of metal used, the least radius of gyration obtained in the box construction is greater than in the other design.

There is a space of \(\frac{3}{16}\) in. between the backs of both pairs of flange angles in the standards; this, owing to the face of the R.S.J. on the front flange and the plate on the back flange forming pockets for the collection of rain, is objectionable as being a source of corrosion. It should therefore be provided
that these spaces be firmly packed with a semi-dry mixture of sand and cement.

**STANDARD BASES:**

In building a brick or concrete tank it very often happens, despite all the care and attention that can be devoted to it, that the diameter varies slightly between each pair of opposing standards, and that the sides of the polygon formed by the holding down bolts varies in length. This causes a certain amount of trouble when erecting the guide framing.

The writer would recommend a type of adjustable cast iron base that has been successfully used. It consists of a base plate and stool, the plates being provided with holes, slotted circumferentially in relation to the tank, to fit over the holding down bolts, and with studs to secure the stool. The holes in the stool are slotted radially. Holes in the top of the stool are provided for bolting down the standards to it. It has been found possible to set this type of base plate to within $\frac{1}{16}$in. of its correct position. The small extra cost of these adjustable bases is more than compensated for by the freedom with which every part of the framing comes together.

This base is especially adapted for existing tanks where it is proposed to erect a new holder. In such cases it is only necessary to build the holder to the smallest diameter of the tank, and the subsequent erection can be carried out with a certainty that no cutting and fitting is required at the site.

**STAIRCASES:**

To render the landings on the three inner lifts of the holder accessible at any point, staircases are provided in one bay of the framing. The head of each staircase passes through the upper strut to which it is attached so as to keep it as close as possible to the landings on the holder. The tops of the struts in the staircase bay are covered with chequer plating extended 2ft. 6in. outside the strut, such extension being carried by brackets. Each staircase and staircase strut is enclosed by a double line of hand-railing. As the staircases are situated in the centre of the bay away from the standards, it is a trying ordeal for men unused to great heights to ascend to the upper bays. The light construction of the framing seems utterly inadequate to the nervous man when viewed at an altitude of say 130ft. or 140ft., and some help should be
accorded him, especially when it is remembered that the Works Engineer in whose charge the holder is, may have urgent occasion to get on the crown of the inner lift when the latter is near its highest position.

The only way to assist him, beyond providing as easy and safe stair as possible, is to confine his view, and for that reason the stairs should be plated in on their backs.

PAINTING:

It should be provided that all steel-work, as soon as fabricated, should have a coat of boiled linseed oil, and, after inspection and before despatch from the contractors' works it should receive a coat of red oxide paint. Castings before oxidation should be given a coat of boiled linseed oil. After erection the whole structure, with the exception of the interior of the holder, should receive another coat of paint.

WEIGHT OF HOLDER:

The quantities of materials in the whole structure would be as follows:

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank</td>
<td>131 tons</td>
</tr>
<tr>
<td>Gasholder</td>
<td>568 &quot;</td>
</tr>
<tr>
<td>Guide Framing</td>
<td>301 &quot;</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1000 tons</strong></td>
</tr>
</tbody>
</table>

CONCLUSION:

Necessarily very much has been left unsaid and undescribed in the foregoing presentation of the design and construction of a gasholder.

For instance, but a few of the large number of detailed drawings, required for the fabrication and erection of a holder can be selected for publication; whilst to explain them fully would require a volume and not the brief limits of a paper.

The plates shown are actual drawings such as would be required for manufacturing purposes, and a study of their details would suggest that the construction of gasholders and steel tanks is well within the capacity of Australian Engineering establishments.
LIST OF LANTERN SLIDES EXHIBITED.

No. 1.—General Design of Holder.

" 2.—Details of One Bay of Guide Framing.

" 3. " Bottom two lengths of Standard.


" 5. " Horizontal Struts.

" 6. " Landings on Horizontal Struts.


" 8. " Tank Balcony and Staircase.


" 11. " Cup and Dip, Cup Carriages, and Vertical Stays in outer lifts.

" 12. " Inner Lift Vertical Stays and Outer Lift Bottom Carriages.


" 15. " Railings on Lifts and General View of Carriages.


DISCUSSION.

The President said they had listened to an interesting description of an interesting work. Those connected with gas undertakings had an advantage over electrical supply authorities in the sense that they were able to store their product, which the electrical supply undertaking was not able to do. That must have an effect on the economical supply of gas. He wondered if the pressure inside the holder varied as the contained volume varied. Could Mr. Grove say what was the maximum pressure on the holder when it was inflated?

Mr. H. E. Grove said it depended on the design of the holder. The pressure might be anything. An inner lift of fair size would be equal to 4½ to 5½ inches of water; a large one might reach 6; 4½ to 5½ would be the average.

The President asked if that pressure was reflected in the gas main?

Mr. Grove said the holder pressure was altogether distinct—it had nothing to do with the working pressure in the main.

The President said it was a very interesting matter. He had wondered to what extent gas-holder capacity had to be
provided for a definite output—whether the storage capacity always bore a certain ratio to the output of the gasworks. He was sure members had all enjoyed the description greatly; and, although much discussion of the paper would be impossible until it had been printed and circulated, if any questions were asked Mr. Grove would be in a position to reply.

Mr. J. N. Reeson said he did not rise to discuss the paper at all. He did not presume to discuss it, as he had had something to do with the design of the holder. But he would like to amplify the remarks Mr. Grove had so lucidly given them, and perhaps by so doing he would help members to understand the great part a holder of that kind bore in relation to the gas supply of a town. The President had said it would be interesting to know what relation the storage of gas bore to the daily output. It should not be less than a day's output, because the conditions of weather, and especially temperature—which affected the gas companies very seriously indeed—had a great bearing on the output of gas. In The Gas Light and Coke Co., the biggest gas company in the world, the output was about 125,000,000 cubic feet per day for the winter; and he had known that output vary on two successive days by 30,000,000 cubic feet. 125,000,000 cubic feet of gas equalled 12,000 tons of coal, and that had been varied by practically 25 per cent. on two successive days. Industrial engineers did not always get much credit for work of that kind; in fact, they generally got the reverse. But that was one of the difficulties they had to face.

The President had rightly stated that the gas companies had an advantage over the electric supply undertaking, in that they were able to store their commodity. That was so; but the storage was at a very considerable cost, and it would be interesting to know that the cost of the holder was practically the cost of a manufacturing plant. The holder shown, which was a comparatively small one, with the tank complete, would cost in England probably about £40,000 to £45,000. Out here it would cost about £80,000 to £90,000; and the difference in the cost had something to do with the difference in the price of the commodity here as compared with that in England. He would like to
impress upon members that, in order to ensure a regular supply of their particular commodity, it was necessary to spend large sums in capital, for which there was really no adequate return forthcoming.

He had hoped that Mr. Grove would have alluded more fully—probably he would do so in reply to the discussion—to the point with reference to the reduction of the columns of the guide-framing to as few as possible, and the use of tangential, as well as radial, guide rollers. He might mention that the principle of the use of tangential guide rollers on a comparatively small holder was not usual. The usual plan would be to increase the number of columns and use radial rollers; but he thought Mr. Grove was right when he said there was a great advantage in the use of tangential rollers, because when it was put down in pounds, shillings, and pence, it would be seen that the slight additional cost of the tangential rollers would be as nothing in relation to the vastly increased cost of providing for more standards, etc.

The Livesey manlid was a very useful contrivance indeed. It was only during recent years it had been in use; its purpose being to enable the staff to examine the mains without losing the gas of the holder. In the old days, before the introduction of the Livesey manlid, they had to lower the holder as far as possible, and take the cover-plate off exactly above the inlet or outlet pipe, and place a bag over the pipe; and then there was four or five inches pressure of gas blowing in the faces of the workmen engaged. But the Livesey manlid overcame that difficulty. Perhaps, after hearing the rest of the discussion, he might be able to make some further remarks which would be helpful.

Mr. JAS. ALEX. SMITH said he had nothing to add in discussion, but, as a member of the Publication Committee he might say the paper had already been set. It was lengthy, and unusually complete. He thought when members had it before them they would find a great amount of material useful to structural engineers generally, which Mr. Grove in his remarks that night had not mentioned. As it was the author’s first paper, he was to be commended upon an excellent production.
The **President** said he presumed the use of the holders would result in a steady output of gas through the 24 hours. Or did they have a fluctuation, notwithstanding the storage capacity? The output of an electric supply works at 12 midnight and 12 noon showed a great fluctuation in comparison with the remainder of the output rate.

The electric supply undertaking had to provide staff and plant to produce power as it was required at any time of the day. The average load during the whole time might be about 25 or 30 per cent. of the maximum. He was wondering whether the use of the gas-holder would result in the production rate of gas being uniform.

Mr. J. N. **Reeson** said that was so.

The **President** said he understood, from Mr. Reeson's remarks, that the introduction of a gas-holder was not an economical advantage, as the capital charges and maintenance of the holder about equalled the cost of plant for making the gas as required. He would have thought that the utilisation of the producing installation and staff on a constant, or "full load" basis, would have greatly assisted economic production.

Mr. **Reeson** said he was simply referring to the cost of the plant. Storage did show an economical advantage. It must be so if the plant could be kept steadily at work, as they were then able to do. In Melbourne the cooking load, in comparison to lighting load, was a great deal more than that in England. The heaviest load of the Metropolitan Gas Co. was at midday on Sunday.

The **President** said further discussion of the paper would be postponed to next meeting. In the meantime he would ask members to show their appreciation of Mr. Grove's efforts, which he was sure all had thoroughly appreciated. The vote was carried by acclamation.

The **President** said they had had a very interesting visit to the Ruwolt Steel Co.'s works, and those who had attended were thoroughly rewarded for their two or three hours abstention from strenuous business. The work had been a revelation of what a young country like this could do when its
mind was made up. He thought it would be one of the blessings of the war that they should discover they were able to do things they had had no idea they could do.

They had seen the production of very large steel castings; and he was very pleased to see them turning out rolling mills for Broken Hill—the rollers weighing about three tons, and every casting was roughly machined. They also saw side frames for bogey trucks for the Prahran-Malvern tramways. It was an illustration of what could be done in a young country when the will was there, and they began to realise they could do those things.

At 10 p.m. the meeting closed.
GENERAL DESIGN OF GAS-HOLDER.
Plate II.

Details of Bottom Lengths of Standards.
DETAILS OF SIDE SHEETING IN HOLDER.

Note: All dimensions and heights are given in inches. The共和内容 has been omitted for clarity.

Inner Lift.

Second Lift.

Elevation of Side Sheeting, Second Lift.

Details of Side Sheeting in Holder.
Plate IV.

Details of Crown Sheeting.
Plate V.

Details of Inner Lift Top Carriages.
hundreds of acres within the last twenty or thirty years. In the case of the Tambo River he believed that in the course of a flood the river was scoured out to something like its original depth, but as the flood eased off the silt was again deposited, and before the flood was over the river returned to its silted-up condition. They had provided for that by carrying their foundations deep enough to allow of the scour taking place without the piers being endangered. There were many things in connection with the siltation of rivers that were worthy of study; and the case of the Tambo was a most interesting one. Discussion closed.

GASHOLDER CONSTRUCTION.

(Paper by H. E. Grove.)

Mr. C. F. Lindblad said he would like to ask Mr. Grove a question with reference to the Brighton gasholder. It appeared to be totally different from the one described. Could Mr. Grove give a simple description of that class of gasholder?

Mr. H. E. Grove said the Brighton gasholder was an excellent example of a Gadd and Mason Holder (so named after its inventors). Those members who had seen that holder, would have observed that there was apparently no external guide framing. The guide framing was there, however, and consisted of heavy bulb-headed rails rivetted directly to the sides of the lifts at an angle of 45 deg. with the horizontal. These rails worked in carriages fixed on the next outer lift, or the tank as the case might be, and each carriage contained four grooved pulleys so arranged that two were on each side of a rail. In action, when the gas was admitted to the holder, the rails would cause the holder to revolve as it rose; any unbalanced conditions, such as wind forces, etc., would be counteracted by the rails locking in the carriages, but the locking would not prevent the free rise and fall of the holder owing to the angle at which the rails were set.

The apparent simplicity of this form of construction did not imply that it had any great advantage over the type of gasholder described in the paper. It was obvious whatever type of holder was adopted, that the forces acting on it were substantially the same, and that sufficient material must be employed.
to adequately take care of the resulting stresses. This system of spiral guiding, as it was generally termed, had only been used for small to medium sized holders up to the present.

The President said Mr. Reeson had stated that the author would probably refer, in discussion, to the reduction of the columns of guide framing to as few as possible; and also to the question of the use of tangential as well as radial guide rollers.

Mr. Grove said at the last meeting he had only given a short precis of the paper, but he had gone into the matter rather fully in the paper. Those were two points he had wanted to emphasise. He did not think he could add anything to what he had given in the paper.

Mr. M. E. Kernot said he would like to express his appreciation of the large amount of work Mr. Grove had put into his paper. The paper as printed was such a full and thorough one that one hesitated to criticise it in any way, but would want to go into the question very carefully before tackling such an expert as Mr. Grove evidently was.

Although he had not had time to do more than skim through the paper, it had revived his interest in gas work, and showed what big work gas engineers were now doing. There had been a tendency to ignore the gas engineer. He had been left alone and ignored, as though gas were a thing of the past. But the paper had shown that gas was still a live industry, and there was much in it.

The construction of the holder had been exemplified so much in detail that it was valuable for their "Proceedings." If he had anything to do in that way he would immediately get Mr. Grove's paper and go through it, and would be able to learn much from it.

He remembered when the gasworks were started in Geelong, they regarded it as a dreadful and horrible thing. It was erected about a mile from the nearest house, and eventually shifted further out, without consideration of all the added capital and loss through distance, etc. There was a foreboding of its being a terrible nuisance. He had lived to see that same town make an electric supply works right in the
town, and he had slept in an hotel close by and thought that the electric works could be more nuisance than the gasworks.

He had often wondered to see gasholders lasting to a great age, and he did not remember having heard of one collapsing through weakness. When he first had to do with gasholders they had heavy balance weights to help them keep up. Now they placed a big weight on top to keep them from going up like a balloon. He supposed it was because of the smaller weight in proportion to the weight of the volume. Such records placed at the service of the younger engineers contained much valuable information, and were an example of how to go into a design of a work thoroughly and work out all the details. He thought the longer a man stayed at working out large works, the more deeply he took the work in detail and obviated mistakes.

Mr. J. A. Smith said the matter had a particular interest for him, since the first gasworks in Victoria was the work of an uncle of his, the late A. K. Smith, M.L.A., etc., in 1854. He had the original plans in his possession, and one noticed the wonderful difference in the methods of the engineer then and now. Those plans were absolute works of art. Now they had the hard, clear-cut utilitarianism that conveyed without any extraneous work what the originator desired. He also had a water colour drawing of the original works at West Melbourne, which spoke eloquently of the advancement of the city and the State. It might be a matter of interest to compare the first work in Victoria with the present and to record that early sketch in the "Proceedings."

Mr. F. W. Clements asked what was the condition of the inside of the plates of a gasholder. Was there a large amount of red oxide scale, or were they protected in any way? He had never known a gasholder to collapse, and he wanted to know if there was any special condition of the inside surface in contact with the gas.

Mr. H. E. Grove said that there was no special treatment of the interior of the holder beyond the shop coat of paint to the plates and sections, and the shop coat of boiled oil to the sheets. Generally the interior of a holder was in a very good
condition at the end of its working life. In the rare cases where red oxide scale had formed, it was due to some abnormal condition that had occurred.

Mr. J. A. Smith asked what was the chemical reaction of the liquids? Was it not almost wholly alkaline? If so, there would be no corrosion.

Mr. Grove said it would probably be alkaline.

Mr. F. K. Eslung said he thought engineers generally were rather mistaken as to the effects of corrosion. About 25 years ago they erected the Flinders street viaduct. He was interested in the design of that structure, and after years of use, took it down again on account of the structure having to be renewed because the loads were heavier; and it struck him it would be a good thing to see what corrosion had done to the plates in the troughing. The troughing was almost unprotected. From the time it was put down it might have been tarred twice, for the simple reason that the traffic was so heavy that any further painting or tarring was a most awkward work. When he took that viaduct down he took some of the troughing out of the work and had it most carefully chipped and cleaned, so that there was no chance of any corrosion being missed, and had them weighed afterwards. They knew the exact weight of the original plates, and in 25 years the amount of corrosion was only 5 per cent.

Mr. J. A. Smith asked if those plates were iron or steel. He fancied they were wrought iron. The old puddled iron was far less susceptible to corrosion than much of the modern steel.

Mr. Eslung said they were Bailey and Westwood's iron troughing. They were exposed to the air on one side in absolutely the worst position.

The President said Mr. Grove's thesis was a description of a very important work, and they had all been struck by the ability displayed in the paper, with its wealth of detail. It almost amounted to a text book on gasholder construction. He had been much struck by the way in which the work had been carried out. In many engineering works the engineer would specify results only, leaving the tenderer to supply designs.
Here the engineer designed his own structure. He thought Mr. Grove's paper would add considerably to the value of the "Proceedings."

In closing, the President said on the whole they could congratulate themselves on having had good attendances and good papers throughout the year; and the "Proceedings" would be a record in the history of the Institute. He wished members a happy Christmas and a more prosperous New Year.

Mr. ESLING moved a vote of thanks to the President for the attention he had given to the work of the profession during the year. He thought they recognised the great efforts put forth for the improvement of the Institute by the President and members of the Council.

Mr. M. E. KERNOT supported the motion. He expected there would be some more formal expression at the close of the President's tenure of office, but he was pleased to support the expression at the present time.

The President said he appreciated the kind remarks made. The Institute was taking its right place in the community. He looked upon this Institute as being the major one in this country. It counted amongst its members the heads of many of the great departments—municipal and Government—and it was not confined to any one section of engineering, but was spread over all its branches. To him it had been a great honour to have served as President during the 1916 session.

At 10 p.m. the meeting closed.
Melbourne's First Gas Works, erected in 1854 by the late Alex. K. Smith, M.L.A., etc.
(From a contemporary sketch.)
Library Digitised Collections

Author/s:
Grove, Harry Ernest

Title:
Gas holder construction (Paper & Discussion)

Date:
1917

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Gas holder construction (Paper & Discussion)