The Fabrication and Erection of the "Dome of Discovery"[1)]

Herstellung und Montage des ,,Doms der Entdeckung''

Fabrication et montage du ,,Dôme de la Découverte''

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1. Introduction

The paper describes the fabrication and erection of the "Dome of Discovery" built on the South Bank of the Thames in London for the 1951 Festival of Britain.

The building, of unique design, was the outstanding feature of the Exhibition. It was the conception of the fertile imagination of the Architect, Mr. Ralph Tubbs, A.R.I.B.A., and the structural design was by Messrs. Freeman, Fox & Partners, Consulting Engineers of London who also supervised the work in the shops and at site.

The contract was placed in September, 1949 for completion by November, 1950 with Messrs. Horseley Bridge & Thomas Piggott Limited of Tipton, Staffordshire, whose Associate Company, Messrs. Carter-Horseley (Engineers) Limited, London, carried out the erection.

2. Description

The building was a composite structure of Mild Steel and Aluminium Alloy, circular in plan, 365 ft. overall diameter, the enclosed floor area being only 260 ft. diameter with its centre 29 ft. eccentric to that of the roof.

The Dome of Aluminium Alloy, 342 ft. diameter, was a segment of a sphere 726′-9″ diameter, with a rise of one eighth, 42′-9″. It was built as a series of curved lattice girders, intermediate rafters, purlins and flat roof sheets. The Dome was sprung from a steel Ring Girder 342 ft. mean diameter, which was supported 47′-3″ above ground level on 48 tubular steel struts, each

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1) The Structural Design of the "Dome of Discovery" — Festival of Britain — **1951** by Gilbert Roberts, B.Sc. Eng.; M.I.C.E. Structural Paper No. 28 — The Institution of Civil Engineers, London.

51′-7.5/8″ long, whose bases were on a concentric ring 365ft. diameter. They were inclined in two directions to resist radial and tangential forces, as well as vertical ones. A cantilever Canopy 7′-0″ wide projected outside the Ring Girder. In addition to the weight of the Dome and Canopy, the Ring Girder supported, from its inner edge, half of the "Apron" or "Skirt" in the form of an inverted truncated cone. The lower edge of the Apron bearing on the 260 ft. diameter Drum Wall. The Apron was of Aluminium Alloy built up of radial girders, purlins and 16 gauge (0.064″) Sheets. See Fig. 1 and 2.

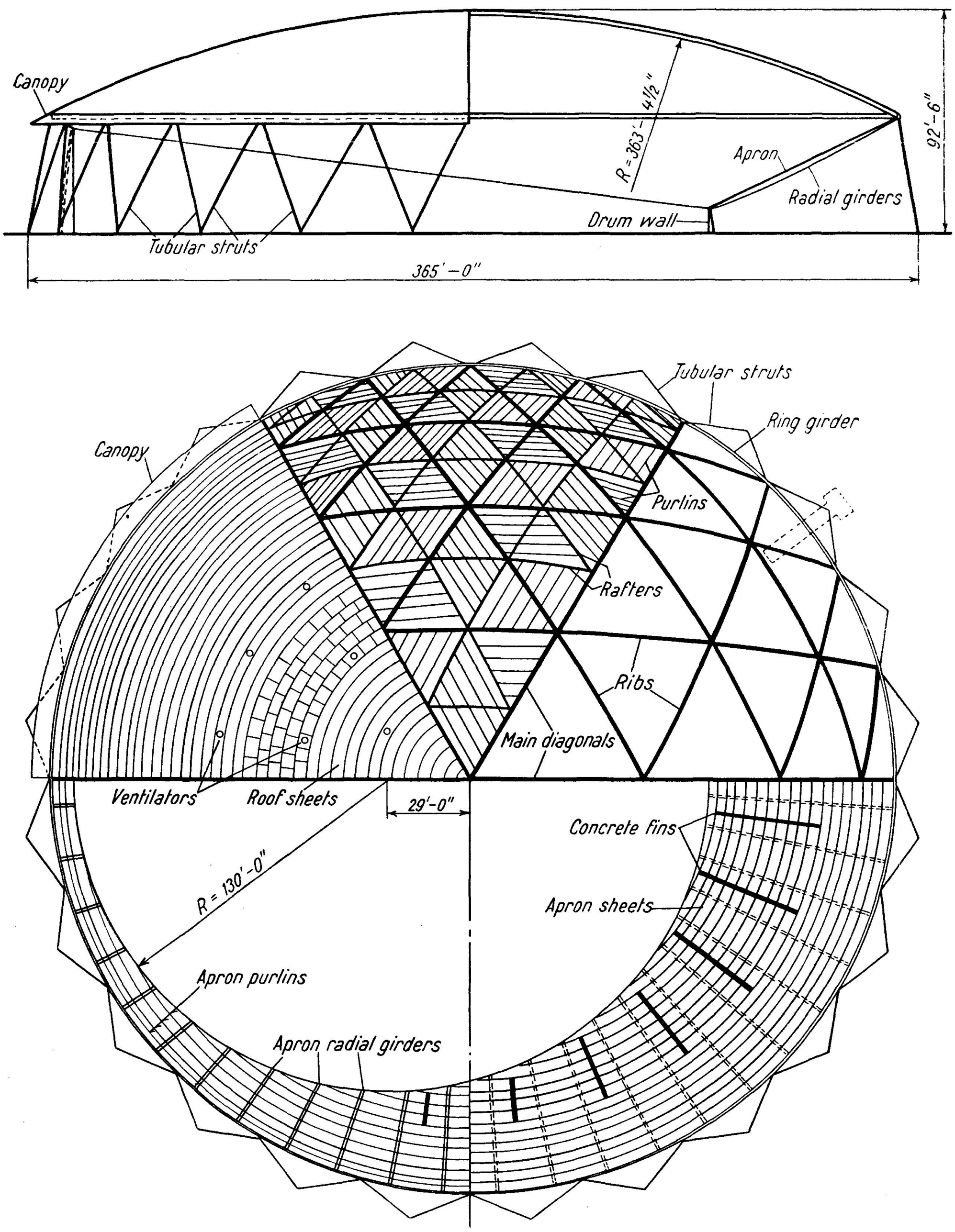

Fig. 1

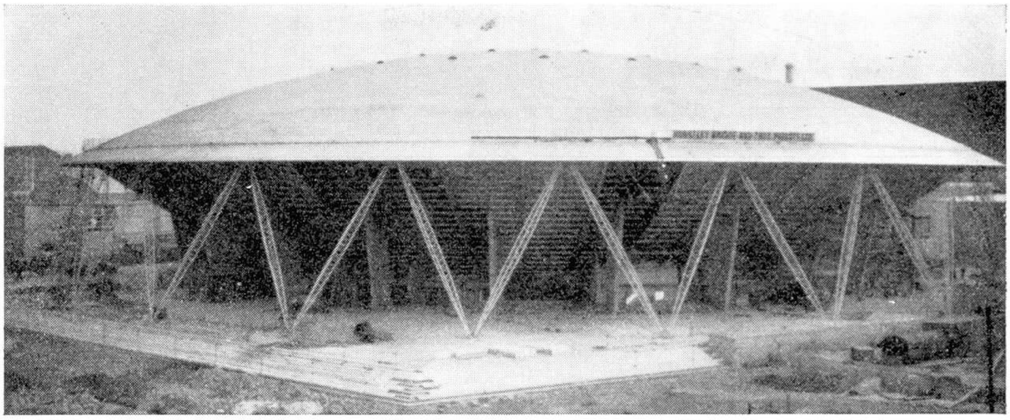

Fig. 2. Dome complete except for Apron Sheets, 28/10/50

The main arch members of the Dome were triangular lattice ribs, all designed as parts of great circles of a 726′-9″ diameter sphere, therefore, each individual rib had a constant radius of curvature. The three main diagonal arch ribs were continuous great circles, which intersected at the crown and divided the Ring Girder into six equal segments. A further six continuous great circles, arranged approximately parallel to the main diagonals, formed two primary spherical triangles whose apices sub-divided the Ring Girder into a further six segments.

A further twelve lines of ribs were arranged inside and outside these primary triangles, but they were not continuous great circles, since it was essential that the six ribs always intersected at a point.

This arrangement divided the Ring Girder into twenty four equal segments 24′-9″ long and in the main diagonals there were twenty four rib members, a further thirty six in the primary triangles and seventy two in the secondary triangles, all of which were identical in curvature, but varied in length. The main diagonals divided the roof into six identical sectors, each containing sixteen spherical triangles. These triangles varied from six nearly equilateral triangles at the crown with sides approximately 55′-6″ long, to very acute angle triangles with sides approximately 48′-3″ and 24′-3″ long adjacent to the Ring Girder, and formed a hexagonal shaped pattern over the whole roof. See Fig. 3 and Fig. 11.

The sides of the secondary triangles were approximately bisected by rafters thus forming tertiary triangles. Purlins were fixed directly on top of the lattice ribs and rafters, finally flat roof sheets were laid over the whole dome area.

The roof sheets were insulated from the main structure and loosely connected to it by long bolts which permitted movement of up to 1″ radius, only one bolt per 100 sq.ft. of roof area being used.

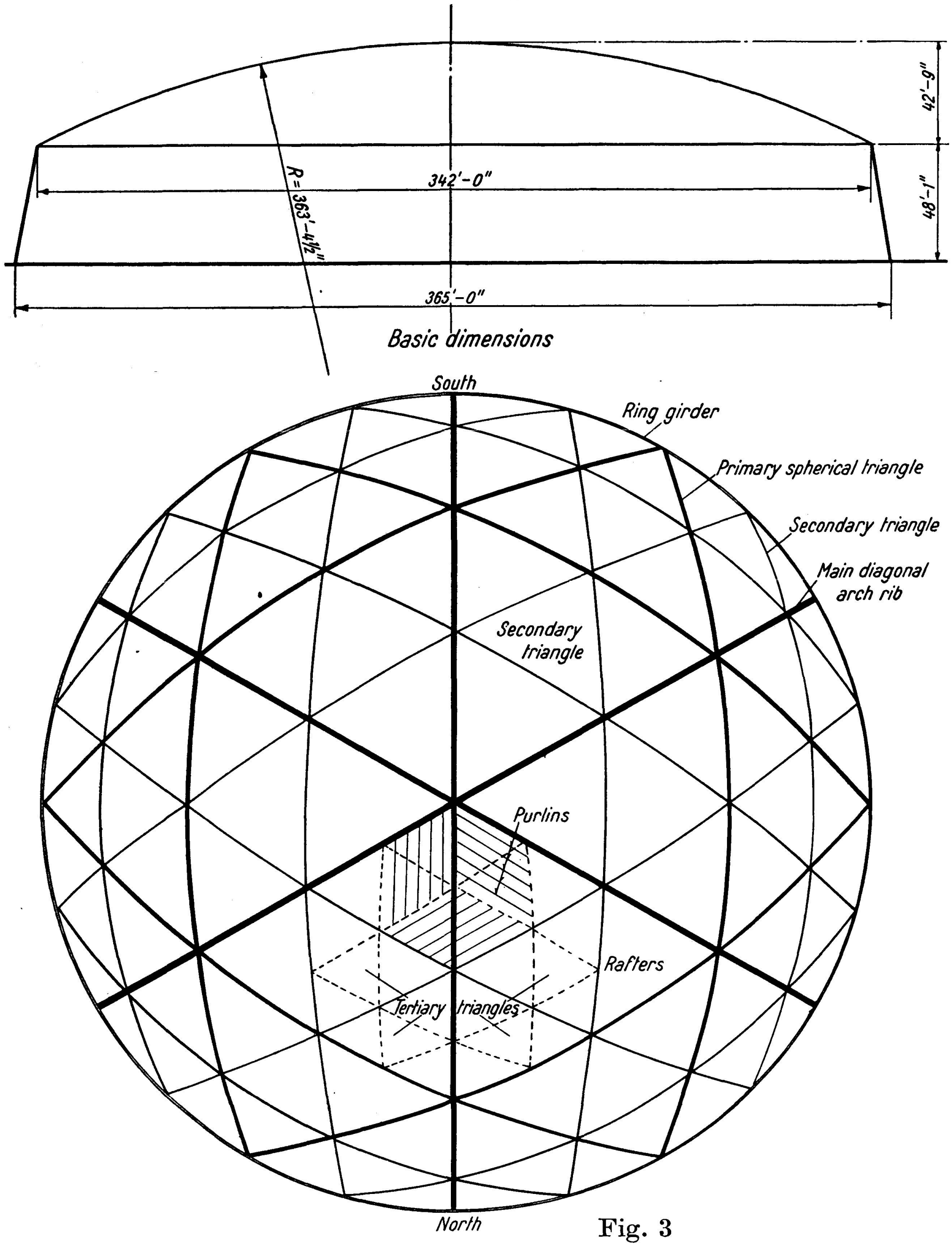

Fig. 3

3. Spherical calculations

Fig. 3 gives the basic data from which all dimensional calculations for the roof were made.

Exceptional accuracy was necessary in preparing the roof calculations since the solution of all spherical triangles was progressive, the dimensions of the outer triangles being dependent on the results obtained from the inner.

For example for the main diagonal arch and the sides of the primary triangles respectively, the calculated chord length, included angle of the arc, and the mean arc length triangles respectively were 342.0′; 56°-8′-41.891″; 356.07658′ and 296.181′; 48°-6′-3.6042″; 305.061′.

The side lengths and included angles of the six spherical triangles that intersected at the crown were calculated as 55.51109′; 8°-45′-10.0937″; 55.51109′; 8°-45′-10.0937″; 55.34891′; 8°-43′-38.06467″ respectively.

The dimensions of the remaining spherical triangles varied in groups of six or twelve to 38.60361′; 6°-5′-12.8113″; 48.29431′; 7°-36′-53.6047″; 49.87792′; 7°-51′-52.5029″; for one of the spherical triangles which occurred adjacent to the ring girder and the main diagonal.

4. Materials

The Ring Girder was built of Mild Steel to B.S. 15 having a nominal ultimate strength of 28—33 tons per square inch.

The Tubular Struts were made of steel to B.S. 1387-Class "C".

The high tensile turned bolts used for making the joints between the ribs and the gusset plates were 35—43 tons per square inch ultimate strength steel, and approximately 10,500 were used.

Aluminium Alloys were used for the other parts of the structure.

Stress bearing structural members such as the Dome Ribs, Rafters and Purlins were of Aluminium Alloy extrusions to the AW10B series with the following approximate analysis:

1.0% Silicon.
0.6% Magnesium
1.0% Manganese.
Max.
Remainder Aluminium.

Tests carried out at the Makers' Works for the rib extrusions gave the following average results:

0.1% proof Stress = 18 tons per square inch.
Ultimate Tensile Stress = 20 tons per square inch.
Elongation = 14%.

Rib gusset plates were of AW10E quality and the roof and apron sheets of AW4C quality.

The 5/8″ diameter rivets used in the main ribs were of AW5 quality for cold driving (3.5% Magnesium, 0.5% Manganese, remainder Aluminium).

Approximate Weights of Materials used

Steel in Tubular Struts and Ring Girder		138 tons
Aluminium in Dome Ribs, Rafters and Purlins	114 tons	
Aluminium in Roof Sheets and Canopy	73 tons	
Aluminium in Apron Radial Girders, Purlins and Sheets	47 tons	234 tons
		372 tons

5. Fabrication

a) Ring Girder — 342 ft. mean diameter

Made of 1/4″ and 3/8″ thick Steel plates. All-welded box section with two vertical sides and sloping top and bottom plates, 2′-10.5/8″ wide by 3′-6″ mean height. After planing and flame-cutting to size the plates were assembled on a steel grillage, fillet welded together with suitable diaphragms and angle stiffeners.

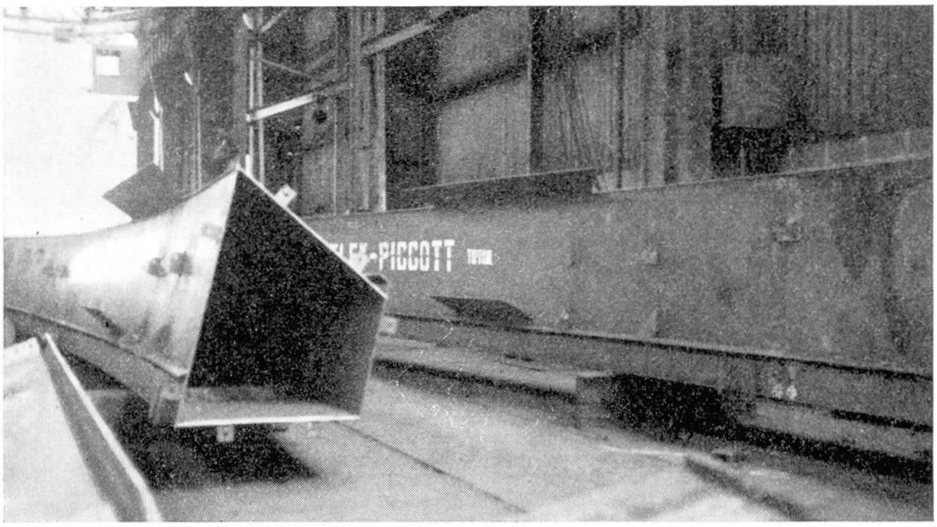

Fig. 4. Ring Girder segment in the Works, 15/4/50

The outer plate was extended upwards to form a rainwater gutter. Curved rainwater pipes 4″ diameter were welded inside the box with projections for site connections. The girder was completely shop fabricated in twenty four equal segments, about 4.5 tons each, fitted with all brackets, and gusset plates for supporting the ventilating fans, roof ribs and canopy girders.

To facilitate erection and to ensure accuracy after site welding, groups of four segments were assembled together on the shop floor and positioned, the chord and versine dimensions being very carefully checked. Eight angle cleats, one near each corner, were shop welded at the end of each segment and datum points 2″ on either side of the site joint were hard marked on the plates before the four segments were separated. Having confirmed the accuracy of the four segments the centre two were first despatched to site and the two outer retained for re-use with three fresh segments for trial assembly, checking, cleating and marking in groups of four as described above.

This procedure was continued, working alternatively clockwise and anti-clockwise until all segments had been fabricated and checked. Photograph Fig. 4. shows several segments completed in the works, the small white crosses on the right indicate the datum marks.

b) Steel Tubular Struts

Forty eight of these were built up of Steel Tubes 3″ o/d. × 5 WG (0.212″) wall thickness for the three main members with 1.11/32″ o/d. × 10 WG (0.128″) tube lattice bracing. The struts were cigar-shaped with lugs at either end for 2.1/4″ diameter steel bearing pins. The struts were 51′-7.5/8″ long measured between centres of pins and weighed 0.6 tons each. The struts were shop assembled in jigs and welded. Due to their circumferential inclination great care was taken to ensure that the bearing lugs at either end were accurately located relative to each other. See Fig. 5.

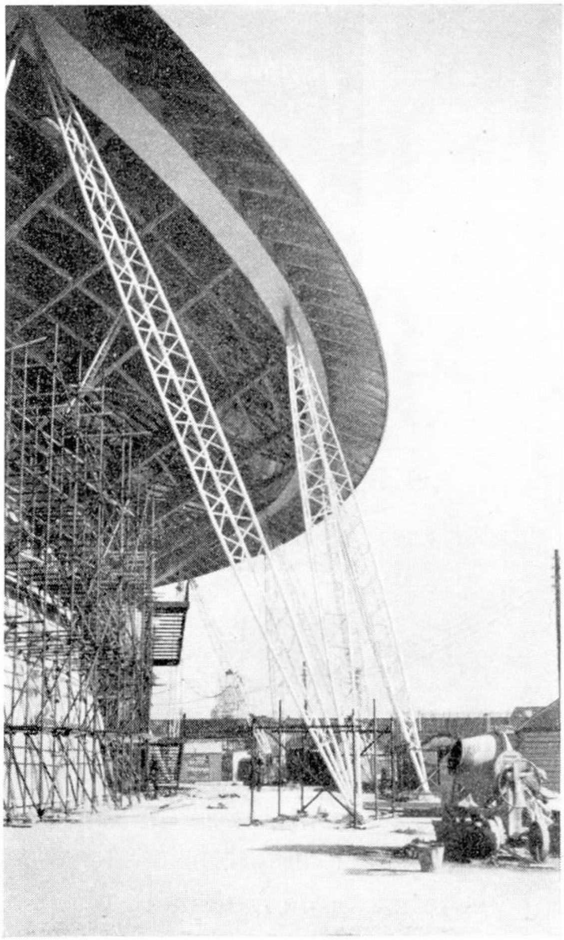

Fig. 5. Apron framing from underside. Struts, Canopy, etc. complete, 4/10/50

c) Main Arch Ribs

There were 132 of these ribs, 2′ 10″ × 2′ 10″ triangular in cross section with lattice bracing. As these members were all parts of similar great circles they were identical in curvature. This greatly simplified shop fabrication. The individual members varied from 55′-6″ to 24′-3″ long. The left-hand portion of Fig. 6 is a photograph of the specially extruded aluminium alloy sections used in the top and bottom booms. Approximately 50 tons of these two sections were supplied, curved at the Extruders' Works to their correct relative curvature by stretching them over specially prepared formers in lengths up to 60 ft. At the fabricators' works these members were assembled in special curved jigs, all bracing angles and channels assembled on the three faces, and the whole member rivetted up complete with 5/8″ diameter AW 5 aluminium alloy rivets driven cold by pneumatic squeeze riveters. Normally snap heads were used but those on the top of the ribs were countersunk. After riveting the members were placed in pairs on a former about 120 ft. long, accurately set to their correct relative position, top and bottom hexagonal joint covers or gusset plates fitted and the holes for site bolts drilled through using steel bushed jigs. Members were drilled progressively in pairs on this former first dealing with the twenty four members in the three main diagonals.

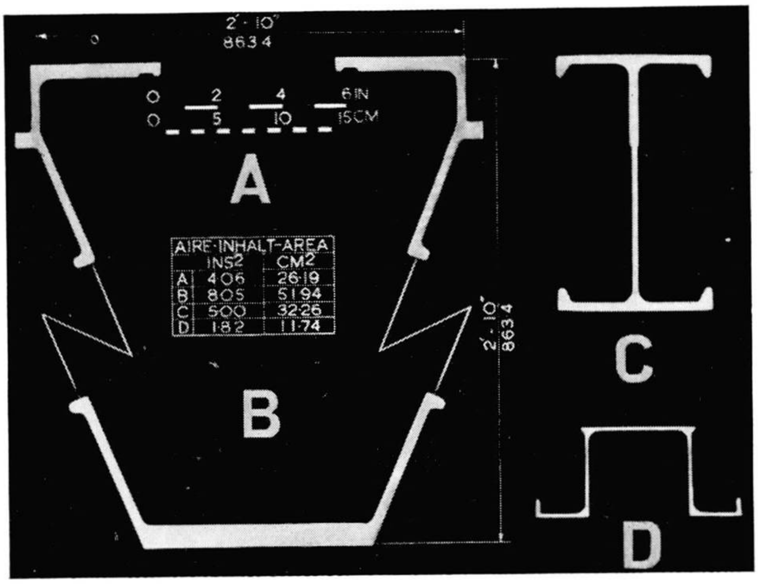

Fig. 6. Extrusions for Ribs, Rafters and Purlins

There were seventeen holes in the top boom and ten in the bottom boom for each end connection. All twenty seven holes were drilled and reamered full size, 13/16″ diameter in both the gusset plates and the ribs ready for immediate erection in the ends of all members which formed parts of continuous great circles, namely the three diagonals and the two primary triangles, but in the latter this complete reamering was omitted at those points where they intersected main diagonals owing to the practical difficulty of measuring with sufficient accuracy the varying included angles at the intersections. This fact limited the number of pairs of ends that could be fully shop drilled and reamered to thirty nine. In 144 ends only eight tack bolt holes were jig drilled 11/16″ diameter through both the top and bottom gusset plates and boom extrusions, the remaining thirteen and six holes in the top and bottom gusset plates respectively were drilled small, 3/4″ diameter, while the rib extrusions were left blank for site drilling, apart from the eight tack bolt holes mentioned above. Where the forty two ribs connected to the Ring Girder, their ends were left blank for site drilling through holes which had been shop drilled in the steel ring girder gusset plates. The top and bottom gusset plates at the crown were the only ones to be shop reamered full size on all six sides.

Shop fabrication was planned in the same sequence as that for erection.

The top and bottom gusset plates were made of 7/16″ and 3/8″ aluminium plate respectively. Due to the six point intersection and the triangular shape of the main ribs, the gusset plates were approximately hexagonal in shape, the top being up to 6 ft. wide and the bottom 3 ft. wide maximum, also the top booms of the ribs were considerably shorter than the bottom. This resulted in a six-sided "flower-pot" structure at each intersection point after

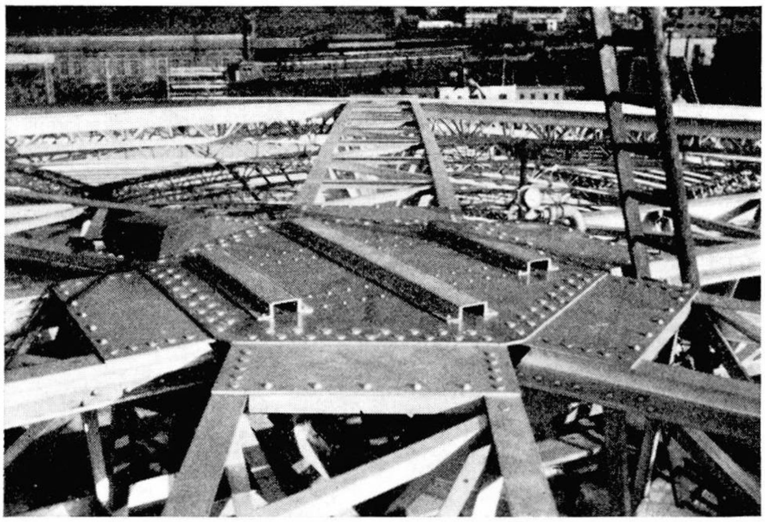

Fig. 7. Crown Detail, 5/9/50

erection and bent aluminium plates approximately 6″ wide × 1/8″ thick were used for connecting the adjacent end channels of adjoining ribs together. See Fig. 7 and 8.

d) Roof Rafters

These were specially extruded 7.3/4″ 4.3/4″ joist section. From C. Fig. 6 it will be noted that the upper portion of the web was increased in thickness to 0.306″ from 0.2″ to provide additional bearing where the joist rested on the 1/2″ square projection on the outside of the top boom extrusion. They were curved to radius at the Extruders' Works. Shop fabrication consisted of notching each end for bearing and providing a slotted hole for the special 1/2″ diameter hook bolts.

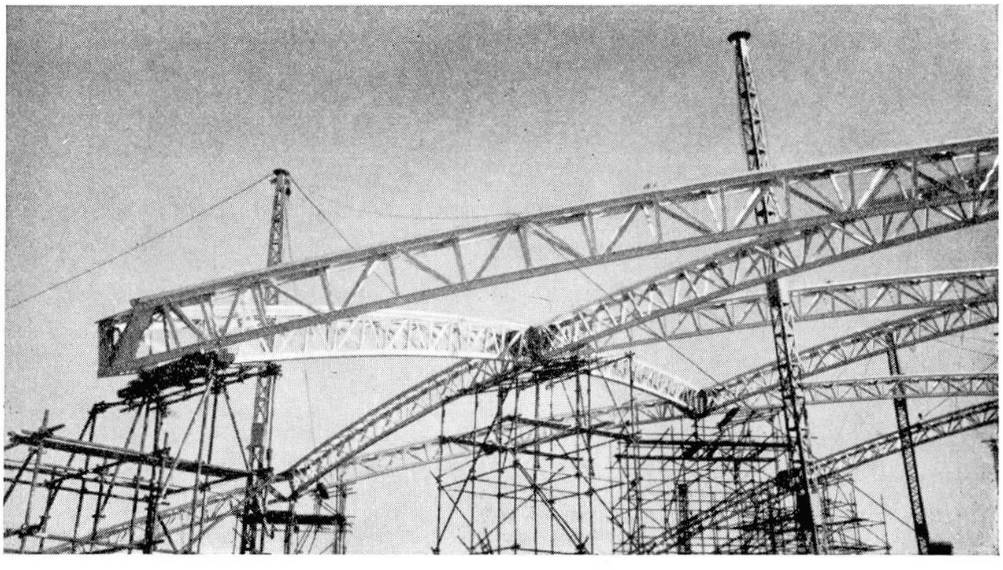

Fig. 8. Rib Erection, 27/6/50

e) Roof Purlins

These were special "top hat" extruded sections 6.1/4″ wide × 2.3/4″ deep (see D. Fig. 6), these sections also being curved at the Extruders' Works.

f) Roof Sheets

Flat rectangular sheets were used 13 gauge (0.092″ thick) 4′-9″ wide, varying from 18′-0″ to 4′-0″ long. To simplify fabrication and for speedy erection the roof was divided into six equal sectors, with a radial make-up joint between each sector. There were 39 circumferential rows of sheets with two semi-circles at the crown approximately 9′-0″ diameter. In the bottom row there were fifty four sheets, plus a further six make-up sheets. The size and position of all sheets in a sector was calculated in the Drawing Office. The sheets were then sheared convexly along their bottom edge and radially along the two sides, the top edge, except for the rows near the crown, were left straight. One side and the bottom edge of each sheet was drilled 0.197″ diameter.

g) Roof Ventilators

Thirty six special Dome-shaped ventilators made of light aluminium spinnings were made and attached in the Works to thirty six of the roof sheets. These ventilators were arranged on the roof in three concentric rings containing 6, 12 and 18 ventilators respectively. They were fitted with baffle plates and wire mesh to exclude light and birds. See Fig. 2.

h) Apron Radial Girders

The main framework consisted of forty eight aluminium trough-shaped girders built up of 11″ × 2″ bent plate channel bottom boom, 13G (0.092″) thick side plates and bent flat angles 2.1/4″ × 2″ × 1/8″ top booms. These girders varied in length from approximately 80′-0″ to 12′-0″ and the bottom boom was curved to give a corresponding variation in depth.

i) Apron Purlins

The same "top hat" extrusion was used as for the roof purlins, but in this case the radius of curvature varied from 101 ft. to 166 ft. in 3′—3.1/2″ increments, the purlins being spaced at 3′-9″ centres.

k) Apron Sheets

16 gauge (0.062″) thick flat aluminium alloy sheets were laid on top of the purlins and were secured to them by means of 1/4″ diameter sheeting bolts. Provision had to be made for expansion, also a light tight joint, at those places where the concrete fins for supporting the 35 ft. level exhibition platform passed vertically through the Apron.

l) Apron Cleaning Trolleys

Two special trolleys, 4′-9.1/4″ wide × 9′-0″ long each carried on eighteen rubber-tyred castor wheels were supplied, having hand-operated rope tackle and pulley blocks for radial movement, each being suspended from a circumferential mono-rail, fitted around the top of the Apron about 3′-9″ from the Ring Girder. This enabled any portion of the conical surface to be cleaned.

6. Erection

a) Concrete Foundations

The Civil Contractors built a continuous ring foundation, 365 ft. mean diameter, enlarged at twenty four points to form concrete blocks for supporting the tubular strut bases and the whole weight of the Dome structure. Recesses were left in these blocks for 7/8″ diameter holding down bolts. Lightning Conductor connections were provided at each of these points.

b) Initial Setting Out

A very careful survey and level was made of the Site so as to determine accurately the centre point of the Dome, the periphery of the Ring Girder, and those points at which site joints would occur in it.

c) Temporary Tubular Trestling

For supporting the ring girder during assembly and site welding twenty four steel tubular scaffolding towers, each consisting of nine vertical members approximately 12 ft. × 12 ft. × 45 ft. high, were built on the circumference of the ring girder. Adjustable wedge packings were provided on the tops of these towers, arranged on either side of the site joint.

d) Ring Girder Erection

Ring Girder erection commenced at the North — see Fig. 3. Each segment of the ring girder was lifted by one 60 ft. derrick.

Work was carried on simultaneously by two squads of men in a clockwise and anti-clockwise direction; segments as lifted being placed on adjustable packings. The position of the ring girder was constantly checked by measuring the included angles, radii of the segments, and levels as the work proceeded, and when the final segment was hoisted into position, at the South End, it was found to be within 1/16″. As the work proceeded the segments were bolted together and packing inserted to ensure the correct gap for site welding. The segments were then tack welded together and after final checking the welding was completed.

Manholes were provided in the inner vertical face of each segment giving access for site welders, painters, etc. Photograph Fig. 9 shows work in progress.

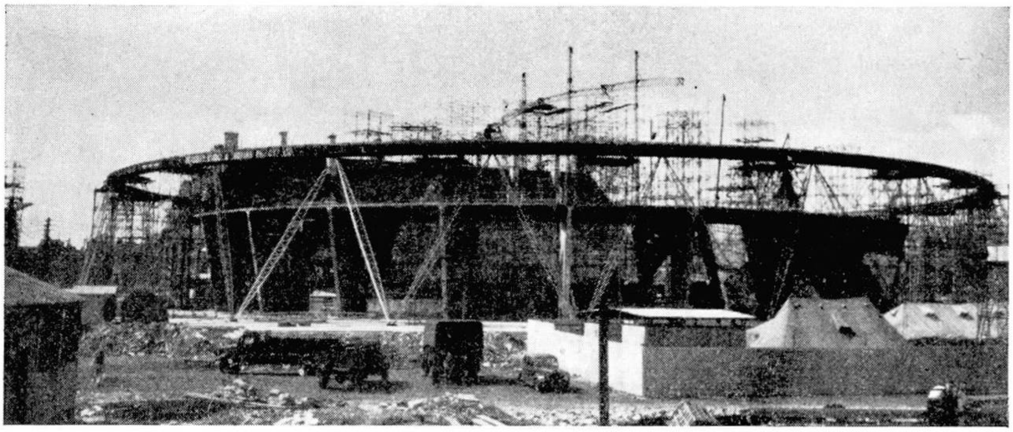

Fig. 9. Ring Girder and Struts complete. First arch being erected, 15/6/50

e) Erection of Dome Ribs

1. Temporary Trestling

Temporary tubular steel scaffolding trestles were erected under each of the thirty seven rib intersection points. These trestles varied from the central trestle which consisted of forty-two vertical members rigidly braced together approximately 30 ft. square and 88 ft. high. Around the centre tower a further thirty-six trestles were arranged in groups of six, twelve and eighteen approximately on the sides of three concentric hexagons, at 55 ft.; 106.5 ft.; and 148.5 ft. from the crown measured horizontally beneath the main girders. These trestles were approximately 84 ft., 76 ft., 72 ft., 61 ft., and 56 ft. high depending on their distance from the crown and varied from 20 ft. square to 12 ft. square in plan. Erection of these trestles proceeded at the same time as erection of the ring girder. Adjustable packings were provided to ensure the correct height and uniform curvature of the ribs. The centre was transferred from the datum point on the ground to the top of the central tower by a heavy plumb-bob and piano wire. To prevent oscillation due to wind it was found necessary to enclose the wire for its full height. See Fig. 10.

2. Main Diagonals

Rib erection commenced with the North-South main diagonals starting from the crown, working simultaneously to the North and South. This was followed by the remaining two diagonals until the full twenty four segments had been erected, positioned and bolted together complete with their top and bottom gusset plates. The underside of the main diagonal segments at the ring girder were supported on a 3/8″ thick steel plate 8″ wide projecting 1″-1″ from the ring girder to which it had been tackwelded at the Works and fully welded at site after its position had been proved. Steel gusset plates 2′-11″ wide connected the top booms to the ring girder. After final checking for line and level the aluminium top and bottom booms were drilled and reamered through the steel gusset plates and bolted together. The top steel gussets were then site welded to the top surface of the Ring Girder. A space of approximately 1″ was allowed between the ends of the aluminium ribs and the vertical inner surface of the steel ring girder so that the whole thrust of the three main diagonals was transferred by shear through the 13/16″ diameter high tensile steel bolts. The three main diagonals were all parts of vertical great circles, all the other ribs were parts of great circles but inclined at an angle depending on their distance from the crown measured normal to the rib.

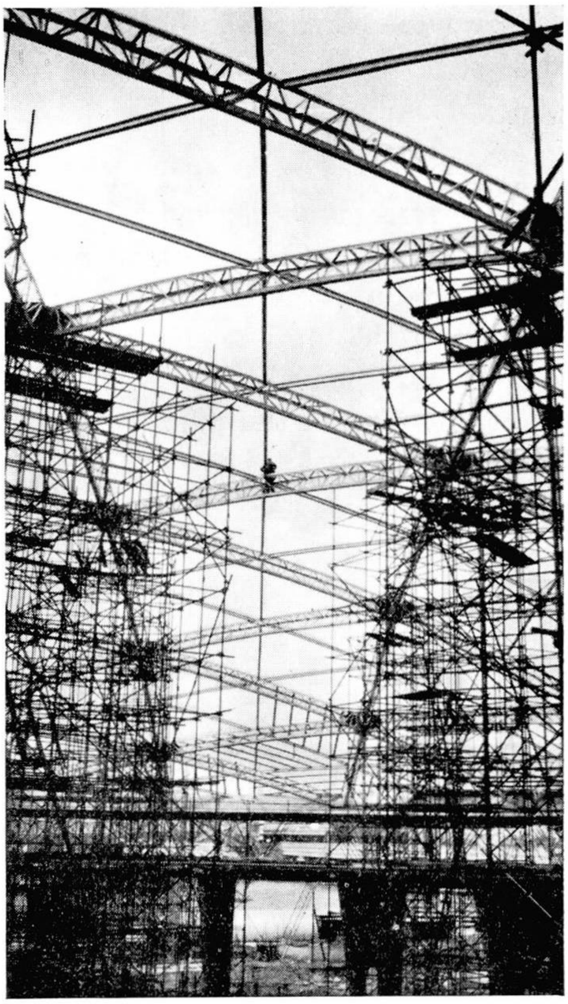

Fig. 10. Aligning rafters. *Note* main rib on left, 24/8/50

3. *Primary Triangles and Secondary Triangles*

To save time erection started simultaneously in the two sectors on either side of main North-South diagonal. Erection was by steel derricks working outwards from the crown and to avoid unnecessary handling their movements were carefully planned. See Fig. 8. In the first instance a steel derrick, by luffing, was able to erect the three secondary ribs nearest the crown. Shorter derricks were then raised to erect, in turn, the two similar triangles whose two sides intersected on the main diagonal and were parts of the primary triangles. Finally, the derricks were moved near the ring girder where they erected in a similar manner the three acute angled triangles, six of whose sides connected to the ring girder. This completed the erection of the eighteen ribs within the sector. It was not always possible to adhere strictly to the above plan. On completing the first two sectors the derricks were moved clockwise and anti-clockwise into those adjacent, and finally moved round to deal with the last two. After completing erection of all ribs, they were checked for line and level at the points of intersection. Site drilling and reamering of remaining small holes then commenced. Fitting of top and bottom aluminium gusset plates proceeded with rib erection. The six ribs at the ring girder were connected to it in a similar manner to the main diagonals by 3/8″ steel plates which were up to 9′-10″ wide on the top and 4′-1.1/2″ on the bottom.

f) Roof Rafters

These members curved to radius, notched and slotted at the Works were then erected and formed tertiary triangles within the rib triangles. The joist rafters had at each end approximately 0.2 sq. in. of bearing on the projection formed in the top boom extrusion. They were secured to the ribs by bent U bolts which passed through slotted holes in their webs and round holes in the top booms of the ribs. See Fig. 10 and Fig. 11.

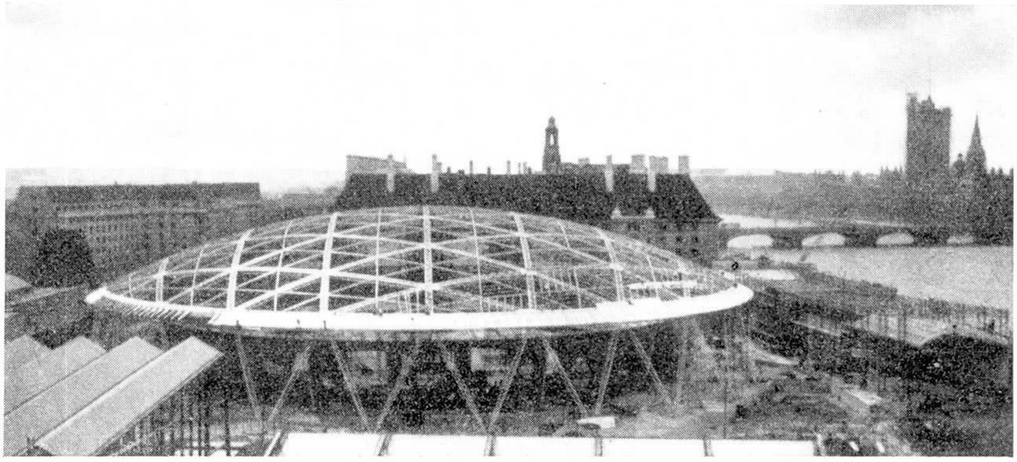

Fig. 11. External view along main diagonal, 24/8/50. *Note* men on Canopy

g) Roof Purlin Erection

The "top hat" extrusions were delivered to site curved to radius; they were erected on top of the rafters and rib extrusions and connected to them by two 1/2″ diameter bolts with two Lindaptor washers at each intersection. Generally they were fixed at about 3′-9″ centres, continuous over three supports, five per panel, arranged in groups of three at approximately 120° to each other. To insulate the roof sheeting from the rafters and to prevent drumming due to relative movement 2″ × 1/2″ thick strips of felt were stuck on to the top surface of the purlins immediately before erection. See Fig. 12.

h) Erection and Loading of Tubular Struts

After completing the ring girder the tubular struts were erected, and the 2.1/4″ diameter bearing pins fitted which connected them to the brackets on the underside of the ring girder. Fabricated welded steel bases were then attached at the bottom end of the struts, which were then located in their correct relative position on the 365 ft. diameter foundation. Holding down

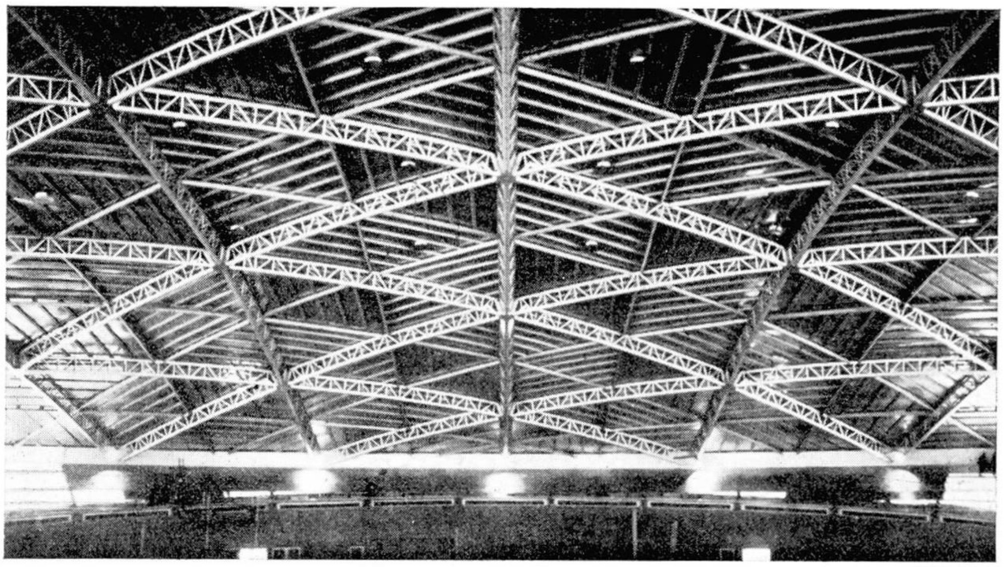

Fig. 12. Internal view along main diagonal, 19/10/50

bolts were suspended from the bases and concrete poured to within 1″ of the base. The bases were finally grouted in after the struts had been wedged up to eliminate any clearances in the top and bottom bearing.

After the concrete grouting had set, the wedges between the trestles and the underside of the ring girder were gradually lowered and the weight of the ring girder transferred to the tubular struts, with no appreciable movement.

i) Removal of temporary trestles from Dome structure

After all the roof ribs, rafters, and some of the purlins had been fixed and the connections between the ribs and the ring girder made, the weight of the Dome had to be transferred from the temporary supporting trestles to the ring girder.

The following procedure was used based on the assumption that as the three main diagonals were the only vertical arch members which spanned the full diameter of the Dome the majority of the load would be transferred through them to the ring girder. As each diagonal had three intersection points between the crown and the ring girder, it was assumed the main loads were carried by the crown trestle and corners of the three concentric hexagons at approximately 55 ft., 106.5 ft., and 148.5 ft. respectively from the crown. The work was commenced on the 21st. August, 1950 and completed by noon the following day, and was carried out in the following sequence:

Operation 1.

The crown intersection point was jacked up and lowered until the Dome was self-supporting over a span of about 110 ft. after deflecting 7/16″. The packings were re-adjusted about 9/16″ clear below the underside of the girder.

Operation 2.

The intersection points at the six corners of the "inner hexagon" at 55 ft. radius were jacked down simultaneously until they were free of load. At this stage the Dome had, in effect, a span of 213 ft. The crown had deflected a further 5/16″ making a total of 3/4″ and the six inner hexagon points had deflected 5/8″. It was particularly noted that on one diagonal, at the intersection point nearest the ring girder, the arch had lifted and there was no load on this trestle.

Packs were re-adjusted slightly lower than the girder at the crown and inner hexagon intersection points.

Operation 3.

The six main diagonal corners of the "middle hexagon" at 106.5 ft. radius were next lowered simultaneously until they were free after lowering about 3/16″ to 1/4″. The main diagonal now spanned about 297 ft. The crown had lifted 1/4″ reducing its total deflection to 1/2″, and the inner hexagon points had lifted 1/8″ reducing their total deflection to 1/2″. The six secondary intersection points at 93 ft. radius, approximately midway along the sides of the middle hexagon, were next lowered simultaneously and were free after lowering 3/16″ to 1/4″.

Operation 4.

All trestles were now free except the eighteen lying nearest the ring girder, six on the main diagonals at 148.5 ft. radius at the corners of the "outer hexagon" and twelve on the primary triangles at 137 ft. radius along the sides of the outer hexagon. These points were dealt with in pairs, first those on the main diagonals which were free of load after lowering about 3/16″ for the first two pairs and 1/8″ for the last pair.

At this stage it was found that no further appreciable movement had occurred at the nineteen points previously released and there was very little load left on the twelve trestles on the sides of the outer hexagon. They were freed after lowering in pairs 1/8″ or less.

A final examination and check was now made of the whole structure and it was found that the crown of the Dome had moved about 1/4″ to the East from its initial setting-out point, and no movement of the ring girder or struts could be ascertained.

k) Roof Sheeting

On account of the large radius of curvature flat sheets were laid directly on top of the purlins whose curvature they assumed and from which they were insulated by strips of felt.

Flexible Aluminium Lightning Conductors between the roof sheets and the main rib were provided.

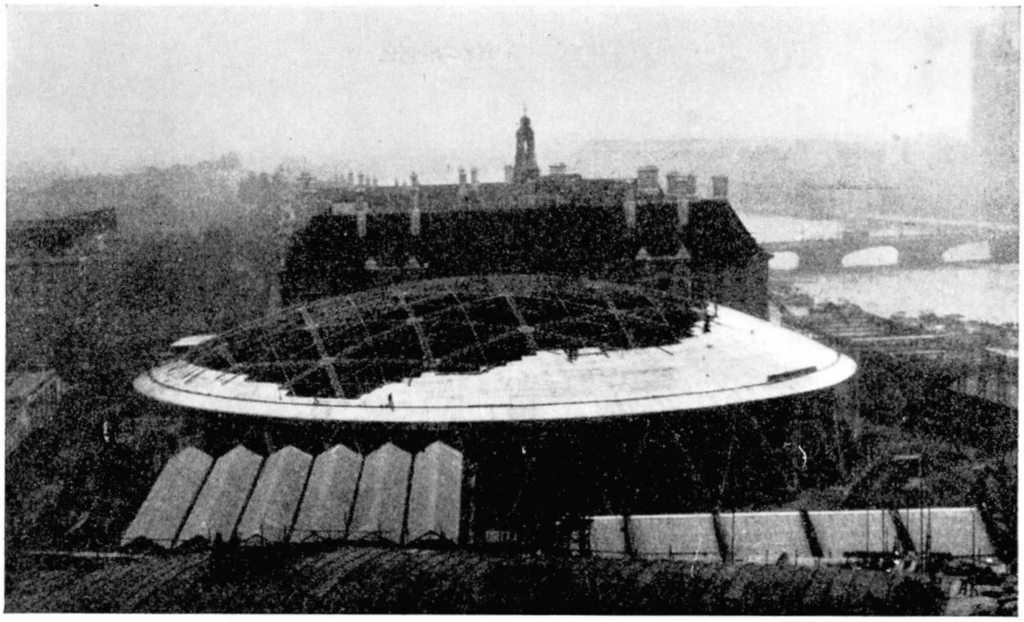

Fig. 13. External view during roof sheeting, 26/9/50

To permit the very large roof sheet area to move relative to the roof framing, due to temperature differences, the sheets were only connected to the roof about once every 100 sq.ft. by means of special cranked 5/8″ diameter 1′-3″ long bolts pin jointed to vertical bracing members of the ribs. These bolts permitted movement with a radius of 1″ at their point of attachment to the roof sheets.

As each of the six sectors were identical it was possible to work simultaneously in all sectors. Each sector was treated as a separate unit, and laying arranged so that the centre line of a sector of roof sheets coincided with the centre line of a main diagonal; laying commenced at this point above the ring girder and proceeded simultaneously upwards and to the right and left.

To prevent undue eccentric loads, as soon as the first few rows of sheets had been laid in the first sector, additional gangs of men started laying the lower rows of sheets in the adjacent sectors until the whole circumference had been sheeted for the lower rows; subsequently, work proceeded upwards towards the crown. See Fig. 13. Between each sector a radial row of make-up sheets was laid, thus counteracting any variation in dimension, and, more important, reducing the effect of temperature on this large area, as the make-up sheets were laid when the temperature was about 60°F. Roof sheets were hoisted on to the roof in batches at a level above which they were to be laid, which enabled them to be slid down the roof. See Fig. 14.

The lower edge of the bottom row of sheets was "Pop" riveted to a 2.3/4″ high aluminium curb channel, which was free to move relative to the ring girder. It was prevented from lifting by special swan-necked aluminium die castings bolted to the ring girder. Before laying the top sheets, the upper

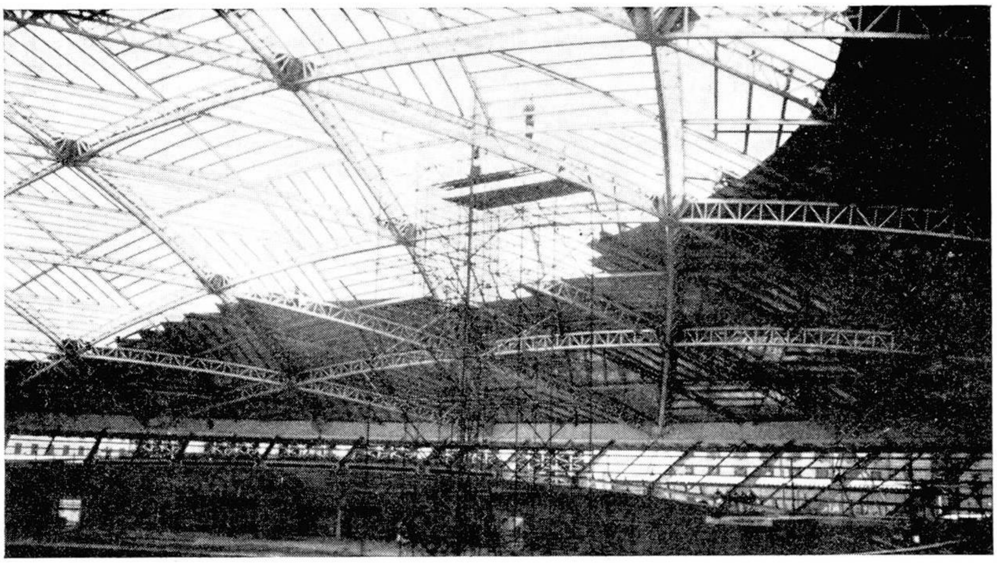

Fig. 14. Internal view during roof sheeting, 26/9/50

edges of the lower sheets were spread with a ribbon of "Secomastic". The radial seams were arranged to break joint, and during laying the radial dimension between each row was carefully checked to prevent excessive variation.

The sheets were laid with a nominal circumferential lap of 1″ and a radial lap of 1.1/4″. The final closure at the crown was made by two semi-circular sheets about 9 ft. diameter cut to size immediately before laying.

After the top sheets were correctly located portable electric hand drills were used to enlarge the 0.197″ diameter shop drilled holes to 0.203″ diameter and drill through the blank bottom sheet. This ensured accurate alignment of holes.

Originally the 13 gauge roof sheets were connected together, at a pitch of five per foot, by approximately 160000 Aluminium "Pop" rivets 0.2″ diameter with caps. Subsequently, it was found that due to the effect of winter storms and possibly the amount of traffic on the roof during sheeting that relative movement was taking place between some of the sheets which loosened some of the rivets and, consequently, it was decided to insert additional monel metal "Pop" rivets 0.187″ diameter with plugs together with special rubber and steel domed washers. These rivets were used in those places where excessive movement had occurred and they were interspersed with the aluminium rivets. A total of nearly 100000 monel rivets were used for this strengthening. Special "Myers" clamps held the sheets securely together during riveting.

The "Pop" rivets completely eliminated the use of internal scaffolding and very considerably expedited the work.

Two 3/4″ pipes were carried up through the dome ribs and a connection made in the crown sheet; these pipes were used for washing the roof periodically.

To prevent undue staining by the London atmosphere the roof was painted with lacquer.

As a safety precaution angle handrail standards with three rows of 3/8″ wire rope were arranged around the top of the ring girder. Further attachments were provided at the crown for securing safety ropes for use when walking on the roof, particularly during wet or frosty weather.

There were 98 000 sq.ft. of sheets on the roof and during the latter stages were being laid at an average of 4000 sq.ft. per day with a maximum of 5600 sq.ft. in one day.

l) Apron

Erection of the Apron proceeded simultaneously with the latter stage of roof sheet erection. The radial girders were first erected and downpipes fitted into every alternate girder. Next the circumferential purlins were fixed by means of 3/8″ diameter bolts; they lay directly on top of the radial girders and generally were continuous over three supports. The top end of the radial girders were secured by four 1/2″ diameter bolts to steel gussets welded to the inner face of the ring girder, and their lower ends rested on the drum wall or steel columns, where provision was made for expansion and they were located by one 7/8″ diameter bolt.

Apron sheet laying commenced from the ring girder. They were laid in circumferential rings concentric to the ring girder. This meant that when both the purlins and the roof sheets over-sailed the drum wall, which had an eccentricity of 29 ft., there were a certain number of triangular sheets to fit in. A special extruded aluminium channel 2.1/2″ deep with one inclined flange was fixed to stiffen the inner edge of the Apron. See Fig. 14 and 15.

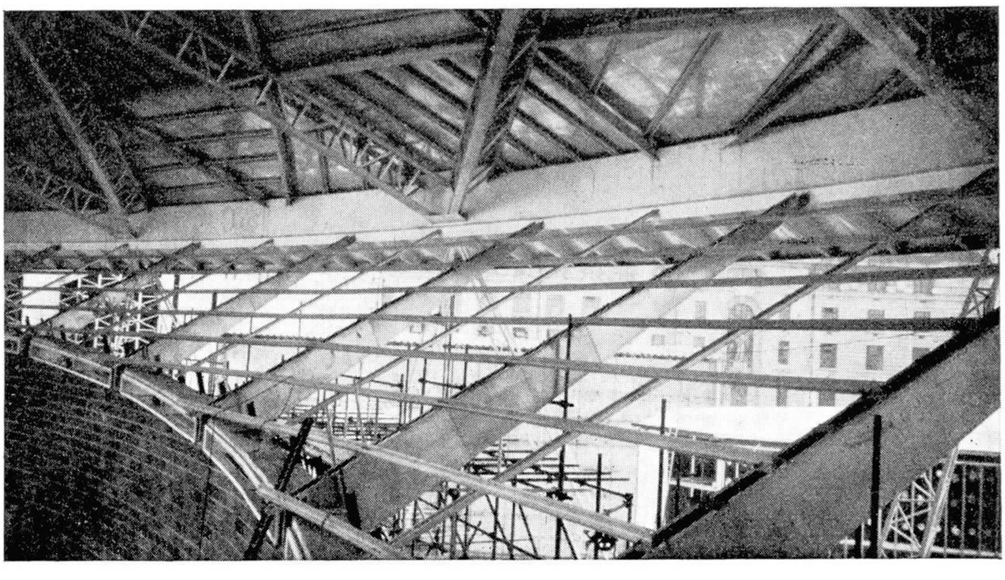

Fig. 15. Details of connections to Ring Girder, 26/9/50

m) Canopy

An aluminium canopy, projecting 7′-0″ was fixed to the angle brackets outside the steel ring girder. This consisted of folded cantilever "V" shaped beams made from 16 gauge (0.064″) sheet and spaced at 4 ft. centres. 18 gauge (0.048″) sheeting was laid on top of, and seam-bolted to, the cantilever beams. The outer edge of the canopy and cantilever beams was closed by a folded curb member. See Fig. 5.

7. General

The very detailed planning at all stages of the contract and the thorough inspection and checking which took place during fabrication enabled the site work to proceed smoothly and expeditiously.

The first segment of the Ring Girder was lifted on to the trestles on the 18th. April, 1950 and the crown roof sheets laid on the 12th. October, 1950. This completed the structure apart from a small portion of the apron which was completed early in November, 1950.

A feature of unusual nature was that the load supporting members, i. e. tubular struts, were not erected until after the Ring Girder had been completely erected and tack bolted.

The extensive use of "Pop" rivets for structural work is, I believe, an inovation and showed a considerable saving in time and labour.

A novelty was the use of a 100 ft. telescopic fire escape ladder for adjusting some of the felt on the purlins which had been displaced during erection.

8. Sub-Contractors

Sub-contracts for various portions of the work were placed with the following firms:

Messrs. Structural and Mechanical Development Engineers, Limited, Slough.
Messrs. Imperial Chemical Industries Limited, Metals Division, Birmingham and Swansea.
Messrs. Mills Scaffold Company Limited, London.
Messrs. Tubewrights Limited, Newport.
Messrs. Geo. Tucker Eyelet Company Limited, Birmingham.

Their enthusiastic co-operation was much appreciated.

9. Acknowledgements

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Summary

This paper describes the fabrication and erection of the "Dome of Discovery" built for the 1951 Festival of Britain.

The structure was unique, built of steel and aluminium alloy. With an overall diameter of 365 ft. it is probably the largest Dome in the world.

The actual Dome was a segment of a sphere 726′-9″ diameter and made entirely of aluminium. The main arch framework consisted of three series of seven "great circles" approximately parallel to each other, and arranged so that the centre arch members of each group intersected each other at angles of 120° at the crown of the Dome. This arrangement sub-divided the surface of the roof into ninety-six spherical triangles with sides varying from 55′-6″ to 24′-3″.

The roof ribs were of triangular lattice construction and their fabrication was considerably simplified by the adoption of great circles as the basis of the design, thus making the curvature of each individual rib identical as all the great circles were parts of the same sphere. The arch ribs were supported on a welded steel ring girder 342 ft. diameter supported 47′-3″ above ground level on forty-eight tubular steel lattice struts.

Approximately 138 tons of Steel and 234 tons of Aluminium Alloy were used in the building.

Zusammenfassung

Der Verfasser beschreibt die Herstellung und Montage des Doms der Entdeckung, der für das Festival of Britain von 1951 errichtet wurde.

Es handelt sich um ein einzigartiges Bauwerk aus Stahl und Aluminium. Mit einem Außendurchmesser von 365′ (ca. 111 m) ist es wahrscheinlich die weitestgespannte Kuppel der Welt.

Die eigentliche Kuppel bildet ein Kugelsegment mit 363′-4$^1/_2$″ Radius und besteht ganz aus Aluminium. Das Hauptbogensystem besteht aus drei Scharen von je 7 unter sich ungefähr parallelen Großkreisen, die so angeordnet sind, daß sich die mittleren Bogen jeder Schar im Scheitel der Kuppel unter 120° schneiden. Dadurch wurde die ganze Dachfläche in 96 Kugeldreiecke mit Seitenlängen von 55′-6″ (ca. 16,9 m) bis 24′-3″ (ca. 7,4 m) unterteilt.

Die Dachrippen sind als Dreigurtfachwerke ausgeführt und ihre Herstellung wurde durch die Annahme von Großkreisen als Netzlinien der Kuppel erheblich vereinfacht, da alle Rippen gleiche Krümmung aufweisen. Die Bogenrippen stützen sich auf einen geschweißten Ringträger aus Stahl mit einem Durchmesser von 342′ (ca. 104 m) ab, der seinerseits auf 48 fachwerkförmigen Stahlstützen von 47′-3″ (ca. 14,4 m) Höhe gelagert ist.

Der Materialbedarf für das Bauwerk betrug ca. 138 t Stahl und 234 t Aluminium.

Résumé

L'auteur décrit la fabrication et le montage du ,,Dôme de la Découverte'', qui a été édifié à l'occasion du Festival de Grande-Bretagne de 1951.

Il s'agit ici d'un ouvrage unique, en acier et alliage léger. Son diamètre de 365′ (111 mètres) en fait probablement la plus grande coupole du monde.

La coupole proprement dite est constituée par un segment d'une sphère ayant un diamètre de 726′ 9″ (222 mètres); elle est entièrement en aluminium. La charpente principale est formée par trois séries de sept ,,grands cercles'' sensiblement parallèles entre eux et disposés de telle sorte que les éléments centraux de chaque série se coupent entre eux sous des angles de 120° au sommet de la coupole. Grâce à cette disposition, la surface de couverture est divisée en 96 triangles sphériques dont les côtés varient de 55′ 6″ (17 m environ) à 24′ 3″ (7,4 m).

Les entretoises de la coupole sont constituées par un treillis triangulaire; leur fabrication a été grandement simplifiée par l'adoption des grands cercles qui forment la base de la conception de cette coupole; les courbures de toutes les entretoises sont en effet identiques entre elles, puisque tous les grands cercles font partie de la même sphère. Les entretoises sont supportées par une poutre circulaire en acier soudé ayant un diamètre de 342′ (104 m), portée elle-même à 47′ 3″ (14,4 m) au-dessus du sol par 48 arcs-boutants en tubes d'acier, en treillis.

Cet ouvrage a demandé environ 138 tonnes d'acier et 234 tonnes d'alliage léger.