OFFICE OF THE UNITED STATES COMMISSIONER GENERAL
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MONTREAL 3, P.Q., CANADA AREA (514) US 1-1776

UNITED STATES PAVILION: STRUCTURAL ASPECTS

DOME STRUCTURE

1. TYPE STRUCTURE

Approximately a "three-quarter sphere" dome. Structure is a double layer space frame. Space frame members occur in 3 systems: outer layer, inner layer, and web connecting inner and outer layers. The outer layer members are connected in a triangular arrangement. The inner layer members are connected in a hexagonal arrangement. The web members are located in planes passing through the spokes of the inner hexagons and complete the triangulation of the inner system. Geometrical principles developed by R. Buckminster Fuller are employed to develop the general arrangement of triangles and hexagons above the equator of the dome. Below the equator isosceles triangles and hexagons are arranged in regular rings of gradually decreasing size.

2. SIZE OF GEOMETRICAL PATTERN

Size of geometrical pattern is based on acrylic skin requirements. Skin is attached to inner layer hexagon and forms a bubble with hexagonal base in each hexagon. Skin is molded from 12 foot sheets of acrylic varying in size from 8 ft. by 10 ft. to 10 ft. by 12 ft. (maximum size available). Thus, inner hexagon size is established to accommodate the 12 foot maximum acrylic sheet size and this also more or less fixes the size of the outer layer triangles and web system.

3. STRUCUTRAL MEMBERS

Outer layer structure is 3-½" o.d. pipe, varying from standard weight pipe in the upper regions of the dome to double extra strong near the base. Inner layer and web system members are 2-7/8" o.d. pipe, varying from standard weight pipe in the upper regions of the dome to double extra strong at the base. Inner layer pipes have a structural "T" welded along the inside to provide a flat surface for attachment of acrylic skin panels. Webs of the "T"s are castellated to reduce weight and give a lighter appearance.

Maximum length between joints is about 10 feet for outer layer member and about 7 feet for web or inner layer members.

4. HUBS

Pipe is connected with cast steel hubs. Each hub consists of a solid steel cylindrical center with rectangular tabs for each member joined. Outer layer hubs have 6 tabs for outer layer members and 6 tabs for web members, a total of 12 tabs. Inner layer hubs have 3 tabs for inner layer members and 3 tabs for web members. There are 2 inner hubs for each exterior hub. There are about 5900 hubs of both types. Geometry of the structure required about 83 different hub patterns (43 interior and 39 exterior).

5. FIELD CONNECTIONS

Pipes were joined to hub connectors by field welding hub tabs to slots in the end of pipes.

6. WEIGHT OF STEEL:

pipe - 600 tons

hubs - 120 tons

Approximate average weight of steel per square foot of dome surface - 10 psf.

7. FABRICATION AND ERECTION ASPECTS:

a) Off-site fabrication consisted of:

(1) Fabrication of footblock weldments

(2) Casting of hubs

(3) Drilling one erection hole in each tab of each hub

(4) Cutting pipe to correct length

(5) Cutting one slot (for a hub tab) and punching one hole in each end of each pipe

(6) Welding of "T" sections on inner pipe members

(7) Properly marking of all pieces.

Except for footblock weldments and a few special pieces at doors, no shop drawings were required. All pipe and hubs were fabricated from schedules of weights and exact lengths of pipe and tab angles and arrangement prepared by the dome architects. All the various dimensions and geometrical layout were obtained by computer. The computer program was developed by Simpson Gumpertz & Heger working with the dome architects who developed the criteria which determined the geometry.

b) On-site fabrication was carried out in two steps:

(1) Sub-assemblies were prefabricated in one of two jigs located near the base of the dome. Jigs were simply a rigid concave spherical surface (constructed from steel shapes and plate) about 30 feet x 50 feet in size. Outer hubs were placed on the surface, pipe positioned using a single erection and positioning bolt in each tab, inner hubs placed on the ends of web pipes and the assembly partially welded. Once started on the spherical table, the assembly process was "self-jigging". The major portion of welding of sub-assemblies was completed after removal of sub-assembly from the spherical table.

(2) The large sub-assemblies (50 ft. approx. max. dimension) were erected by crane and adjacent assemblies were secured by the erection and positioning bolts in hubs at the interface.

c) Total time for site assembly and erection was approximately 5 months. Progress toward the end was considerably more rapid as procedures became familiar and standardized.

No serious problems arose with the assembly and erection procedure. The dome frame was closed without difficulty. Tolerances proved satisfactory for fit with prefabricated acrylic skin panels.

d) Welding was inspected visually and by ultrasonic methods.

8. STRUCTURAL ANALYSIS

Structural analysis of dome was carried out with the aid of computer analyses in 3 steps:

a) Dome assumed an isotropic shell. Membrane stress analysis carried out by computer for wind load, dead load, snow load (both balanced and unbalanced) and live load from hanging exhibits.

b) Because of the geometry difference between outer layer members and inner layer members, a space frame analysis was carried out by computer for a typical portion of the structure to determine the distribution of forces between inner and outer layers and to the various members. There were too many joints and members in the entire structure to warrant application of this technique to the structure as a whole.