Spaceship Earth:
EPCOT Center's Gateway to Tomorrow

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EPCOT Center is Disney's newest entertainment world at Walt Disney World in Florida. Developed by WED Enterprises, the design arm of the Disney organization, it has two parts: Future World, a collection of exhibits of the new ideas and technologies which are emerging from the creative centers of America; and World Showcase, a meeting place to display the cultures of many nations. The focus of the entry courtyard is a 160-ft diameter geodesic sphere, raised 14 ft above ground and covered with faceted aluminum panels. Conceived as a symbol of EPCOT Center and the global impact of the technoloy of the future, the sphere was appropriately named Spaceship Earth. Because EPCOT Center is an entertainment complex, the exterior design tends towards a "show" facade while simultaneously presenting Disney's vision of the technology of the future.

"We wanted to create an atmosphere for our guests that raises their spirit and kindles an excitement for the human experience in the future," stated Gordon Hoopes, WED's project designer for Spaceship Earth. "We knew that having the entire sphere raised above the ground would cause substantial engineering problems but the psychological uplift for our guests would be worth it."

Underneath the geodesic-patterned metallic skin of Spaceship Earth is a complex steel structure carefully tailored to satisfy the varied requirements of WED's show designers and engineered to transfer the various loads to the foundations with the greatest economy consistent with the other program requirements.

Early WED Concepts

In early 1979, WED Enterprises retained Simpson Gumpertz & Heger Inc. (SGH), structural engineers, and Wallace, Floyd, Associates Inc. (WFA), architects, to develop the design of the Spaceship Earth pavilion from WED's concept sketches.

Through many studies over several years, WED's concept designers had determined the size of sphere they wanted at the entry to EPCOT Center. They had also established the concept for a support system that would be aesthetically desirable and which could be integrated into the surrounding facilities. Their early sketches showed three pairs of legs rising from ground level to support a patterned sphere of approximately 160-ft diameter.

Development of Sphere Enclosure

Because Spaceship Earth was intended as

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Sleek monorail circles pavilions of Future World. Spaceship Earth looms high above EPCOT Center, kindles excitement for vision of future. Photos courtesy Walt Disney Productions

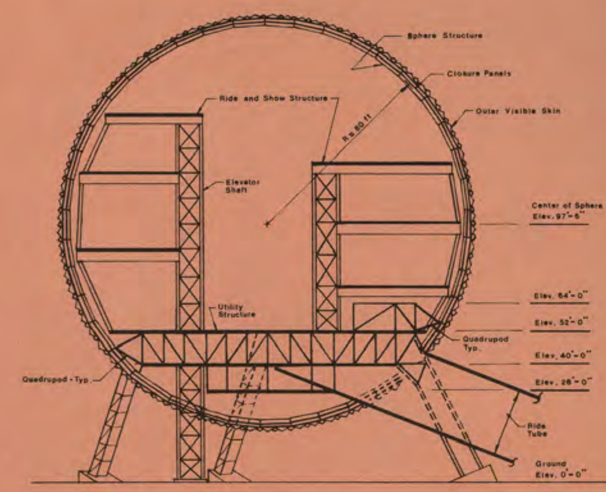

Figure 1—North-south section through Sphere

the main focal point and the "logo" pavilion of EPCOT Center, appearance of the sphere was of extreme importance. WED's designers initially indicated a preference for a geodesic pattern similar to that used for the Expo '67 dome in Montreal. But a final pattern for the exterior could not be determined until a preliminary structural design for the sphere had been developed.

The selection of the material for the sphere's enclosure involved several essential, but seemingly conflicting considerations. Reliable waterproofing was necessary to protect the costly ride equipment and show set; fire-resistive construction was essential for protection of the building occupants; and, of course, the selected material had to be appropriate aesthetically.

No single material satisfied all of these requirements. Sheet neoprene, for example, was deemed to provide the best water resistance, but its appearance was considered entirely inappropriate. This quandary led to the "double-skin" solution for the sphere enclosure. An inner shell, covered by a waterproofing neoprene sheet, was attached directly to the sphere structure. At a radius approximately two feet greater than that of the inner skin, a purely cosmetic cover was erected. This separation permitted the visible outer shell to be fabricated from more aesthetically desirable material.

The exterior panels do not need weatherproof joints, and the only structural requirement is that they be capable of resisting wind load perpendicular to their surfaces. The outer skin is supported from the hub points of the inner structure by aluminum pipe outriggers or standoffs. The two-foot space between skins provides access for maintenance of the waterproofing and the inside surface of the cosmetic skin.

The double-skin solution solved another problem: excessive runoff of rainwater to the pedestrian circulation below. By means of open slots between facets of the outer cosmetic panels, rainwater percolates to the inner waterproof skin where it is collected and carried away by a hidden gutter system at the sphere's equator.

Primary Structural Systems

A key design task during the conceptual phase was to devise a structure to support the interior ride track and show sets (the Ride and Show Structure; see Figure 1) that was independent of the structure of the geodesic sphere (the Sphere Structure). This was done to avoid concentrations of force in the sphere and interruption of its natural shell action, in an effort to keep the Sphere Structure members as light as possible. This structural separation also afforded WED's designers more flexibility in locating the ride tracks and show platforms, and it allowed the design of the sphere to proceed concurrently with, but independent of, the development of the ride and show.

The requirement that the Sphere Structure be totally elevated above the ground posed an unusual engineering challenge. To support all of the Sphere Structure loads directly on the legs would have created discontinuities and concentrations of force in the sphere, and would also have destroyed the shell behavior. The solution was to support the Sphere Structure as uniformly as possible at a ring of sphere hubs at the approximate elevation of the tops of the six legs. Ultimately, the Sphere Structure was kept entirely independent of the legs.

It was necessary to develop a major steel structure to transfer all of the loads from the Sphere Structure and most of the loads from the Ride and Show Structure to the six legs. Most of the mechanical equipment space from Elevation 28 to Elevation 52 was available for this purpose, but a major penetration for the ride entrance to the sphere (the Ride Tube) allowed only limited space between Elevation 52 and Elevation 64 at the southern part of the sphere. The structure provided in this space, designated the Utility Structure, developed into something akin to a huge six-legged table, on top of which was supported the Ride and Show Structure, and from which was suspended the Sphere Structure at the utility levels.

Sphere Structure

Although the Disney organization had developed its own EPCOT building code for Walt Disney World, the wind loading criteria that it contained were not applicable to a structure as unusual as Spaceship Earth. Preliminary structural design was based on wind-loading data derived from prior experience with spherical structures. Later, wind-tunnel studies were performed on a $\frac{1}{16}$ in. = 1 ft scale model of Spaceship Earth and its surroundings at the Wright Brothers Memorial Institute of the Massachusetts Institute of Technology. In addition to establishing pressure coefficients for the design of the Sphere Structure, the study was used to determine pedestrian level wind pressures. Design wind velocities for application of the wind-tunnel pressure coefficients were derived from the EPCOT Building Code, from American National Standards Institute data and from historical meteorological data for central Florida.

Several considerations bear on the selection of the geodesic geometry type and frequency for a geodesic structure:

- To minimize bending moment and buckling effects, the lengths of members should be limited.

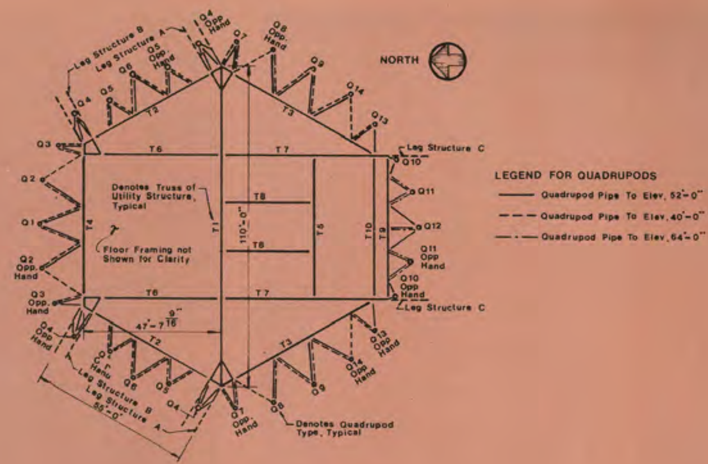

Figure 2—Key plan for utility structure, elevation 52 ft

- For economy of fabrication and erection, as few members and as few differing lengths of members should be used as possible.
- For efficiency, the difference between the maximum length of member and the minimum length of member should be minimized and member forces should not vary over too great a range.
- Since the geometry of the visible shell is related to that of the supporting structure, the selected geometry should be aesthetically pleasing.

After various structural studies by SGH and various pattern studies by WFA, and in consultation with WED, an eight-frequency "triacon" geodesic geometry was selected. This resulted in eight fundamental sphere-strut lengths and four (with opposite-hand complements) panel types. The struts range in length from 12-16 ft.

Steel wide-flange shapes were the natural choice for the Sphere Structure members. They are easily connected at their ends, and their strong bending axes can be oriented to efficiently resist dead loads and wind loads perpendicular to the sphere surface.

The struts were fabricated from A572 Grade 50 steel in three sizes: W10x45, W10x33 and W10x22. From the level of the supported hubs to the top of the sphere, these struts occur in three bands, the weights of the sections decreasing with increasing elevation. Most of the struts below the level of the support hubs, where the structure is essentially hanging, are W10x22, but heavier members were required at the structural discontinuities created by the penetrations for the legs, the elevator and the Ride Tube.

At hub locations, the struts are connected at their top and bottom flanges by circular steel plates which are stamped to a conical shape. This simple and economical type of connection is now commonly used in geodesic domes.

Prefabricated metal panels (closure panels), which fit into the triangles created by the struts, form the inner shell to which the waterproof membrane is applied. These panels support rigid-board insulation on their interior surfaces and they also participate with the outer visible skin in the resistance of wind loads perpendicular to the sphere surface. Their only structural function, in addition to resisting wind loads, is to laterally brace the wide-flange struts. These panels are formed from standard 3-in. deep 20-ga. metal roof deck with an 18-ga. flat outer sheet which provides a smooth surface for the neoprene waterproofing. Cold-formed, light-gage steel edge rails and structural tee clips provide attachment to the outer flanges of the wide-flange struts.

In total, the Sphere Structure is composed of 1,339 struts, 467 hubs, and 954 closure panels. The total weight of structural steel, excluding the closure panels, is 400 tons.

Utility Structure, Legs and Foundations

The key task in the design of the Utility Structure was to develop a structural system which would support the sphere as uniformly as possible while it transferred the sphere loads to the six legs. Candidates for rings of sphere hubs to be used as support hubs were identified. The hub elevations necessarily undulate because of the geodesic sphere geometry and because the Ride Tube penetration requires a rise in the level of the adjacent sphere support structure.

Essential considerations in the development of this system were economy of fabrication and simplicity of erection. It was desirable to shop-fabricate to the greatest extent possible, but shop-fabricated assemblies were restricted to a 12-ft wide shipping envelope. A number of early schemes examined employed box-type plate girders or three-dimensional trusses spanning between the six legs. These members were curved in plan to follow the perimeter of the sphere, and the schemes required them to carry substantial torsional loads because the sphere support points were outboard of straight lines struck between adjacent legs.

A major simplification and savings over these schemes was achieved by using the floor structures at Elevations 40 and 52 to carry the torsional loads by means of resistive couples developed by diaphragm forces in these floors. This solution was based on a hexagonal pattern of 12-ft deep trusses, designated T2, T3, T4 and T10 on Figure 2. The top chord of each truss is located at the floor at Elevation 52 and the bottom chord is located at the floor at Elevation 40. These trusses carry only vertical loads.

The sphere's support hubs are attached to these trusses by a system of four-legged assemblies called quadrupods. Extending from a common working point at the sphere support hub, two legs of the quadrupod attach to adjacent panel points of the upper chord of a truss, and two legs attach to adjacent panel points of the lower chord. The horizontal component of force in these members is carried by the 12-ft deep truss at the edge of the hexagonal platform. An exception to this system occurs at the southern area of the sphere, where the usable space between floor levels is inter-

Spaceship Earth from north

rupted by the Ride Tube. Here, a box-type space truss, designated T5, T9 and T10 on Figure 2, carries vertical and torsional loads.

Some of the columns of the Ride and Show Structure are also supported by this hexagonal pattern of trusses; outriggers are used to transfer loads from outboard columns back to the hexagonal trusses. Interior trusses T1, T6, T7 and T8 support other columns of the Ride and Show structure.

Legs Type A and Type B (see Figures 1 and 2) are box-type truss members. Legs Type C, very restricted in width to fit within the Ride Tube, are planar-type trusses with web plates covering their two sides.

Foundations are end-bearing, concrete-filled steel pipe piles, approximately 100-ft long. Reinforced concrete grade beams tie the pile caps and carry horizontal thrusts from the inclined legs.

Quadrupod Support System

The quadrupods carry the sphere loads to the Utility Structure and make the critical transition from the geodesic sphere geometry to the geometry of the hexagonal trusses. Each quadrupod typically consists of four pipe struts (6XX, 8STD or 8X), which connect a sphere hub to four panel points on a hexagonal truss. Some of the quadrupods are actually tripods because of pipe strut interferences with other structural components. Some of the quadrupod pipe struts attach directly to the leg structure rather than to the hexagonal trusses. There are 30 quadrupods in all, shown in plan on Figure 2.

Because of symmetry of the structure about the north-south axis, however, there are only 14 quadrupod types. Three additional hangers, similar to quadrupods but with only one strut, provide additional support for the sphere at the Ride Tube penetrations. The inner ends of the quadrupod pipes connect to the Utility Structure by means of compact weldments, which are bolted to the upper and lower chords of the trusses and are field-welded into slots at the ends of the quadrupod pipes. The outer ends of the quadrupod pipes connect to the sphere with a set of complex weldments, each based on a six-legged spider of steel plates; these are also field-welded into slots at the end of the quadrupod pipes.

An essential consideration in the design of the quadrupod support system was practicality in erection and fitup. The design allowed for field alignment of the sphere support hub points during erection by the use of erection bolts in slotted holes at each end of the quadrupod pipes. These connections allowed independent adjustment during erection of each support hub working point in each Cartesian coordinate direction. Once the support hubs were precisely set, these connections were welded off.

Additional horizontal adjustment was provided by shims between the truss chords and the previously described compact weldments at the inner ends of the pipes. Thus, accumulated fabrication and erection tolerances and the dead-load deflections of the sphere support system could be adjusted out of the system to obtain the precise alignment of the support hubs required for sphere erection.

Development of Outer Skin Panels

WFA performed the early pattern studies. They were concerned principally with the scale and geometry of the facets because the support points of the outer skin panels were determined by the geometry of the inner steel structure, and by the triangular sections thus defined. WFA studied possible patterns within these basic triangles by constructing cardboard mockups. The alternatives considered included a pattern that emphasized the accumulation of six triangles around a hub, resulting in an overall surface pattern of hexagons; a pattern which reflected the basic triangle and scale of the underlying steel structure; and a pattern that subdivided these triangles into smaller triangles of approximately eight feet on a side.

The final pattern, chosen by WED's John Hench, senior vice president for creative development, was a subdivision of the flat triangular facet of the structural steel geometry into four smaller triangles. Each smaller triangle is covered by a triangular pyramid of approximately one foot in altitude. A ⅛-in. scale mockup of the entire sphere was constructed with this pattern for final approval by WED's designers.

Concurrently with the pattern studies, color, material and lighting investigations

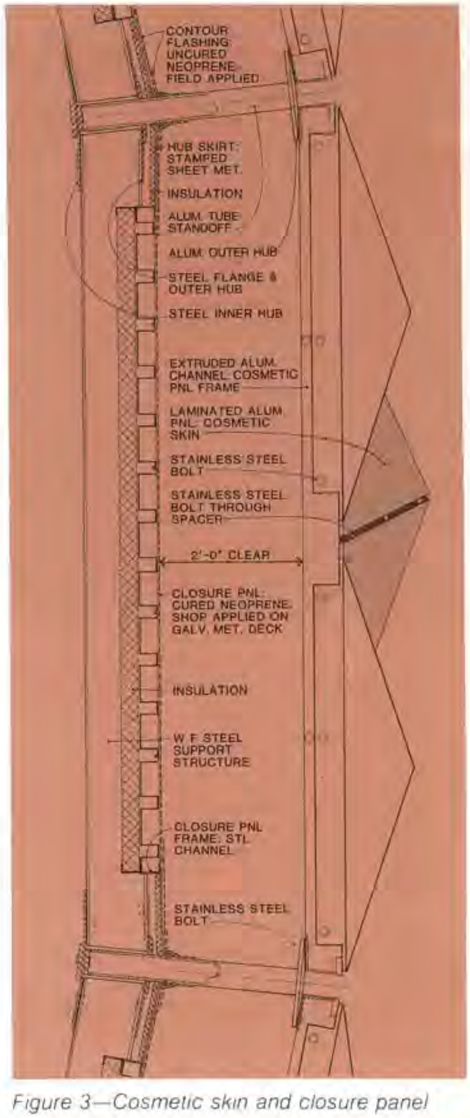

Figure 3—Cosmetic skin and closure panel

were undertaken. WFA investigated several different materials, placing particular emphasis on the program requirement for a color-fast coating and the dramatic effects which might be achieved with exterior lighting. The three generic types of materials considered were metal panels, fiberglass panels and glass.

Through several early study models, WED had investigated an exterior covering of reflective glass. WED asked WFA to investigate the possibility of backlighting a skin of reflective glass to create a glowing sphere at night. Although it appeared that a reflective glass enclosure backlit with long-life sodium bulbs was feasible, this solution was considerably more expensive than either of the others, and it would have involved long-term maintenance requirements. In addition, a similar effect could be achieved at night by using special exterior floodlights.

A wide choice of colors could be obtained from the formed fiberglass or metal panels coated with a high-performance coating.

WFA performed several color studies for review by WED designers. Of particular interest was an attempt to simulate the appearance of the earth as photographed from satellites by NASA. The intent was to outline the general features of the earth as one would see them from space without actually building a replica similar to a globe. Tinted aluminum sheets with transparent dyes for the various colors were proposed. This would have allowed the metallic quality of the material to register at the same time as the overall desired image.

As the design of the triangulated substrate developed, WED indicated a preference for a machinelike metallic look. The ease of forming aluminum and its ability to accept a wide variety of high-performance finishes made it a natural choice. Eventually WED's designers selected a clear anodized aluminum as the desired finished appearance. Several composite panels with aluminum facings, equal to aluminum plate in finished appearance, were also considered.

WFA and SGH recommended that a performance specification be used for the panel material, and that, where the aluminum structure interfaced with the steel sphere structure, details and member sizes be included in the bid documents. In addition, profiles of the faceted panels and the critical geometry for the pattern were developed. The performance specification was written to ensure that the design would meet critical environmental conditions without any permanent change in appearance. Because the sphere would be one of the most visually prominent features of Epcot, the performance specification also included quality control requirements. (Figure 3 illustrates the final design for the visible exterior panels and substructure.)

Fabrication and Erection

The steel fabricator used the repetitive nature of the sphere system geometry to maximum advantage by fabricating the sphere struts and hub plates on computer-controlled punching and cutting machines.

To minimize the effects of the deflections of the hexagonal trusses on the Sphere Structure, it was necessary to ensure that a certain amount of dead load was applied to the Utility Structure before erection of the Sphere Structure. Thus, after the legs and trusses of the Utility Structure were erected, the steel and concrete floors at Elevations 28, 40 and 52 were placed, and most of the steel of the Ride and Show Structure was erected.

Next, the quadrupods were erected with a full interconnecting ring of sphere struts. The support hub working points were approximately set by level survey, and the adjustable connections of the quadrupods were temporarily fastened by erection bolts. Erection of the struts continued until three full sphere rings of the sphere were complete. The quadrupods were further adjusted during this stage as the struts drew the support hubs to the precise geodesic geometry. When the erection of three full sphere rings was complete, the geodesic geometry was considered set, and the adjustable quadrupod connections were welded off.

The erector worked upward from this support-hub level. Units of two, three or four struts were assembled on the ground and erected on the sphere in circumferential rings. This procedure was used up to approximately 50 ft in diameter, was assembled on the ground and hoisted into position to complete erection of the upper portion of the sphere. Next, the sphere components below the support-hub level were erected. No scaffolding or other temporary support of the sphere was required during erection.

The steel closure panels of the inner skin were erected with cable slings. Contract documents prescribed that erection of these panels closely follow the erection of the sphere struts so that the necessary lateral bracing of the struts would be provided before substantial loads were applied to the sphere. Next, the aluminum standoff pipes used to support the aluminum outer shell were erected. Flashing around the standoff pipes was installed, and the application of neoprene strips at the joints between closure panels completed the waterproofing. ☐

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