# STRUCTURAL FEATURES OF THE UNISPHERE

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Some months ago American Bridge Division of United States Steel was handed one of its most intriguing and challenging assignments: the fabrication and construction of the UNISPHERE, theme symbol of the New York World's Fair. Upon completion, the UNISPHERE will be presented to the New York World's Fair Corporation by United States Steel.

Essentially, the UNISPHERE combines problems in esthetics and engineering, common ingredients in most structures. However, their complexity in the case of the UNISPHERE, we believe, makes it unique. Peter Muller-Munk and his team of industrial designers, who are the consultants, described the esthetic problems this way:

> The Unisphere cannot be treated as a building or other traditional monumental structure, for in reality it is a piece of open sculpture. This is perhaps the most demanding form of art. It must exist from all sides with no one texture, surface, or line out of harmony with another.

The basic framework of the UNISPHERE is an armillary sphere, 120 feet in diameter, made of stainless steel meridians and parallels. This framework supports the land masses portraying the continents and principal islands of the world with their mountain ranges and recognizable shore lines. These, too, are stainless steel. Capital cities of the various countries will be indicated with lights. Surrounding the sphere are three stainless steel orbits, symbolizing man's achievement in space.

The axis of this structure is tilted 23½ degrees from the vertical, corresponding to the earth's inclination to its orbital plane. The entire light, yet massive, symbolic spherical structure is supported on a sculptured tripodic steel base and is surrounded by a reflecting pool and fountains.

Let's examine each element of this unusual structure, or monument, in greater detail, with special emphasis on the structural parts in which you gentlemen have the greatest interest.

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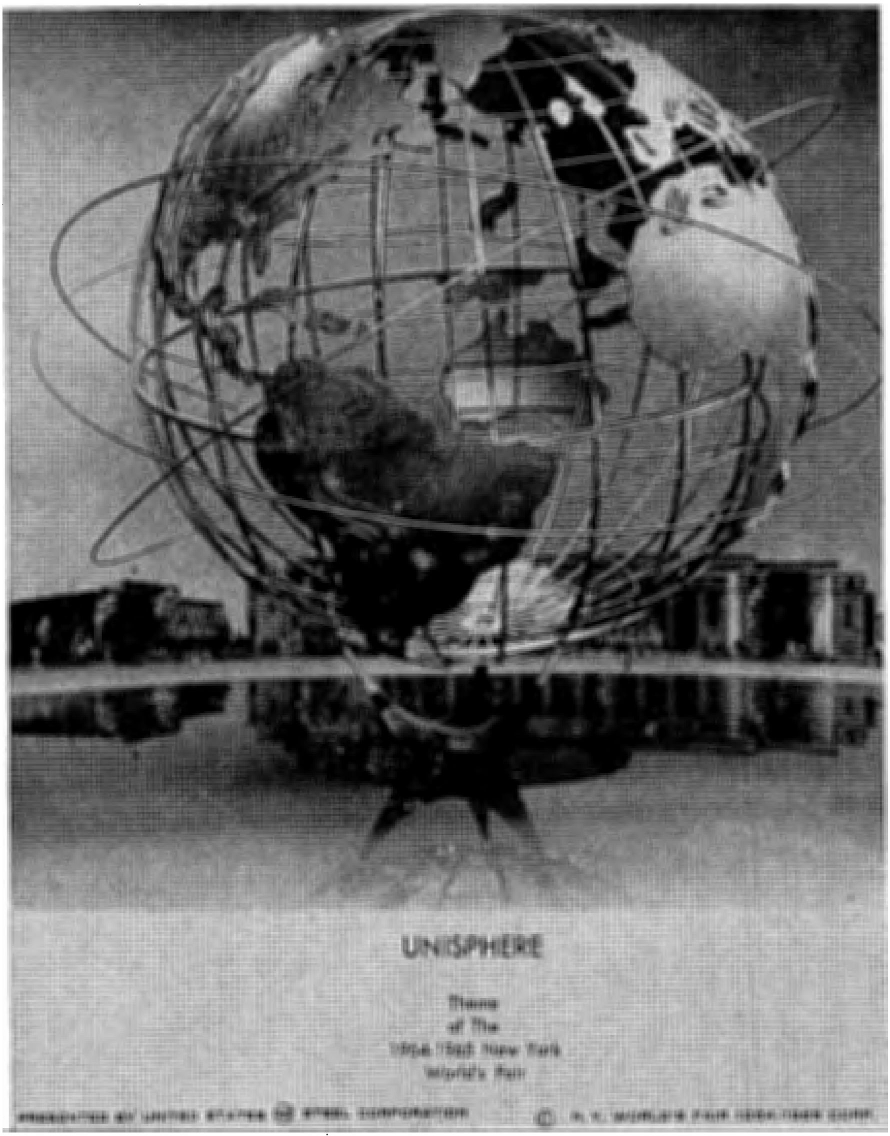
The framework is exposed for all to see. Exposed structural steel and its incorporation into the esthetic treatment of a structure is not new—we see examples of it more and more frequently. In this case,



however, we have the ultimate in emphasis on the all stainless steel framework.

The first consideration was the spacing of members. The usual spacing on maps and globes is ten degrees for the latitudes or parallels, and fifteen degrees for the longitudes or meridians. Since it is desired that the UNISPHERE have educational value for the thousands of school children who will see it, this familar arrangement was desirable if it could be used. It was fortunate that the spacing satisfied other requirements. The distance between parallels is about 10 feet and the distance between meridians varies from 15 feet at the Equator to 2½ feet at eighty degrees of latitude. Esthetically, the arrangement gave the openess wanted and, structurally, the spans of the members between joints were not excessive. A much greater spacing would have complicated the problem of supporting the land masses, especially the islands and peninsulas.

To aid in the determination of the shape of the members, four 2-foot diameter models were constructed—one with all round members, one with all square members, one with rectangular meridians and square parallels and one with rectangular meridians and round parallels. Rectangular meridians and round parallels were chosen since this presented the best appearance and gave an interesting contrast in the form of the members. Also, the joint details were less troublesome than if all round members had been used.

There are many types and grades of stainless steel. Several have been developed for highly specialized service to resist extremes in temperature or highly corrosive agents. In this case a steel was required that has good resistance to atmospheric corrosion and desirable weldability. USS 18-8 S stainless steel conforming to AISI Specification 304 was selected. This material has proven itself in many previous applications to be suitable for this purpose.

After deciding on the shape of the members and on the material, the approximate dead load was readily determined with a few assumptions and simple calculations. Approximately 600,000 pounds of stainless steel are required.

It was then necessary to determine the magnitude of the wind forces on the structure. It was easy to make qualitative predictions. For instance, it was almost a certainty that the maximum drag would occur when the majority of the land masses were on the leeward side. A turbulent flow would certainly be set up when the wind passed through the grid formed by the members on the windward side, and there would no doubt be some shielding of the leeward side by the land masses and members but the effect of turbulence and the degree of shielding could not be predicted with any degree of accuracy. It was decided that the only reliable method of determining the wind forces would be to conduct wind tunnel tests on a scale model. One of our architectural models was used for this purpose. The tests were made at the University of Maryland wind tunnel.

The model was tested at three wind velocities: 50, 75 and 100 miles per hour. At each wind velocity the model was turned in direction to the wind in 15-degree increments for a complete 360 degrees. Resisting forces and moments were measured at a reference point near the base for each test. All tests showed consistent results and there was no "velocity effect," since the ratio of velocity pressure to drag was constant. The results confirmed our prediction that the maximum drag would occur with the majority of the land areas on the leeward side, but the magnitude of the drag was greater than had been expected. It was of interest to note that despite the unsymmetrical arrangement of the land masses, there was practically no yawing or twisting movement.

Using the drag coefficients determined from the wind tunnel tests, the UNISPHERE was designed for a wind velocity of 110 miles per hour at the allowable unit stresses permitted by the New York City Building Code. This will provide adequate factors of safety for gusts up to 130 miles per hour. The total drag at 110 miles per hour is 396,000 pounds, or 35 pounds per square foot of the projected area of a solid sphere.

Making a stress analysis was the toughest problem. There are well over 2,000 redundants considering that there are three unknown force components and three unknown moment components at each joint. Obviously, some method of simplifying the problem had to be found. The possibility of using one of the usual methods of dome analysis was considered—at least for the upper portion. However, all of these methods required some simplifying assumption, such as neglecting the out-of-plane bending moments in the rings or parallels. This may be a reasonable assumption when the spring line of the ribs is at a large angle to the vertical and when a separate system of bracing is used to resist lateral forces. In this case the ribs, or meridians, are nearly vertical in the area of the Equator, and, since there can be no bracing, the large transverse wind shears and the transverse components of the dead load can only be resisted by the bending moments in the parallels.

Simplified manual calculations were used to determine the approximate relative stiffness of the members. It was then necessary to locate an electric computer facility with the greatest available capacity. The facility selected was that of General Dynamics Electric Boat Division which is used in the design of the hulls of atomic submarines as well as other complex structures. Even this computer could not handle the problem without considerable simplification. An elastic analysis was used, considering each member as a straight line between joints.

The sphere was first divided into two half-sections by passing a vertical plane through the inclined axis midway between two points of support. This cut the number of joints in half. To further reduce the number of unknowns, the section from 40 degrees north to the North Pole, and the section from 70 degrees south to the South Pole, were considered as rigid shells with the meridians fixed around the perimeter of the shells. A conservative manual analysis was made of the members in these sections and stresses were later compared for consistency with the stresses in adjacent members. For the most part, minimum thickness material could be used.

The remaining section was then divided transversely to form two overlapping parts. The top part extended to 20 degrees south, where the ends of the meridians were assumed to be fixed. This analysis was used to design the members from 40 degrees north to the Equator.

The internal stresses in the meridians at the Equator, as determined from this analysis, were then applied as external forces along with the other loads in analyzing the lower part. The rigid shell was assumed to be hinged at the South Pole. Hinges were also assumed at the other two support points. Even with the divisioning into sections, the solution of the lower part alone involved the solving of 670 simultaneous equations.

This analysis did not permit the application of wind loading in all directions but it was found that the maximum wind load stress in any member for the one condition analyzed could be used to design all of the members at any particular latitude, except in the region of the supports. A separate elastic analysis of the support area was made for three different wind loading conditions, and by comparing results with the other solutions a stress distribution pattern in this area was established.

It is interesting to note that the largest moments always occurred at the joints. The effect of axial stress was almost negligible compared to the bending moments caused by the transverse loads. In the center portion of the sphere, points of counterflexure were approximately at the centers of the members, except where the meridians join the Equator. Due to the stiffness of this section, the joints of counterflexure were closer to the 10-degree parallels, causing larger moments at the Equator ends of the meridians.

Except in the area of the supports, the meridians are 8 inches wide and 12 inches deep, and are fabricated from four welded plates. The parallels are tubular sections 8 inches o.d. above the Equator, 9 inches o.d. immediately below the Equator, and 10 inches o.d. in the lower portion of the Southern Hemisphere. The Equator is a rectangular box section 18 inches wide and 14 inches deep. Wall thicknesses vary from 3/16 inch to 1 inch, except at the supports. At the two supports on the 50-degree parallel, both meridians and parallels are 10 inches wide and 3 feet deep with flanges as thick as 3 inches. At the South Pole support, the meridians are 8 inches wide and 2 feet deep with ½ inch thick walls.

It was apparent from the beginning that only welding would be suitable for the field connections. No other method could give the continuity of action and appearance that was required.

Many joint details were studied and it was finally decided to fabricate the meridians in long sections, butt welding the parallels to the sides of the meridians in the field. Tubing diaphragms of the same size as the adjoining parallels are shop-welded inside of the meridians at each joint. Each meridian is fabricated in four shipping sections.

The field welding process that will be used is a type of metallic inert gas welding, known as short-circuited arc. This process utilizes a coiled wire which serves as a consumable bare electrode providing the filler metal for the weld. The weld zone is protected from atmospheric contamination by a continuous blanket of inert gas fed through the tip of the welding torch. A motorized wire feed unit pushes through the welding torch at a speed selected by the operator. The operation requires a constant potential welding power source. It usually operates on lower arc voltages (14 to 19 volts) than the spray arc technique. This pin points the arc heat and produces a small relatively cold weld puddle which minimizes metal distortion.

Overhead welds can be made fairly easily and short gaps, which invariably occur in field fit-up, can be spanned with no difficulty, making the process ideal for our purpose.

Of course the structural design of the UNISPERE frame could not be completed without concurrent consideration of the design of the land masses. The first thought was to use a wire mesh that would be open enough to reduce the wind drag on the structure. If the land areas were made of solid material we would, in effect, have a "big sail" that would catch the wind in the same manner as the spinnaker on a sail boat. Many types of mesh were investigated; some appeared quite promising at first but all became virtually invisible when held up against the sky. Even a mesh with as little as 20 percent voids faded when held against the bright backdrop. Even a full-scale mock-up was made and mounted 50 feet in the air above Flushing Meadows at the exact site of the UNISPHERE. After extensive studies, it was necessary to face the fact that we were "stuck" with our "big sail." A mesh dense enough to produce the desired visual effect would not appreciably reduce the wind load and could even ice over so that in fact it would become a solid sheet.

Attention was then turned to solid materials, and after much investigation a non-directional patterned rigidized stainless steel sheet was selected, especially designed for the UNISPHERE.

Steel is shown to its best advantage when it is used in crisp, angular fashion, so it was decided that the mountains, instead of being formed of sheets pounded into irregular shapes like wrinkled tin foil, would be built up layer cake style in a series of steps, creating the effect of a huge contour map. This treatment also will have educational value since the edges of the steps represent 1,000 meter contour lines. The mountains are made to an exaggerated vertical scale forty-four times the true scale since, in their actual proportions, they would appear insignificant.

The rigidized stainless steel sheets are mounted on a subframework of channels and angles. Of course these are stainless steel, too. This framework is joined to the UNISPHERE members by welding and bolting. The large areas will be fabricated in sections, preassembled and fitted in the shop. The sculptured sheets will be attached to the subframe with pop rivets—naturally of stainless steel.

This symbolic world will be encircled by three stainless steel orbits which, according to an early press release, "float in space with no visible means of support." Actually, the orbits will be anchored to the earth with small stainless steel strands, as the rim of a bicycle is anchored to its hub. Although faintly visible, these ties will not detract from the sculptured contour of the Theme Center.

By this time, quite a support problem had accumulated dead weight of the material, the wind blowing on our sails, and the orbits waving in the breeze. There was a temptation to design a substantial base with a rigid ring girder and a series of rugged steel columns, or even a foundation of massive masonry. However, the consultants, Peter Muller-Munk and Associates, thought it would be nice if the earth were supported on three needle points—again, practically no visible means of support, as in nature.

Thus, they developed an open sculptured base supporting the world at three points and holding it 15 feet above the reflecting pool at its inclination of 23½ degrees. Of course the feasibility of this three-point support was investigated before making the final stress analysis. Naturally, the base is covered with stainless steel. However, for the structural core the only departure was made from the selected material, stainless steel. This structural core is USS Cor-Ten steel. This base consists of three tapered, welded girders, each with one very narrow flange and one wide flange. The intersection at the center is secured with A325 high strength bolts. The superstructure is attached to the base at each point of support with a ring of high strength stainless steel bolts. Each corner of the base is anchored to the foundation with ten 2½-inch diameter bolts of USS-Tl steel. The foundation will be designed by consultants of the Fair Corporation to transfer the load to the same pile cluster that supported the Perisphere of the 1939-1940 World's Fair.

With the completion of the design, the problems are of course far from over. There are still hurdles in fabrication and erection but we are convinced of one thing, that is, the right material is being used—steel. Like the man says on television: "Only steel can do so many things so well." Its inherent properties have enabled us to achieve the fine line appeal that was desired without resorting to bracing or by otherwise compromising esthetics.

While, perhaps the birth of the UNISPHERE is not as exotic as problems connected with space explorations, it, nevertheless, represents a delicate, intricate exercise in design and engineering skills.