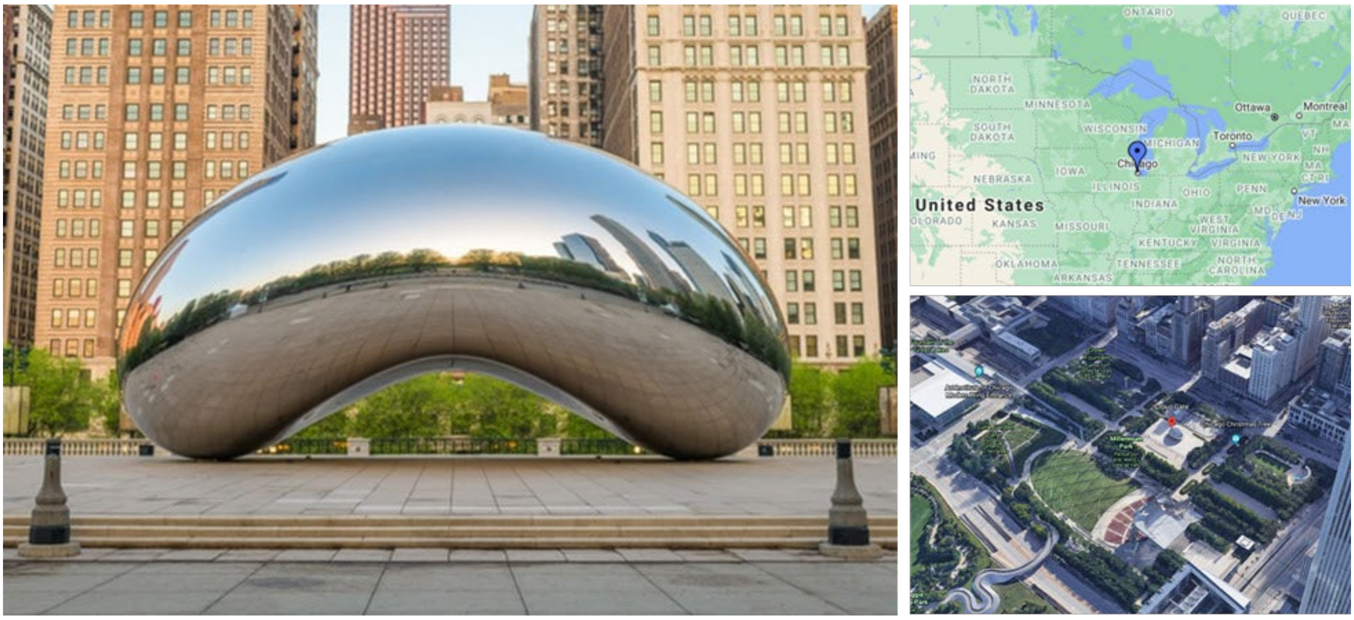
Article

The Bean: Atmospheric Corrosion of the Cloud Gate Structure



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1. View and location of the Cloud Gate structure

Overview

Continuing with the initiative of showing the beauty of iconic structures from a corrosion point of view, we now turn our sights to the United States of America, in the city of Chicago where you can find the stainless-steel sculpture “Cloud Gate”.

Designed by the Indo-British artist Anish Kapoor, the structure caught my attention not only for its beauty but also for its peculiar shape, materials used and construction process. Its surface reflects the famous Chicago skyline and the clouds in the sky, and at its bottom, it contains a concave chamber called *Omphalos* (meaning navel in Greek) which represents a doorway to those clouds.

Located at the AT&T Plaza at Millennium Park, Cloud Gate has been affectionately named **“The Bean”** and there is no need to explain it - just by looking at it we can see its bean-like resemblance.

I was researching corrosion in the presence of mercury in natural gas processing plants and suddenly an article about this structure being somehow related to mercury appeared, so it begs the question - w h a t is the relationship of this stainless-steel structure with mercury?

The simple answer is that the design and concept of the artist Kapoor was inspired by the amorphous appearance and shape of liquid mercury, which on a structural level could be achieved by using the reflective properties of polished stainless steel. The popularity of stainless steel as a building material is growing in the world’s major cities. Many of the recently completed or planned high-profile construction projects use stainless steel because of its excellent properties and corrosion resistance.

Looking through the historical archives of the Chicago City Public Library I was able to discover that to decide which structure was the most appropriate for this initiative, a design competition was held in which more than 30 different artists participated, and Anish Kapoor’s proposal was chosen with an initial estimated budget of 6 million dollars, which then increased to 11.5 million dollars by the time the park opened in 2004. The final amount reached 23 million dollars in 2006 financed by donations from individuals and corporations.

It took more than five years of development by more than 100 metal manufacturers, cutters, welders, finishers, engineers, technicians, blacksmiths, assemblers, and managers to complete the structure. Building the concept for the 110-tonne, 66-foot-long by 33-foot-high stainless-steel sculpture was the task of the manufacturing companies, Performance Structures Inc. (PSI) and MTH Industries.

Due to a delay in the assembly of the structure, it was exhibited temporarily unpolished and therefore unfinished on 15 July 2004. The seams between the sections of the shiny metal skin were not sealed or polished, making them visible. The work remained exposed for several months, until the tent surrounding it was set up again in January 2005 to allow the workers to grind, sand and polish the seams, giving the sculpture its mirror-finished appearance.

If we go back in time, we could imagine some of the questions the artist and the companies in charge of the assembly and construction could have asked themselves. How can 168 stainless steel plates the size of a car be fitted to a superstructure? How can a huge, curved structure be welded without leaning on it? How can the welds be penetrated without being able to weld from the inside? How can a perfect mirror finish be achieved on stainless steel welds in an outdoor environment? What happens if it is struck by lightning?

In this article, we will try to answer all these questions based on a review of all the information available about this impressive structure, a structure that has attracted the attention of millions of people since its inauguration, helping to achieve the perfect memory snapshot of its conception.

About The Design

The Bean was designed using computer modelling based on the Non-Uniform Rational B-Spline (NURBS), which represents a mathematical formula (Euler's equation) that employs the geometry of curves, circles, arcs, and surfaces in space 3. Freeform surfaces and curves can be created and edited with a high level of flexibility and precision.

A company provided the structural design of the frame and suspension systems and supervised the assembly process. Firstly, the biggest challenge here was to design an internal structure that would hold the sculpture upright without the risk of distortion due to overloading specific points. Secondly, it was to allow the shell to expand and contract freely with the extreme temperature changes in Chicago, which could easily distort its 1 cm thick polished skin.

To maintain its perfect form, a suspension system was designed, based on two large steel rings, which support the sculpture as it moves independently of each other. This also allowed independent movement of the casing from the rings.

Based on the close collaboration between the companies involved in the project, it was decided to balance the weight of each of the plates individually using springs, allowing them to fit together perfectly without collapsing due to gravitational distortion.

32 custom-made suspension units support the entire 80-tonne weight of the construction, allowing it to resist extreme wind conditions and seasonal changes.

About The Material

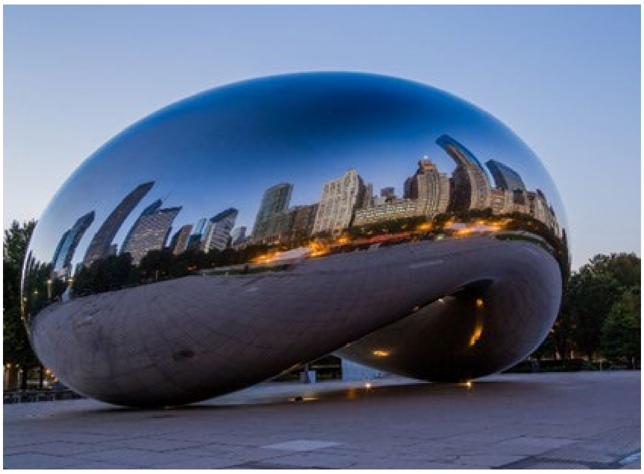
The material used for the construction of the skeleton of this impressive structure was austenitic stainless-steel type 304 for the skeleton, zinc-rich structural steel substructure/ frame, and 316L for the plates forming part of the casing.

A company manufactured each piece of plate to a precise curvature before shipping it to Chicago for its assembly. The entire assembly process took two years to grind and polish the plates and one additional year to weld 2,500 linear feet of joints between the plates. Stainless steels are alloys of iron, chromium, and carbon, sometimes complemented with other elements, mainly nickel. It is the addition of chromium that gives the stainless characteristic to these steels. In oxidising media such as air, chromium forms a very thin and compact oxide layer which insulates the material from corrosive attacks.

Stainless steels are classified under the different elements and the relative quantities of each one of them involved in their composition. In general, five basic families of stainless steels are considered: martensitic, ferritic, austenitic, duplex and precipitation hardening (PH).

About The Construction

Substructure - The first indication was to build a substructure to support the shell/skin made of stainless-steel plates, so the construction, installation, and assembly of a 30,000 lb. zinc-rich steel substructure began. One of the challenges was how to support this wobbly structure to keep it upright during the construction and assembly process. Complex anchoring systems were used, including mechanical pre-tensioning systems and some chemical anchors that allowed to fix the structure to the concrete and thus continue with the fabrication process. This substructure included two large fabricated 304 stainless steel O-rings, one at the north end of this structure and one at the south end. The rings are held together with cross-linked tube armatures.



2. Structure views before and after polishing

The auxiliary ring-core frame is constructed in sections and bolted on-site with reinforcements welded using GMAW and electrode welding.

Setting Up the Tent - To be able to continue with the assembly process, a tent was built to allow the continuation of the work in a more controlled environment and at the same time to hide it from public view. In only a few months, it was necessary to open one of the ends due to the high temperatures inside, which created a difficult working environment.

Preparation - Once the fixing stage, the assembly of the rings and the cross-linked tube support system were finished, the process of placing the stainless-steel plates began. For the preparation, cutting and moulding of the plates, computer technology was used to dimension the plates and make the precise cuts and curvatures required to ensure that they all fit together correctly. The largest plates had an average width of 7 feet and a length of 11 feet and weighed up to 1,500 pounds. Some plates were square, and others were pie shaped.

Cutting the 1/4-to-3/8-inch thick 316L stainless steel plates with plasma was quite difficult. After cutting, the plates were rolled on a three-dimensional roller that was specifically designed to roll these plates (see figure 10). Each plate was bent by moving it back and forth on the roller, adjusting the pressure on the rollers until the plate was within 0.01 inch of the required dimension.

Plates Placement - Once the plates were cut, they were then placed in the defined positions by the location plan. One by one, they were installed using the technical personnel's own hands and lifting equipment that allowed the accurate placement of each one.

Welding of Plates - The next major fabrication challenge of this project was to weld the seams without losing shape accuracy due to the weld shrinkage distortion. Plasma welding provided the necessary strength and rigidity, with minimum risk to the plates. A mixture of 98 per cent of argon and 2 per cent of helium worked better to reduce the incrustations and improve the fusion.

The welders employed a keyhole plasma welding technique using a Thermal Arc® power supply and a special tractor and welding torch developed and used by PSI.

Final Grinding & Polishing - The third and final phase of the project was the final grinding and polishing, to eliminate the visibility and roughness of the seam left by the welding process. I can't imagine what a challenge it was for those responsible to think of and define a procedure to mask every welded seam made by the welding process of the stainless-steel plates, as the ultimate goal was to achieve a uniform mirror-like appearance throughout the whole structure.

At last, finishing the weld was a 12-step process, starting with coarse grinding of the weld close to the existing surface using 60-grit zirconium paper on a circular belt, followed by semi-automatic belt sanders with wheels that had adjusting screws to allow the required finish to be achieved. Subsequently, a special grade of 400 grit ceramic sandpaper, called CF-Trizact™ type, was used. The company 3M developed new banding systems to achieve a high gloss finish.

Mirror Finish - The mirror finish is considered the industry standard for a highly reflective mirror appearance. This is achieved by directional polishing with abrasive compounds in several stages, followed by polishing with a colouring compound. The surface produced is shiny and highly reflective and is virtually free of sand lines, although at certain angles some are still visible.

Potential Corrosion Mechanisms

Currently, no corrosion damage has been found, nor could I find any information about this. However, in the future, it would be worth keeping an eye on the surface condition of the stainless steel of the plates, especially as they could suffer from pitting, even though they are in an area far from the sea winds coming from the Atlantic Ocean.

The proximity of the structure to Lake Michigan could favour the presence of humidity, which combined with pollutants and even the fluids and grease left by the visitors when touching it daily, could also cause attacks on the stainless steel. Considering the internal side, where other materials such as galvanised steel have been placed, a visual inspection could also be made to verify if there are any signs of a corrosive process.

2. Structure views before and after polishing (left)

3. Image examples illustrating the computational modelling process (right)