Dec 18

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(Approved by AICTE, Govt. of India and affiliated under Maulana Azad Kalam Azad University of Technology)

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CIVILONEWS

Statue of Unity: Structural and Construction Features of the World's Tallest Statue

The Statue of Unity depicts India's first deputy prime minister Sardar Vallabhbhai Patel. It is situated near the Sardar Sarovar dam in the state of Gujarat. With a height of 182 m, the statue stands conveniently taller than its predecessor, the Spring Temple Buddha in China. It also consists of a museum of the Adivasi (indigenous people) of the region, who were relocated to make way for the construction of the statue.

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The statue is a structural system comprising of two semi-elliptical reinforced concrete cores. It also has a reinforced concrete podium that acts as a base for the statue clad in bronze, supported by structural steelwork fixed on to the concrete cores. About 21,0000 m^3 of concrete, 18,500 tonnes of reinforcement, 6500 tonnes of structural steel, and 1800 tonnes of bronze were utilized for the construction of the statue. It took 13 months for the design process and the actual construction was completed in just 33 months. The construction of the Statue of Unity was completed in 2018.

1. Site Location

The Statue of Unity is situated on a strong rock on the banks of the river Narmada in Gujarat, India. It is 90 kilometers south of the city of Vadodara and around 3 kilometers downstream of the Sardar Sarovar dam.

2. Geology of the Site

The following points describe the geology of the site:

The project site is occupied by the Deccan basalt flows underlain by sedimentary rocks.

The sedimentary rocks at the site consist of quartzite sandstone, argillaceous sandstone, shale, pebbly sandstone, and limestone.

Basic dykes are exposed in the area. Dykes are aligned in the NE-SW direction.

The project is located in the seismic zone III of the seismic zoning map of India.

The data on earthquake occurrence shows that the Maximum Credible Earthquake (MCE) in this area can have a magnitude of 6.5.

Based on the studies of the area, the nearest fault exists at a distance of 22 km from the site of the statue. This fault has been assumed as a causative fault for the seismic design of the statue.

The island is accessible from at least one side via land for about eight months of the year as the water level recedes post-monsoon season.

During the monsoon season, the water level typically rises by 5 m, and goes up to 20 m, with very strong currents.

Access to the island is available via two ways. Primarily, a built-up rock bridge which is constructed at the normal flood level, and then a Bailey bridge that is built above the high flood levels.

The Bailey bridge has two lanes, one dedicated to vehicle and material movement, and the second one for access to workers.

Several options were evaluated for maintaining access to the island during the Monsoon floods. These included a cofferdam, a rock bridge, and an elevated steel bridge.

3. Materials Required for Construction

The following points describe the materials used for the construction of the statue:

The statue is located at a remote location, therefore, the material delivery, staging, and erection posed unique challenges for the project.

For the construction of the statue, the required concrete strengths varied between 40 MPa to 65 MPa. The statue required 21,0000 m^3 of concrete, reinforced with 18,500 tonnes of grade 500 MPa bar.

Additionally, the composite cores of statue, suspended space frame, cladding substructure, and podium framing required 6500 tonnes of structural steel with a minimum grade of 355 MPa.

The structural steel in the cores and space frame of the statue is comprised of W-360 I-shaped sections.

As a part of the 'Loha' campaign, iron tools were collected from farmers across the country with the intent of it being melted and converted into rebars for use in the foundation.

The ordinary portland cement used is of the grade 53.

The concrete was supplied by two batching plants of 56 m^3 per hour capacity.

The structural steel was supplied by Tata Steel and SAIL.

4. Foundation of Statue of Unity

The details of the foundation of the statue of unity are explained below:

The hillock over which the statue is constructed had several fracture planes. For the successful construction of the foundation, the fracture planes were treated with grout injection and grouted anchor rods.

The levelling of the hillock was done in order to construct the foundation mat of the statue. As the mat sits on the strong rock, pile foundation was not required. However, grouted rock anchors were used to reduce the localized tension.

The foundation was high in tension due to the overturning moments from the lateral loads. These loads are resisted by rock anchors socketed into the rock and tensioned at the foundation level.

Based on the site investigation results, the average bearing strength of the rock was found to be 2300 KN/m^2, which is more than sufficient to support the statue.

Self-compacting concrete of M60 grade was utilized for the mat foundation. In addition, the temperature level was maintained between 18°C to 22°C for the placement of concrete in mat foundation.

The surface area of the mat foundation was covered with a polythene sheet and, on top of the sheet, a layer of 100 mm dry sand was placed to avoid any thermal differences.

Construction of raft foundation of Statue of Unity

A quantity of 4354 m^3 concrete was used in the construction of the primary raft which was completed in a single constant pouring of concrete in 132 hours.

Throughout the constant pouring of concrete in the raft, two on-site batching plants were continuously used to produce concrete. The positioning of concrete was done by a mix of fixed pumps. Additionally, concrete was pumped horizontally for 420 m through a 125 mm sized steel pipeline.

5. Concrete Design System

The construction of the world's largest statue required about 21,0000 m^3 of concrete. For such a large quantity of concrete, a qualitative design of concrete was needed. The major factors which affect the quality of concrete are the production, pumping, and durability of concrete. These factors have been discussed below:

5.1 Concrete Durability Design

Concrete durability is a major requirement for any project therefore the following points were considered for a durable concrete design:

The life span of the structure is estimated to be 100 years and may go beyond it as the structure lies on the river bed and faces no danger of attack from chlorides and sulfates to the strengthened concrete structure.

The structure is anticipated to come in contact with water only during monsoon season. However, the water would be devoid of any contaminants.

The superstructure including two concrete cores are dressed in bronze. Thus, bronze serves as the main shield to the structure. Furthermore, there is no source of air-borne chlorides in the area because the site is far away from the shoreline.

This is the first structure in India to have a contractual requirement for a desired life span of 100 years, despite no significant danger to it.

In the absence of chlorides, carbonation-induced deterioration was determined as the primary cause of rust to the reinforcement. This was mitigated in the design phase itself by utilizing concrete of low water-cement ratio (w/c), high compressive strength, and appropriate cover to support.
From the utilization of concrete grades, it is anticipated that the structural efficiency will surpass the designated life span of the structure. The chances of alkali-aggregate reactions are negligible as reactive aggregates were not used in the construction of the structure.

5.2 Concrete Production and Pumping
The details regarding the concrete production and pumping equipment are discussed below:
Two Schwing Stetter batching plants of 56 m^3/ hour production capacity were set up. In each batching plant, silos were set up for storage of the cementitious products. Moreover, three silos of 200 tonnes each, one silo of 120 tonnes, and one silo of 50-tonne capacity were set up for Portland cement, fly ash, and micro-silica, respectively.
Coarse and fine aggregates were stored in a total of four (two for each) compartment bins of 40 m^3 capacity.
Two ice-making systems of 20 TPD (tonnes per day) and two chiller systems with 100 TR (ton of refrigeration) capacity each were used basically to produce temperature-controlled concrete.
Ten transit mixer trucks each of 6 m^3 capacity were used.
Concrete pumps of 400 KW with a displacement capability of 116 m^3/hour operating at an optimal pressure of 220 bar were used.
One fixed and three mobile booms (SPB35) were used.
A steel pipeline of 125 mm size was used for conveying the concrete from the pump to the positioning place.
Throughout the concreting of the raft foundation, a 440 m pipeline was used to transfer concrete horizontally.
For core walls, a vertical pipeline of 320 m was set up to carry concrete vertically by using a variety of bends in the line plan.

Silos used for the storage of materials

Belt conveyor arrangement for feeding aggregate into silos

View of batching plant at work site

6. Structural System **of Statue of Unity**

The main structural components of the statue of unity consist of the base and the core walls. These components are discussed below:

6.1 Base of the Statue
The following points describe the base of the statue:
The base of the statue was constructed on shallow foundations (i.e. raft foundation) supported over a strong rock.
The level of the base differs from +45 m to +52.5 m.
The ground floor is at +58 m level. It is made of structural slabs supported by columns and walls.
Both concrete and steel were used thoroughly from +58 m level to +83 m level.
The slab at +78 m, +83 m, and inclined roofings are made of composite deck slab resting on structural beams and trusses.
6.2 Core Walls
The following points describe the core walls of the statue:
Two primary vertical core walls of the statue are elliptical in shape.
The dimensions of the core walls are 11.30 m x 8.40 m.
The elliptical core walls are 154 m high with openings for lift lobby and fire stairs.
The core wall basically starts from +56.575 m level and continues up to +209.50 m level.
The coupling wall is linked to the core walls from +115.0 m level to +193.0 m level.
Core walls are confined by an external oval concrete wall up to the podium level at +83 m.
Above the podium level, where the facade geometry of the statue appears, the cores are coupled together with two RC walls (known as coupling wall) up to the entire height of core walls.
The thickness of the core wall is continuous throughout the height, whereas the thickness of the coupling wall varies from 0.55 m to 1.33 m.
The elliptical shape of the core wall was achieved by bending the rebar of 32 mm diameter around the core wall.
The core walls were constructed with a self-compacting concrete (SCC) of M65 grade.

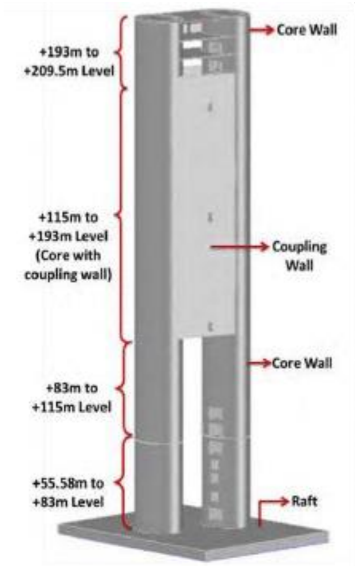

Figure depicting core wall and coupling wall

Construction process of core wall

7. Construction Sequence

The construction process of the Statue of Unity was made as simple as possible. The composite core construction follows a methodology that is typically used for composite columns and walls in tall buildings. The suspended truss frame was either welded or bolted to core walls.

The construction sequence of the world's tallest statue is described below:

The fracture planes of hillocks were treated via grout injection and grouted anchor rods.

Leveling of the hillock was done in order to construct the mat foundation.

After that, the casting of the raft foundation was done.

Structural steel of shape W-360 was embedded in the composite core walls.

The W-360 shapes of structural steel were then connected with the internal bracing of the 150 mm x 150 mm (6” x 6”) angles.

After the structural steel was erected 5-10 m above the foundation, the casting process of the cores began.

Further, the structural steel truss frame was erected from the concrete cores. For this process, W-360 steel shapes were shop-welded to the internal steel shapes in the cores.

Internal steelwork was continued and followed by the casting of the cores.

After that, the bronze-cladded panels were connected to the truss frame. For this purpose, the exterior of the structural truss frame was welded to a subframe of steel. This subframe was connected to the clad panel to support the weight of the cladding system and to resist earthquake and wind forces. Also, the clad panels were designed to have overlapping panels that allow the vertical and horizontal movements of panels.

The above process was repeated until the completion of the statue.

Construction process of core wall

Construction process of structural steel truss frame

Picture depicting the process of construction

Cladding installation process