Planetarium Concrete - Structural & Construction Feasibility Analysis

Introduction

The New Science Building at Texas A&M International University in Laredo, Texas features a planetarium that is constructed of an architectural concrete structural base, a steel structural dome, and a four-sided glass pyramid that serves as the outermost protective envelope. The planetarium itself is housed within the dome. All four sides of the planetarium are symmetrical.

The architectural concrete supports the steel structure of the planetarium, and also acts as an integral part of the architectural feature. The base stands 9'-0" above the ground, and is 6'-8" thick at the bottom. The exterior façade of the base is angled to match the angled form of the glass pyramid. (To view the entire section of the planetarium, see Appendix C)

Because the erection of the steel for both the dome and the pyramid was difficult and required extremely small tolerances for proper installation, coordination between the concrete contractor and the steel erector was extremely important. However, little attention was given to this important issue, and in the end it delayed the schedule because the steel erector needed
much more time than expected to erect. The tolerances for the horizontal face of the concrete that the steel was supported by were less stringent than those needed for the steel. This was overlooked due to the lack of coordination prior to the creation of shop drawings.

**Project Difficulties**

The architectural concrete was designed to be an as-cast structure with a smooth finish. It was expected that after the formwork was removed there would be no need for further work to the exterior exposed concrete. However, after the formwork was removed, it became evident that those expectations were not achieved. The integral color was not uniform throughout the façade of the concrete, and the locations of the formwork seams were also visible.

Upon review of the concrete condition by the architect and owner, it was determined that the finish was unacceptable, and that spot repairs would not be cost effective. The decision was then made to repair the finish by applying grout to the entire exterior of the architectural concrete façade. This process would be very difficult and time consuming, due to the uniformity that both the architect and owner expected throughout.

**Concrete Specifications**

In order to determine whether or not there may have been any discrepancies regarding the design criteria for the architectural concrete, formwork, or installation of the concrete, the project specifications were compared to standard specifications provided by ACI (American Concrete Institute).

**Standard Specifications**

The Standard Specification for Cast-In-Place Architectural Concrete (ACI 303.1-97) provides specification guidelines acceptable for the design and installation of architectural concrete. Also utilized was the Specification for Structural Concrete (ACI 301-99), which goes into further detail regarding the structural aspect of the concrete, and is referenced many times within the Standard Specification for Cast-In-Place Architectural Concrete.
According to these specifications, for colored concrete, trial batches of the final design mix should be prepared with specified slump at the highest and lowest ambient temperatures anticipated during construction. This was not specified in the contract documents, and was not performed for the project.

**Project Specifications**

The project specifications provide information in more detail than the standard specifications, and also specify material types and manufacturers approved to be used for this project. All specifications for this project meet the requirements in the ACI standard specifications. However, of special interest are the materials specified for use, particularly the formwork, and the conditions of placement of the architectural concrete.

The architectural concrete finish for the project is specified as colored slick as-cast architectural concrete finish. Portland cement was specified as ASTM C 150, Type I or III light gray-butt cement, and aggregates were 3/4” maximum for course aggregate and clean local Medina River concrete sand for fine aggregate. Water-reducing and/or retarding agents (ASTM C494, Type A, Type D) was required, as well as a form release agent. Fly ash was not permitted.

The project specifications indicate the use of “slick as-cast colored concrete finish-smooth plastic laminate faced forms.” The specific form type was “B-B plyform class 1” with high-pressure laminate, GP-50 (0.050” thick), Formica “lacquer” finish, shop fabricated. Form ties were to eliminated as much as possible. Cresset Chemical Company’s “Crete-Lease 880” form release agent was also specified.

Mockups and pre-installation meetings were specified, however, due to time constraints, these items were not utilized, which likely contributed to the failure to achieve the expected finish. Instead, small samples of both the formwork and the architectural concrete were submitted. These samples did not accurately portray the imperfections that could occur on a significantly larger mass.

The architectural concrete was placed in mid-July, which in Southern Texas is extremely hot. This area of Texas is also a desert, which results in large temperature drops at night. This could affect the slump of the concrete as well as the finish. Because of the high temperatures, water can quickly evaporate from the concrete mixture, which in turn could alter the properties, including the color and texture of the cured concrete. If the formwork and rebar were not cooled prior to the placement of the concrete, there could have been differential heating and cooling throughout the concrete; this could also contribute to alterations in color and texture and also produce lift lines.
The formwork was specified to be well sealed at all joints using a silicone sealant and backup material to prevent leakage and fins. It was fairly evident that this was not done properly because the edges of the forms can be seen on the concrete finish.

Formwork Types

The architectural concrete was formed using conventional formwork. Conventional forms are most often used for frames and retaining walls, require hand-stripping (no cranes required), and create an as-cast concrete finish when used alone. They can be reused up to ten times. This type of system is more efficient in areas of high quality, low cost labor forces, because while the system itself is simple, it is important that it is constructed properly to ensure that the forms do not bust when applied with the concrete load and to maintain a high quality concrete product.

Form release agents are necessary to easily remove formwork from the concrete face without the need to pry or force the form from the concrete. It is important to choose an agent that will not react with the architectural concrete, and will not affect the appearance of the finish. The form release agent for this project did not contribute to the poor quality of the concrete finish.

As-cast concrete finishes typically show irregularity and usually contain surface defects. These finishes are usually used where appearance is not a factor, such as in warehouses. Architectural concrete requires careful selection of formwork that includes stiffer form liners, tighter joints, smoother finishes, and more care in implementing chamfers and rustications.

Upon inspection of different formwork types, it became clear that conventional formwork was the best choice for this project, considering its limited height and number of uses necessary for the forms. However, the smooth plastic laminate finish did not create the expected finish and therefore needs reconsideration.
Conclusion

The outcome of the finish of the architectural concrete for the planetarium could have been different if certain considerations were taken into account.

Fly ash is derived from burning coal, and is a valuable additive that makes concrete stronger, more durable and easier to work with. In making concrete, cement is mixed with water to create the “glue” that holds strong aggregates together. Fly ash works in tandem with cement in the production of concrete products. Concrete containing fly ash is easier to work with because the tiny glassy beads create a lubricating effect that causes concrete to flow and pump better, to fill forms more completely, and to use up to 10 percent less water. Because the tiny fly ash particles fill microscopic spaces in the concrete, and because less water is required, concrete using fly ash is denser and more durable. Fly ash also reacts chemically with lime that is given off by cement hydration, creating more of the glue that holds concrete together. That makes concrete containing fly ash stronger than concrete made only with cement. Fly ash is also a cost-effective resource. When fly ash is added to concrete, the amount of cement that is necessary can be reduced.

The use of fly ash in the architectural concrete could have improved the quality of the color and the finish by creating a mixture that was easier to work with in large quantities. The number of visible voids at the surface of the concrete could have also improved the quality of the finish. Fly ash requires less water for the concrete mix, but still increases the workability, so it might have been an advantage to use fly ash to combat the difficulties with pouring concrete in high temperatures.

A wide variety of environmental circumstances are deleterious to concrete, such as reactive aggregate, high sulfate soils, freeze-thaw conditions, and exposure to salt water, deicing chemicals, and acids. Laboratory research and field experience shows that careful use of fly ash is enormously useful in countering all of these problems. Texas rainfall is quite acidic, so the use of fly ash could also serve to protect the concrete from acid assault.
The finish was specified to be smooth as-cast with no working after the removal of formwork. This is an extremely difficult goal to achieve for a large mass of concrete. Many pieces were required for the formwork, which increased the number of joints, and thus the number of possible repairs needed to eliminate seepage lines. Also, a smooth finish makes all imperfections more visible. A textured finish, such as a fine sandblast, as shown below, could reduce the number of visible imperfections without compromising the intended vision of the structure.
A mockup of a large mass of architectural concrete cast on a hot day in the summer could have brought to light any potential problems that might arise due to the temperature, finish, formwork type, and admixtures.

The formwork was specified as smooth plastic laminated plywood shored externally, with no ties. Because of the large mass of concrete within the formwork, shoring the concrete was necessary, but supplementing the shoring with internal ties would reduce the amount of deformation of the forms, and reduce the amount of leakage at the joints. Ties were not used due to the appearance of the holes left behind at the surface of the concrete, which would require undesired repair. However, fiberglass ties could be used instead. These ties are made to match the color and texture of the concrete, and after removal of the forms, the ties are cut to the surface of the concrete, making them invisible.

The smooth plastic laminated plywood could be changed to a plywood form with a plastic liner. The liners come in many textures (as seen above) and are reusable up to 100 times depending on liner material. One-use liners are extremely inexpensive and five-use liners are comparable in price to that of using the plastic laminated forms as discussed above.

Coordination between the concrete contractor and the steel erector is vital to construction as intricate as the planetarium. Before the creation of the shop drawings for each contractor, coordination meetings need to occur, both organized and facilitated by the construction manager, to eliminate any potential problems that may arise from something as simple as tolerance differences.
**Recommendations:**

1. Use plywood formwork with a textured plastic liner in lieu of smooth plastic laminated plywood. Use a form release agent that will not affect the appearance of the concrete finish.

2. In addition to the use of shoring, provide fiberglass ties to support the mass of concrete and reduce the amount of leakage between forms. Ensure that all form joints are properly sealed to prevent leakage.

3. Consider the use of fly ash in the design of the architectural concrete. Fly ash contains properties that may help resolve the problems encountered.

4. Be sure that any additives, such as water reducing agents and curing compounds, will not alter the finished appearance of the concrete.

5. Provide a large-mass mockup of the architectural concrete using same materials and methods of placement to ensure the quality of the final product. Be sure to pour the concrete for the mockup at the same temperature as is expected for the actual pour.

6. Maintain similar temperatures for concrete, rebar, formwork, and any other affected materials at all times when concrete is being poured to eliminate color and texture variations and lift lines.

7. Coordinate all interested parties, particularly the concrete contractor and steel erector, before the production of shop drawings, to ensure that all parties are aware of others’ requirements for construction so that delays and additional costs can be avoided.