Award-winning design / build project

Internally Post-Tensioned Water Reservoir

by William M. Klorman

Recently, California Polytechnic State University at San Luis Obispo undertook the major task of a comprehensive utility upgrade program. Among the primary elements of the upgrade was a new 0.5 million gal. (2 million L) culinary water reservoir. The original bid documents specified a wire wound tank. An unsolicited bid proposing an internally post-tensioned tank was submitted.

After an extensive review, the University elected to accept the unsolicited design/build internally post-tensioned proposal. Their decision was not only based on the cost efficiency of the internally post-tensioned tank, but also its corrosion protection, construction schedule, and overall high performance and long-term durability. Although this was not a large tank, the sizable savings achieved would be even greater as the size of the tank increases. It is also important to note that this is not a proprietary system. It can be built by any well-qualified contractor and uses construction means and methods readily available and used in daily construction activities today.

The tank was to be partially buried below grade approximately 18 ft (5.5 m). The bottom of the tank is located at an elevation of approximately 652 ft (200 m) above sea level and will service the university, which is located at an approximate average elevation of 150 ft (46 m) above sea level. The existing soil contained water-soluble sulfates in the mid-range of moderate (0.10 to 0.20 % of SO_4 by weight) as outlined in ACI 318 Table 4.3.1

Structural design

Slab-on-ground: The slab-on-ground was designed with 1/2 in. (13 mm) dia. 270 ksi (2 GPa) unbonded encapsulated post-tensioned tendons in both orthogonal directions along with a substantial amount of bonded mild reinforcement. The slab thickness was designed as 5 in. (125 mm) but was installed as 8 in. (200 mm) to facilitate additional needs of the owner. The slab was placed monolithically with both the continuous perimeter wall footing and the upturned column pedestal type pad foundations (see above Fig.). This method also helped to reduce restraint cracking. The design required concrete with a 28-day compressive strength of 4000 psi (28 MPa).

Suspended roof slab: The suspended roof slab was also designed as a two-way post-tensioned slab with banded tendons in one direction and uniformly distributed tendons in the other (Fig. 2). Slab spans were a maximum of 26 ft (8 m). The slab maintained a constant soffit elevation and the thickness varied from 6 to 10 in. (150 to 255 mm) for drainage. The design required concrete with a 28-day compressive strength of 4000 psi.

Columns: Supporting interior columns were 14 in. (355 mm) dia. conventionally reinforced and spaced at a maximum 26 ft span in either direction. The design required concrete with a 28 day compressive strength of 4000 psi.

Perimeter tank wall: The vertical and horizontal wall reinforcement was designed with a combination of 0.5 in.

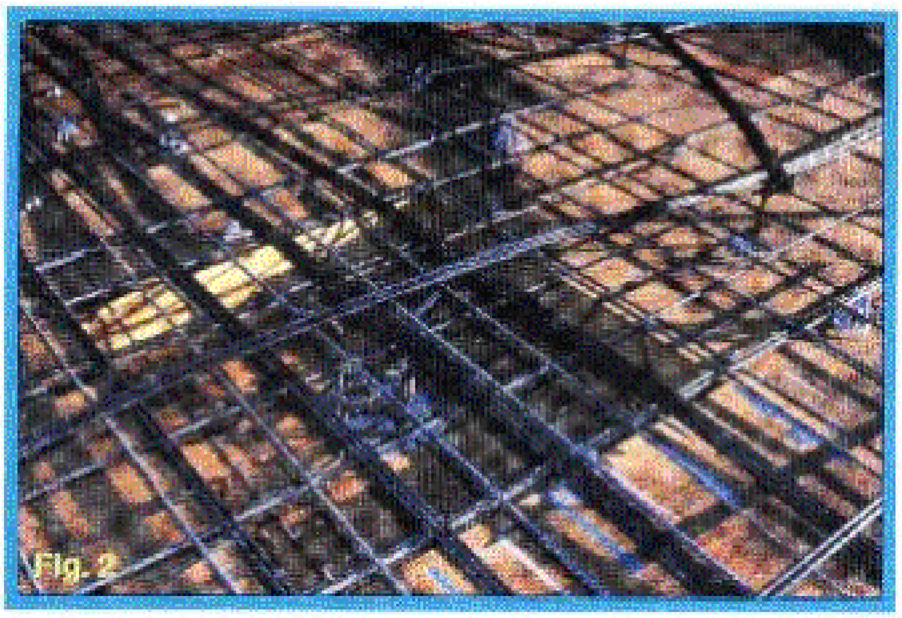


Fig. 2

(13 mm) and 0.6 in. (15 mm) bonded tendons in 2 in. (50 mm) round ducts. The vertical design consisted of alternating groupings of two and three 0.5 in. strands spaced at 30 in. (760 mm) on center. The bottom 2 ft (0.6 m) approximately of the duct was deleted so that the dead-end strand anchors could be splayed to allow for additional anchorage. The horizontal forces were developed with the use of alternating groups of 0.5 in. and 0.6 in. mono strands in bundles of four (Fig. 3). The strands were stressed at alternating pilasters (a total of 3) with the strands being divided in 270 degree and 90 degree sections (Fig. 4). Stressing of the bundled, multistrand horizontal tendons was done with a single strand stressing jack in progressive elongations as opposed to the use of a larger multistrand jack.

Corrosive environment: To protect the slab-on-ground and the roof slab from the aggressive corrosive environment of water-soluble sulfates, the unbonded monostrand tendons were encapsulated (Fig. 5). The water-cementitious material ratio (*w/cm*) was reduced to 0.48 per ACI 318 for sulfates in the mid-range of moderate. To further protect the perimeter tank walls, the vertical and horizontal tendons were bonded in grouting ducts and the exterior of the tank wall was coated with a 120 mil (3 mm) waterproofing membrane (mil x 0.001 = inch).

Durability/material selection

Concrete mixture: As with many areas outside of large urban centers, ready-mix suppliers and users do not all have access to the same materials or knowledge of materials. Since the concrete mixture design is one of the most important items ensuring a quality and durable concrete project, careful research was done to define the desired results of the concrete's performance in placing, finishing, strength gain, shrinkage, curing, heavy congestion within the form surfaces, and reactiveness.

w/cm: For this project, a mixture design was selected that used a good quality 1 in. (25 mm) granite aggregate that was available through one of the local ready-mix suppliers. Type II cement and a low *w/cm* of 0.48 was used (less than the 0.5 required per ACI 318). Type V cement was not required because of the mid-range of moderate water-soluble sulfates contained in the onsite soil as shown in ACI 318 Table 4.3.1. To help obtain the 0.48 *w/cm* and provide other valuable features to the mix, a mid-range water reducing agent was used. To reduce the specific amount of cement, increase the flowability, and help compensate for the accelerated hydration process resulting from long distance hydraulic placing methods, approximately 17 percent fly ash was also used in the mix.

Superplasticizer: A through review for reinforcement, other embedded items, and anchorage congestion within the formwork was conducted. It was determined that enough space existed in all areas to allow the use of the 1 in. (25 mm) aggregate mixture design; however, at the bottom 2 ft (0.6 m) of the exterior tank wall there was a concern. In addition to the upper and lower bundled No. 6 (19M) right angle dowels spaced at 12 in. (300 mm) on center for the connection of the closure strip and the No. 8 (25M) "U" bars x 4 ft (1.2 m) spaced 12 in. on center at the bottom of the wall, the alternating groups of two- and three-strand tendons were required to be terminated with dead-end anchors and backup bars. Full-scale details were drawn to review this section.

As a result of this investigation, it was determined that the aggregate, with its allowable variations in size, would work; but to ensure that sufficient amounts of high quality paste would encompass all elements of the reinforcement, a high-range superplasticizer was added to the concrete mix for the bottom 4 ft of the perimeter tank wall. Additional durability advantages were also obtained from the use of the superplasticizer, such as increased placing performance and easier consolidation to encapsulate the horizontal waterstop. It should be noted that additional formwork considerations must be accounted for when using superplasticizers. Since the plasticizer has an effect similar to electrically charging the molecules of the ready-mix concrete, formwork pressures are increased. Additionally, the hydration process is altered and time and sequencing become extremely critical.

Therefore, adjustments to the strength of the forms and rates of placement were thoroughly considered. To accurately control the quality and desired performance of the concrete, the ready-mixed concrete was delivered to the site at an approximate 2 in. (50 mm) slump and then reduced to an approximate 7 in. (180 mm) slump at the point of placement by adding a specific amount of superplasticizer to the concrete onsite.

Placement method: Placement is another key element to durability. All portions of this project were placed with large hydraulic boom pumps (91 to 171 ft [28 to 52 m]). Pump selections were based on manpower requirements, job site accessibility, overall distances to be reached during a given placement operation, and the quantity of ready-mix concrete required to be placed to maintain proper scheduling within budget. Certain elements, such as the grade slab and foundations, as well as the columns and walls, were placed simultaneously. One column was placed simultaneously with wall segments No. 2, 3, 4, and 5.

The walls of this tank are approximately 21 ft (6.4 m) tall. A 4 in. (100 mm) metal tremie pipe was used in conjunction with the boom pump to deliver the concrete for the vertical elements. This performance enhancement method was selected to limit free falling, avoid excessive placement portholes through the formwork, and increase labor efficiencies. This method also reduced and/or eliminated other factors that could jeopardize the final product such as hose entanglement and reduced rates of placement, cold joints, and additional la-

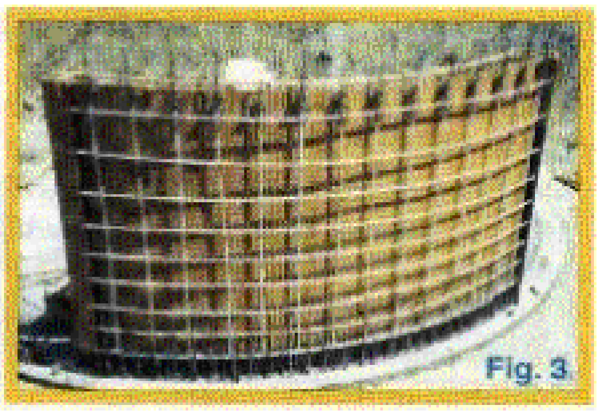


Fig. 3

bor that can be associated with the use of methods such as chutes and plastic elephant trunks. Boom pump/tremie placement also reduced the risk of damage to the horizontal ducts. Additional mixture design modifications which are normally necessary to allow for the friction-related drying (hydration) associated with this method of delivery were unnecessary.

Vibration/consolidation: Poor vibration techniques have ruined more than one project. With respect to the slab-on-ground and the suspended roof slab, good concrete consolidation is critical to encapsulate the post-tensioning fully and, most importantly, to obtain proper consolidation at the stressing and dead-end anchors. Proper vibration methods also increase labor efficiency. All of the concrete for this project was consolidated with electric vibrators that were placed directly into the plastic state concrete. Different size and strength equipment was used as dictated by the needs of the structural element.

The wall concrete was placed in 2 ft (0.6 m) lifts. The forms were designed to withstand a vertical rate of pour of 8 ft (2.5 m) per hour, plus a safety factor. With each successive lift, the vibration equipment (internal type) was delivered (inserted) through the newly placed lift and the two previous lifts below (total of 6 ft [2 m]). To avoid cold joints and honeycombing, it is important to ensure that vibrating crews do not insert or remove the equipment too fast or space it (distance between insertions) too far apart. For wall placements, two vibration crews were used: one positioned ahead of the point of placement and the other behind. Each crew was additionally equipped with flashlights to help with continuous visual inspection during the placement.

Observation/access holes (pour holes) were placed at 8 ft (2.5 m) max. on center horizontally and at 4, 10, and 16 ft (1, 3, and 5 m) vertically. It is important that formwork design accommodate properly sized pour holes based on the specific equipment that will be used. If the placement hole cannot be made large enough or wide enough because of the falsework, placing may be jeopardized. Pour holes were sealed once the concrete height reached that level. Once the concrete was at a height of approximately 10 ft (3 m), one vibration crew was repositioned to the top of the wall with vibration equipment that would adequately reach and deliver sufficient vibration. Special attention was given to vibration equipment's capacity when developing the placement sequencing.

Finishing: The slab-on-ground received a hard trowel finish. The suspended roof slab received a fine broom finish. To produce a proper finish, the finishing process cannot be started too early. If finishing had begun prematurely, the durability of the concrete would be jeopardized. Premature

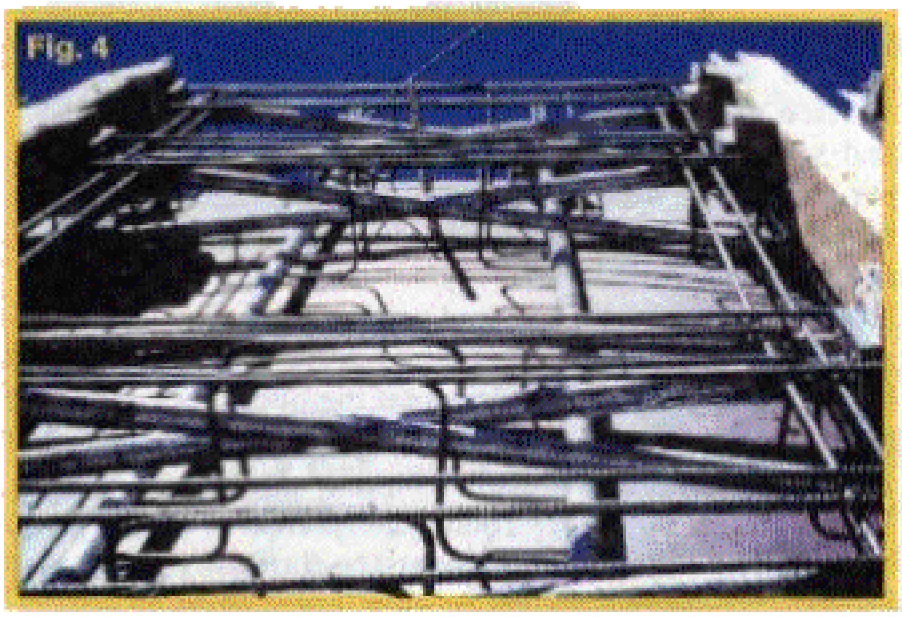


Fig. 4

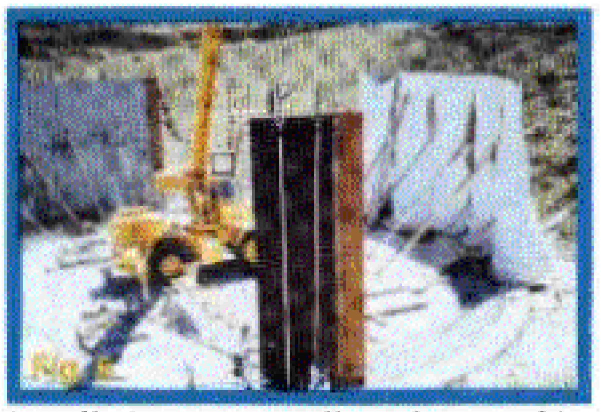
Fig. 5

finishing can trap bleedwater in the concrete, tear the surface layer and decrease the floor's flatness tolerance, and promote slab curl, amongst other things. The slabs were initially struck level with wood roods (straightedges) approximately 11 ft (3.3 m) in between 1.5 in. (40 mm) dia. metal elevated pipe screeds. They were then tamped and floated with 6 ft (2 m) wood bull floats and 10 ft (3 m) channel floats.

Once the bleedwater dissipated and the concrete supported the weight of a finisher without leaving more than a 0.25 in. (6 mm) depression, the slab surfaces were broken open (mortar brought to surface) with power trowels using combination blades. The floors were then restraightened with 12 ft (3.6 m) bump cutters in two directions and then finally closed again with power trowels. The edges were worked with 6 ft (2 m) tools to limit any edge curl. When the floor slabs require a greater degree of flatness, it is this author's normal procedure to use pan machines in conjunction with the bump cutters to restraighten the floor. Once the floors were completely sealed, the specified surface finish was implemented and the slabs immediately covered with a liquid curing compound.

Curing: Proper curing was obtained through a combination of in-form, bur-leen (a combination of burlap and polyethylene sheeting) blankets, visqueen (polyethylene), water, and spray-applied liquid curing compounds. At the completion of the concreting process of the slab-on-grade, a uniformly applied liquid curing compound was applied with Hudson sprayers to all exposed surfaces. Immediately following the application of the curing compound, the entire slab surface was covered with 10 mil (0.3 mm) visqueen (mil x 0.001 = inch). The slab was allowed to cure in this state for seven days. Since potential curing discoloration of the slab was not a concern, there were no objections to the use of the visqueen. It should be mentioned that this method was used instead of water flood curing as outlined in AWWA D115.

The vertical elements required a more labor intensive curing process. When developing the casting cycle for the wall forms, special consideration was given to the curing sequence. Since only 1/6 of the total wall surface formwork was to be used, it was critical that the casting cycle be developed to maximize the equipment and not unduly delay the overall construction schedule. As a result of balancing resources (manpower and equipment), a schedule was developed that allowed each wall section to be placed on a Friday (with the exception of one that was interrupted by a legal holiday). The wall forms were left in place for three days. Once the forms were initially cracked, the wall was flooded with water. As soon as the forms were removed, a liquid curing compound was spray-applied to the ends of the wall



section. Along the top of the wall, a "soaker" hose was installed and which allowed for maintaining correct moisture beneath the bur-leen. The bur-leen blankets were then installed over the walls and secured in place. The total curing process was seven days (Fig. 6). The suspended roof slab was finished and cured with a similarly approved liquid curing compound as was used on the slab-on-grade.

Quality construction

Pre-construction project management: In the design/build industry, pre-construction management is essential. Design/build teams live and die by communication and management skills. Since the team is forced to conceptualize the entire project both in design and construction prior to any working documents, it is essential that all team members be technically strong in both their respective disciplines and in their working knowledge of the other team members. It is important to alert all of the concerned members in how each element of the structure will be designed and constructed. It is important that the constructor notify the designers of why they would prefer one method for construction versus another and together develop the most efficient application for the project.

A constant dialogue between all the members is essential all the way to the presentation of the bid proposal. The team has to remain flexible and have the ability to make last minute changes in the design and construction techniques to ensure they propose the most efficient, durable, and quality project possible. Because of this particular project team effort, a very cost efficient, durable, and high quality project was developed, designed, and constructed. This design is not one of an extremely large tank. If this were a design for a higher volume tank, the cost efficiencies recognized on this project would have been even greater.

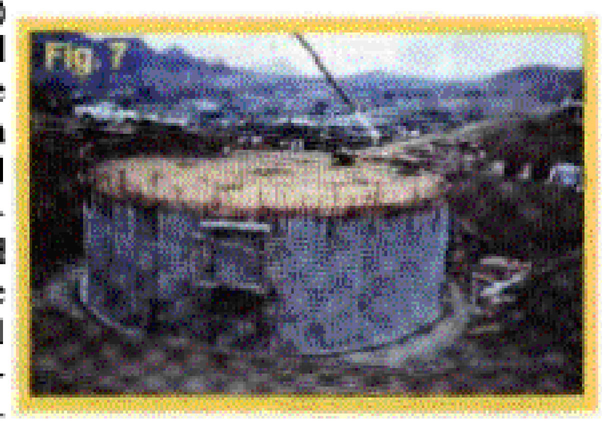
Construction project management: The actual construction project management is a continuation of the pre-construction management. Management entails continued cost estimating, scheduling, and proper sequencing of material and manpower, refinements to details, accurate project records and constant communication between the field personnel, subcontractors, design professionals, the design/build contractor's main office, the owner, and local authorities. The design/build contractor used a proprietary, custom-designed computer program to track and record all correspondence, transmittals, submittals, subcontracts, insurance requirements, RFI's (request for information), change orders, modifications to the construction schedule, manpower and equipment resource availability and costs. Consequently, the contractor was able to avoid potential delays and make calculated adjustments during the project to keep the project running smoothly.

The updated construction schedule was also maintained on computer, which allowed for accurate tracking and control. Additionally, another specially developed software program by the contractor was used to track the actual job costs and constantly compare them to the original budget. Finally, an integrated accounting program encompassed all of the elements to produce comprehensive project financing controls and records for an accurate picture of the overall project.

Another unique management tool was site specific weather forecasting. The design/build contractor retained a meteorologist to provide daily site specific weather updates. The advantages to having constant site specific weather forecasts allowed the contractor to better coordinate work and avoid weather-induced delays. Furthermore, it provided for an impressive case history and additional critical documentation. A thorough review of shop drawings and interface details was also a key element in avoiding delays and poor construction conditions.

Formwork selection

Slab-on-ground: The slab-on-ground required edge forming and hanging forms for the monolithic elevated pedestal-type column pad foundations. The perimeter form was made with a plywood face. The backup was of radius ripped plywood plates top and bottom with 2 x 4 in. (50 x 100 mm) vertical backups at 24 in. (610 mm) on center. The hanging forms were made of 2 x 12 in. (50 x 300 mm) solid lumber.
Column forms: The column forms were one piece, of split fiberglass material.
Wall forms: Form selection was considered critical to both time and cost of the project. A modified gang type form system was selected for the wall work. It incorporated steel walers (horizontal reinforcement), steel channel stiffeners, aluminum vertical backups, two layers of plywood (one substrate and one faced), tapered ties and through bolts. It was most cost efficient to provide 1/6 of the total wall surface area in forms. This maximized the reuse of the equipment and minimized the learning curve of the field crews. It also allowed for all the components of the wall to be utilized in the most efficient, economical means possible to ensure a quality product and reduce exposure to error, oversights, and inclement weather conditions. Time of completion is always a key element to any project. The material and labor savings offset the increased cost of crane hoisting equipment to move the gang forms. Another advantage to using larger forming members was the reduction in tie penetrations through the forms, which also resulted in less cost for labor and material.
Suspended roof slab: An aluminum tower frame system was used. The frames (4 ft [1.2 m] wide) were required to be stacked three high. Aluminum stringers and joist were the primary horizontal elements supplemented with 4 x 4 in. (100 x 100 mm) timbers. 5/8 in. (16 mm) MDO (abrasion and water resistant) plywood was used as the sheeting. The perimeter edge form and safety handrail system was constructed with wood and secured to the perimeter tank wall by using the existing through bolt-holes at the top of the wall and coil tie bolts. The intermediate backups for the edge forms were wedge anchored between the coil bolted horizontal members. The curbs on the deck were placed monolithically and the wooden forms were suspended mechanically (Fig. 7).



Total quality control: Total quality control is not just a catch phrase. It is a comprehensive thought process and project attitude that results in great effort from all participants involved in the project and is necessary to produce high quality and durable concrete projects. No part of the process can be ignored - - from the design to the type of concrete, procedures for installation, sequencing of trades, selection of materials, considerations of the climate and terrain, availability of materials, desired finishes, manpower and equipment availability, project documentation, payment procedures, or site observations. Each step must be and was dissected, discussed, and refined to ensure that all requirements would be met to ensure the project's success.

Communication

As repeatedly mentioned throughout this article, communication is key to every step of the project from the initial decision to get into the race for a project and, if one is lucky enough to be awarded the project, to see it through to completion. Poor communication between the participants will have obvious undesirable consequences. This project team, through its excellent communication was able to develop and maintain a "partnering" type alliance with all of the participants, resulting in a very successful project. The typical adversarial relationship between an owner/construction manager and the contractor was completely precluded from this project.

Summary

Through good design, careful material selection, proper construction practices, and continuous communication from the beginning through to completion, a durable and quality concrete construction project was achieved. It should further be noted that this project was honored as "The Best Concrete Project in California for 1997" by McGraw-Hill/F. W. Dodge's *California Construction Link* magazine and featured in the December, 1997 "Best of California" issue.

Acknowledgment

The author gratefully acknowledges the substantial contribution made to this project by Kenneth B. Bondy.

- Project Owner: Trustee of the California State University
- Design/Build Contractor: W.M. Klorman Construction Corporation
- Structural Engineer: Seneca Structural Design, Inc.
- Owner's Representative: Hoffman & Associates, Construction Management
- Construction Manager: Swinerton & Walberg Company
- Project Location: Cal Poly University, San Luis Obispo, Calif.
- Tank Size: 0.5 million gal.
- Elevation: 673 ft (205 m) above sea level
- Structural Design: Internal Post-Tensioning
- Corrosive Environment: Soil containing water-soluble sulfates
- Seismic Zone: Zone 4

Selected for reader interest by the editors.

ACI member **William M. Klorman** is an active contractor, design/builder, and developer. He is a licensed general contractor, structural concrete contractor, and a registered special inspector for reinforced concrete. He is the president of W.M. Klorman Construction Corporation, and the executive vice president of Accurmac Development/Pacific Enercon, Inc., with corporate offices in Los Angeles, San Francisco, Hong Kong, and Beijing. He is a member of the ACI Standing Board Committee on Responsibility in Concrete Construction, and Committee 350, Environmental Engineering Concrete Structures.