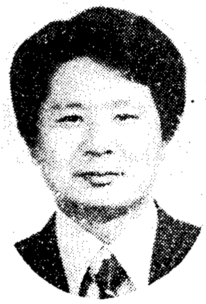

Post-Tensioning Alternative Reduces Construction Time(上)

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개 요

사우디아라비아 육군사관학교(KAMA) 본관 및 부속건물 건립공사를 진행하면서 기술개발한 시공방법으로 공사를 추진하여 공기와 비용을 절감하고 성공적으로 공사를 마무리지은 사례를 ACI(American Concrete Institute)에서 원고로 채택하여 Concrete International Design & Construction Vol. 10 No. 2 Post Tensioned Concrete Feburary 1988에 아래와 같이 소개되었읍니다.

When post-tensioned precast beams were substituted for conventional cast-in-place reinforced concrete channel beams in the Physical Education facility at the King Abdulaziz Military Academy in Saudi Arabia, both construction time and costs were reduced.

The construction schedule for the King Abdulaziz Military Academy (KAMA) in Saudi Arabia required all facilities to be completed within three years of the contract award date. This schedule severely limited the time available for each phase of the $1.2 billion project. The Korean firm Chin Hung International (CHI) used extensive preconstruction planning in completing their phase of the KAMA project on time. Their most significant time saving resulted precast concrete beams for conventional cast-in-place reinforced concrete beams in the Physical Education building.

Nineteen international contractors were involved in construction of the campus, located about 36 miles (60 km) northwest of Riyadh. CHI's $232 million contract, the largest awarded at the KAMA site, included production of 2.8 million ft^2 (260,000 m^2) of cast-in-place architectural concrete and erection of 20,800 precast elements in the main academic campus. Ready-mixed concrete and precast elements were produced and delivered to the site by others under separate contract.

Preconstruction planning

Most general contractors claim to be looking for new ideas, but sufficient time is not often

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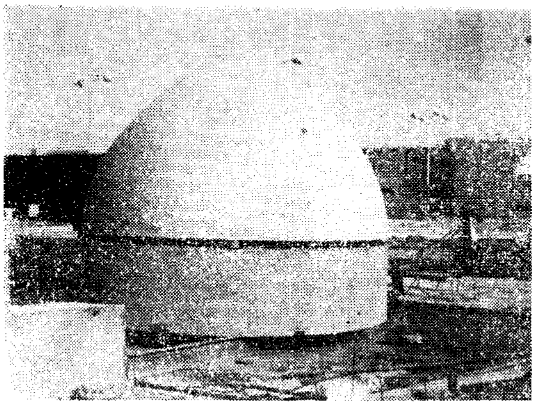

Fig. 1 Precast Concrete Domes for the Man Mosque

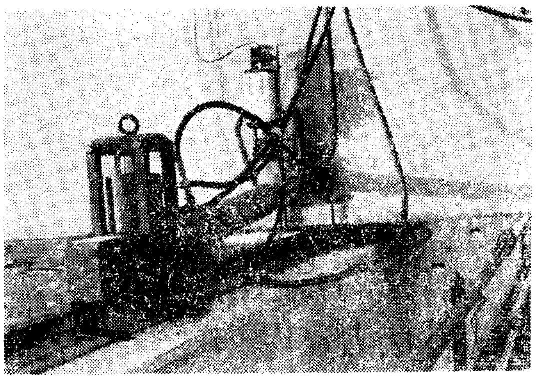

Fig. 2 A Short Vertical Ram Locked the Jack to the Rail and a Long Ram pushed the Beam along the rail.

devoted to studying the contract documents prior to the start of construction. An in-depth review of the plans and specifications is an essential part of any preconstruction planning. At the KAMA project, CHI used the six month mobilization period during which housing, kitchens, mess halls, and recreation facilities were established for their labor force also do much of their preconstruction planning at the site office.

During preconstruction planning material costs were balanced against manpower requirements. Maximum manpower utilization was critical, since all labor for the project had to be imported under a tight visa allowance. Some seemingly small construction modifications resulting from these evaluations had a significant impact on both manpower requirements and construction time. For example, the increased materials cost of $7, 600 was insignificant compared to the 350 man-days of labor saved by using soil-cement instead of compacted fill in the V.I.P. garden area.

Four major construction modifications were recommended:

- Construct basement utility areas instead of backfilling and compacting with control fill.
- Change 17 small domes at the main mosque from cast-in-place to precast concrete.
- Modify the shoring method for the open pyramids at the V.I.P. reviewing stands.
- Substitute post-tensioned precast concrete beams for conventional cast-in-place reinforced concrete channel beams at the physical education building.

Structural floor slab

The gatehouse, the physical education facility, and the education building originally required a conventional slab-on-grade covering utilities buried in 18 to 30 ft (5.5 to 9.0 m) of control fill. This fill was eliminated, leaving an unfloored basement with a structural floor slab replacing the slab-on-grade. The mechanical conduit and pipes were hung directly from the structural slab, and access panels were provided in various walls, making the utility lines accessible. The exposed lines can be readily checked for leakage or other problems and most repairs can now be handled by the normal maintenance staff.

About 58, 000 ft^2 (5, 400 m^2) of building area was modified in this manner. Savings of 1800 man-days plus 51,000 yd^3 (39,000 m^3) of control fill offset the $430,000 cost for construction of structural slabs. Although the financial cost of the two methods of construction was about even, the 1800 man-days saved were critical to CHI's overall schedule.

Precast concrete domes

In the main mosque area of the academic complex, 17 small cast-in-place concrete domes, each about 16.2 ft (4.9 m) in diameter, were detailed. Converting these domes into precast elements eliminated a substantial amount of complex forming and shoring. Only 230 man-days were required for mold making, production and erection of the precast domes, thus saving 970 man-days. (Fig. 1).

Open pyramids

Non-conventional shoring methods used in constructing the 24 open pyramids at the V.I.P. reviewing stands saved both time and shoring, freeing men and equipment for other operations. The 33-ft (9.9-m) square by 21-ft (6.3-m) high pyramids each having a mass of 230 tons, are located 37.5 ft (11.4 m) above floor grade. Rather than using conventional shoring founded on the floor slab, a special support platform was built from wide-flange steel beams spanning between gusseted angle plates. Each angle plate plate was attached to a cast-in-place concrete beam or wall using eight expansion bolts working primarily in shear. Conventional concrete forming was used above the platform.

A minimum safety factor of three was used in designing the beams and connections to support forming and wet concrete loads. Elimination of conventional shoring freed the floor space, so that other operations could proceed simultaneously with the construction of the pyramids. An estimated 1020 man-days of construction time were saved, and a considerable amount of shoring was freed for use in sandblasting, construction material inventory, and clean-up operations on the architectural cast-in-place concrete. A similar system was used to support cadet mess hall channel beams during construction.

Post-tensioned channel beams

The original design of the channel beams at the roof level of the 800-ft (244-m) long physical education building required massive 4.0-ft (1.2-m) wide by 8.0-ft (2.4-m) deep cast-in-place concrete beams spanning 120 ft (36.3 m) between cast-in-place concrete lateral support beams. Each channel beam tapers to a 7.0 ft (2.1 m) depth at the end of its 11.0 ft (3.3 m) cantilever, resulting in an overall length of 141.6 ft (42.9 m). The beams have a total mass of 170 ton and an architectural surface area of 4670 ft^2 (432 m^2). These channel beams are located 56 ft (17 m) above ground level and spaced at 16.3 ft (4.95 m) on center.

Architectural forming methods, minimization of normal deflection cracking, and sequence of

* Keywords; beams (supports); concrete concrete slabs; consolidation; economics; exposed aggregate concrete; finishes; formwork (construction); grouting; posttensioning; precast concrete; reinforcing steels; shoring safety; structural analysis.

construction all required careful consideration. The long-span beam construction was very challenging because all 47 channel beams are of architectural concrete with a light to medium sandblasted finish, and therefore required additional care in selection of forming systems, reinforcement location, concrete placement, consolidation and final finishing.

Crack control was a potential problem with both the channel beams and the precast elements at lower levels. The deflection forces at the mid-span of the channel beams would have to be carried by shoring to the precast elements on various floors, and then transferred to ground levet. Even using good shoring procedures, it would not be desirable to transfer the heavy shoring and concrete placement loads through the lightweight precast tribeams and floor slabs. Since the tribeams are hollow to carry the air conditioning supply and return lines, the anticipated distortion and deflection in both shoring and precast elements would result in undesirable cracking. Twenty-eight of the 47 long-span channel beams would have to be shored through multiple floor levels. The difficulty in obtaining perfect vertical reshoring would probably result in point overlodds at some locations.

Due the severe time restrictions on this contract, construction sequencing was of prime importance. For this reason, beginning contruction of the lower floors after the channel beams were complete would unacceptably extend the total construction time.

Various construction methods were considered. The conventional support method, using shoring of precast elements to transfer loads to ground level, was eliminated because of the problems previously mentioned. Segmental (three-piece) post-tensioned construction was eliminated because of capacity problems with the available cranes and the alignment difficulties that would arise for a contractor unfamiliar with segmental construction. Precasting the beams at the production area was unacceptable because of problems with the beam weight and transportation over uneven terrain; also, work on levels one and two would have been delayed until after erection of the channel beams because of crane access requirements.

Casting and post-tensioning the beams in a central location at the 56 ft (17 m) level was selected because it allowed other work to continue at all levels and zones of the building while the channel beams were being fabricated. It also minimized shoring and eliminated transfer of loads through the precast elements.

The 16,000 man-days saved by substituting post-tensioned precast concrete beams for conventional cast-in-place concrete beams in the Physical Education building was the major time saving from a change in construction method on this project. The average CHI laborer in Saudi Arabia at this time was working a minimum of 12 hours per day, and the approximately 192,000 man-hours saved on channel beam construction became critical later when they were used in another area with substantial time over-runs. Additional men could not be hired and brought to Saudi Arabia due to visa restrictions; the four months CHI saved on their critical path allowed the project to be completed on time.

Preparation

Staging supports were erected to act as a construction platform 56 ft (17 m) above the ground floor. Temporary rails were mounted along the cast-in-place concrete lateral support beams, upon which the channels would eventually rest. The lateral beam reinforcement design was calculated for the different moving load positions as well as the in-place loadings. Of particular concern in the design of both lateral beams and channel beams was the possibility of torsional moments induced by poor rail alignment or the application of uneven jacking forces. To avoid these problems:

- Rails were laid dry on lateral beams, shimmed, and fixed in place on both sides with bolts and clamping plates.
- The maximum tolerance allowed for setting the rails in either the vertical or the horizontal plane was 1/8 in. (3 mm).
- Four metal beam shoes were embedded in the concrete of each channel beam, allowing the beams to slide more easily along the metal rails as they were moved into their final location by hydraulic rams.
- High density plywood bottom forms were set on staging at an elevation slightly higher than the top of the temporary rails. After the concrete was partially cured, these forms could be lowered, leaving the channel beam resting on its four beam shoes.

The planned production cycle for each beam was six days, including three days of curing. Sufficient staging was set up to allow crews to work on five channel beams at a time, giving an ideal production schedule, Although various delays extended the beams' total production time beyond the 11 weeks scheduled for this phase, a total of four months of general construction time was saved by precasting these channel beams at their elevated location.

Production

Except for the unusually large beam size and the height at which the labor force was working, production followed that of any architectural concrete post-tensioning project. Forms were constructed of high density non-absorptive plywood. The butt joints of the plywood were filled with silicone caulking, then struck level and smooth. Any gaps or surface imperfections were filled, trimmed flush, and covered with thin clear plastic tape. The inside from section for each leg was set in place and treated with a form release agent prior to the installation of the reinforcing steel and the post-ten-sioned system sheathing.

Reinforcing steel cages were assembled on jigs in advance of production, then lifted into their final position in the forms. Strand sheathing was laid continuously along the full beam length. The spiral end reinforcement and anchorage plates were properly located and tied into position. Seven-wire strand was then threaded through the sheathing to insure minimum friction losses. The end closures and any joints or breaks in the sheathing were taped to prevent concrete from leaking into the sheathing during placement and consolidation of the fresh concrete. All reinforcing steel was inspected to insure adequate clearance was provided for placement of the architectural concrete. All four beam shoes were rechecked for correct horizontal position and level bottom surface. The remaining side form was then placed and secured in position.

Architectural concrete was pumped directly from the transit mixers into the channel beam forms. The extremely hot weather, with air temperatures varying up to 120 F (49 C), required an air-en-training agent and a retarder in the concrete mix. The high congestion due to the conventional reinforcing steel and the sheathing for the post-tensioning strand required the use of a superplastisizer to ease concrete placement. Extra vibration was provided at the beam ends adjecent to strand bearing plates and spiral reinforcement to insure proper consolidation in this particularly congested area. Special care was taken to insure that the alignment of the sheathing did not change during consolidation of the concrete.

Concrete was covered with wet burlap and plastic, then left to cure to a minimum compressive strength of 3500 psi before the strands were tensioned. The tensioning procedure followed a computer program which determined the required gauge pressure and elongation for each strand group. Strands were individually stressed to a temporary overload force (jacking force) equal to 70 percent of the ultimate strand capacity. The overload force was held briefly, then reduced to the design transfer stress; the strands were then anchored. Once all of the strands on a beam were properly stressed and anchored, the ends were cut inside the stressing pocket recess. Strands were then grouted in the sheathing with Tricosal mortar, and the recess filled with architectural concrete patch mix.

It was essential that all strands in a strand group be tensioned to the design stress to avoid applying an unbalanced force to the beam. Work platforms were constructed at both ends of the production area to allow all strand to be stressed from either end, since high friction losses or accidental bonding might prevent the design stress from being achieved if a single jacking point was used. After anchoring, the elongation and gauge readings for all strand were within 5 percent of the corresponding readings specified by the computer program.

Moving

Prior to moving the channel beams into their final positions, each rail was checked for level and accuracy of alignment. The u-head screw jacks holding the bottom forms in place were then manually lowered, allowing the entire beam mass to rest on the beam shoes. Four holes were drilled in the side of each channel beam above the rear shoes, and the jacking system (consisting of two hydraulic rams) was bolted to the beam at both these locations. Television cameras installed on each end of the channel beam monitored the orientation of the beam while it was being jacked along the rail. Any problem with unequal ram movement on the two jacking set-ups could be immediately detected from gauge readings visible on the camear monitors.

Each jacking system consisted of two hydraulic rams: a short vertical ram to lock the jack to the rail using shear friction, and a long ram to push the beam along the rail(Fig. 2). With this double ram system, one man operating remote controls could move both the beam and the hydraulic jacks along the rails at a rate of 33 ft/hr (10 m/hr). Beams were cleared from the production area and stored at 12 ft (3. 3 m) intervals along the rail. During the next production cycle, these beams were moved to their final location, clearing the storage area for the next group of beams.

After the channel beams were moved to their final locations, the hydraulic ram jacking system was detached. A crane was used to place a steel lifting frame over each end of the channel beam; each frame was then attached to the top of the channel beam by four bolts screwed into heavy duty inserts cast in the beam. A fifty ton hydraulic jack was set up under each of the

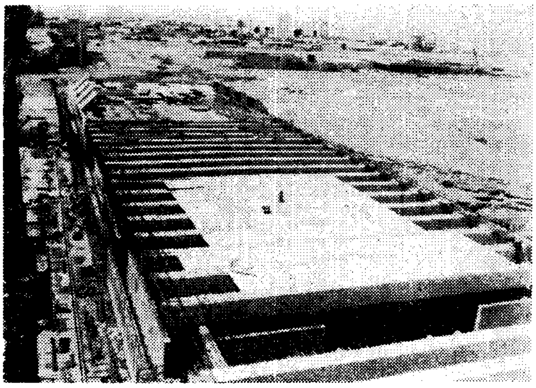

Fig. 3 The Channel Beams were moved to their final locations.

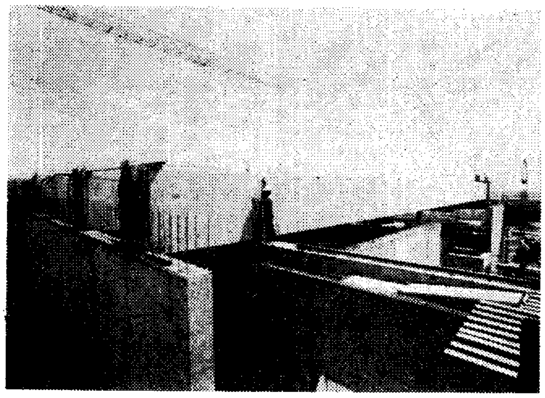

Fig. 4 Final Placement of Post-Tensioned Precast Concrete Channel Beams on the cast-in-place concrete beam and wall.

four legs of a lifting frame and shimmed level, and the channcl beam was then raised by these eight jacks operating in concert. The rails were removed and a thin epoxy mortar bed was laid under the channel beam's bearing points. The metal shoes were removed from each beam. A thick neoprene bearing pad was placed on each epoxy mortar bed, and the channel beam was then carefully lowered into its final position by the hydraulic jacks. The two lifting frames were then moved to the next beam and the lifting insert holes filled with epoxy mortar.

Completion

After all of the channel beams in a section of the physical education building were in their final positions, 3.5-in. (90-mm) thick precast concrete planks were placed on the ledges built into the top of each beam(Fig. 3). Concrete topping pumped across the top of the planks and the channel beams tied the precast and site-cast elements together to provide a wind-resisting diaphragm.

Fig. 4 shows the comparative dimensions of a post-tensioned conrete channel beam and the typical end conditions where a beam terminates in a cast-in-place concrete wall.

Conclusions

The days of unlimited construction time and ample budgets are long past. Only those companies willing to develop new methods and approaches to the construction of large projects will remain profitable in the 1990s. The KAMA project has proven that preconstruction conferences involving the contractor's engineering and construction staff and outside consultants can provide innovative ideas that result in substantial savings in time and money.

CHI's elevated precast operations saved a substantial amount of man-hours and kept the project within a difficult schedule. Labor efficiency and a high quality finished product were obtained by confining the production of the post-tensioned channel beams to one area. These operations have shown that long-span post-tensioned beams can be economically produced without using large cranes or incurring high forming costs.