POST-TENSIONED STRUCTURAL SYSTEMS— DALLAS-FT. WORTH AIRPORT

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The first phase of this giant jet-age airport complex was dedicated on September 22, 1973. The four air terminal buildings and their adjacent elevated roadways and parking facilities make extensive use of precast and prestressed concrete, all exposed buff-colored concrete with a sandblasted textured finish. Over 12,000 pieces of precast concrete were used in the buildings and 8000 pieces in the elevated roadways.

The terminal buildings are semicircular in plan but are developed from rectangular two-story modules consisting of precast columns, prestressed beams, double-tee floors, and precast wall panels using welded connections. The members are given additional stability by post-tensioning.

The elevated roadways follow the curve of the buildings and match their architectural design. Cast-in-place prestressed concrete frames at 62-ft centers support prestressed double tees, precast fascias, and cast-in-place post-tensioned roadway toppings. Phase 1 construction exceeds $700 million.

This paper describes the construction techniques used in erecting the air traffic control tower, terminal facilities, enplaning and deplaning traffic structures, and parking facilities.

Fig. 1. Artist's rendering of Phase 1 project showing four terminals, runways, and roadways. Control tower is at center.

The mammoth Dallas-Ft. Worth Airport complex, the world's largest airport, was dedicated on September 22, 1973. This vast complex occupies over 17,000 acres of land. The total cost of the airport is estimated at $700 million. In addition, the project has already generated more than a billion dollars worth of new construction on its periphery.

The airport is located about 17 miles from both downtown Dallas and Ft. Worth. Currently, it is being served by eight airlines. However, it is anticipated that the Dallas/Ft. Worth Airport will be an international air hub with a yearly passenger turnover of 16 million by 1975 and 30 million by 1985.

Passengers will be able to park within 250 to 300 ft of departing planes. By the year 2001 it is expected that 14 passenger half-loop buildings will be completed, of which 13 will be passenger terminals using 234 gates, the other a field transit and mass transit terminal.

In final form the air space will be able to handle as many instrument flight operations, as the three major New York airports combined. Unquestionably, the airport will assume a major role in the development of the revised air transportation network in the United States.

Approximately 8500 acres of land will be used for runways, taxiways, and terminals (see Fig. 1). Other acreage will be used for cargo, maintenance, air mail, utilities, fuel and automobile parking facilities.

Three runways will be constructed for the opening phase. The two north-south runways will be 11,400 ft long

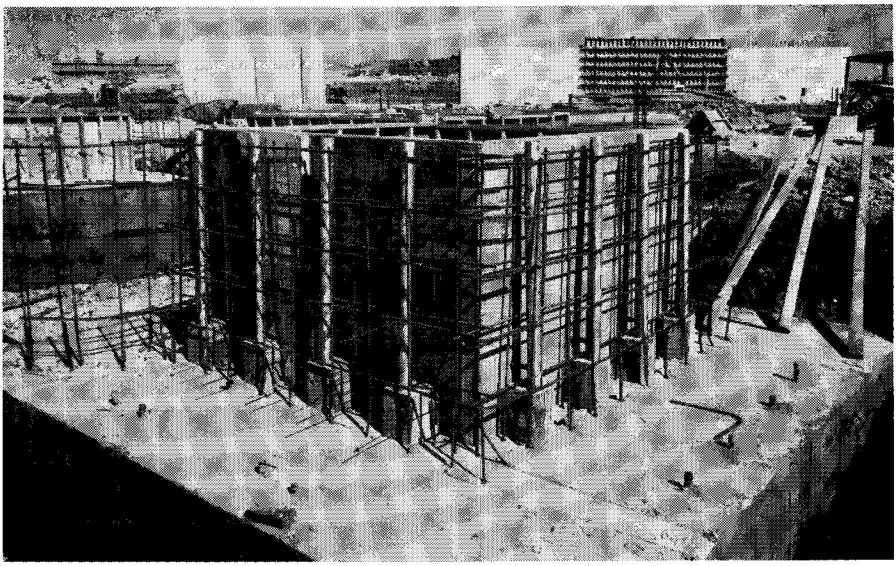

Fig. 2. Foundation pad for one of the four adjacent service cores for control tower.

and may be expanded at a later date to 13,400 ft. The third runway for crosswing landings will initially be 9000 ft long but can be expanded to 11,000 ft. To illustrate the airport's expansion capabilities, the north-south runways can be constructed and extended up to 20,000 ft. Another crosswing runway can be constructed so all runways are designed to provide maximum capacities for simultaneous take-offs and landings, under instrument flight conditions.

Altogether, about 1,500,000 cu yds of concrete and 36,000,000 tons of reinforcing steel were used for the three initial runways, taxiways, and parking aprons. Eventually, 620 acres of land will be covered with 15 to 17 in. of concrete.

Initially, there will be four terminal loops. Each loop can be expanded in length, width, and height. This is primarily due to the architect's modular design concept which uses straight precast concrete sections. The curve of each terminal loop is achieved by interspersing 12-ft wedge sections on 93½ ft center to center. Advantages in the use of precast concrete are controlled appearance, availability, flexibility, economy, and ease of construction.

The following pages will describe the construction techniques used in erecting the air traffic control tower, terminal facilities, enplaning and deplaning structures, and parking facilities.

AIR TRAFFIC CONTROL TOWER

The Federal Aviation Administration Air Traffic Control Tower is centered in the terminal complex and has an unobstructed view of the entire 17,000 acre site. The tower consists of four service cores made up of ninety-two 20-ton precast concrete modules (see Fig. 2).

The modules are stacked vertically to 180 ft and topped by a 16-ft high, 11-sided steel cab and equipment level. One core houses an elevator and the second contains a stairway. The other two cores hold cables for air traffic equipment and utilities.

The precast box components measure 10 x 10 ft in plan and are 7½ ft high. They were cast 120 miles from the site and trucked to the job.

Erection of the modules required a 150-ton crane with a 200-ft boom (see Fig. 3). At the peak of production 20 modules were set per week. Modules are positioned on shims and the joints drypacked (see Fig. 4).

Vertical continuity between components was achieved with post-tensioned 1¼-in. diameter Dywidag thread bars (150-ksi strength) anchored into the foundation slab under each service core. Thread bars were installed through 3-in. voids in the 12-in. thick precast modules in 30-ft lifts and stressed to 131 kips (see Fig. 5). Couplings at 30-ft intervals provide full continuity of prestress across joints after stressing.

To resist lateral loads, 14 bars were

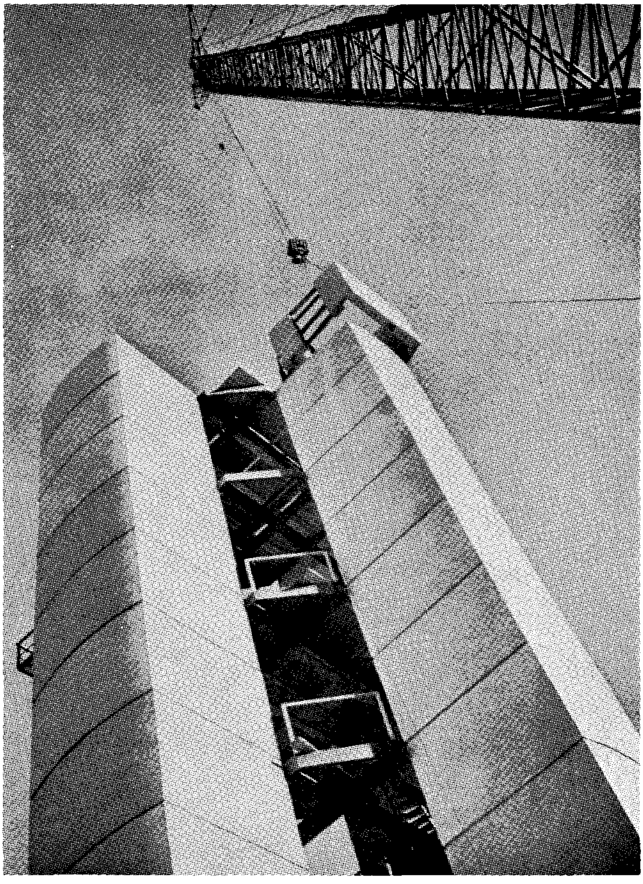

Fig. 3. 150-ton crane with 200-ft boom placing 10 x 10 x 7½-ft high 20-ton box module. (There were 92 individual modules for four cores).

required at the base of each core extending to the 30-ft elevation; ten bars extend to the 90-ft elevation and six bars continue to the 180-ft elevation. Grouting of the duct was accomplished in 30-ft sections after all post-tensioning was complete. Structural steel platforms at 15-ft intervals connect the four service cores (see Fig. 6).

At the base of the tower is a 26,000 sq ft office and service area.

Designed for the Federal Aviation Administration the $2.5 million tower is a prototype of the airport control tower of the future. Plans have been devised to adapt this precast concrete system to future towers having heights of 120, 150, and 180 ft.

TERMINAL FACILITIES

The airport design takes into account aircraft dimensions larger than the Boeing 747. Taxiways will be able to accommodate aircraft entering and exiting the runways and terminal aprons without bottlenecking aircraft movements. The taxiway and runway separation, and the capacity in turning radius of the taxiway are designed to avoid delays. The circular design of terminals

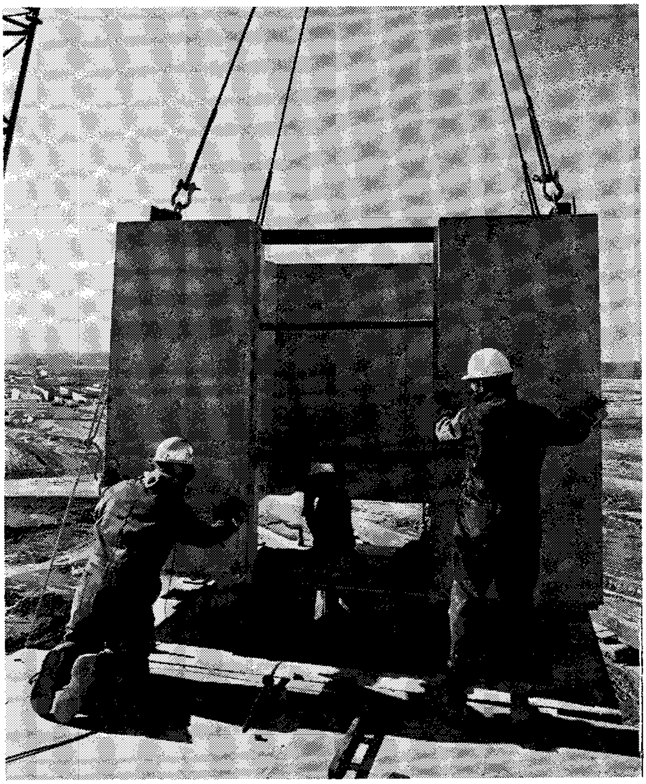

Fig. 4. Close-up of placing module on metal shims. Joints were dry packed after they were set in place. Modules were set 20 per week.

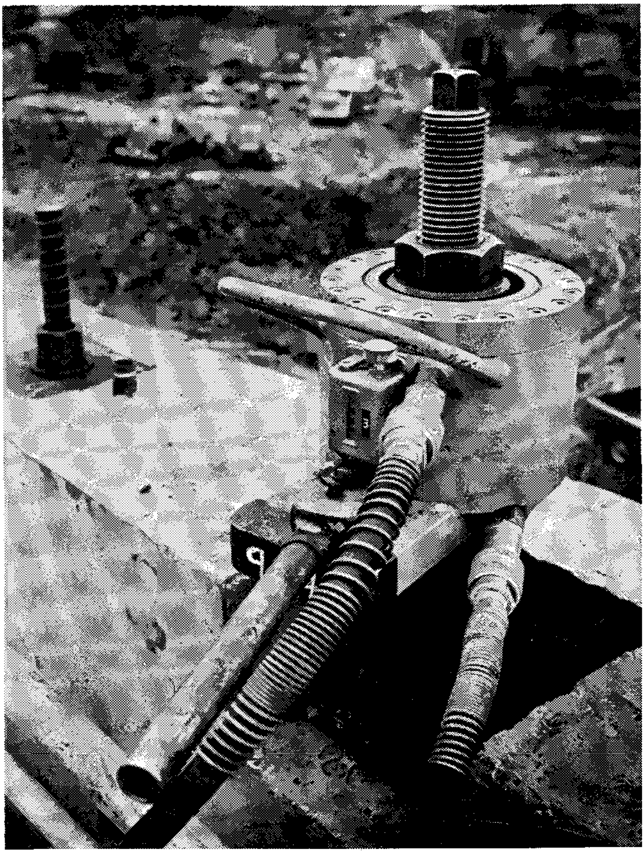

Fig. 5. Closeup of 1¼ in. diameter Dywidag thread bars providing vertical continuity between modules. Bars are inserted in 3 in. diameter void in 30-ft lifts. Bars are coupled at 30-ft lifts and stressed to 131 kips.

simplifies aircraft movement (see Fig. 7).

The decentralized concept of one gate, one airplane, and parking in front, is a revolutionary turn-around back to simplicity and convenience, though requiring a vast amount of land. A fully developed building will consist of three concentric rings. From the airfield side to the land side, the rings consist of a gate ring, main lobby ring, and baggage section ring at the upper level. An automated passenger and baggage system will operate below the baggage claim area. The distance from curb side to boarding gate is about 120 ft. A passenger will only have to walk about 300 ft from the parking area to a terminal.

The terminals, the ones under construction and those of the future, will form an approximate semicircle. A fully developed terminal consists of a 216-deg arc with an approximate 1800-ft diameter and a circumference on the air side of about 3300 ft.

All of the terminal buildings at Dallas Love Field will fit in this single half

Fig. 6. Modules are stacked to 180 ft and topped by 16-ft high, 11-sided steel cabs and equipment level. Structural steel platforms were set at 15-ft intervals to connect the four service cores.

loop and the park-like infield in the center of the half loop could house a stadium the size of the Cotton Bowl. The only complete loop terminal (Terminal No. 2W) will be occupied by Braniff Airways, Inc. and will have the full compliment of 24 gates.

The fully-developed, 13-terminal complex will accommodate 234 Boeing 747 aircraft simultaneously. A completely developed terminal will be able to handle 18 jumbo jets or 24 smaller aircrafts simultaneously. The terminal is designed for vertical expansion in anticipation of aircraft requiring more than one level of passenger entry.

The design and construction of the terminals were handled by two construction management teams. The opening phase alone contains over 50 separate construction contracts which totalled more than $300 million. Contracts for construction of each terminal were broken up in three contract phases. Foundation contracts were awarded only after the precise terminal layout was determined. Precast concrete and post-tensioning systems were purchased in advance when the structural frame design was completed.

Following the bidding of the general contract work, advance purchase contracts were assigned to the successful general contractors. Since the components were either ready for shipment or in production, this staging of contract awards shortened terminal construction by about 18 months.

Before final plan preparation was complete, any contract other than the foundation contracts were awarded, a full scale model terminal section was constructed at a cost of about $233,000. This 7000 sq ft model of a typical terminal section was built on the airport property and provided a means to test the frame connections and help correct flaws in the general system, before the precast units were mass produced.

Because the terminal system was designed to be modular, different requirements in dimension and space by the varying airlines can be accommodated. The design, a beam and column concept, carried out with precast, post-tensioned concrete members, allowed the Airport Board by an advance procurement procedure to buy $8,000,000 in

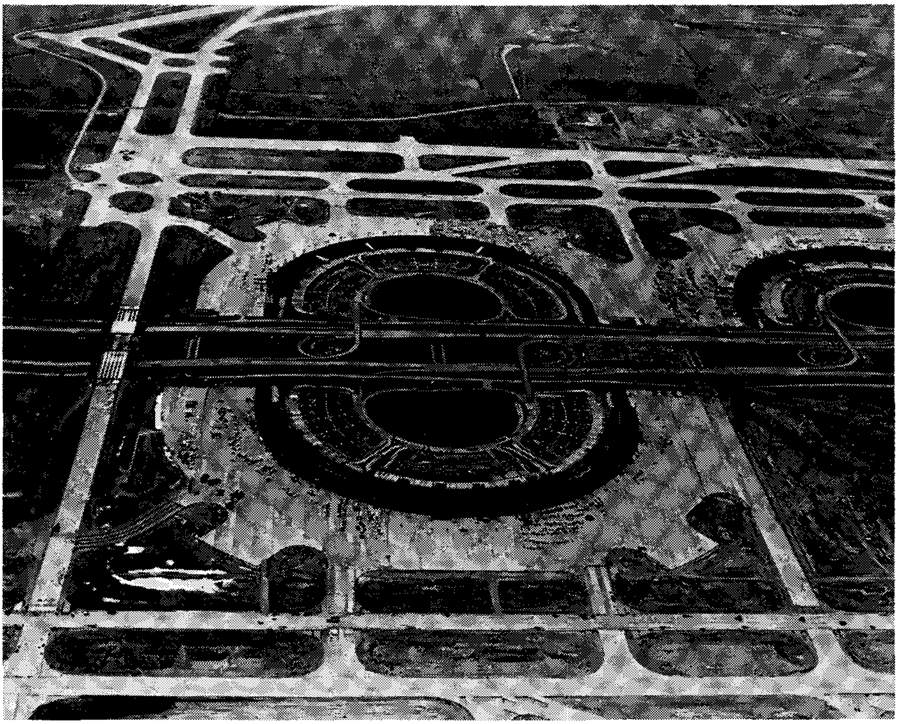

Fig. 7. Two opposing terminals (complete arc) and 24 boarding gates.

Fig. 8. Terminal building (2W). Primary structural system used precast beam and column frames in both longitudinal and traverse directions. For architectural considerations haunches were eliminated for longitudinal beams. Shears and moments were transferred from beams to columns using shear keys. Continuity in the longitudinal direction was provided using Cona multistrand tendons pulled into place after precast erection.

precast concrete and post-tensioning materials before a general contract for terminal construction was awarded.

Phase 1 construction was planned for five semicircular terminals—one complete loop and four partial loop terminals.

After the Airport Board had awarded $1.2 million in foundation contracts, the downturn in the economy hit the airline industry. Three of the eight carriers committed to the new facilities asked to combine their space and reduce their initial commitment. The Airport Board agreed and only four of the initially contemplated five terminals will be functional by the end of 1973.

To meet the different requirements in dimension and space of the various airlines, a modular structural system was chosen. The basic building module is 120 ft in length, 90 ft in width on the air side, and 80 ft on the land side. Wedge-shaped sections connect the basic modules which are used for elevators, stairwalls or additional floor space (see Fig. 8).

The primary structural system (see Fig. 9) consists of precast beams and column frames spanning from land side

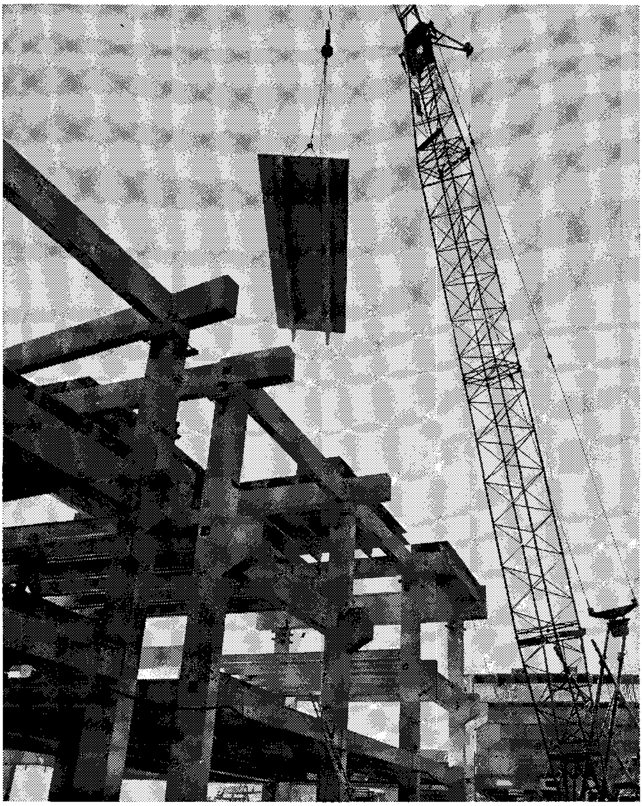

Fig. 9. 18-in. precast double-tee unit being hoisted into position longitudinally and transversely in both floor and roof system.

to air side. Rigid frame action transversely is achieved by connecting precast beams seated on column haunches to the column at the top of the beam by steel weld plates. The joints are designed to allow rotation and thereby distribute moments.

Roof beams spanning the main lobby connect adjacent end-to-end rigid frames using a grouted dowel and sleeve connection on top of the columns. Columns were connected to the concrete foundation piers by anchor bolts which were drilled and set in grout to match column base plates. Transverse frame beams were post-tensioned in the precast yard for dead load and all superimposed loads.

To handle specific design loads an unsymmetrical parabolic tendon was chosen in many cases. The varying post-tensioning forces were delivered with multiple and/or combination of 1- and 1¼-in. diameter grouted Dywidag thread bar tendons.

The concourse level floor framing consists of castellated steel girders, secondary beams, and metal deck with a concrete topping to allow flexibility in

Fig. 10. Concourse level framing consisted of castellated steel girders, secondary beams, and metal deck with a concrete deck (to allow flexibility in the future floor penetration). Use of friction clamps to support longitudinal frame members eliminated need to shore to grade.

future floor penetrations. The remaining floor and roof systems are framed with precast prestressed double tees spanning between parallel frames (see Fig. 10).

Longitudinal rigid frame action is achieved by connecting transverse frames with precast beams. The members are post-tensioned by tendons which are pulled through 3¾-in. diameter preplaced beam and column voids after precast erection (see Fig. 11). Longitudinal beams are pretensioned for dead load and handling stresses. Pull-through tendon system develops negative moment capacity for all loads other than beam weight for one span or three spans at 23 ft 6 in. Cona multistrand tendons vary from four to twelve ½-in. diameter 270-ksi strands (see Fig. 12).

Longitudinal column haunches were eliminated for architectural effect. Beam shear keys transfer shears and moments after multistrand tendons were pulled into place. The grout tight sleeves connecting the column sleeve and beam sleeves placed through the keyways were grouted with 6000-psi nonshrink grout (see Fig. 13). Tendon grouting followed. The friction joint, a development of LeMessieur Associates, worked flawlessly except in one instance where joint failure occurred due to tensioning before the keyway grout had attained proper compressive strength.

E. L. Derr Construction Company devised a friction damp system to support the precast beams prior to post-tensioning. This eliminated the need for shoring to grade.

All the precast members have an exposed aggregate buff-colored finish. This texture was achieved with the aid of sandblasting (see Fig. 14).

Each terminal building is designed to accommodate an additional level should a future aircraft have more than one level of passenger cabin decks.

ENPLANING AND DEPLANING TRAFFIC STRUCTURES

Enplaning and deplaning traffic as well as service vehicles are accommodated by the 10-lane divided limited access toll International Parkway. The International Parkway bisects the airport complex and runs the entire length of the 8-mile long complex. Individual left turn exit loops allow direct but

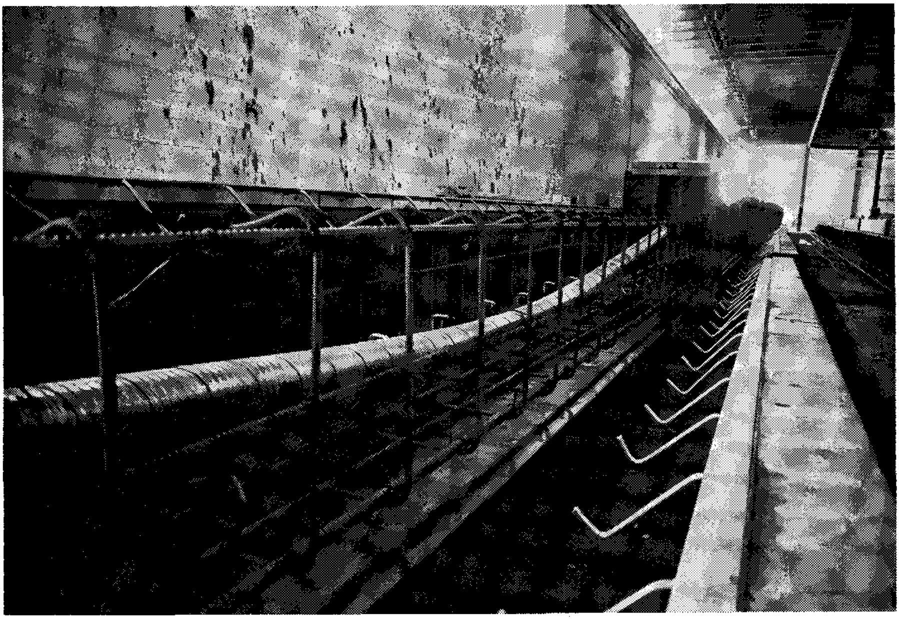

Fig. 11. Precast longitudinal frame beams were pretensioned for their own dead load and handling. Note that the 3¾ in. diameter draped tendon duct was placed in the beam at time of casting. Multistrand tendon was pulled into position in field to create one and three-span rigid frames.

separate access to each terminal loop eliminating traffic bottlenecks.

The airport's internal roadway network will segregate traffic by function and feed into two separate roadway systems. One system will serve passengers and visitors. The other system will handle roadway services. Three lanes of traffic in each direction with expansion capability to five lanes are built into the master plan.

Identification pylons (90 ft high) are

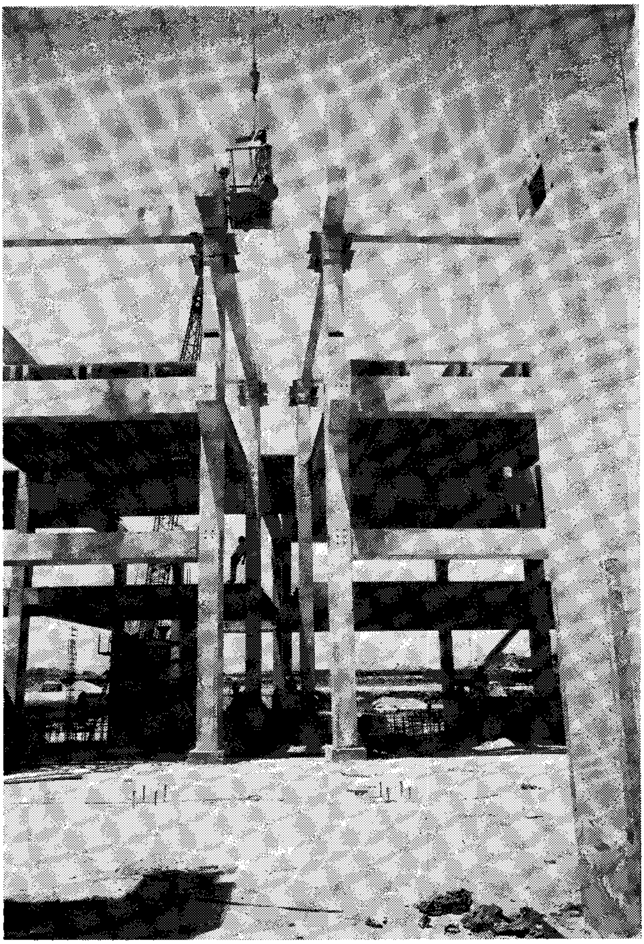

Fig. 12. Basic frame module is 120 ft long (perpendicular to picture) and 90 ft in width on air side and 80 ft on land side. All precast members are straight and span the chords of arc in longitudinal direction. Four to twelve strand tendons are pulled into beam and column void, stressed and grouted using work cage suspended from column in to wedge between modules.

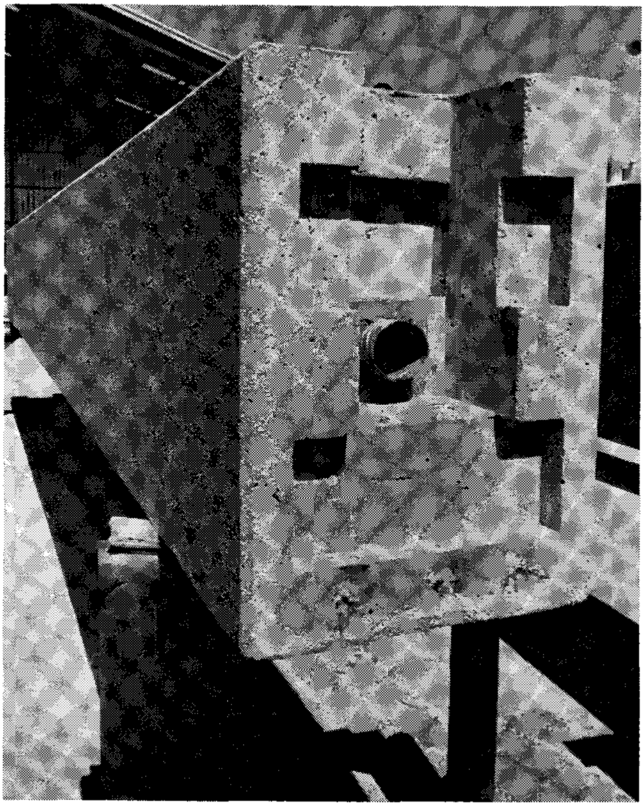

Fig. 13. Shear key is formed in ends of precast beams. After sleeve-connecting beam and column tendon duct are secured, keyway is grouted with 6000-psi concrete.

located in each traffic loop. These pylons carry the logos of the various airlines to direct traffic to their desired destination.

These precast modular towers were constructed in seven lifts with vertical continuity provided by vertical post-tensioning. Dywidag thread bar tendons (1¼ in. in diameter) are anchored in the foundation and tensioned to the top of the structure. Tendons above the foundation mat are inserted in 3-in. diameter voids in the precast components. Joints were dry packed and all bars tensioned at each lift. Bars are coupled after stressing to provide continuity.

Enplaning and deplaning roadways trace the arc of each terminal and connect to the parkway via service roads at the extreme ends of each terminal (see Fig. 15).

Enplaning traffic remains at grade while deplaning traffic runs on an elevated structure directly overhead. The elevated deplaning roadway structures for all four terminals were framed with 62-ft span, 57x28-in. cast-in-place post-tensioned girders, supporting 18-in.

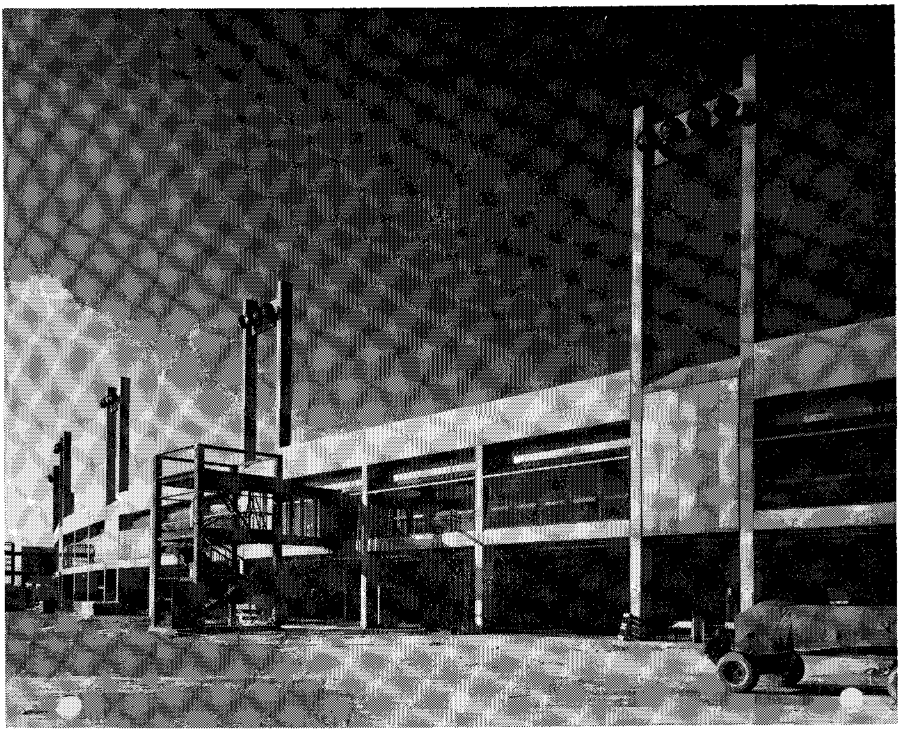

Fig. 14. Exposed aggregate sand-blasted buff colored cement was used on tower, terminals, and deplaning roadways.

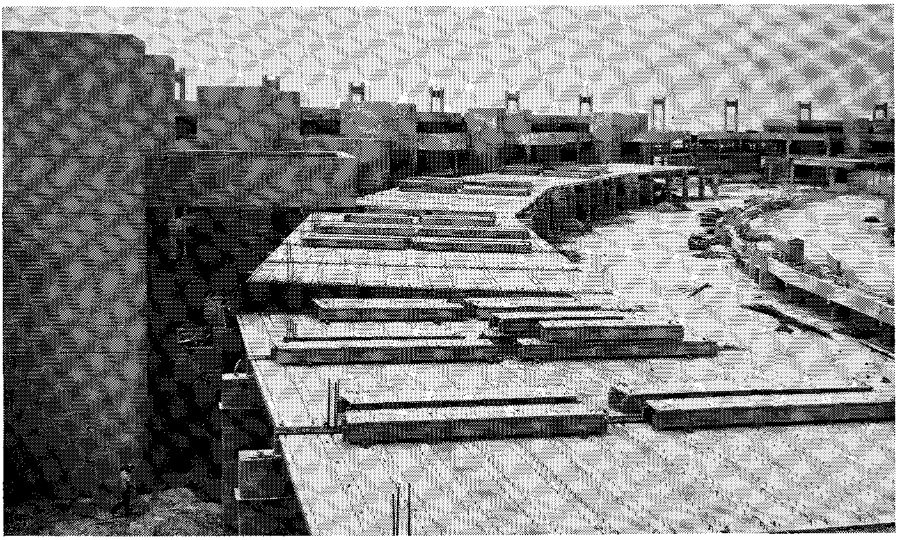

Fig. 15. Deplaning traffic circulates on roadway adjacent to structure. Intermediate ramps provide connection to service roads.

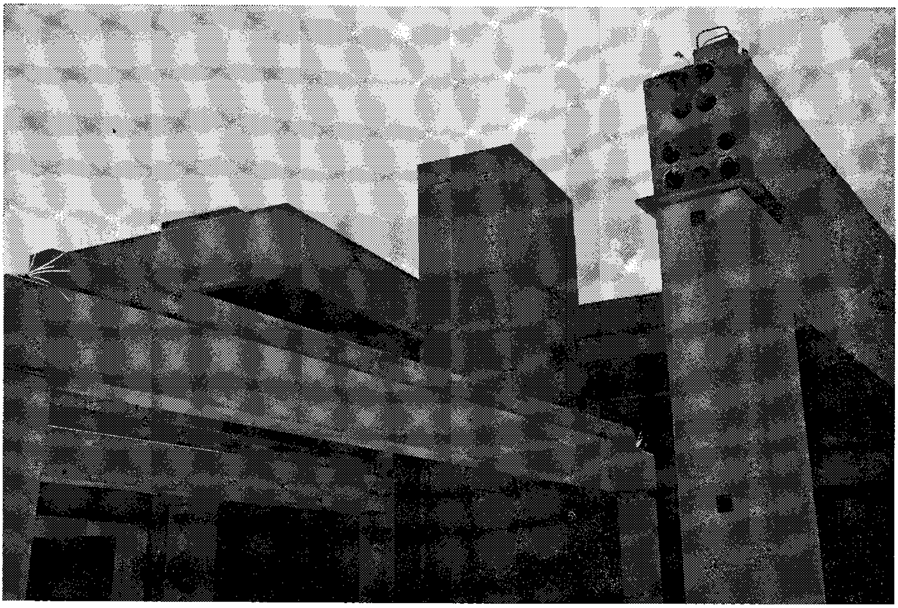

Fig. 16. Deplaning structure 62-ft spans, 57 in. deep. 28-in. wide cast-in-place girders notched to receive 18-in. deep double tee sections. Post-tensioning was applied in two stages as superimposed load was applied. Vertical column dowels were sleeved and horizontal slippage surface under beam bearing was used to avoid inducing bending moment into columns when post-tensioning was applied.

deep modified double tees and a topping slab.

Designed originally as plant produced members, two-stage stressing was specified. The members were to have been pretensioned in the precasting yard for dead load and handling stresses and then fully post-tensioned in the field for superimposed loads. However, to eliminate handling and transportation problems, the contractor cast the girders in place but maintained stage stressing.

Multiples of grouted 1¼-in. diameter Dywidag thread bars were tensioned to 131 kips. Initial post-tensioning was applied prior to erection of the double tees to allow form removal. After erection of the tees and casting of the topping slab, the balance of the post-tensioning force was applied (see Fig. 16).

The 5-in. topping slab over the double tees is post-tensioned with ½-in. diameter unbonded Cona single strand tendons to produce a 200-psi compression perpendicular to the span of the tees (see Fig. 17).

PARKING STRUCTURES

To handle the large number of enplanements, some 23,000 employees will work at the airport in 1973, with 35,000 by 1980. Including employees, daily passengers and visitors, tourists and other personnel, the airport complex will have an average daily population of over 100,000 people in 1975. To handle this volume, some ground level parking is provided in the loop adjacent to all four terminals and parking structures.

The structural parking for Terminals

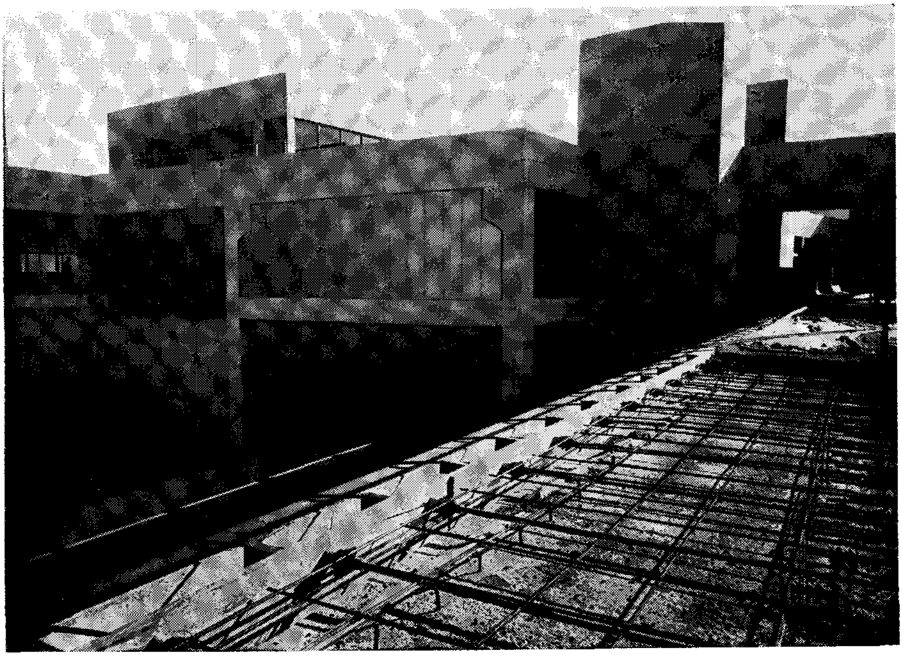

Fig. 17. Deplaning structure. A 5-in. topping slab over double tees is post-tensioned with ½-in. diameter unbonded Cona strand tendon to produce a 200-psi compression perpendicular to span of tees.

2W, 3E, and 4E follows the arc of the terminal and the deplaning roadway structures. Cast-in-place tree columns (see Fig. 18) carry L-shaped ledger beams and 30-in. deep cast-in-place double tees spanning 62 ft. Cast-in-place post-tensioned girders were used for certain special conditions.

Double tees were topped with a 3½-in. cast-in-place slab. The slab is post-tensioned with ½-in. diameter unbonded Cona single strand tendons to produce a 200-psi stress perpendicular to the span of the tees (see Fig. 19).

AIRPORT OPERATIONS

Transportation between terminals and from remote parking and service facilities and terminals is provided by the airport transit system. This system, called Airtrans, is a $31,000,000 electric guideway operated system that moves people, baggage, mail, supplies and solid waste throughout the facility.

The transit system will initially have a 12-mile ground transportation network and will in effect be a horizontal elevator that carries 8000 passengers aboard computer controlled modules. The guideway system when elevated is supported on precast, box prestressed sections with the guide rails (see Fig. 20).

Opening phase construction contract costs approximate $350,000,000. Other costs, including airline investments, will bring the total to approximately $700,000,000. Except for the cost of land acquisition, the airport will be self liquidating in this debt amount, and will also be self-supporting through revenues earned from airport users.

The regional airport will see phenomenal growth through air cargo, as well as passengers, equalling and perhaps surpassing the industries growth rate. As the airport develops, cargo tonnage handled will increase from almost 90,000 tons in 1975 to 410,000 in 1985. If the air cargo facilities fully develop to match the Boeing 747 capacity, the Dallas/Ft. Worth Airport, with its ultimate 200 cargo gates, will handle more freight than any current seaport in the world.

The airport has two separate construction management organizations. Tippetts-Abbett-McCarthy-Stratton (Tams), New York City, the General Airport Consultant, is charged with the overall projects supervision, as well as construction, management and design of the entire airfield system—runways, taxiways, aprons, utility roads, everything except the terminal complex spine road and international transit system. Tams is overseeing about $158,000,000 in construction.

CONCLUSION

Clearly this 1973 PCI award winner is the single most significant achievement in the first quarter century of prestressed concrete con-

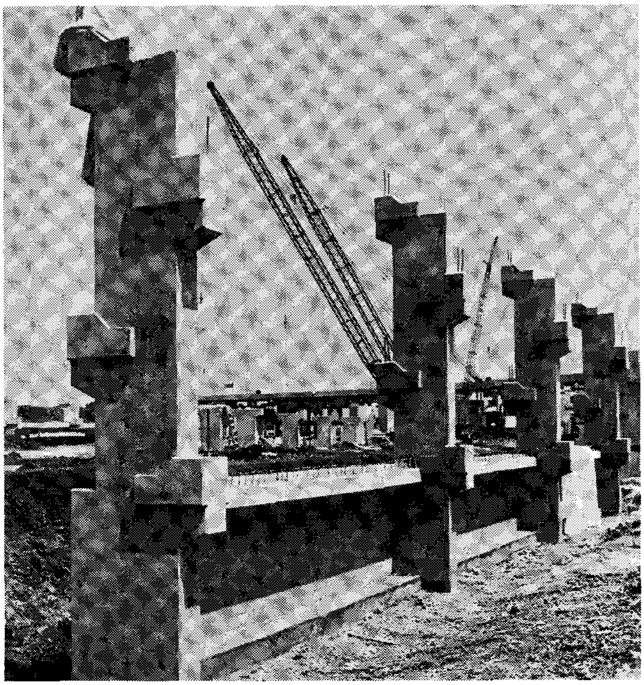

Fig. 18. Elevated parking structures were provided for Terminals 2W, 3E, and 4E. Cast-in-place tree column L-shaped ledger beams support 30-in. deep precast double tees spanning 62 ft.

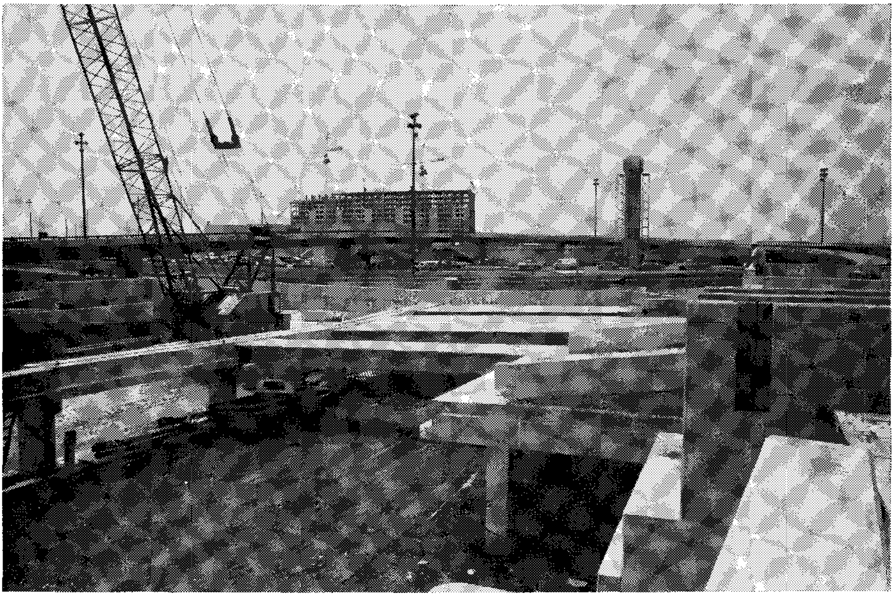

Fig. 19. Precast double tees are topped with 3½ in. cast-in-place slab post-tensioned with ½ in. strand tendon to produce a 200-psi compression perpendicular to span of tees.

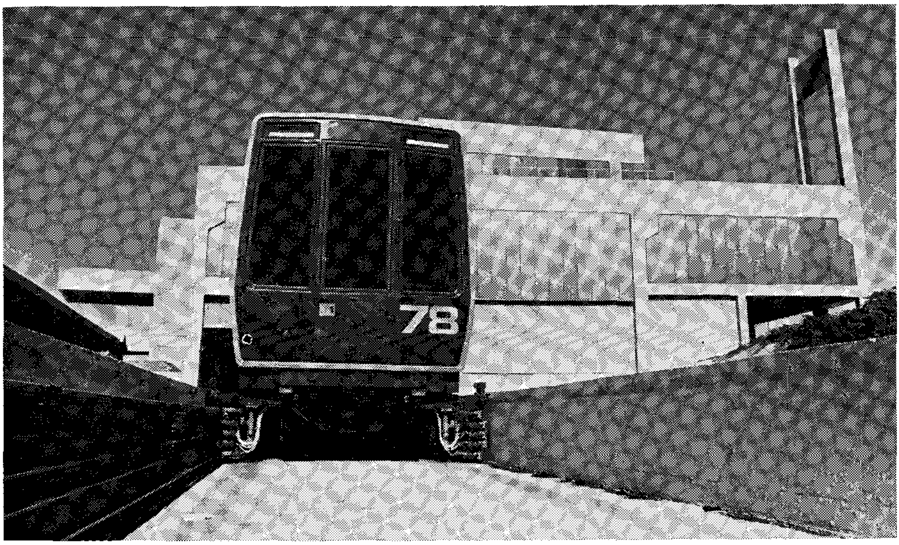

Fig. 20. Transportation between terminals and remote facilities for people, baggage, mail, and supplies is provided by computer controlled modules. Modules travel under terminal. There is a 17-mile network which passes through terminal. In some locations it is airborne.

struction in the United States. Considering the breakthrough in design concepts and building techniques, the Dallas-Ft. Worth Airport complex is the world's best planned airport and may be the pioneer of a new breed of jet ports to serve this exciting generation of jumbo jet aircraft.

CREDITS

Architect (Terminal Complex): Joint venture of Hellmuth, Obata & Kassabaum, Inc. and Brodsky, Hopf & Adler.

Structural Engineer: Le Messurier Associates, Inc.; Terry-Rosenlund & Co.

General Airport Consultants: Tippetts—Abbett—McCarthy—Stratton.

Architect (Control Tower): Welton Becket & Associates.

Structural Engineer (Control Tower): Ellisor Engineers, Inc.

Precast and Prestressed Concrete: Texas Industries, Inc. (Terminals 2W and 4E, structured parking, deplaning roadways, graphic pylons, and air-trans remote stations).

Post-Tensioning: Inland-Ryerson Construction Products Co. (Terminals 2W and 4E, control tower, structured parking, deplaning roadways, and graphic pylon structures).

General Contractors: Hensel Phelps Construction Co.; Cates Construction Co.; Walker Construction Co.

Owner: Dallas/Fort Worth Airport Board.

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