FEATURE ARTICLE

A Terminal Upgrade

The city of Kansas City, Missouri, is replacing its original airport, constructed in 1972 as a "drive-to-the-gate" facility, with a modern, single-terminal facility with just over 1 million sq ft (92,903 sq m) in area along with an adjacent 6,300-space parking structure. It is the largest infrastructure project in the city's history. The project team designed and oversaw the installation of 12–24 in (305–610 mm) diameter augered cast-in-place (ACIP) piles to a range of depths with the pile toes located in underlying alluvial clay, weathered shale or on intact limestone, depending on the required loads at each column location. The specific ACIP piles used were auger pressure grouted (APG) piles. Additional information regarding the ACIP pile installation process can be found in the *Augered Cast-in-Place Pile Manual, Third Edition* (2016) prepared by the DFI Augered Cast-in-Place and Drilled Displacement Pile Committee. This article includes a summary of the subsurface conditions, the foundation support requirements, the extensive performance test program — started before production installation but not completed until well into production phase of the project — and the resulting production pile installation requirements. The approach resulted in about $700,000 in foundation program savings to the city. The reduced construction time of about 10% less than originally estimated also added to the overall savings beyond the direct foundation savings.

Terminal Structural Approach

The facilities proposed for the new terminal had a variety of structural details and several different approaches were used for the various areas of the terminal. Subsequently, the resulting column loads across the proposed structure were also highly variable. Final design of the terminal included 790 columns across the facility with the following range of column reactions:

- Compression: less than 50–1,000 tons (45,360–907,185 kg)
- Tension: 0–440 tons (0–399,161 kg)
- Lateral: 0–422.5 tons (0–383,286 kg)
- Base moments from columns of up to 2,800 kip ft (3,800 kN)

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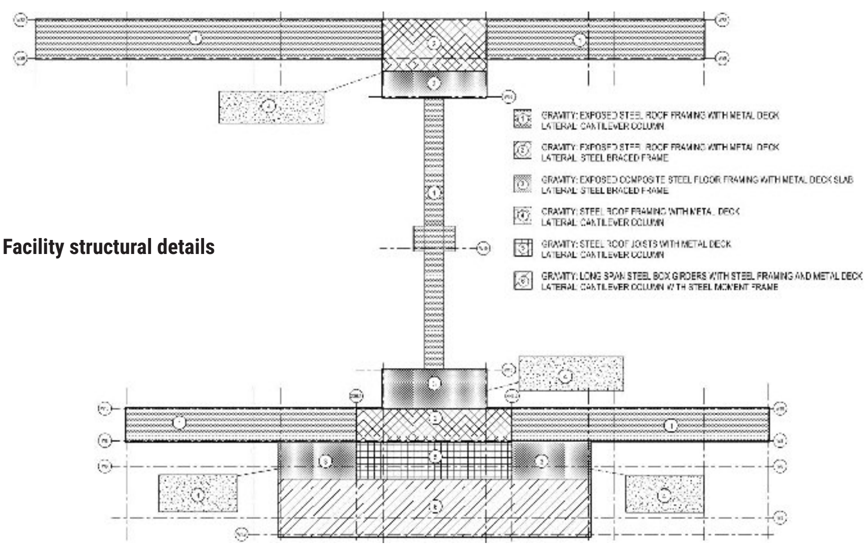
Left: The original airport, Right: Proposed airport design

Site Location and Subsurface Profile

Kansas City International Airport (KCI) sits about 20 mi (32 km) north of downtown Kansas City on a floodplain about 10 mi (16 km) east of the Missouri River. The floodplain consists of alluvial deposits that overlay Pennsylvanian Age bedrock. Between 20–50 ft (6–15 m) of uncontrolled fill and select fill were originally placed in the late 1960s and early 1970s to bring the site up to the current grade of the original airport (considered to be about EL +1,000 ft [305 m], local datum). The alluvial deposits are generally moderately overconsolidated due to historic groundwater fluctuations. The weak and strong shales are intermediate geomaterials that are typically drilled and sampled as a hard soil during the site characterization but that demonstrate strength and stiffness parameters that are significantly higher than what might be indicated by in situ tests such as N-values from standard penetration tests. The limestone is typically unweathered and results in practical refusal of the ACIP pile installation tool when encountered. A generalized profile of the depths of the various soil and rock types encountered during the most recent site characterization performed for the new airport is shown in Table 1.



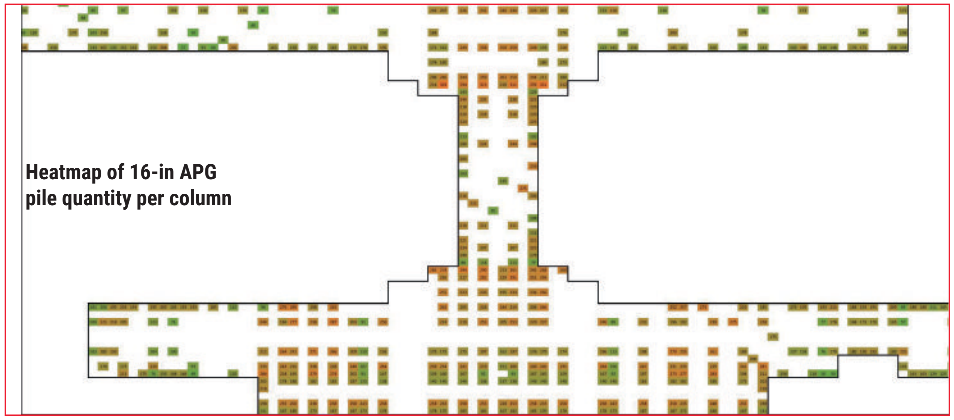
Facility structural details

Foundation Selection

As part of the site characterization for the new terminal, general design guidance was provided for shallow foundations on improved fill, drilled piers, driven steel H-piles and ACIP piles. A review of the range of column loads to be supported along with installation feasibility and efficiency led to the selection of ACIP piles as the project foundation system. A pre-bid load test program was performed including compression, tension and lateral testing of 16 and 18 in (406 and 457 mm) diameter ACIP piles (one of each test was performed for each diameter). The results of this program were provided to the prospective foundation contractors with a request to price a base quantity of 18 in (457 mm) diameter ACIP piles including additional pre-production load tests, as well as requests for value engineering proposals. Preliminary column reactions were also made available upon request.

The range of column loads to be resisted, along with the overall size of the project meant that using a single pile diameter for every column location was relatively inefficient for a majority of the project. Berkel & Company Contractors evaluated a range of APG pile sizes from 12–24 in (305–610 mm) diameter to determine the most cost-effective option. Various combinations of pile diameters were considered to optimize not only the pile costs, but the pile cap costs as well. To aid in visualizing the relative compression, tension and shear requirements across the site, the team created heatmaps of pile quantity and per pile loads at each column location for each diameter. These heat maps were also helpful in ensuring that material efficiency did not come at the cost of production efficiency. By comparing and combining heatmaps, the team was able to develop a column-specific approach consisting of 12, 16 and 24 in (305, 406 and 610 mm) diameter APG piles that optimized pile and pile cap costs as well as production time.

Constant and clear communication was required between the contractor and the project engineer of record, Skidmore, Owings & Merrill, who maintained design responsibility for the pile caps, with design assistance from Berkel engineers. This collaborative effort resulted in a very robust foundation redesign process and streamlined resolution of production issues such as short refusals.



Monitoring

Due to the range of pile sizes and lengths, the proposed APG pile system was planned for installation from multiple crane-supported, swinging-lead platforms with the gearbox and augers tailored to the piles to be installed by that platform.

The installation platforms were outfitted with automated monitoring equipment to measure, calculate and record specific parameters during pile installation. Parameters recorded and calculated at one-second intervals during pile drilling included: tool depth and penetration rate, torque applied to the auger, and the rotation rate of the auger.

These parameters can be observed in real-time as piles are being constructed, either onboard the installation platform or remotely via wireless display. This real-time observation is referred to as monitoring while drilling. For the subject project, penetration rate and torque were correlated to the soil and rock strata of the subsurface profile during each phase of pile load testing and used during production installation as a check to ensure that piles were installed within the target stratum for the loads that pile was to support.

Table 1: Approximate lower levels of soil/rock profile

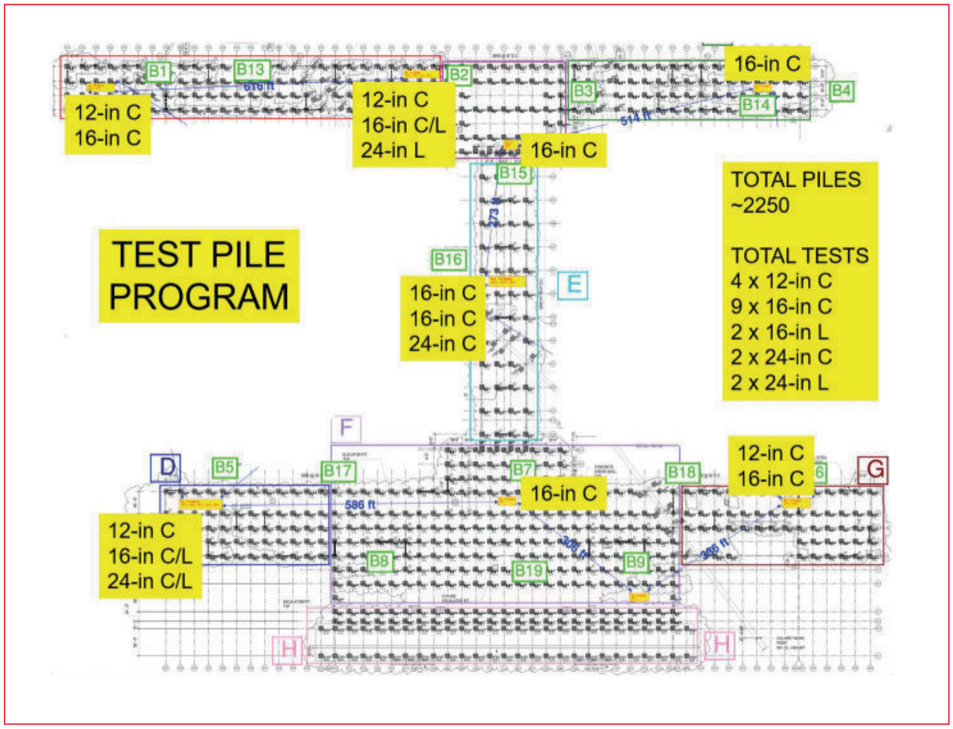
Approximate Elevation in ft (m)	Soil Classification
Above 945 (288)	Existing Fill
945–930 (288–283)	Native Clay
930–910 (283–277)	Weak Shale
910–900 (277–274)	Strong Shale
900–885 (274–270)	Limestone
Below 885 (270)	Shale with Limestone

Testing, Final Design and Production

The project team divided the site into zones represented by micro-localized models to expedite construction schedule and optimize production foundation lengths. The alternate approach required an extensive load test program to verify the performance of the range of proposed diameters in the various proposed bearing strata; from friction piles embedded in the overconsolidated alluvial soils, to piles socketed into weak shale, and piles installed to practical refusal on intact limestone. This program added about $300,000 to the estimated cost of the approach, however it resulted in the reduction of overall pile cost by just under $1 million in time and materials saved from the optimized approach.

There was a minimal preproduction test phase that started with 16 in (406 mm) diameter piles in the southwest corner of the project site. As production pile installation commenced, additional test piles were installed as more areas of the site were opened for construction. The results of each phase of the program were used to calibrate the micro-localized zone models to set final design lengths for each pile type at each column location within a particular zone.

Tailoring each pile size and length to each column left no excess resistance for piles with location issues due to the penetration of 20–50 ft (6–15 m) of fill. Additionally, occasional boulders in the alluvial soils resulted in early termination of piles intended to be founded in lower strata. A feedback loop was established that consisted of regular, cyclic communication between field personnel and pile designers, the general contractor, and the project structural engineers. This created an efficient process to address any requirements for production approval or any required corrective action, without disruption to the project flow and schedule.



Test Pile Location Plan

Additional Work

Due in part to the success and efficiency of the design and installation completed for the new KCI terminal, Berkel was also selected as the subcontractor to design and install foundations for a new parking garage located directly east of the new terminal. Using the knowledge gained during the testing and production phases of the terminal project led to the rapid development of a deep foundation design for the parking garage that, again, maximized the efficiency of the overall foundation cost and schedule. As the parking garage generally had more consistent load distribution across the site than the terminal, as well as lighter shear resistance requirements at individual column locations, a single-diameter 16 in (406 mm) APG pile design was determined to be the most efficient solution for this project phase. Overall, about 4,700 piles were installed at the combined terminal and parking facilities.

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W. Morgan NeSmith, P.E., D.GE, Berkel & Company Contractors. NeSmith is Berkel's director of engineering and the DFI trustee liaison to the DFI Augered Cast-in-Place and Drilled Displacement Pile Committee.

Richard Guenther, P.E., Berkel & Company Contractors. Guenther is a structural engineer at Berkel and was directly responsible for daily oversight of the piles installed for the KCI project.