A new arts center on the campus of Dartmouth College features separate spaces dedicated to the study of specific arts that seek to facilitate interaction among the various disciplines. The different uses of the various spaces necessitated a wide mix of slab construction types, and the foundation design was complicated by challenging geotechnical conditions. Simplified solutions, including pits dug by hand, were devised to address the intricate conditions, and the building’s structural steel elements required carefully coordinated framing techniques to achieve a simple architectural expression.

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A new arts center on the campus of Dartmouth College features an exterior massing that strikes a balance between the conservative brick facades elsewhere about campus and a desire for transparency, enticing passersby to experience the exhibited works.

The dualism inherent in positioning these types of study so close together was intentional, for in this way students would have the opportunity to commingle with these numerous audios, visual, and tactile applications in their various fields of study. As Hanover has slowly evolved from a distant outpost of colonial New England to what is now a concept, bustling town above the banks of the Connecticut River, Dartmouth College too has grown. At its inception, Dartmouth was completing its first century of educating students in these same principles.

The town of Hanover, New Hampshire, is nestled into what is known locally as the Upper Valley and sits atop a hillside overlooking the meandering flow of the Connecticut River and the opposing promontories of Vermont. Errected proudly in the town center is Dartmouth College, its splendor evident to all who come to this part of the state, its quadrangle a natural extension of pedestrian-traveled Main Street. The proximity to the center of Hanover is a remnant of a time long past when posting a letter or traveling a main road necessitated a nearby posting a letter or traveling a main road necessitated a nearby.

The interior design of the center is an inversion of the exterior, featuring a large central gathering and showcase hall referred to as the art forum, which is replete with glass and balconies. Beyond this focal point, the arts center provides distinctively separate segments of space dedicated to the study of particular arts. The quaint of the film studio abuts the grinding of the welding shop, the reflection of the painting classrooms is adjacent to the hammering heard within the sculpture court; and the acoustics of the screening room is next to the cacophony of the exhibit hall. One hears the dictum frequently heard within the sculpture court; and the acoustics of the screening room is next to the cacophony of the exhibit hall within the sculpture court; and the acoustics of the screening room is next to the cacophony of the exhibit hall within the sculpture court; and the acoustics of the screening room is next to the cacophony of the exhibit hall within the sculpture court; and the acoustics of the screening room is next to the cacophony of the exhibit hall. The dualism inherent in positioning these types of study so close together was intentional, for in this way students would have the opportunity to commingle with these numerous audios, visual, and tactile applications in their various fields of study. Once the Black Family Visual Arts Center was complete, the user experience would bear the intended fruits of this programmatic layout. However, the attendant design considerations first needed to be understood, distilled to their principal components, and then solved efficiently.
Center would depart from this norm. Truthfully, the opposite appeared to be more likely. Indeed, the site and layout of the arts center would require such specificity in detailing that almost no condition would be repeatable, leading to detail upon detail upon detail to be deciphered by the general contractor, Boston-based Suffolk Construction. The soil and rock conditions, which were investigated and quantified by the project’s geotechnical engineer—Haley & Aldrich, Inc., of Burlington, Massachusetts—indicated a steep, narrow spine of bedrock passing through the center of the site. The sides of the bedrock sloped precipitously, ruling out the use of self-stabilized foundation elements on the rock, and the overlying fill was of such poor quality for bearing that the allowable pressures were so low as to be impractical for any building taller than a single story. A mix of foundation bearing elements, both shallow and deep, appeared to be the prudent approach, even though it would introduce multiple levels of intricacy in the foundation design. In fact, just getting the project out of the ground would require an extraordinary design effort. Even after completion of the foundation and the basement, the ground floor was extensively nuanced because of the proximity of the spaces to the areas that would be used by students and intact with little fracturing. Though suitable for bearing, the top of the bedrock was hard to the design team to alert its members of the impending foundation planning challenges that lay ahead. The initial boring program indicated a very narrow, steep spine of solid bedrock crossing the site on a mostly north–south path, complicating foundation design and construction. The proposed solution, involving cast-in-place drilled shafts in the region away from the bedrock spine and limited excavation of the bedrock spine to allow for a level bearing surface for spread footings near the center of the building. To increase the overall efficiency of the foundation placement, the contractor suggested that larger lifts be dug by hand, and while some shafts continued to be slowly drilled elsewhere on-site. Complicating matters, a localized crater, center, was found in the midst of the bedrock spine. A narrow, steep spine of solid bedrock discretely had the potential to result in a disorganized amalgam of redundant structure and architecture that would clog the passages through which ideas should flow freely. Careful consideration of the first-floor slabs and the steel framing was compiled into thoughtful solutions. On the other hand, some challenges encountered during excavation initially stymied the design team before freeing it to see the overarching simplicity possible in detailing and installing the foundation elements. Haley & Aldrich informally reached out to the design team to alert its members of the impending foundation planning challenges that lay ahead. The initial boring program indicated a very narrow, steep spine of solid bedrock crossing the site on a mostly north–south path and abutted on either side by fill material that had been placed and disturbed during the past 100 years. The fill was determined to be unsuitable for bearing. The bedrock was hard and intact with little fracturing. Though great for bearing, the top of the bedrock surface quickly sloped downward to the east and west. Therefore, this slope was not an ideal platform for shallow foundations. 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construction manager. The bedrock spine was so steep on its sides that spread footings could not simply be placed atop it. Rather, it would be necessary to carve out benches or install rock dowels to mitigate the tendency of the footings to slide when subjected to gravity loads. At the east and west extents of the site the bedrock surface was so deep that spread footings would be impractical because of the volume of overburden that would need to be excavated to install the footings.

The primary solution proposed was to use cast-in-place drilled shafts in the region away from the bedrock spine and to excavate as limited a region of the bedrock spine as possible to allow for a level bearing surface for spread footings nearest the center of the building. In a measure that aided the placement of many of the spread footings, Machado and Silvetti Associates designed a basement in the building that was conveniently situated directly atop the highest ridge of the bedrock spine. Although the basement required leveling of appreciable regions of bedrock, this geometry of the building allowed for a stable, flat bearing surface in the central portion of the structure. As bookends to the excavation, two “transition zones” were established to the east and west of the spine, where the bedrock was sufficiently deep that excavating and installing spread footings would not have been cost effective.

Therefore, drilled shafts would be necessary outside the transition zones. Because the spine ran through the center of the site, the columns in the regions outside the transition zones on the east and west sides of the site would be supported by drilled shafts and grade beams, whereas the columns in the center portion of the site (between the transition zones) could be supported on spread footings. An initial assessment of the column loads indicated that most of the design loads were within approximately 20 percent of one another, many of them being lower than the threshold capacity resulting from the smallest practical drilled shaft diameter. This finding meant that a single shaft design would suffice for the suite of shafts required for the project. In this way, normalizing the shaft design was the first step toward simplifying the foundation scheme and the construction approach. The subsequent two steps in the process entailed having to address an unforeseen anomaly in the bedrock topography and the variable resistance of the bedrock to drilling. However, together these steps resulted in an unexpected boon in terms of simplifying the foundations.

While the bedrock was being pulverized by up to half a dozen hydraulic impact hammers simultaneously working away at various outcroppings, the drilled shafts farthest to the northeast were being placed. The drilled shaft design called for each shaft to be socketed into solid bedrock to a depth ranging from 4 to 12 ft. The drilled shaft contractor—the Schnabel Foundation Company, of Sterling, Virginia—estimated that the rock could be drilled at a rate of about 1 ft per hour, meaning that a shaft with an 8 ft socket could be drilled in a single work shift. When approaching the bedrock elevation of the first shaft, the contractor fit the drilling rig with the drill bit and started in on the rock. Four hours later, the contractor had advanced the drill no more than 2 ft. After 12 hours of drilling, no more than a 6 in. socket had been cored. Assuming that this delay was caused by an aberrant rock condition, the contractor shifted the rig to the next shaft to be placed and experienced similar advancement rates in the drilling, to say nothing of the two drill bits that were exhausted in this effort. Assessing the effect on the schedule of drilling at a rate of 0.5 in. per hour instead of the estimated 1.2 in. per hour, the contractor quickly reached out to the design team.

As field conditions began to threaten the schedule, the drilled shaft contractor recommended various solutions to mitigate the drilling impediments: increase the bearing capacity of the bedrock to reflect the encountered rock strength, redesign the shafts to be completely end bearing, or implement annulated shafts having a large-diameter bearing on the rock surface and only a smaller diameter of the shaft socketed into the rock. To implement shafts as entirely end bearing and thereby eliminate the supplemental capacity deriving from skin friction, the bearing area of the shafts would have to be proportionally increased. To increase the overall efficiency of the foundation placement, the contractor suggested that larger pits be dug by hand while some shafts continued to be slowly drilled elsewhere on site. The proposed hand digging involved timber lagging to support the excavation. A single worker shoveled soil into a bucket by hand, and the bucket was then lifted from the pit base to the surface. Ironically, a simple technique used to excavate mine shafts in Thoreau’s era would become critical to the success of a state-of-the-art 21st-century construction project. So atypical was this type of construction that the workers and engineers present at the site came to refer to the work as 1850s foundations.

Because digging larger shafts by hand did not require any updates to recommended design values or additional explorations, which may have delayed construction, Haley & Aldrich approved this method. LeMessurier confirmed that the associated designs of pier caps, grade beams, slabs, and other structural elements at the lowest level would not be affected by the change in shaft geometry, immediately freeing the contractor to commence this work. Responding to the additional information revealed by the difficult construction, Haley & Aldrich revised the allowable bearing pressure of the bedrock from 30 to 30 kips/ft². LeMessurier then verified an attendant reduction in the area of the shafts yet to be installed, whether via drilling or via digging by hand.

The pits excavated by hand proceeded at a relatively slow pace, one bucket at a time. Some of the pits proceeded to depths of more than 30 ft. One can only wonder what skilled, experienced miners of the 19th century would have thought of the progress made by the contractor digging in this century. At the bottom of some of the pits dug by hand, sloping bedrock surfaces presented yet another design challenge. To resist the tendency of the shafts to slide, two options immediately presented themselves: level the surface with a jack hammer or install rock dowels. Because operating a jack hammer 30 ft beneath the ground surface in confined conditions would raise health and safety concerns, the rock dowel option was implemented.

Considered robust, the preconstruction boring coverage had consisted of 8 new borings to supplement 11 existing borings, or about one boring for every 2,000 sq ft of building footprint. However, surprises are part of nature, as all engineers will learn as they develop gray hair. The boring data indicated that the overall breadth of the known rock spine was only about 80 ft wide, its sides falling away at a vertiginous 6½:1 slope. Despite the thorough boring program, another unanticipated condition was uncovered in the midst of the deep foundation redesign when a void was found in the surface of the rock spine. Imagine momentarily how unprecedented the conditions would need to be to halt the rock removal operation completely. At the south end of the basement excavation, a 30 ft long, 20 ft wide, and 25 ft deep crater revealed itself when a hydraulic impact hammer plunged into the soft soil rather than bouncing off the hard rock as anticipated. The foundation installation schedule, already lagging

As the visitor moves inside the building, the simplicity of the design is analogously exuded by the glass, wood, and plaster surfaces of the art forum, which is bounded by straight lines that are vertical, horizontal, and even diagonal as the grand staircase descends from the upper levels.
because of the earlier drilling difficulties, could hardly accommodate another slowdown.

The design team was alerted immediately and asked to quickly confer on possible solutions, and the general contractor worked with Dartmouth to assess the effects on project cost and schedule. Because details for deep foundations were already within the project scope, tailoring existing drawings and available trades to this condition was a possibility. Since the original lowest level in this region of the building involved spread footings and slab on grade, a small but complex web of deep foundation and self-supporting slabs would need to be interwoven into the surrounding, partially completed construction. The time to redesign around these constraints would impair the schedule, and the updated structural elements would increase project costs. Therefore, this was not a viable solution. Alternatively, because the void was shaped like a bowl, filling it with a suitable bearing-type material would be inherently stable and very expedient, as material could be ordered and filling could begin immediately. The material cost to fill the crater with lean concrete so as to replicate the allowable bearing pressure of the bedrock was on par with the deep-foundation option but without the redesign time component. Dartmouth, Haley & Aldrich, and LeMessurier agreed that this was the optimal solution.

Originally calling for the repeated use of a single type of drilled shaft, the subsequently altered foundation design implemented the two most straightforward solutions available: mining-inspired shaft pits dug by hand and lean concrete fill. Had all of the found conditions been known at the outset, the comprehensive foundation system atop the irregular bedrock strata would probably have been significantly more complex. Even with the complications in the foundation construction, the intricate concrete work on the arts center project extended into the finished spaces, as the architect’s vision also included multiple floor finishes in an arrangement dominated by an exposed concrete finished floor.

Next to牵cibly Linked to the interfacing programming as well as to the bedrock topography and the attendant foundation design, the first floor of the Black Family Visual Arts Center was designed to be built by means of minimal construction types: slabs on grade, one-way slabs, lightweight composite slabs on steel deck, and an elevated cast-in-place acoustical isolation slab. With the inherent variations in concrete weight, strength, and placement and in the thickness of these slabs, achieving a uniformity of color and finish was effectively impossible for the exposed topping slabs. From the early design phases, Machado and Silvetti Associates wrestled with how best to achieve a uniform slab finish while facilitating the multiple transitions to the various flooring materials, which included slate, wood, tile, rubber, and carpet.

Studying the intended uses of the arts center, consulting the slab literature available in the ACI Manual of Concrete Practice, published by the American Concrete Institute (ACI), of Farmington Hills, Michigan, and reviewing the collective experience of its own office, LeMessurier recommended a bonded architectural topping slab. Although it would be natural to consider the best specific solution for topping slab construction associated with each base slab construction type, LeMessurier proposed just the opposite, namely, a single specification for preparing, placing, curing, and finishing the topping slabs to be implemented over each of the several base slab construction types. The practicality and efficiency of this approach would be proven when coordinating topping placements for the first-level slabs, where foundations, programming, and lowest-level construction would necessitate more than 25 discontinuous regions of base slab construction, each with different sizes and aspect ratios.

Among the potential pitfalls of any topping slab, the most challenging to account for are curling of the free edges and cracking during curing. Designing the topping as unbonded allows the slab to cure independently of the base slab, reducing the stresses induced by bonding and drying that are felt throughout the material and thereby reducing slab cracking. Conversely, no bond exists to counter edge curling, which results from differential drying between the top and bottom surfaces of the topping. Designing the topping as bonded results in the opposite effect; that is, curling is resisted by adhesion to the base slab, but the top surface of the topping is able to shrink as it dries, leading to more potential cracking at the surface. What is more, with the topping bonded to its substrate, any cracks in the base slab telegraph through the topping slab. Consequently, no bond exists to counter edge curling, which results from differential drying between the top and bottom surfaces of the topping. Designing the topping as bonded results in the opposite effect; that is, curling is resisted by adhesion to the base slab, but the top surface of the topping is able to shrink as it dries, leading to more potential cracking at the surface. What is more, with the topping bonded to its substrate, any cracks in the base slab telegraph through the topping slab.

Experience had taught LeMessurier that curling was the more challenging obstacle to overcome. Therefore, a bonded topping was recommended, but a balance was struck to reduce the effects of shrinkage. Close attention was given to specifying the curing, premoistening, and finishing of the topping slab to produce a slab of the highest quality. The placement of the topping slab would be deferred and would take place only after allowing 90 or more days for any cracking from drying or from early use to occur in the base. This approach would reduce the effects of crack telegraphing. To minimize the cracks resulting from drying, the topping would be wet-cured for 10 days and moist-cured for the balance of the 28-day curing period. Before the finish was applied, the topping would have contraction joints cut throughout in an effort to control the location of any unavoidable future cracking. Even with the attention paid to these portions of the topping design, the substrate preparation was determined to be the most critical factor for the performance of the topping.

To prevent the unwelcome side effects that are most common with deferred topping—bonding, curling, drying and cracking—proper base slab preparation was a necessity. Because no bond breaker was used between the base and topping slabs, moisture from the wet concrete placed atop the base slab would be wicked away into the dry concrete below, expediting the drying process and thereby increasing the cracking in the topping. To combat this, the base slab was specified to be saturated—that is, wet but without standing water—for 24 hours before topping placement to eliminate the moisture wicking. Saturating the base slab in conjunction with wet-curing the topping slab established a uniform moisture gradient across the depth of the topping, reducing cracking during drying. A related benefit of premoistening the substrate is that it enhances the chemical bonding between the wet concrete of the topping slab and the base slab.

To further facilitate bonding, the regions of base slab scheduled to receive a topping were roughened by means of rakes to a scratch finish having an amplitude of approximately 0.125 to 0.25 in. A separate bonding method was considered, namely, mechanically fastening the two slabs together by means of a network of reinforcing steel dowels. However, the cost of labor was deemed too high to justify only a slight benefit to the bonding effect. LeMessurier (Continued on Page 95)
Simplifying Complexity

(Continued from Page 91) specified the most frequently recommended and tested bonding technique—cementitious chemical bonding coupled with aggregate interlock—eschewing the other complex, chemically based, highly sensitive, and expensive bonding methods discussed in the American Concrete Institute literature.

Using the most fundamental physical and chemical mechanisms to prepare the substrate and selecting a single procedure for placing, curing, and finishing instilled confidence that the finished product would meet the high standards of Dartmouth and the design team. While the finished floors were outwardly complex, as evidenced in the numerous steps, jogs, and interrupted finishes, the remainder of the building was framed with structural steel, enabling the simplicity of design to cut the other way. The organized appearance of its interior and exterior surfaces belied the complexity of its supporting framing.

THE GEOMETRY of the walls, roofs, floors, and soffits of the Black Family Visual Arts Center is predominantly rectilinear in form, and the various features lend themselves to straightforward framing techniques. The challenge posed by the interior and exterior massing of the arts center is intrinsically linked to providing framing at the nuanced locations informed by the architecture. This challenge is the direct opposite of those encountered during the foundation design and the topping slab specifications. The foundations and slabs required simplified solutions to accommodate the intricate underlying conditions, while the structural steel required highly constrained and coordinated framing techniques to achieve what, on the surface, is a very simple architectural expression.

Approaching the building from the south, west, or east, a visitor first notices a sequence of projections and recesses in the alternating glass, masonry, and metal facade, each plumb on its sides and level along the tops and bottoms. It is unlike-