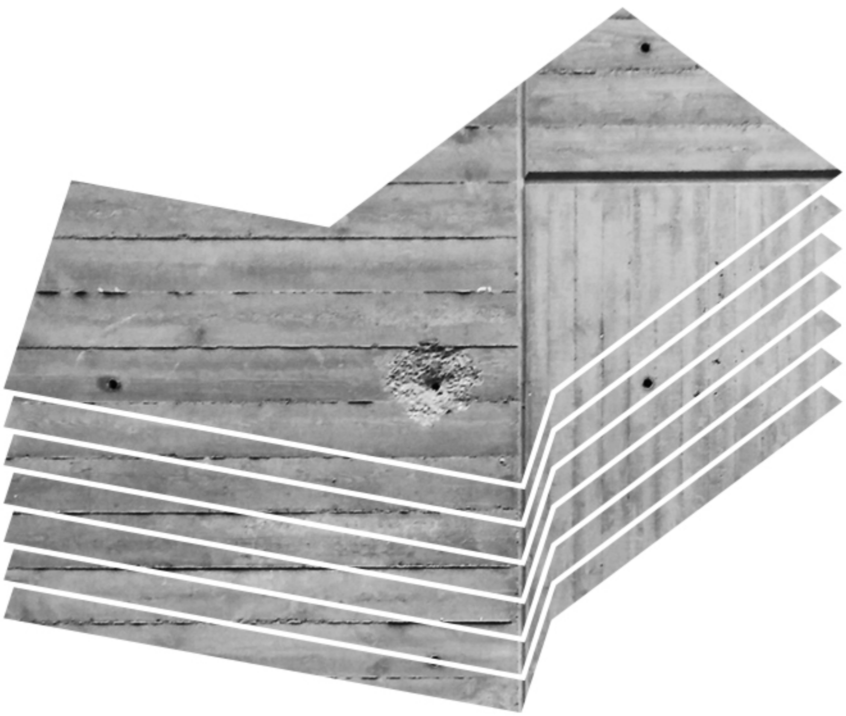

Easy Double Boxo

Building a Campus Concrete Building

ARCH260 Final Assignment
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Dec. 14, 2015

Contents

Concrete?

The newest addition to Cal's Haas School of Business, a simple building programmed with classrooms, study space, and a café, is being built out of reinforced concrete.

Why is that?

The answer isn't something simple like "We're in D.C., everything is made of concrete because the industry is massive." A wooden building is out of the question given the long spans needed to create the large classrooms, and masonry, rammed earth, or gothic stone vaults are out the window because that is the world we live in. This leaves us with concrete or steel, and, as it is sited a stone's throw away from an earthquake fault, it would seem ideal to build it out of an elegantly beefy steel system similar to that of the nearby music library. But that is not the case.

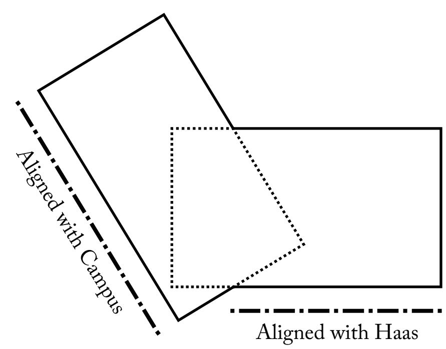
Perhaps it is because concrete allows for large spans with a relatively thin floor thickness compared to steel, especially when the slabs are post-tensioned. While considerably lowering the height of the building makes it fit better in its context, it does not seem like a compelling enough reason on its own.

Perhaps the noncombustible nature of concrete is important, as it has a very high peak occupancy when all the spaces are in use, and in many cases the building is rather unfinished, with a lot of the structure exposed. But this is still possible to achieve with steel.

Perhaps it has to do with the fact that there is very little staging space on the site, and a steel system needs a lot of room to arrange all the lego-like prefabricated pieces before they are assembled. But do architects really think about this when they design a building? Maybe they do. The most compelling single reason is respect for the context. In fact, the only real architectural move made in the design (besides tetris-ing the square footages into a pancake section) was splitting the plan into two boxes that connect at an angle: one that aligns with the Haas School courtyard and finishes its edge, and another that aligns with the rest of the Berkeley campus.

The rest of the Haas school is made out of concrete – specifically, board-formed concrete. Therefore, and also for the aforementioned reasons, the Haas school addition shall be made of concrete – specifically, board-formed concrete.

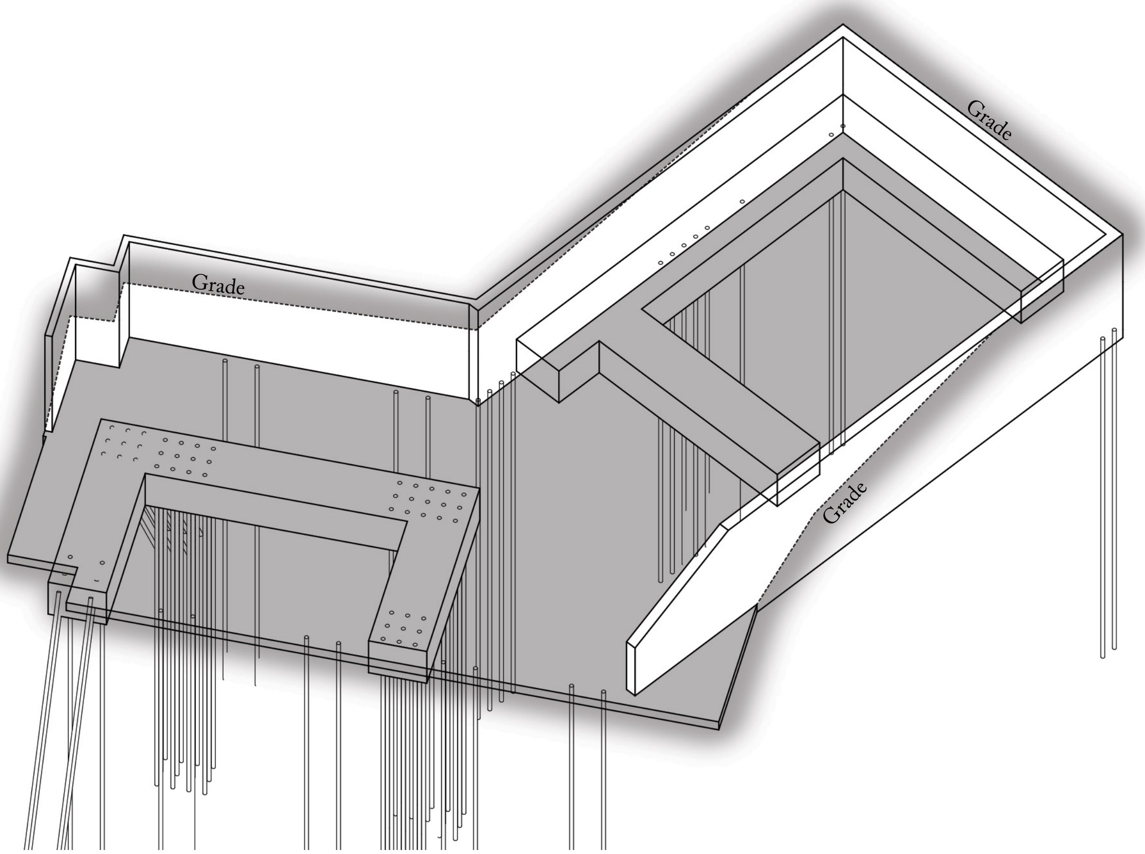
The sitecast structural system for the double-box is composed of four simple elements: a foundation beefy enough to stand on shabby soil, monolithic post-tensioned shear walls chock-full of steel that resist lateral loads, a grid of columns quickly assembled from prefabricated formwork, and six pancaked post-tensioned floor slabs.



Above: Building Diagram.

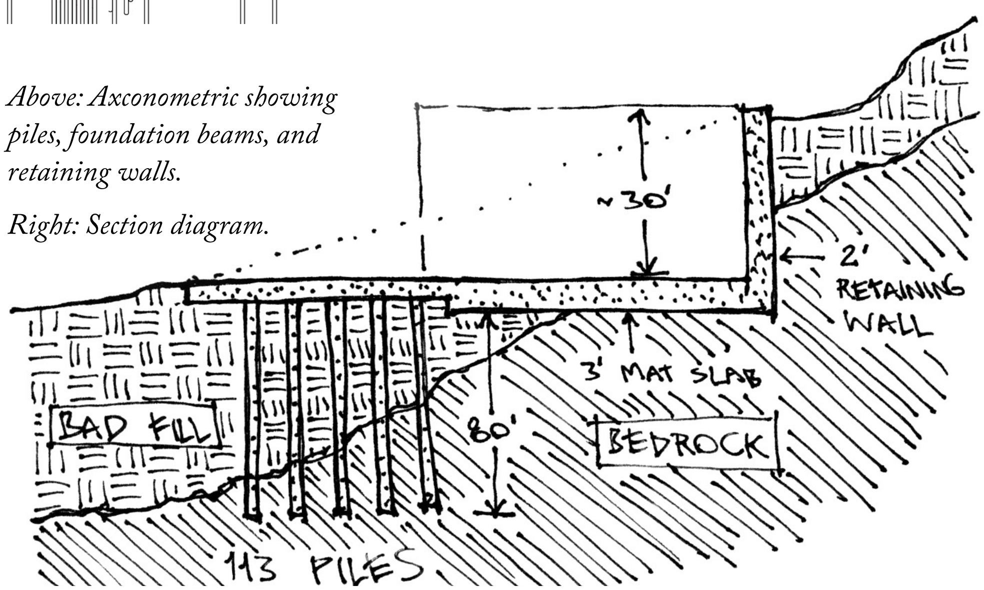
Below: Existing Haas Building.

Liquid Soil (The Foundation)



Above: *Axconometric showing piles, foundation beams, and retaining walls.*

Right: Section diagram.



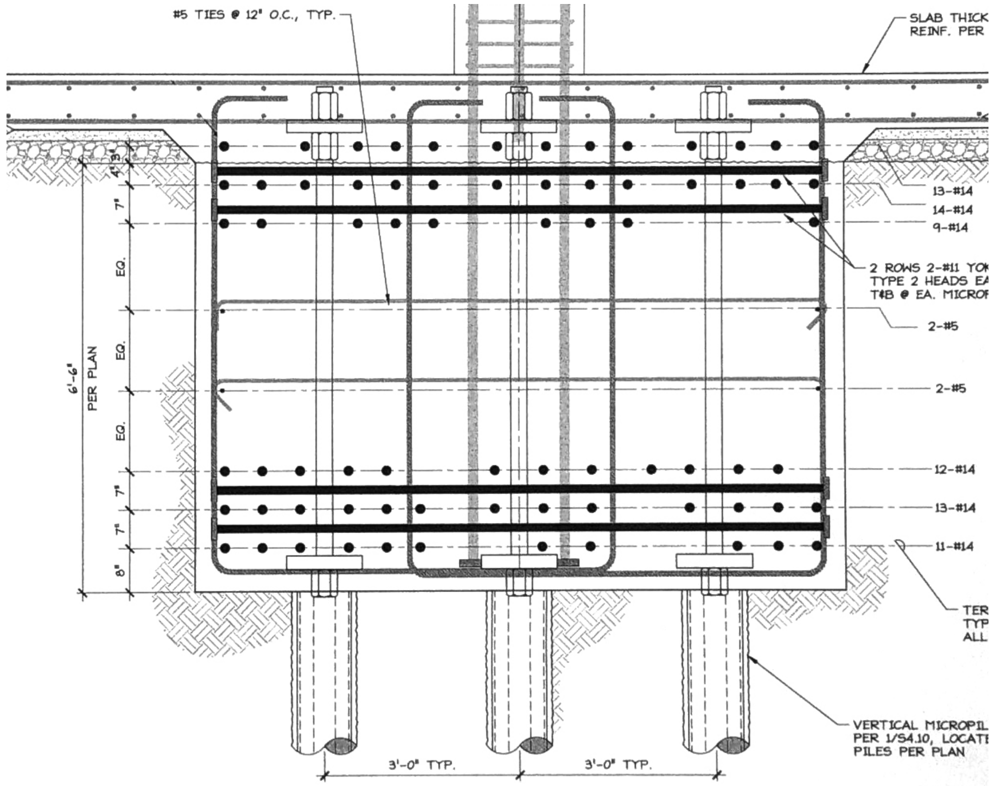
One of the major concerns when building in a seismic zone like the San Francisco bay area is soil liquefaction. When loosely packed earth is shaken by an earthquake, it tends to behave more like a liquid than a solid and ceases to support heavy loads; when a building is built on this kind of soil, its foundations must either attach to solid bedrock or do a really good job of spreading its load wide and thin over the virtually nonexistent earth. The soil underneath the Haas addition is exceptionally poor, since the entire hillside is made of the earth that was excavated nearly a century ago to build the nearby memorial stadium.

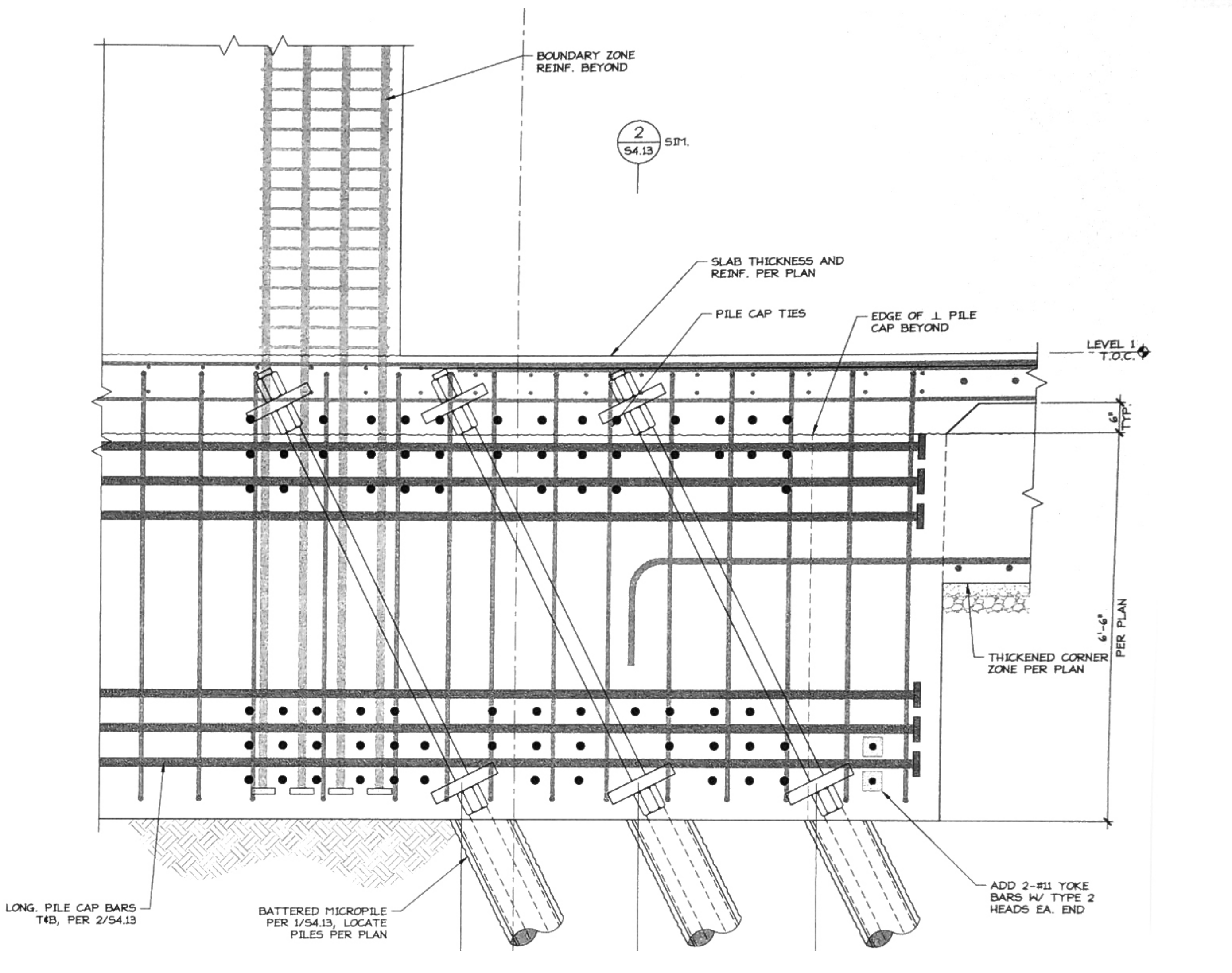
Since the building is on a slope, the shallow half of the foundation is attached to the ground with an array of 80-foot-long micropiles, while the deep half sits on a thick mat slab within the slope, with a few piles added for good measure. In both areas, six-foot-thick foundation beams support the monolithic shear walls above them.

The piles were originally designed to be battered into the ground; however, due to noise complaints from the nearby faculty club, they were bored instead. This, according to the superintendent, was a wretched and (literally) dirty process that set the project several months behind schedule.

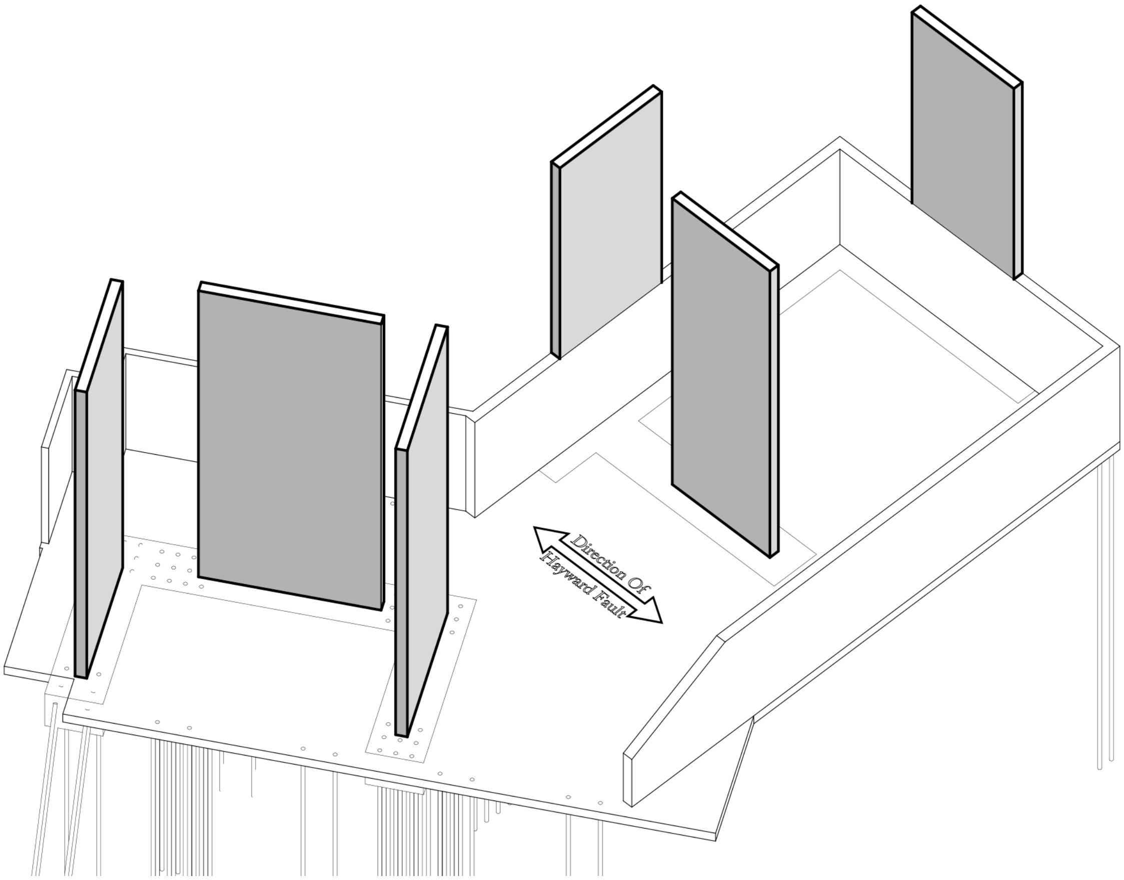
Right: Foundation beam below shear wall, transverse section.

Below: Foundation beam below shear wall, longitudinal section.





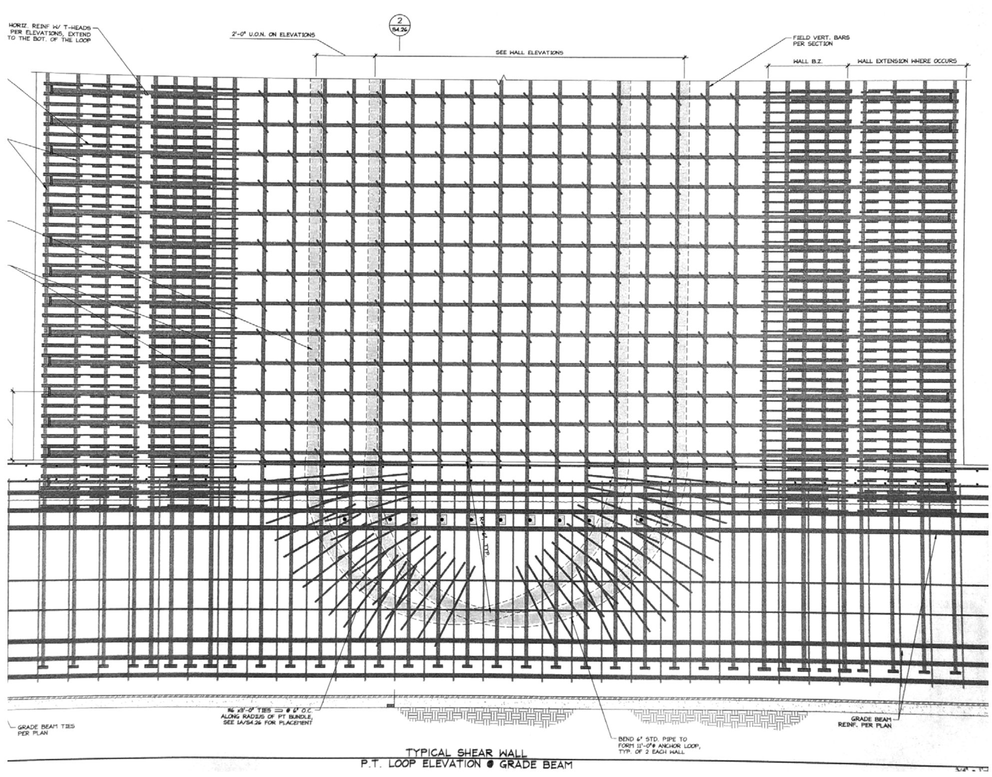
Earthquake Country (Shear Walls)



The main components that distinguish the Haas School addition from any similarly generic building on the East coast are the vertically post-tensioned shear walls. While they are aligned with the column grid and take the according gravity loads, their purpose is to resist the tremendous lateral earthquake loads that are transferred to them by the floor slabs. Traditional steel reinforcement bars – which they are absolutely full of – are not enough

Above: Axonometric showing shear walls.

Right: Typical loingitudinal section through the bottom of a shear wall. Visible are the PVC pipe loops through which the tensioning cables are fed.

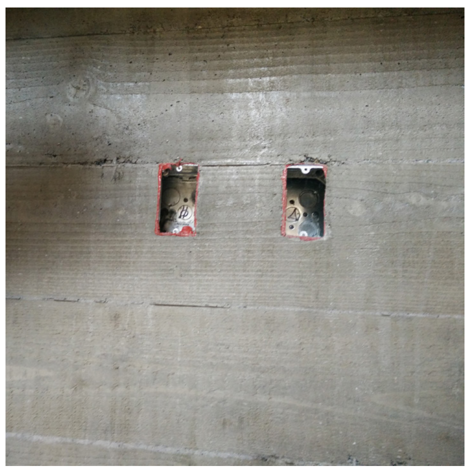


to handle these loads; thus, they are given extra strength by vertical steel tension cables.

Post-tensioning, the technique of casting steel cables in concrete and then stretching them with a hydraulic jack, was originally developed for slabs and beams in order to allow them to span longer distances. Vertical post-tensioning is not as common, but has recently increased in popularity in situations like this, where a vertical element needs to resist forces other than axial compression.

When each level of the walls is cast, PVC tubes are inserted in order to feed the cables and tension them once the entire height of the walls is complete. At the bottom, the tubes loop around and come back up to the top, where both ends of the cables will be anchored.

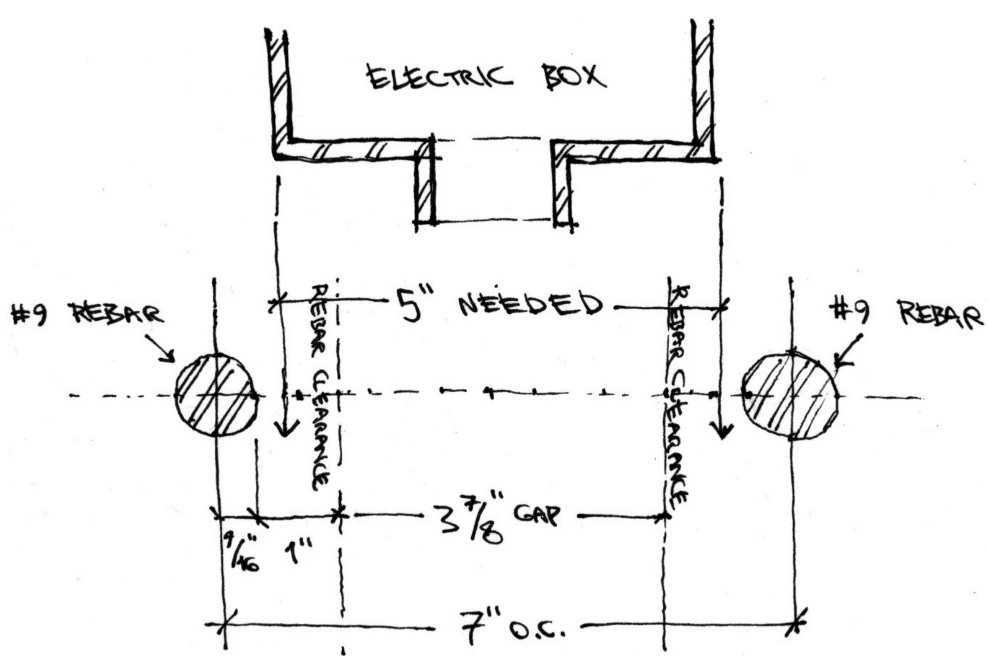
With the tremendous amount of rebar and the thick PVC tubes, there is little space left for other objects to be embedded in the concrete. In one wall, the structural engineer specified vertical #9 (9/8") rebar spaced at 7" on center, with at least 1" of clearance on either side, while the electrician specified 5" wide electrical boxes to be fitted on the same wall. The 3-7/8" gap between the rebar clearances was too small, and the problem was not detected until the moment the forms were being built. Ultimately, the contractor was able to obtain a go-ahead from the structural engineer to lower the clearance thickness if the electric boxes were raised farther away from the point where the wall meets the slab.

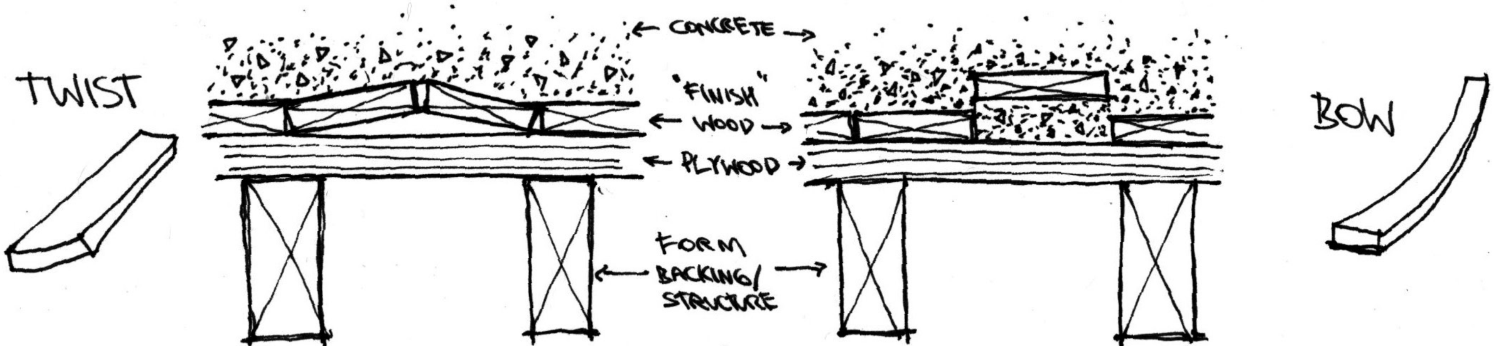


Above: one of the shear walls above the third floor slab. This wall is not exposed to the interior, so boardform was not used.

Left: Electrical boxes for televisions embedded in a shear wall.

Below: Plan diagram of a section of the shear wall. The electrical box could not fit between the rebar without reducing the clearance.





Most of these shear walls will be exposed to the interior of the building; as a result, the architects decided to imprint a texture onto the concrete matching the existing Haas buildings by using boardform. In the early twentieth century, concrete forms were made with lumber, before plywood entered widespread use for this purpose; Corbusier's Ronchamp chapel is a good example of this. Nowadays, boardform refers to the technique of nailing lumber to the inside of a prefabricated plywood form in order to emulate the historical technique.

This method did not work perfectly in the case of the Haas addition. Abnormalities in the lumber resulted in extreme deformations of the wall surface; in some cases, pieces of the boardform would be stuck in the concrete itself. It is hard to imagine the architects feeling anything other than frustration when seeing these walls.

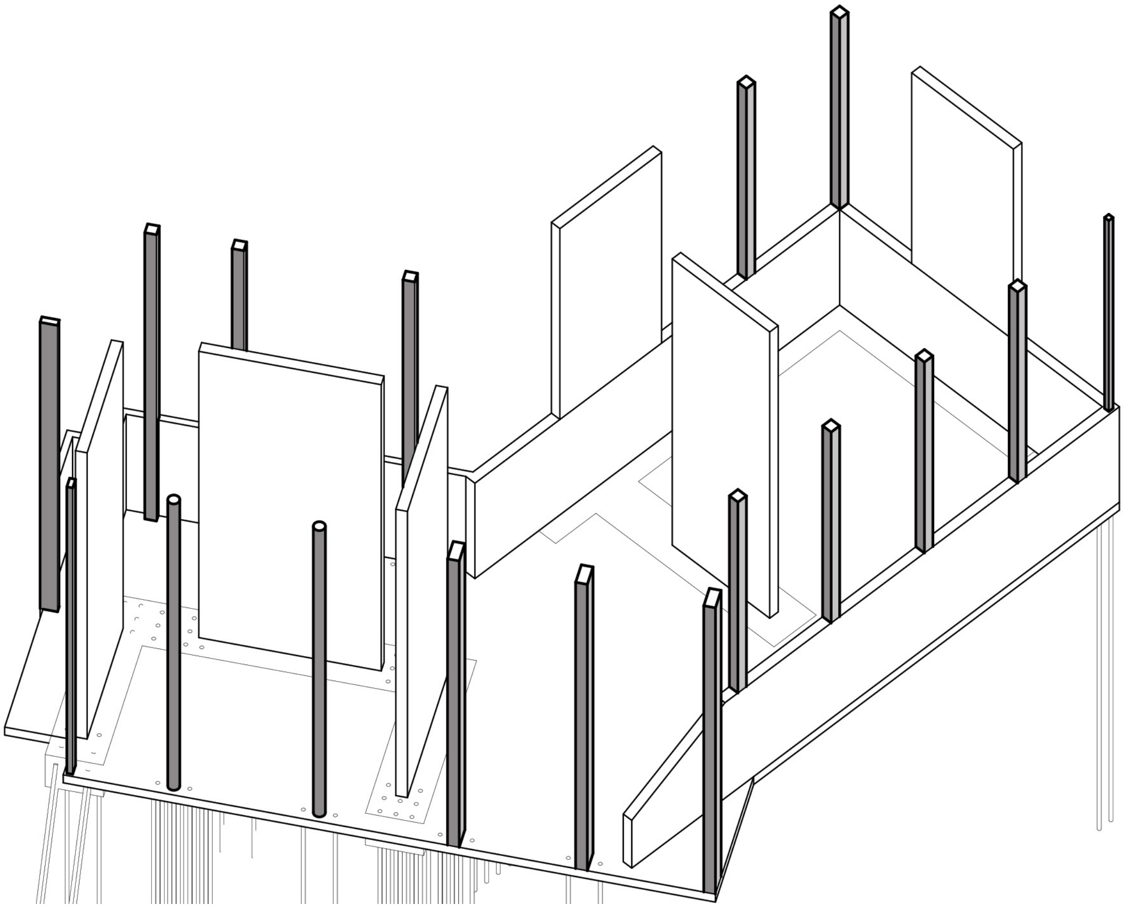
Finally, taking into account the fact that the building is LEED-certified, it is interesting to note that the boardform lumber is only used for a single cast. After it is stripped for the modular plywood forms to be re-used (with a new set of boards), it may find some utility as bracing for scaffolding, but ultimately it is thrown into the trash.

Above: Diagram of boardform warping.

Left: Results of warped boardform.

Below: the fellas finishing their tear-down of a shear wall form, with the discarded boards in the center. The steel-backed plywood forms are huge, and must be lifted into place with the crane.

Takes Two Seconds (Columns)

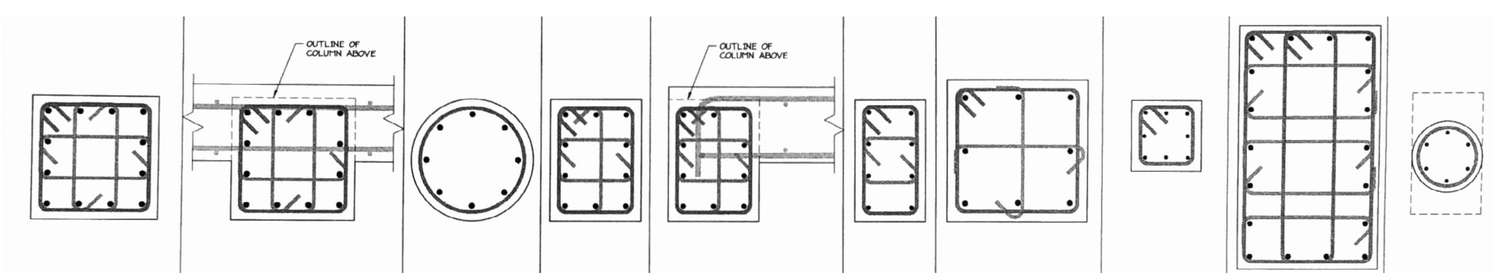


The columns are a very simple matter, since both the forms and the rebar cages are prefabricated, modular, and reusable. A rectangular column is assembled from four simple components:

1. A steel reinforcing cage assembled off-site. There is almost no modification to the prefabricated piece outside of connecting it to the next level via coupling nuts.
2. Formwork panels made of 1” plywood and 2x4, cut and assembled off-site. These panels are reusable.
3. Scissor clamps to hold the forms together in place of form ties, which are impractical for square forms. These can be used on many sizes of columns.
4. Chamfers made from wooden strips that are easily cut to size. These prevent sharp corners in the concrete, which usually do not fill well and are subject to abuse.

For a circular column, the composition is even simpler:

1. A circular reinforcement cage.
2. A paper-based formwork that is essentially a giant toilet paper roll.

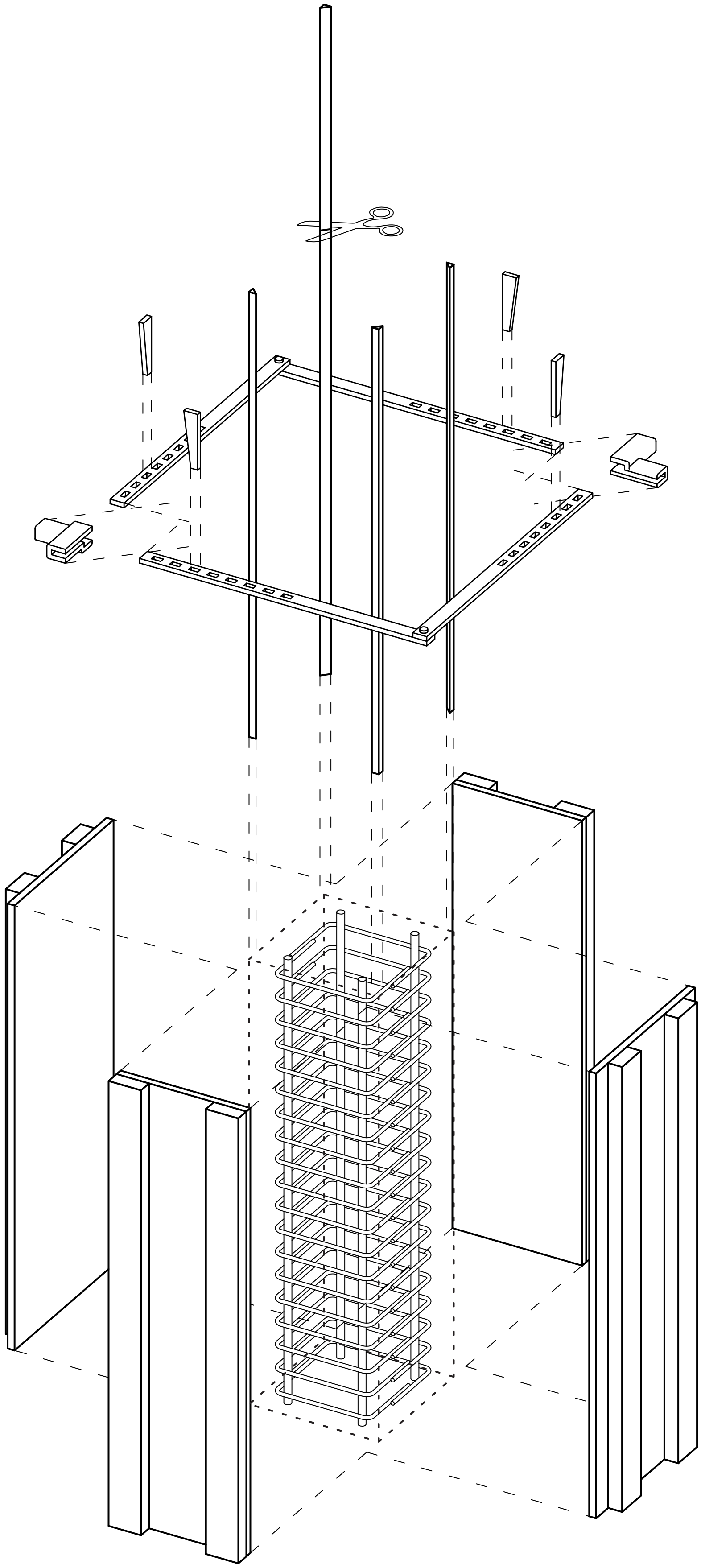


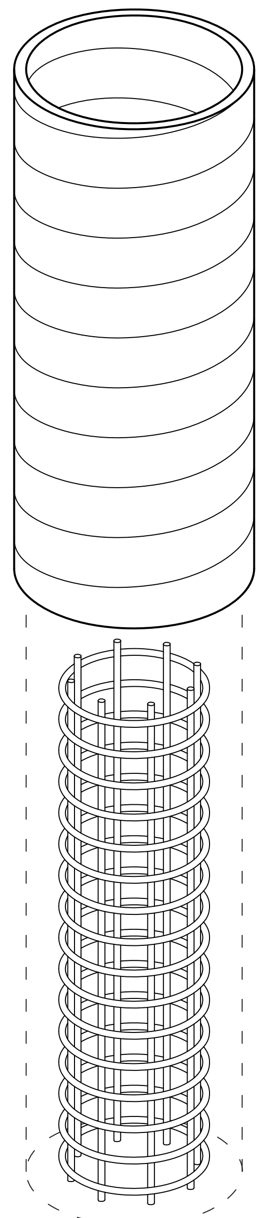
Previous page, above: Axonometric showing column locations.

Previous page, below: Column schedule from C.D. set

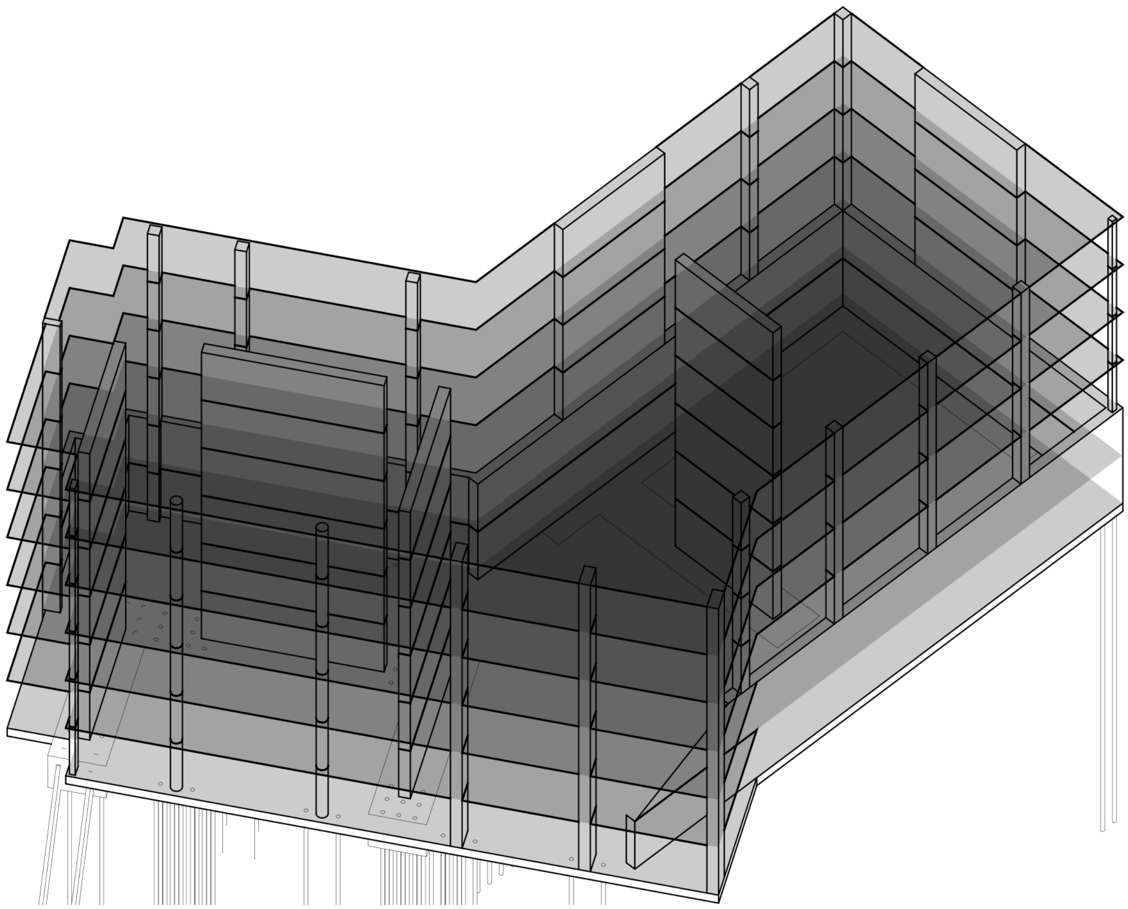
Left: Axonometric of rectangular column reinforcement and formwork.

Right: Axonometric of circular column reinforcement and formwork.



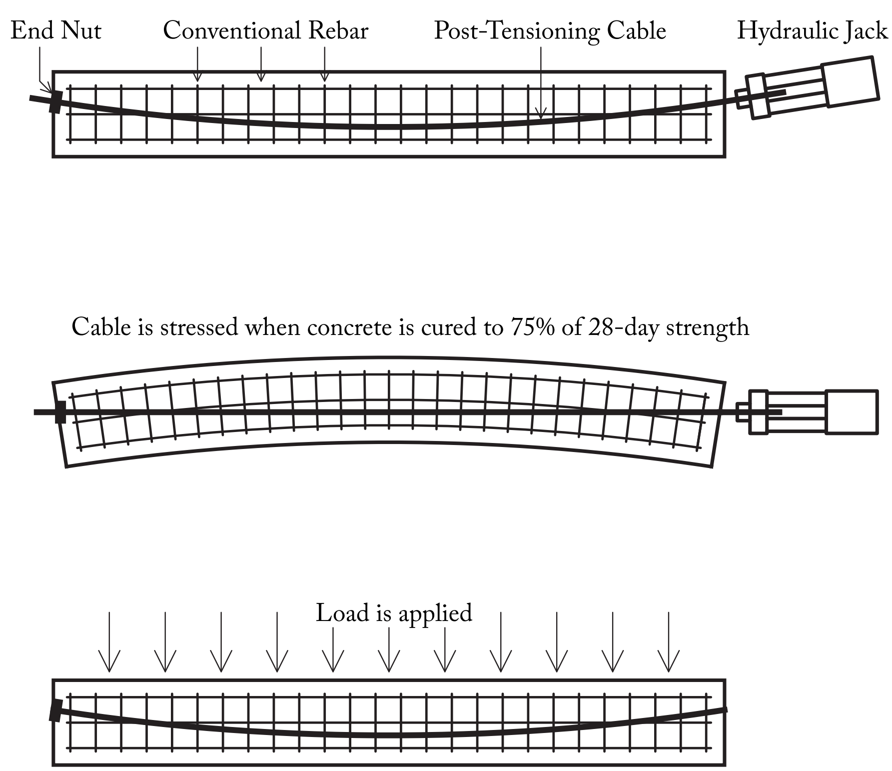


Takes Two Weeks (Slabs)



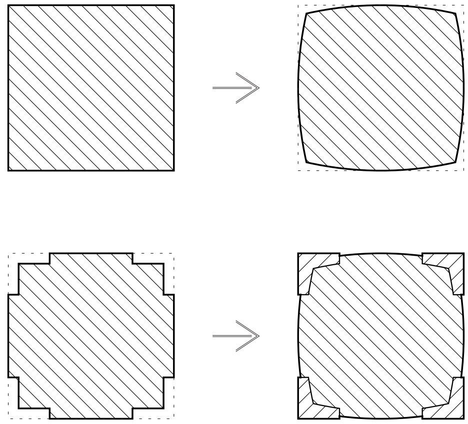
Post-tensioned concrete refers to a concrete element that has a steel reinforcing cable which is artificially stretched tight in order to raise the tensile strength of a specific part of the element. These cables are always placed in the lower half of a beam or slab, as this part that is in tension when the element undergoes bending stress, and they are used alongside conventional rebar. The cables are tensioned after the concrete has cured to about 75% of its 28-day strength, which can be as soon as a week after pouring.

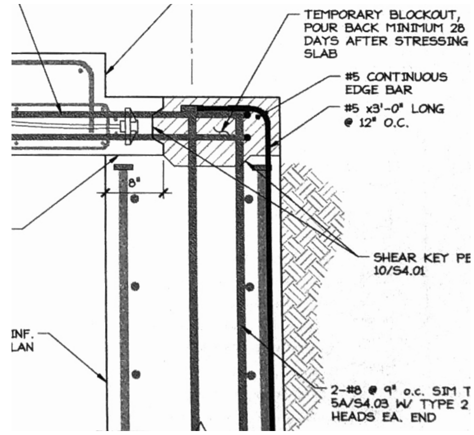
The floors of the Haas addition are put together with post-tensioned beams and slabs. The beams run



along the column grid, are relatively shallow, and are poured at the same time as the slab. The slabs could be considered two-way slabs, meaning that they are reinforced in both the x- and y- directions, but they are more of a one-and-a-half-way slab given the way they interact with the beams.

The stress of post-tensioning is so extreme that the slab will actually shrink afterwards; as a result, the last twelve or so inches of the corners of the slab are poured about 28 days



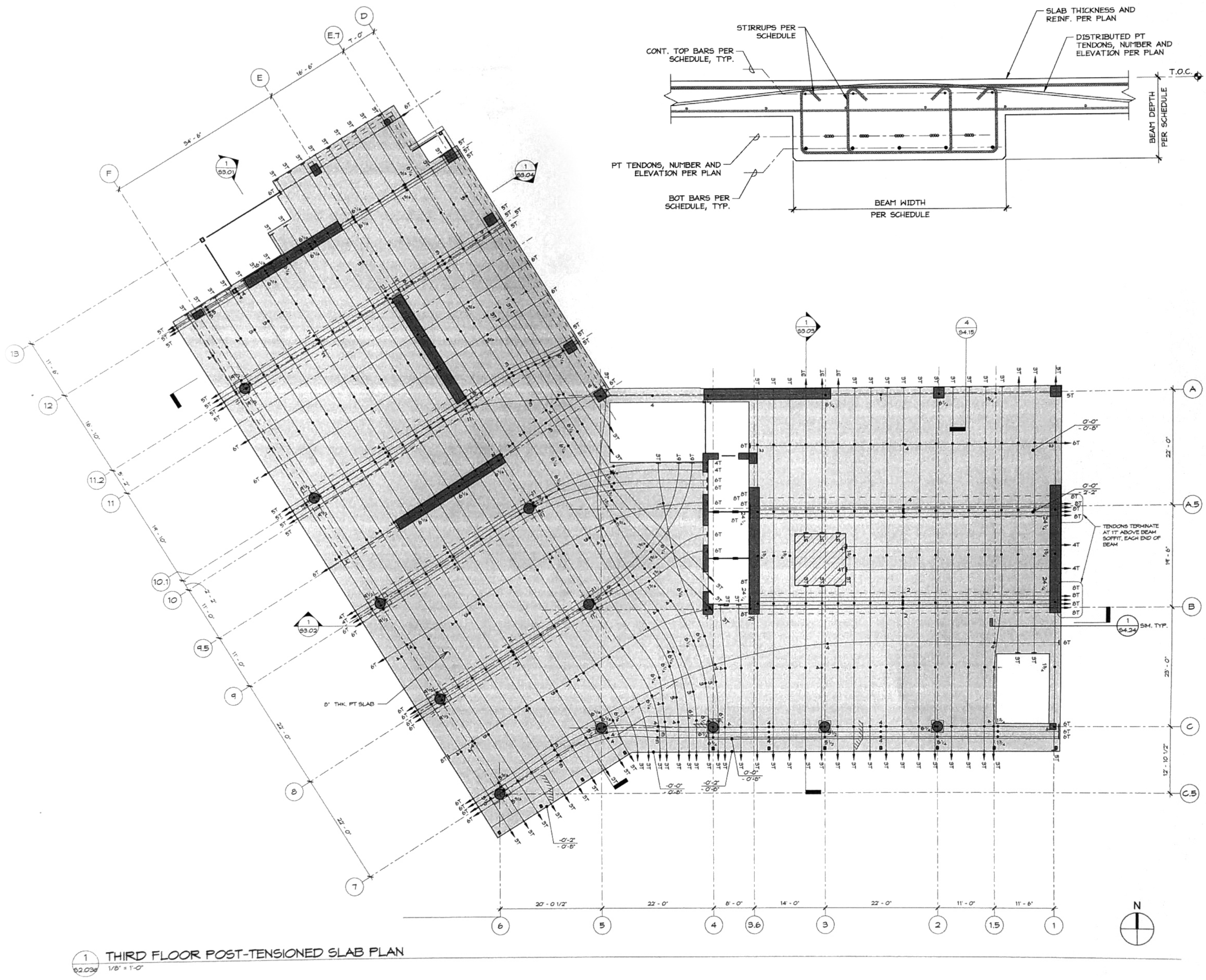


Above, left: Plan diagram showing the shrinking slab.

Above, right: Section of the edge of the slab at a retaining wall from CD set.

Below, left: Plan of winding post-tensioned cables from CD set.

Below, right: Section of P.T. beam, showing P.T. cable. curving upwards.



after the initial pour.

Since drilling into the slab runs the risk of hitting a post-tensioned cable, which would send it flying out the side of the building at the speed of a bullet, every single perforation or attachment to the slab must be designed and prepared before it is poured. The construction of each slab is a lengthy and tedious process, and special tools, such as a GPS tracker, must be used in order to place each and every one of the hundreds of anchor points on the formwork.

These objects include:

Traditional rebar, thicker at the outside edges of the slab.

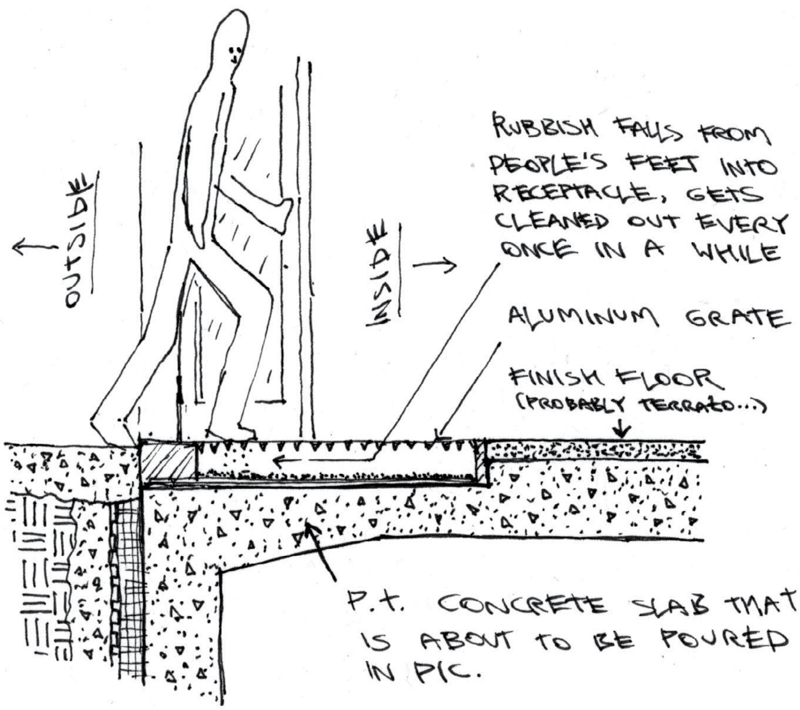
Blue P.T. cables, rising upwards when they meet a beam.

Electrical conduit (green) and boxes.

Ceiling plugs (red) found throughout the bottom of the slab, for attaching things like lights, HVAC ducts, etc.

Steel connections (orange) for attaching things like staircases and handrails.

An industrial doormat (blue) that is thicker than the finish floor and thus must be cast into the slab.



Left: Diagrammatic section showing industrial doormat.

Final note: all drawings and photographs by me, except for line drawings that look like they were made in Revit.