▲ The project site along Friars Road, showing a 1:1 slope before construction and indicating the location of the proposed soil nail wall and SDG&E tower.
Photo credit: FFRES

FEATURE STORY

SOIL NAILING SOARS TO NEW *HEIGHTS* IN SAN DIEGO

DESIGN OPTIMIZATION AND CONSTRUCTION CREATIVITY RESULT IN THE TALLEST PERMANENT SOIL NAIL WALL IN THE U.S.

BY PIROOZ BARAR, S.E., PB&A, INC.

Raw land for building is scarce in the City of San Diego. As such, area developers are turning to dense vertical infill, often on constrained, challenging parcels which require creative programming and innovative engineering. Such is the scenario at The Heights at Fashion Valley.

The Heights project — located north of, and across the street from Fashion Valley Mall in the rapidly densifying Mission Valley corridor — involves the demolition of three existing commercial buildings to accommodate seven-story residential buildings over two levels of above grade parking. The housing complex is sited on a narrow, 750-foot-long strip of land sandwiched between the busy east-west artery of Friars Road and a massive 1:1 slope.

The precipitous hillside rises hundreds of feet to the Linda Vista community above, and in the median is a primary San Diego Gas & Electric (SDG&E) easement with soaring high-tension electrical and communication towers that serve the surrounding neighborhoods and beyond.

That's its own challenge…but we'll come back to that.

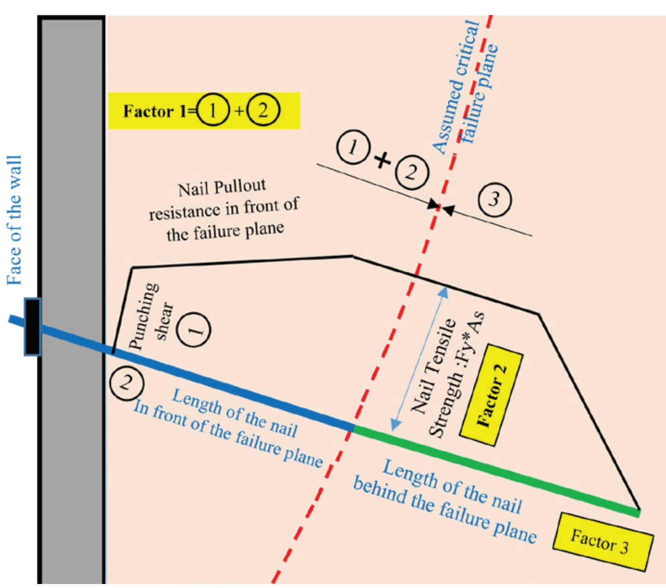
The sheer size of the hillside required a significant earth retention effort. To accommodate the development, the requisite retaining wall would need to be over 1000 feet long around the west, north, and east boundaries of the project, and at least 100 feet high at its highest point — a daunting undertaking both in feasibility and economic considerations.

This is where design optimization transitions from being important to being essential.

OPTIMIZING EFFICIENCY IN THE SOIL NAIL SOLUTION

A previous soil nail wall design had been completed for the project, which recommended 115-foot-long soil nails in a permanent installation, with large diameter rebars and 19- to 17-inch-thick shotcrete facing throughout the height of the wall. All told, the design amassed 115,000 total feet in soil nail length, weighing approximately 1.2 million lbs., 2,625 cubic yards of concrete, and a construction cost of $7,000,000.

This solution was found to be well beyond the economic constraints of the project. George Burrough, Condon-Johnson's & Associates' (CJA) Regional Vice President, suggested to the owner of Fairfield Residential Co., LLC, to contact PB&A. PB&A provided value engineering on the design and optimized the soil nail solution to reduce costs and improve construction scheduling.



▲ Typical tensile force diagram of a soil nail. Credit: PB&A

Typically, through an iterative process, a critical failure plane that meets the various factors of safety (FOS) and design criteria are identified. This is where the optimization process diverges from the standard design.

For each soil nail, three factors are considered in the evaluation of the overall FOS of the wall — punching shear, yielding, and pull-out. The contribution of each soil nail to the overall FOS is limited to the minimum value of these three factors. An optimum design is achieved when all three aspects, in all the nails throughout the wall, are in balance.

Factor 1 – Punching shear plus pullout strength of the length of the nail in front of the failure plane

Factor 2 – Yield strength of the soil nail, e.g., size of the rebar

Factor 3 – Pull out the strength of the soil nail length behind the failure plane

Achieving optimization requires examination of each nail to adjust the specific factor that is limiting or is in excess in its contribution.

Generally, upper nails are designed long to push back the critical failure plane — they do not necessarily even cross the failure plane, and therefore have little tensile stress. Moving down the wall, the distance between the critical failure plane and the face of the wall decreases. As a result, the available pull-out nail length in front of the critical failure plane decreases, which in turn increases the punching shear demand, thus making nails long at the bottom is unnecessary.

At the mid-height of the wall, the critical failure plane intersects the middle of the soil nails. The tensile forces in the soil nails, on either side of the critical failure plane, are roughly equal requiring increased demand on the strength of the nails. Therefore, in an optimum design, the nails at the mid-depth have a larger diameter.

With this understanding, PB&A used the cutting-edge program, Snail Plus by Deep Excavation LLC, to analyze soil nail stability under static and seismic conditions to reduce length and size. The team also calculated soil nail head forces to design a permanent facing for the wall that would increase the thickness of the shotcrete at the bottom of the wall.

The review of the original soil nail wall design showed that optimization could be applied to increase efficiency in several key areas:

— Soil nail length: the original design included very long soil nails — 115 feet at the top and 65 feet at the bottom. As noted above, punching shear increases as the failure plane comes closer to the wall, so the longer nails beyond the failure plane at the bottom of the wall do not contribute to the FOS. Top to bottom, PB&A was able to reduce the length of the soil nails by 44 percent.

— Soil nail rebar diameter: the original design used the same diameter rebar for nearly the entire height of the wall. As mentioned, it's only at the mid-height of the wall that demands soil nail strength increase, and thus using the same diameter rebar for the entire wall is inefficient. PB&A's optimized design reduced the overall weight of the required steel by 65 percent.

— Permanent facing: the original design specified a consistent permanent facing shotcrete thickness of 17-19 inches over the height of the wall. However, by the methodology discussed above, PB&A was able to reduce the facing to 10 inches for most of the height of the wall, except for the bottom 15 feet, which were increased to 18 inches. The soil nail-facing optimization resulted in a 23 percent reduction in concrete over the entire length of the project.

The primary objective in design optimization for any soil nail wall is to maximize the efficiency of each nail. This becomes increasingly important the taller the wall, especially one exceeding 100 feet. This kind of efficiency is derived not from standard processes, but rather through advanced technological analysis, and a nuanced understanding of how the output data informs the balance of critical factors to arrive at the ideal engineering solution.

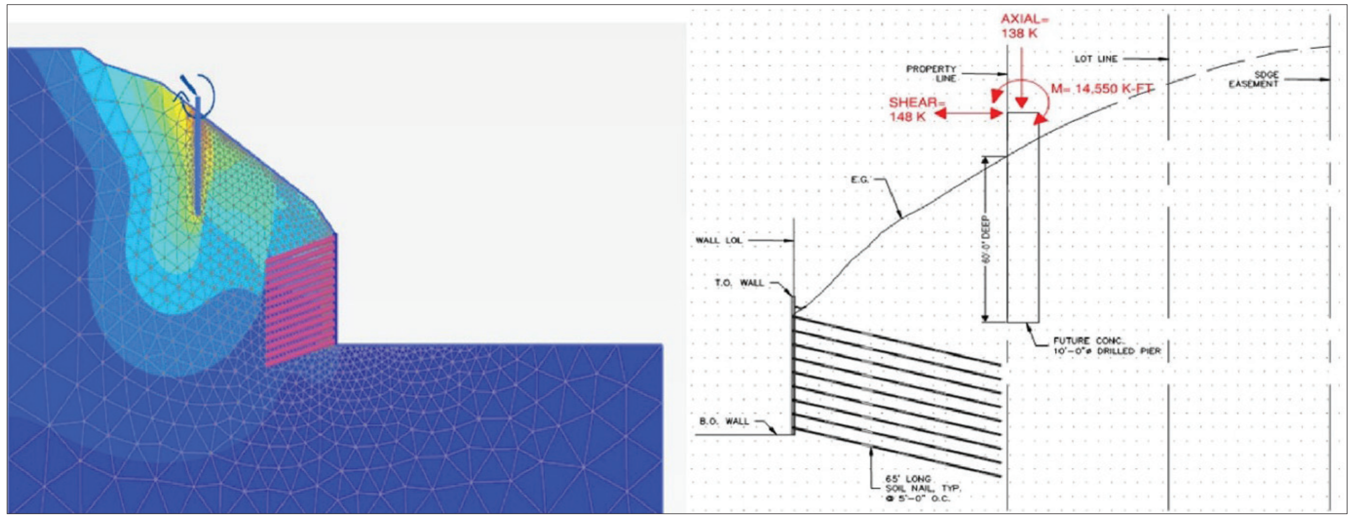
According to John Compagnone, CJA's San Diego Area Manager, PB&A's design optimization saved approximately $2,000,000 in construction costs and improved construction scheduling and productivity.

THE FUTURE FOUNDATION PROBLEM

Now back to those high-tension electrical towers.

Upon submitting the plans to the City of San Diego for permitting, the project hit a snag: the intrusion of some of the soil nails into the SDG&E's easement and, specifically, the transmission and communication towers that sit 63 feet up from the face of the soil nail wall.

The utility had plans to replace the existing tower behind the retaining wall at an unspecified future date, with a single-pole tower that would require a 10-foot diameter cast in a drilled hole (CIDH) pile foundation, extending up to 60 feet below grade. Further, SDG&E stipulated the foundation of the new tower would be drilled just inside the southern border of the easement.



▲ PLAXIS model output shows deformations around the drilled shaft and the diagrammatic sketch of the model. Credit: PB&A

The California Public Utility Commission (CPUC) had to receive the green light from SDG&E to allow adjustments to SDG&E's easements. To obtain SDG&E's approval for the soil nail wall design, PB&A had to determine the general boundary of the areas where the CIDH foundation of the new tower could be constructed and meet SDG&E's criteria for the future CIDH.

To address the interaction between the future tower foundation and the soil nail wall, PB&A used finite element analysis software, PLAXIS 2D, to model the two elements.

In PLAXIS, the soil nails were modeled as 6-inch drilled holes with typical horizontal and vertical spacings of 6 feet and 5 feet. The factored loadings of the CIDH — 138 kips of axial load, 148 kips of shear, and 14,550 K-feet of the moment — were applied at the top of the drilled shaft. Under these factored loading conditions, the drilled shaft was allowed to deflect 1.48 inches and rotate 0.3°. These severe restrictions were required to minimize the impact of the CIDH on the permanent soil nail wall.

Initial PLAXIS results showed a very limited area where the new tower could be installed and still meet the SDG&E criteria. Therefore, PB&A made a series of changes to the soil nail design to expand the new tower installation area, including increasing the length of the nails and permanent facing thickness. The PLAXIS models were then modified with the revised soil nail design. The results presented four modeled cases showing an area where the tower foundation could be placed to meet design criteria, with a load factor of 2.0.

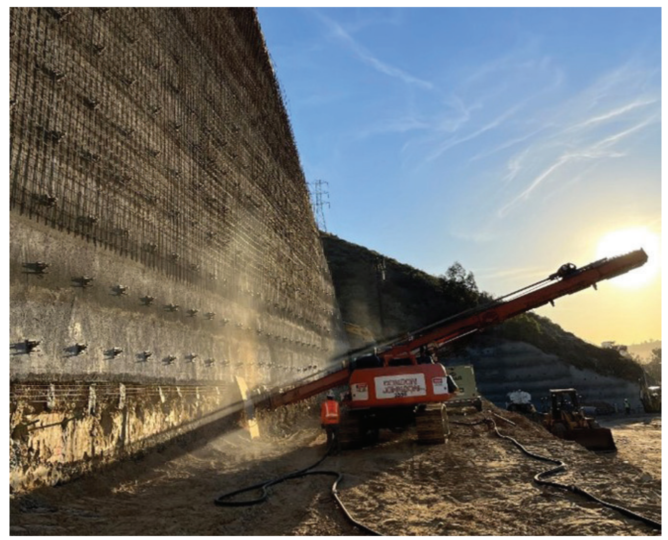
SDG&E concurred with the findings of the analysis and forwarded its approval to CPUC. Shortly after that, the project received final approval to proceed.

CREATIVITY IN CONSTRUCTION

Soil nailing requires a top-down construction method. Given the 1:1 slope of the hillside, the largest challenge confronting the drilling contractor, CJA, was how to get the necessary equipment to the highest point of the hill to begin drilling the uppermost nails.

The top of the soil nail wall had an existing ground elevation of 148 feet — an elevation change of 88

The western portion of the wall was built to create a 4:1 ramp and 25-foot construction bench. Credit: CJA



Installing soil nails at bottom of the wall and application of the initial layer of shotcrete Credit: CJA

Architectural shotcrete being applied, working downward from top to bottom. Credit: Boulderscape, Inc.

feet from the sidewalk, which sits at an elevation of 60 feet. To reach that height, a significant amount of dirt was needed to build a temporary ramp at a gentle slope of 4:1, with 25 feet of the bench at the top. Complicating this task, the sidewalk was only about 130 feet from the face of the soil nail wall, which meant that virtually the entire site would need to accommodate the modified slope.

To accomplish the task, the team worked together to initially construct the west and east soil nail walls to generate the dirt to build the hill. Once enough dirt was amassed, the team constructed the ingress/egress ramp for concrete/material deliveries and a pad at an elevation of 143 feet suitable to begin the critical path construction activities. This solution enabled the construction team to build the wall, top to bottom, including all structural reinforcements and application of the initial shotcrete facing.

When the initial structure was complete, Boulderscape, Inc. (BSI) was brought in to apply a second, sculpted layer of shotcrete. BSI installed the back formwork at the top and control wires to support up to 18-inch-thick shotcrete. The first pass proceeded bottom to top, with shotcrete placed at the base of the wall and built up in 6- to 8-inch-high bench layers. At higher levels, the second layer of shotcrete was applied from the basket reaching up to 105 feet above the bottom of the wall.

Once the second layer reached the top, the control wires were cut from the wall and the architectural shotcrete was applied, once again working downward from top to bottom. This process continued until all shotcrete had been carved and textured, and then stain was applied for aesthetics. Given the unusual height of the wall, a hydraulic lift with a man basket was required to hoist the BSI employee into a position to apply the architectural shotcrete.

Construction was completed in July 2022. The 105-foot soil nail wall — the tallest ever to be constructed in the U.S. — now stands ready to welcome the future residences of The Heights.

Fairfield Residential LLC Project Manager, Construction, Eric Schwing had this to say about the project, "Fairfield Fashion Valley is proud and pleased with the recently completed Soil Nail Wall System designed by PB&A. Tremendous effort and collaboration by PB&A with all the project stakeholders resulted in its success and striking appearance."

PROJECT TEAM:

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** Indicated ADSC Member*

Completed 105-foot soil nail wall. Credit: Fairfield Residential Co., LLC