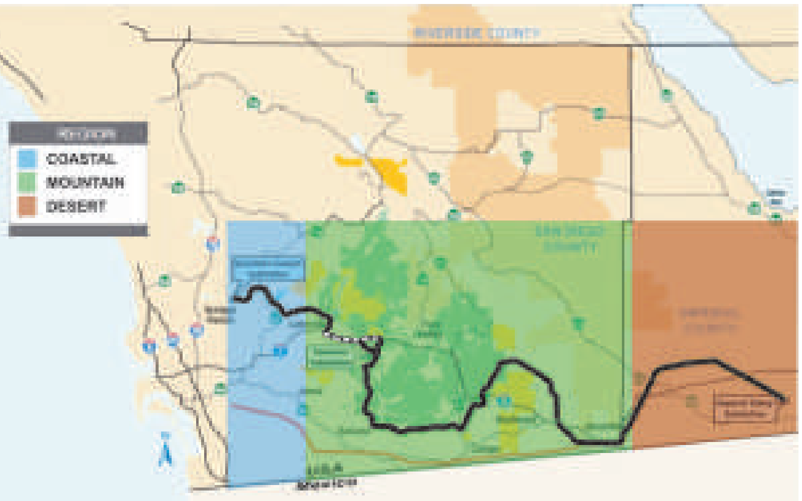
COVER STORY

Sunrise Powerlink: An Innovation in Foundation Design

Micropile installation

The Sunrise Powerlink project received numerous industry awards for excellence. The DFI C. William Bermingham Innovation Award recognized the innovative use of prefabricated steel micropile caps to increase safety, accelerate project schedule and minimize the project carbon footprint. DFI's Outstanding Project Award (OPA) and World Cup of Micropiles Challenge Award honored the project as a whole and its positive outcome and industry example.



Project alignment map

Sunrise Powerlink involved construction of San Diego Gas and Electric's (SDG&E's) new 117 mile (188 km) 500/230 kilovolt transmission line from Imperial County to San Diego County, Calif. The alignment traversed a wide variety of geotechnical conditions, including desert, mountain and marine environments, and many of the 421 lattice tower structures used to carry the transmission lines were located in remote, rugged or environmentally-sensitive terrain.

Micropiles were introduced as a solution to foundation construction in these challenging areas, which ultimately involved the design and application of Crux Subsurface Inc.'s patented steel micropile cap at 234 tower locations. This was the inaugural application of the technology, and a significant component to ensuring a successful project outcome.

Foundation Challenges

The alignment crossed a number of protected environments, including National Forest land, critical habitat for bald eagles and Peninsular big horn sheep, and numerous private properties. As a result of the remote, rugged terrain, it was initially determined that 75 lattice tower locations would not permit road construction access and would require helicopter-only construction techniques. A strict in-service date combined with long permitting lead times eventually increased this number to 234 sites.

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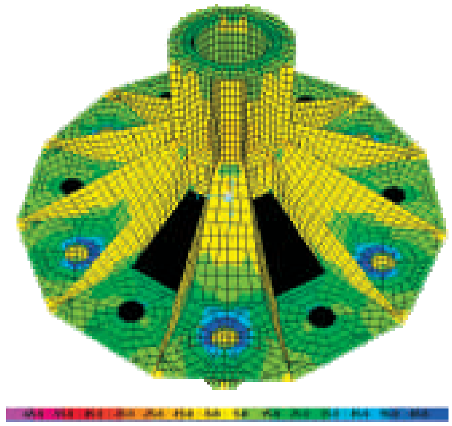
Preconstruction access constraints prohibited site-specific geotechnical sampling, so initial foundation designs were completed using only available seismic geophysical surveying and preliminary mapping data. The combination of these challenges required a foundation alternative that could accommodate variable subsurface conditions, required a minimal environmental footprint for installation, and featured lightweight materials and equipment that could be transported by helicopter.



Finite element model of steel pilecap

Selection of Micropiles

Micropiles were ultimately selected as a deep foundation alternative for all 234 lattice tower helicopter sites. The remaining 187 sites allowed for conventional access with heavier equipment, and employed large-diameter drilled shaft foundations.

Micropiles are small-diameter, high-capacity piles, ideal for helicopter transport due to their size and weight. Foundation contractor, Crux Subsurface, provided lightweight drill rigs and installation equipment, specifically intended for helicopter transport. The equipment was designed to accommodate steep slopes and minimize excavation impacts. Beyond access advantages, micropiles offered the benefit of adaptability to a wide variety of subsurface conditions, from deep soft soils to hard rock. Predetermined foundation schedules allowed for installation of various pile quantity and length combinations to match structure loads and subsurface conditions.

Introduction of Steel Pile Caps

Construction start times were delayed for a number of reasons, several of which were environmental and permitting-related. In combination with a firm in-service date for the line, this condensed the construction schedule from 24 months to 18 months. To assist with schedule challenges, the design team developed a prefabricated steel pile cap to replace the cast-in-place concrete caps originally specified by the owner. The steel caps were manufactured in prequalified offsite facilities, reducing onsite construction time and allowing for accelerated schedule adherence.

The steel cap had to maintain the specified project performance requirements; limiting maximum foundation deflection to 1.0 in (25.4 mm) under factored loads. This was particularly challenging due to the disallowance of field welding imposed by project restrictions. The design team responded by developing an all-bolted assembly, and worked with the owner to develop fabrication and inspection standards. The design life was defined as 75 years and, due to the rigorous environment the system would be employed in, the caps would need to perform without regular scheduled maintenance.

Steel Cap Design and Validation

Finite element software was utilized to model the steel cap prototypes due to their complex geometry. This analysis procedure allowed a more detailed estimation of critical stress locations for weld design and plate buckling. The models also included iterative analyses of variable pile support conditions, allowing the design team to calibrate the steel cap design for a range of supporting pile quantities. The 3D modeling permitted better refinement of steel weight and conflict resolution between the alignment of micropiles, pile cap and lattice tower structure. In the process of optimizing the design for weight and transportability, the final design focused on a series of stiffening and bearing plates welded together in a radial form.

To further validate the finite element design and fabrication procedure, two prototype steel caps were fabricated and installed at a test site near the alignment. The test applied 1,000 kips (453.6 tonnes) of compression load and 300 kips (136 tonnes) of lateral load simultaneously. Deflections in the micropiles and the pile caps were measured during the load test and compared with the finite element analysis to confirm the model's predictions. The execution and success of this full-scale load test marked the preliminary acceptance of the steel cap design.

Rig and platform for micropile installation

Corrosion Protection

Various methods of corrosion protection were contemplated by the project team. The method would need to provide corrosion protection resistance in case of partial burial for short periods of time, as a majority of micropile foundations were located on steep slopes. Difficulty of access to remote sites also necessitated a corrosion protection method that could withstand aggressive conditions between longer inspection intervals. Several methods were considered and eventually narrowed to self-weathering steel (ASTM A588) and hot-dip galvanizing. Both methods were found to satisfy the corrosion protection requirements. Hot-dip galvanizing was ultimately selected to eliminate uncertainty associated with factors outside the normal performance of the system.

Hot-dip galvanizing of the complex weldment proved to be challenging. Thermal stresses caused by the hot-dip process exceeded stress that would be induced during the normal performance of the pile cap. Multiple variations in fabrication and dipping were tested to formulate a thorough and repetitive process

Steel pile caps at foundation site

for dipping without manifesting stress indications. An inspection process was developed by Crux and accepted by SDG&E to inspect the galvanized caps for heat induced indications. Once in full fabrication production, no indications were identified.

Crux and SDG&E developed a set of fabrication specifications that relied heavily on AWS D1.1 for the majority of the pile caps and D1.5 for the attachment of the tower's stub angle to the top plate of the pile cap. Fabricators were selected, prequalified and audited for QA/QC procedures at their facilities.

Steel Cap Implementation

After a yearlong collaborative effort, the bolted steel pile cap was approved for use on the Sunrise Powerlink project. Of the total 936 footings (234 towers), 888 received steel pile caps and 48 received concrete caps. The majority of the 48 concrete caps were installed prior to the acceptance of the steel cap, as final approval did not come until after construction had begun.

There was some initial concern regarding alignment issues, since the steel caps were prefabricated and had less tolerance than concrete to accommodate piles outside of their intended locations. However, of the nearly 900 steel pile caps installed, only 3 were converted to concrete due to misalignment of piles or tolerance considerations.

Foundation Design

To capture the true behavior of the foundations as a system of structural components, the piles were modeled in 3D as a group with the cap. This method took into account the sloping terrain creating differential pile reveals around the circular pile array, as well as the fixity of the piles with the pile cap. The analyses produced deflection and moment curves for a variety of geometric and geotechnical conditions, considering the variable depths of soft soils, medium-dense soils and rock. Numerous iterations were run to fix critical variables for constructability, such as casing size, bar size and pile array diameter. This also allowed the project team to determine the quantity of piles required to meet the full range of geotechnical conditions anticipated at a particular site or group of sites.

The results of the iterative geometric and geotechnical analysis were utilized to develop a patent-pending decision matrix in the form of a foundation schedule. The matrix provided a number of scenarios and solutions for each micropile foundation site, allowing the construction team to optimize the foundation at the time of installation. Foundation schedules provided various pile quantity and cased and bond length options to align with geotechnical conditions as they were characterized during installation.

Steel Cap Benefits

The utilization of the steel cap accelerated the construction schedule and provided additional safety, environmental and quality assurance benefits to the project.

Schedule: Narrow work windows at difficult-access sites were often restricted further by unpredictable variables such as weather, environmental regulations and cultural mitigations. Foundation installation speed in these highly-regulated areas had a direct impact on overall project completion time, as foundation activities had to be completed prior to tower erection or wire stringing.

The steel caps were fabricated in a controlled, offsite facility, and installation required an average of 5 field crew hours per footing. Concrete caps were constructed onsite by importing 1 yd^3 (0.76 m^3) of concrete at a time, and required an average of 14 field crew hours per footing. The implementation of steel caps at 888 footings reduced field labor time by an average 64%. This ability to construct within a shorter, more predictable time frame allowed project managers to predict the activities that could be completed within each window with greater accuracy.

Foundation for lattice tower

Safety: A 64% reduction in field labor subsequently reduced worker exposure to safety hazards during cap construction activities by the same factor. In addition, the steel caps required an average of 1.75 helicopter hours per footing. Concrete caps required an average of 6.75 helicopter hours per footing. The employment of steel caps at 888 footings reduced the total number of helicopter hours for cap construction by an estimated 70%. Helicopter use generated a certain amount of safety exposure, and a reduction in exposure subsequently resulted in a decreased risk of safety incidents.

View of micropile connection to steel cap

Environmental: The 70% reduction in helicopter hours decreased emissions and assisted in minimizing the overall carbon footprint of the project. Additionally, the use of steel caps minimized site disturbance and reduced the extent of excavation. In order to effectively transfer loads from the tower to the micropiles, concrete caps were taller and wider than steel caps, requiring deeper and larger excavations. The reduction in excavation was significant in volume, and, with near surface bedrock present at the majority of the sites, the smaller excavations often eliminated hard rock excavation and blasting.

Quality: Design methods performed for steel pile caps on Sunrise were superior to design methods employed for cast-in-place concrete. These methods provided a higher and more quantifiable assurance of the long-term performance of the system. In addition, the steel pile caps were fabricated in a controlled environment under ideal inspection conditions, and field installation was limited to bolted connections. Each of the bolted and welded connections of the system are exposed and can be inspected throughout the life of the structure.

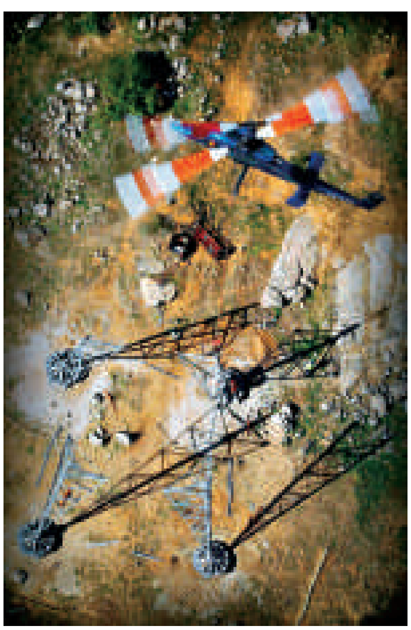
Summary and Industry Implications

The Sunrise Powerlink project was successfully completed on schedule and went into service on June 18, 2012. Micropiles provided a deep foundation solution at the 234 helicopter-only lattice tower sites where road construction was not feasible. The introduction and installation of 888 prefabricated steel pile caps generated significant schedule and safety advantages on these challenging construction sites, and contributed to the overall success of the project.

As the industry continues to expand, project owners are encountering a number of the same challenges experienced on the Sunrise Powerlink project. Investment in high-voltage electrical transmission is expected to exceed $41 billion in the United States between 2011 and 2020. Current resources have been exhausted, and consumers and state mandates are calling for an increased presence of renewable resource options. The task of transporting this power to metropolitan areas frequently requires traversing remote and environmentally-protected terrain, which generates a number of access and permitting obstacles. The introduction of steel cap micropile foundations had a significant impact on the positive outcome of the Sunrise Powerlink project and will serve as an example to similarly challenged projects in the future.

Project Timeline

December 2010:	Crux awarded project
February 2011:	Expected start date
April 2011:	Limited Notice-to-Proceed (NTP) at 8 structures in desert region
August 2011:	Limited NTP in protected species habitat
October 2011:	First milestone in protected species habitat
December 2011:	60% completion of foundation work
April 2012:	Substantial completion of foundation work
June 2012:	Sunrise Powerlink energization



Transport of lattice tower via helicopter (left), and completed transmission line