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Risk management and Flexible Foundation Design for electricity tower construction in the Swiss Alps

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Abstract

Electricity tower construction for a new 380 kV transmission line was proposed in Valais, Switzerland. The line followed steep elevations in the Alps where most of the towers were located. The project posed critical risks that needed to be actively addressed: 1) a constrained construction window in the summer months (May to September) 2) aggressive sulphate rich ground which necessitated the highest possible corrosion protection 3) non-uniform ground conditions and elevations across the line 4) logistics limited by the available transportation methods of machines. The paper describes an active and early risk management regimen adopted jointly by the Contractor, Designer & Supplier which resulted in a successful project construction plan.

The risk management measures included: designing the foundations with additional safety factors in accordance with SIA (Swiss codes); having a unique design for each tower taking into account the loadings, ground conditions and elevations; using TITAN INOX grouted micropiles which are corrosion protection applicable in any condition; planning logistics with packaging machines and materials intended to be transported via helicopters. These measures resulted in a durable solution for the entire design life of the structures ensuring that the electricity supply to Switzerland would be uninterrupted by avoiding any future corrosion related failures.

Keywords

Risk management, Micropiles, Electricity tower foundations, Difficult access, High corrosive aggressivity, Stainless steel, INOX.

1 Historical Context and Introduction

Following the Fukushima nuclear accident in 2011 in Japan, many countries took note and rethought their energy and power policies internally. Switzerland, already having an inherent advantage in producing hydroelectric power due to experiencing high precipitation and the presence of Alps which cover 58% of the country's landmass, was amongst those countries which decided to wean off their existing nuclear sources of power and increase their production and supply of hydroelectric power. Five years later in 2016, this led to the creation of the Swiss Energy Strategy 2050 (Swiss Federal Assembly, 2016). The aim of the Strategy is to restructure the national energy system to achieve climate neutrality by 2050 and to increase the overall electricity production levels without disrupting existing supply routes.

To implement this strategy, significant new infrastructure and upgrading of dated power infrastructures was required. Many different programs were launched and one amongst these was Swissgrid's Strategic Grid 2025 (Swissgrid Ltd, 2015). One of the objectives of the Swissgrid Strategic Grid was to upgrade the existing 87km long electric corridor between Metteln and Ulrichen from 220 kV to 380 kV. This required the construction and installation of new higher capacity electricity transmission towers. While most of the construction along the entire 87 km line was carried out using conventional methods, a specific 8.8 km section between Mörel and Ernen (Fig. 1) characterized by helicopter-only access and highly aggressive ground conditions is the focus of this paper.

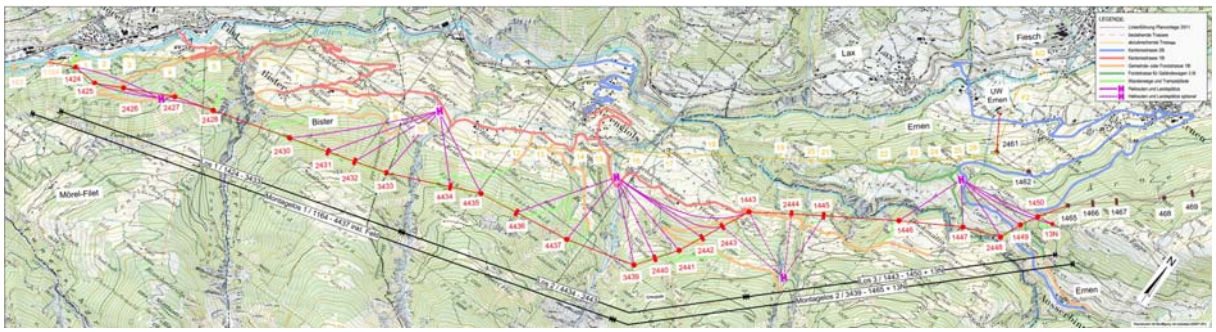


Fig. 1 Overview of the Mörel–Ernen 8.8 km line section with mast locations (Swissgrid Ltd, 2020).

In this context, risk management became a key driver for foundation design, requiring systematic identification and mitigation of geotechnical, environmental, and logistical uncertainties to ensure constructability and long-term performance in alpine conditions. The paper presents a case study of the design, construction and risk management system approach adopted for these foundations in a constrained environment.

2 Project Description and Site Conditions

The proposed construction comprised 27 new380kV transmission towers of various types(Swissgrid Ltd, 2020).Three of these masts, 2448, 1443 and 3439, were designed as extended Type A4 dead-end structures, carried the highest loads and underwent several redesign iterations during the project. Each tower consists of four legs, with each foundation leg designed to resist compression loads in the range of 800 to 4500 kN, tension loads up to 4500 kN, moments up to 3200kNm in both directions accompanied with varying lateral loads.

The principal design engineer was AFRY Schweiz AG (formerly Pöyry), Baden, responsible for both tower structural analysis and foundation design under project number 4590 with preliminary foundations designs especially concerning micropiles being prepared by Friedr. Ischebeck GmbH.

The elevations of these proposed towers ranged from around 900 to 1200m above sea level up on extremely remote access locations. The south-facing slope above the RhôneValley introduced geometrical challenges for the foundation construction, as even within a single mast all four legs were positioned at different elevations and founded in varying ground conditions. Fig. 2 shows an example of differing elevations of the legs of a single tower.

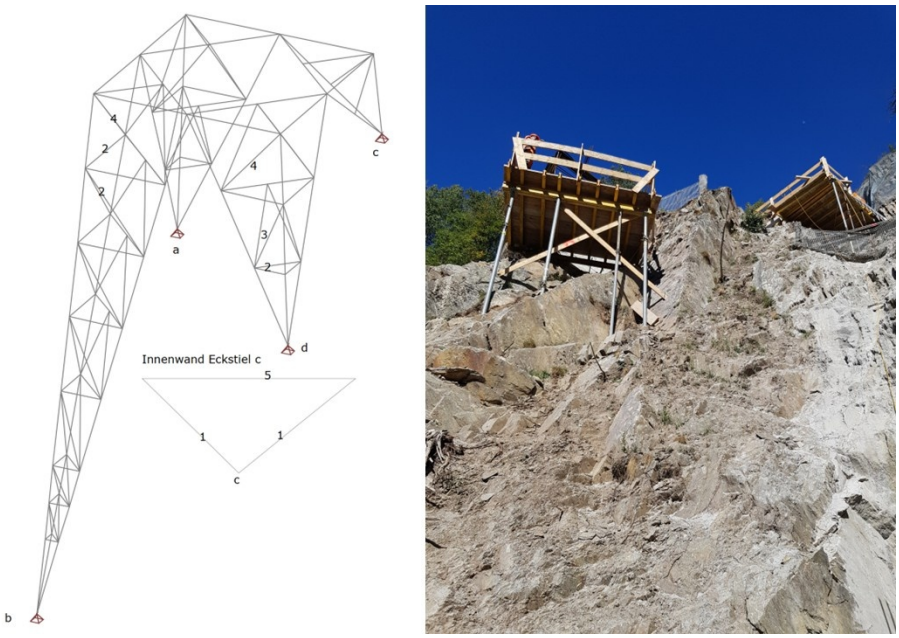


Fig. 2 An example of differing elevations of the legs of a single tower.

The general geological profile along the proposed construction corridor was of loose, weathered moraine and colluvial material overlying competent crystalline bedrock predominantly gneisses and related metamorphic rocks. However, the depth of the weathered rock from the surface varied significantly. The line was divided into 3 sections. In the lower sections (Construction Scopes 1 & 2) the loose strata presence is significant with a depthof up to a few metres. In contrast, in Construction Scope 3 which is the upper section, hard rock was encountered at or immediately below the surface. These highly variable geological conditions posed significant challenges for foundation pile construction, requiring adaptable installation methods.

Furthermore, soil chemical investigations carried out confirmed the presence of high amounts of sulphates in the groundwhich confirmed the exceptionally high corrosion risk for the foundation design acc. to SIA 267(SIA, 2013).

3 Foundation Design and Durability

The foundation design process for this project was highly iterative, with multiple revisions made to address risks that successively emerged during the design and construction phases, while maintaining high utilisation ratios and resulting in an efficient final design.

The engineering office stated that a sulphate attack on the foundation could occur which together with the required service life in accordance with SIA 267led to the classification of corrosion potential asLevel 3b, corresponding to very high corrosion exposure and the need for enhanced durability measures. In addition,challenging construction conditions limited the possible corrosion protection systems. For instance, it could not be ensured that fully prefabricated grout bodies with plastic-sheathed (DCP) micropiles would be transported into the Alps without damage. Additionally, solid bar with DCP systems with couplings (instead of fully prefabricated micropiles) do not comply with the Swiss requirements for double corrosion protection. Under these constraints, stainless steel hollow bars qualified as the only acceptable solution.

Consequently, the designer specified that the micropiles had to be manufactured from stainless steel, leading to the selection of TITAN 40/16 ($R_k = 530\ kN$) INOX, which satisfied both the durability requirements and the construction and schedule constraints. This became the standard micropile type for all foundations within the project scope. All designs were therefore based on this micropile type, with the number and arrangement of piles in each foundation cap determined so that the internal forces from the tower leg reactions remained within their resistance.

The design process made it essential to design each tower leg separately, since the 27 towers exhibited significant variation in loadings, overall ground elevations, individual leg elevations and ground conditions. Initiallythe loads from each tower leg were transferred into a selected micropile

configuration within the given pile cap footprint, and several combinations of vertical and inclined micropiles were proposed to optimize the solution. These calculations were performed in ENSOFT GROUP software with the pile caps modelled as rigid elements and the micropiles having a pinned connection to the pile caps which allow for rotation and displacement in all directions. The design verification was carried out in accordance with the Swiss geotechnical design standard SIA 267:2013 and across the different foundations, the minimal configuration required 6 micropiles per leg, while the maximal required 22 micropiles per leg.

However, this initial approach proved insufficient once the three-dimensional mountain geometry was considered.When the preliminary micropile layouts were superimposed on the actual terrain, it became evident that some of the piles would protrude outof the slope face and therefore could not be constructed in their proposed positions. Fig. 3 shows the initial micropiles arrangement proposal for a given tower location, with two micropiles marked with red circles protruding beyond the slope face. The terrain thus directly constrained the feasible pile orientations and necessitated further redesign to adjust the micropile layout so that all piles remained fully embedded within the mountain slope.

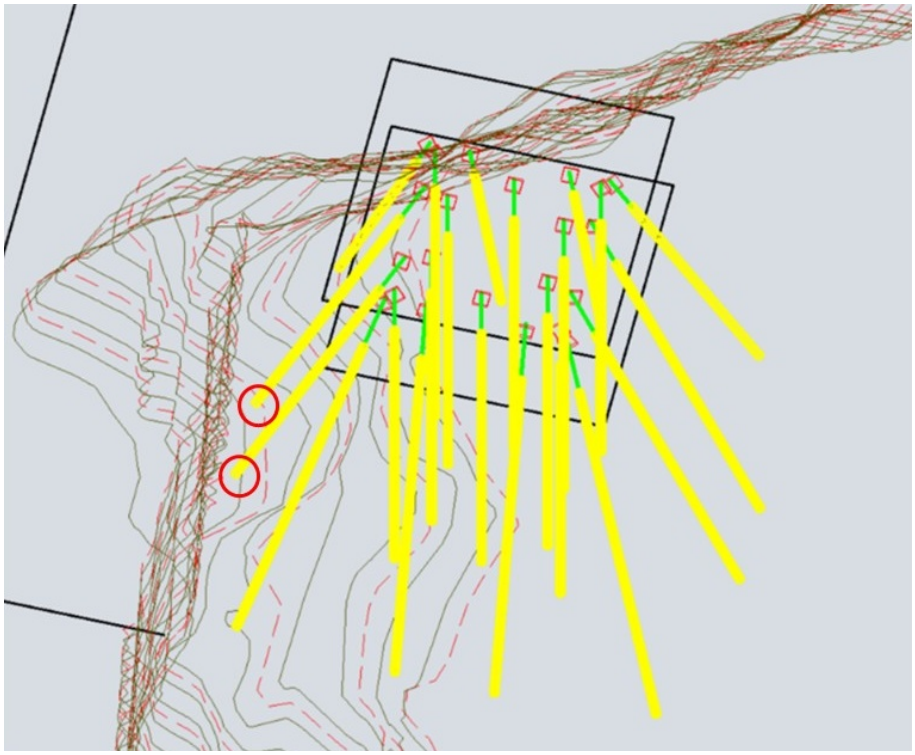


Fig. 3 Installed micropiles at one tower location prior to pile cap concreting.

4 Construction and Logistics

Construction issues governed several of the design choices of the project. The tight construction window meant that the principal designer could not afford to lose any time after mobilization and therefore required bulletproof forecasting of potential problems.

To manage the construction activities, the towers were first divided into 3 scopes: Construction Scope 1, 2 and 3. Construction Scopes 1 and 2 were on the lower elevations while Construction Scope 3 was situated on the higher scope. As access by road or cableway was not possible, all materials and equipment had to be transported exclusively by helicopter. Accordingly, threehelicopter landing spots were chosen, ensuring that the helicopters could be safely landed. Fig. 4 shows the location of one of the proposed masts along with the helicopter landing location.



Fig. 4 The construction site access by helicopter and installed micropiles at one tower location prior to pile cap concreting.

This logistical constraint also dictated the choice of the micropile system, as discussed previously. In addition, reliable and short delivery times for all materials were essential, further favouring the chosen micropile system over alternatives with significantly longer lead times. To mobilize effectively with helicopters, all materials and machineries were packed into max packing weights of 950 kg for the helicopter to be able to transport these without posing any safety concerns. In this context, INOX hollow-bar micropiles were selected over other DCP systems because their modular, segmental form and lower individual component weights were compatible with helicopter transport to the remote alpine sites.

There were also some modifications made to standard procedures: although TITAN INOX 40/16 is typically used as a self-drilled system, for this project the installation method was changed to installation in pre-bored holes to achieve higher efficiency in hard rock conditions, with the bars installed as central reinforcement. After installation, the micropiles were then grouted using pre-installed grouting hoses. The static tension load tests performed on the executed micropiles confirmed the quality of workmanship and demonstrated that the required design resistance was achieved. Fig. 4. shows the installed micropiles at one of the locations prior to pile cap concreting and Fig. 5 presents the assembly of steel lattice tower.



Fig. 5 Assembly of a one of lattice mast supported on micropile foundation in the Mörel–Ernen section.

5 Risk Identification and Risk Management

The project illustrates early, proactive risk identification and clear communication between all the parties involved in the construction, enabling the successful management of the risks outlined in the previous sections. It also demonstrates a high degree of flexibility in both foundation design and construction techniques, allowing the team to adapt to changing conditions and constraints as the project progressed. Building on this framework, the key risks and the corresponding mitigation measures adopted for weather, durability, design, logistics, and geological/installation aspects are summarised in Table 1.

Table 1. Overview of key project risks and mitigation measures.

Theme	Risk	Consequence	Measure
Weather	Limited construction period in summer months due to harsh weather during winters	Postponement of entire project for 6 – 9 months if not completed within the summer months	Early procurement & mobilization at site. The design and construction activities for various masts and areas were performed concurrently
Durability	High sulfate concentration in ground	Reducing durability and increasing the chance of corrosion of the installed micropile foundations	Stainless steel micropiles were chosen over other possible solutions which couldnot fulfil the logistical constraints ortechnicalrequirements
Design	Variation in loadings, ground elevations and geometry	Either unsafe or overdesigned micropile numbers and lengths	Customized, specific foundation design for all individual legs of all towers / masts
Geology / Installation	Hard crystalline rock at or near surface	Better drilling progress with down the hole hammerin the limited construction period	Adapt pre-bored holes with TITAN INOX 40/16 as central reinforcement
Logistics	No access	No possibility to reach the site and mobilize plant & equipment	Arrangements were made to fly all equipment via helicopters. The maximum weight of all packing units was restricted to 950 kg

6 Conclusion

The project demonstrated that early and systematic risk management, combined with flexible foundation design and construction, enabled the successful design and construction of critical energy infrastructures in highly constrained alpine conditions. Adapting both the micropile concept and the construction methods to logistics, geology and durability requirements proved essential for maintaining safety, constructability and schedule. In particular, the use of INOX hollow-bar micropiles provided a robust corrosionprotected solution that could be transported by helicopter and efficiently installed in hard rock, while still achieving the required design performance. The experience from the Mörel–Ernen section underlines the value of close collaboration between designer, contractor and supplier, and shows that such stainless-steel micropile systems can effectively address combined challenges of difficult access, variable ground and high corrosive aggressivity.

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