Research on Horizontal Directional Drilling Scheme for Large Cross Section Submarine Cable Crossing Hard Rock

Fenqian Wu[1], Xiaoyu Huang[1,2], Haoci Qiu[1,3] Shaoyuan Lin[1], Xiaoxiang Chen[4*]

[1]State Grid Fujian Electric Power CO., Ltd. Fuzhou, Fujian, 350003, China
[2]Economic and Technological Research Institute, State Grid Fujian Electric Power Co., Ltd., Fuzhou 350000, Fujian, China
[3]State Grid Quanzhou Electric Power Supply Co. Ltd., Quanzhou 362000, China
[4]POWERCHINA Fujian Electric Power Engineering Co., Ltd., Fuzhou 350003, China

Abstract. With the increasing number of submarine cable projects, the terrain and geological conditions of the landing section are becoming increasingly complex, and the traditional implementation of trench burial is becoming increasingly difficult. A landing construction plan for large-section power cables suitable for steep terrain and rugged rock formations is studied and proposed based on sorting out existing submarine cable landing plans. Using directional drilling construction machinery ideal for rock formations, natural cable protection pipes are formed in rock formations after dragging and expanding the holes, meeting submarine cable protection's safety and economic requirements. In the climbing section of the submarine cable from the seabed to the rock hole, measures such as bottom sandbag raising and top rock throwing security are adopted to avoid vortex-induced vibration and erosion caused by the cable hanging in the climbing section. The construction plan of the directional drilling passage through hard rock and the construction and protection plan of the submarine cable do not affect the current situation of the existing coastal reefs and can effectively protect the submarine cable from external damage, achieving green and environmentally friendly construction.

1 Introdauction

With the continuous development of marine resources, there are increasingly island power grid projects and centralized transmission line projects for offshore wind power. At the same time, the voltage level of related line projects is also getting higher [1]. The cross-section of power cables often needs to exceed the manufacturing limit of 2500 mm2. Playing and operating large-section submarine power cables have higher requirements for bending radius [2]. On the other hand, with the continuous development of marine resources, the landing points of submarine cables have gradually shifted from flat and soil formations to steep and rocky formations, often making the protection of submarine cable landing a complex problem in engineering construction.

According to existing technical solutions, submarine cables often use slotting and burying, stacking bridges, and channels to build channels on the land surface before landing [3-4]. However, when encountering steep rock formations, the above methods will lead to difficulty slotting rocks, vertical slope landing and burying, and erosion prevention [5-6].

A horizontal directional drilling rig is a construction machinery that lays underground public facilities (pipelines, cables, etc.) without excavating the ground's surface [7]. It is widely used to construct flexible pipelines for water supply, electricity, telecommunications, natural gas, oil, etc. It is suitable for sand, clay, and other conditions and can also pass through weathered rock layers with high rock strength [8].

For the landing conditions of submarine cables in coastal hard rock (ftk≥ 60MPa) reefs, directional drilling machinery, and even anchor frames are installed at stable locations on the reefs. Horizontal directional drilling is used to drill and gradually drag and expand the holes to a through hole with an outer diameter of 1.5 times or more of the required submarine cable. For a single-core line, porous parallel laying is used, and the apparent distance of directional drilling is three times the diameter of the drag hole. The directional turning and crossing construction process is "hole by hole drilling and pulling back, jumping hole construction." The drilling construction methods include: ① directional drilling, ② graded pulling back and expanding the hole, ③ hole cleaning, ④ mud protection wall hole by hole drawing about large cross-section submarine cables, etc [9-10]. The construction method adopted by the present invention is less affected by the marine environment. It has the advantages of fewer changes to the shore reef environment during construction and better anti-erosion protection for submarine cables compared to trench burial laying or landing bridge laying.

*Corresponding author's email: chenxx919@126.com

2 Existing login schemes

Currently, the commonly used methods for submarine cable landing in engineering include slotting direct burial protection, cover protection, cable trench-type wharf landing, exposed overhead steel wharf landing, and casing protection.

2.1. Slotting and Direct Burial Protection

Trenching and direct burial protection are suitable for landing sites with flat terrain and the ability to excavate and bury trenches. Equipment for excavating trenches is often used during construction to mine the tracks first. Then, the submarine cables are directly buried, or reinforced concrete is poured into the channels before laying the cables, improving the ability of submarine cables to prevent external damage. This type of login protection is currently the preferred practice in engineering (as shown in Figure 1).

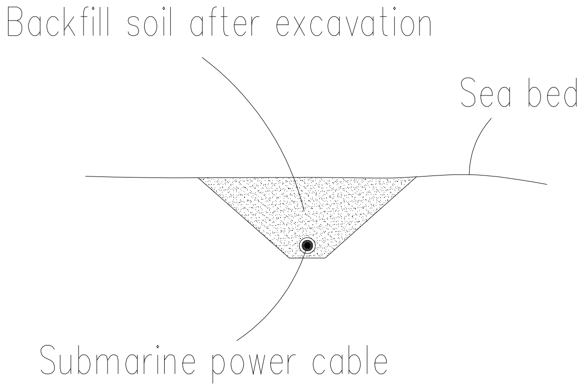


Figure 1. Direct burial protection.

2.2. Cover protection

When the excavation of trenches at the landing point is difficult, such as landing in a reef area, or although the landing point has the conditions for direct burial, frequent manual activities, or severe erosion around it will endanger the safe operation of the cable without taking additional protective measures. Based on this, specific protective measures can be covered outside the line to meet the requirements of cable safety protection. The criteria for protecting security include cover plate protection, riprap protection, and concrete bag or sandbag protection.

Stone-throwing protection is the most typical covering protection method. In the non-landing section, specialized ships are usually used to load onto the laid cables, and flexible falling stone conduits extend to a position 1m to 2m above the submarine cables for stone-throwing, avoiding significant impact on the submarine cables. The submarine cables exposed to the seabed are protected by double-layer stone throwing (as shown in Figure 2), and the inner layer is covered with smaller stone particles to cover the submarine cables; the outer layer is made of larger-sized stones to form a rockfill dam. Using small rocks in the inner layer can reduce the impact of the stone-throwing process on the cable, while employing large stones in the outer diameter can increase the stability of the rockfill dam in ocean currents. The slope toe formed by riprap protection should not exceed 30 °.

The cover plate can be divided into concrete cover plate and gabion cover plate. The cover plate has a significant weight and is applied in areas with high flow velocity or potential erosion.

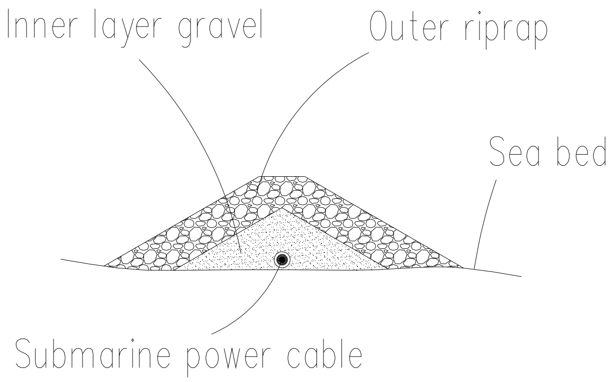


Figure 2. Riprap protection

2.3. Cable trench-type wharf landing

Cable trench-type wharf landing generally refers to pouring a specialized structure with a particular slope but relatively flat in a complex and steep excavation area for laying submarine cables. To meet the stability requirements of the concrete pier, several anchoring anchor rods can be installed at the bottom of the dock. The length of the anchor rods can be manageable, and generally, 2 meters in challenging rock areas can meet the requirements (as shown in Figure 3). Several stainless steel cable supports can be installed in the trench, and several openable concrete cover plates can be set at the top of the track for anti-floating and easy maintenance while also meeting anti-erosion requirements.

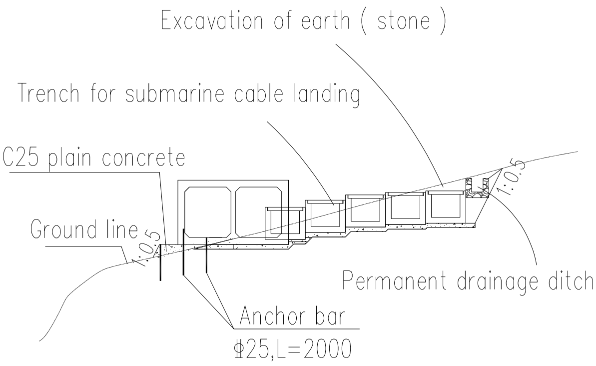


Figure 3. Cable trench landing bridge for the submarine cables

2.4. Exposed Steel Stack Bridge Landing

Public information shows that the practice of setting exposed steel pallets on steep slopes for submarine cable landing has been adopted both domestically and internationally. However, this process often faces difficulties in the anti-corrosion construction of steel pallets and susceptibility to external damage of submarine cables. Timely installation of protective pipes, such as steel pipes on the outside of submarine cables, can also lead to issues such as steel pipes being affected by direct sunlight and cable current carrying capacity. Therefore, this process is not very common.

3 Using directional drilling to cross complex rock landing plan

According to the existing submarine cable landing plan, it is mainly suitable for landing sections with relatively flat terrain and soil foundation as the primary foundation, such as trenching and burying, casing, concrete pier, etc. For horizontal directional drilling, the soil foundation crossing the seabed and the relatively flat section traversing the mountain are also the main sections. For submarine cable landing sections with significant height differences and complex rock foundations, there are important limitations:

(1) The laying construction plan of trench burial is adopted. For the landing section with steep slopes, significant height differences, and intricate rock layers, the construction difficulty is high, the construction period is long, the protection of submarine cable landing is challenging to implement, and significant safety hazards are in the construction process.

(2) The pouring of reinforced concrete piers in steep complex rock layers with significant height differences not only requires a tremendous amount of work but also poses challenges such as difficulty in pier construction, erosion protection, and changing the appearance of the existing coastline, which may affect the applicability of the subsequent coastline. There may also be issues concerning the landscape in places with scenic views.

(3) The trajectory control of directional drilling constrains existing horizontal directional drilling construction and cannot solve the problem of significant height differences.

(4) Using exposed steel structure piers or other overhead laying poses adverse conditions such as theft and disaster prevention. In contrast, seaside steel structures' corrosion and erosion prevention issues are prominent.

Therefore, the study adopts horizontal directional drilling construction technology and proposes a landing plan suitable for passing through hard rock.

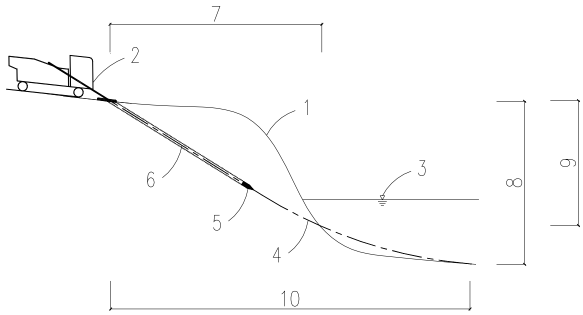
3.1. Where to place horizontal directional drilling through hard rock

The main steps for horizontal directional drilling to pass through hard rock and form a complete channel plan are as follows:

(1) The directional drilling rig is located above the rocky shore reef and meets the safety protection requirements at a distance from the landing point of the submarine cable (as shown in Figure 4 and Figure 5); Directional drilling machinery with the ability to form holes in rock formations travels downward from a high position at a certain angle to create directional holes; When seawater treatment is carried out at low tide, the expansion head begins to be pulled back, and after one or more expansion holes, a circular end hole with a diameter exceeding 2.5 times the outer diameter of the cable is formed in the rock layer (as shown in Figure 6).

(2) According to the different cable laying requirements, multiple holes can be divided for hole expansion, with a clear distance between holes more excellent than twice the outer diameter of the hole.

(3) Excavation construction involves anchoring wells, onshore cable trenches, and anchoring devices inside the wells.



1- Hard rock slope at the landing point of submarine cables; 2- High power directional drilling rig suitable for hard rock drilling and backhaul; 3- Sea surface at high tide level; 4- Directional drilling preset trajectory; 5- Wire drill bit; 6- Hole formation during wire drilling process; 7- Horizontal distance for landing directional drilling; 8- Height difference of submarine cable landing section; 9- Height difference of submarine cable crossing challenging rock sections; 10- Horizontal distance of submarine cable landing of the slope section

Figure 4. Close-range directional drilling construction

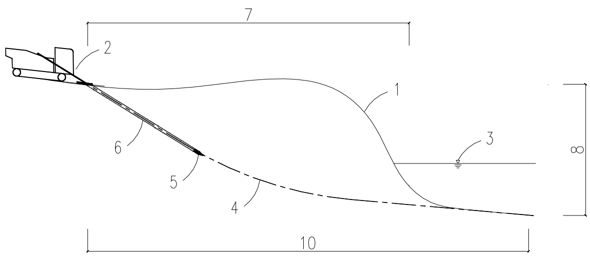
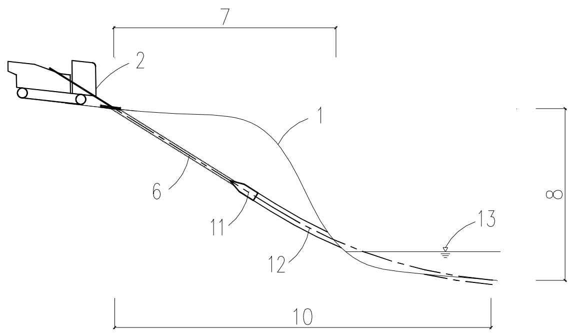


Figure 5. Long-distance directional drilling construction



11- Directional drilling expansion head suitable for hard rocks; 12- Final hole of drag back expansion in complex rock layers; 13- Water surface at low tide

Figure 6. Back drag and expansion hole construction in complex rock layers

3.2. Construction and Protection Plan for Large Section Submarine Cable Laying

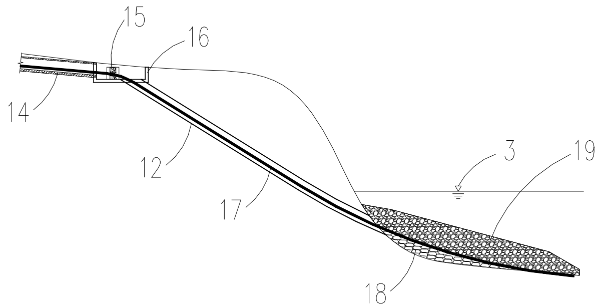
After the completion of the channel formed by horizontal directional drilling construction,

(1) After laying the submarine cable to the shore and forming an Ω shape, the cable traction rope is threaded through a circular hole in the formed rock layer to the beach. Sandbags are laid at low tide according to the position of the cable-pulling end hole and the position of the line being excavated on the seabed (as shown in Figure 7).

(2) By using a traction rope, the submarine cable is pulled from the directional drilling and expansion hole to the anchoring well, and the armor of the line is stripped and anchored to the anchoring device of the well, and it is docked with the cable trench behind the anchoring well. At the same time, during low tide, adjust the sandbags around the suspended section of the submarine cable between the rock hole and the seabed reasonably to ensure that the submarine cable falls evenly on the sandbags.

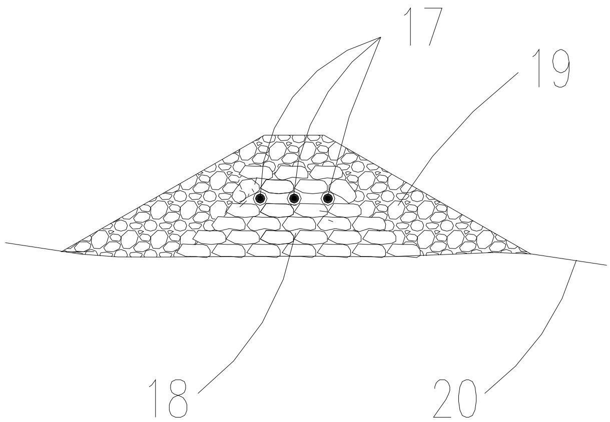
(3) After laying 2-3 layers of sandbags on the cable, stones are thrown outside the sandbags. The inner side of the stone is small, and the outer side is large, ultimately forming a rockfill dam with a slope of less than 30 ° on both sides. The rockfill dam is higher than the rock hole to prevent the cable from being exposed (as shown in Figure 8 and Figure 9).

(4) Check the changes in surface riprap after several ebb and flow tides and supplement thinner riprap areas if necessary.



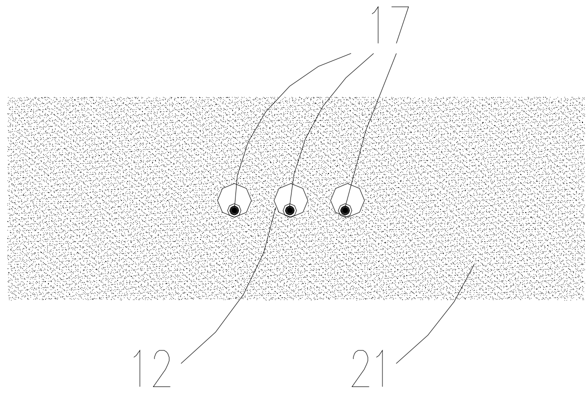
14- Cable trench for the land power cables; 15- Anchor device; 16- Anchor well; 17- Large cross-section submarine cables with amor; 18- Sandbags for the suspended part of submarine cables from the seabed to challenging rock sections; 19- Riprap protection at the top of submarine cables

Figure 7. Landing laying and protection construction of submarine cables in hard rock layers



20- Landing section seabed surface

Figure 8. Laying and Protection Construction of Submarine Cable Landing Section in Hard Rock Layers



21- Hard rock mass

Figure 9. Laying and Protection Construction of Submarine Cable Landing Section in Hard Rock Layers

4 Conclusion

Based on sorting out the existing submarine cable landing plans, research the landing construction plan for large-section power cables suitable for steep terrain and rugged rock formations. Using directional drilling construction machinery ideal for rock formations, the natural cable protection pipe in rock formations is formed by dragging and expanding the hole, meeting the safety and economic requirements of submarine cable protection. In the climbing section of the submarine cable from the seabed to the rock hole, measures such as bottom sandbag raising and top rock throwing guard are adopted to avoid vortex-induced vibration and erosion caused by the cable hanging in the climbing section. The construction plan of the directional drilling passage through hard rock and the construction and protection plan of the submarine cables are okay with the current situation of the existing coastal reefs. It can effectively protect the submarine cable from external damage. This scheme provides a new solution for laying, constructing, and protecting large cross-section submarine cables in complex rock formations.

Acknowledgments

This work was financially supported by State Grid Fujian Electric Power CO., Ltd. through Grant No. 52130N220011.

References

1. HUANG Xiaowei, LI Xiaojun, ZUO Ganqing. Application Status and Prospect of Submarine Cable Projects at Home and Abroad[J]. Wire & Cable, 2023(1):1-6.
2. ZHOU Ziqiang, WANG Shaohua, ZHONG Xiaobo. Some Scientific Problems in Development and Engineering Application of 500 kV XLPE Submarine Cable[J]. ZHEJIANG ELECTRIC POWER, 2020, 39(6):1-7.
3. Pan H.TRAI releases recommendations on 'Licensing Framework and Regulatory Mechanism for Submarine Cable Landing in India'[J].Submarine Fiber Optic Communications Systems, 2023.

4. Zhang Z , Dong Y , Yuan Z ,et al. Innovative floating support technologies for submarine cable landing[C]//Asia-Pacific Power and Energy Engineering Conference.2020.
5. CHEN Jun, WU Cong, CHEN Cheng, et al. Scouring Mechanism and Protective Measures of Submarine Cable[J]. CHINA OFFSHORE PLANFORM. 2020,35(6):68-73.
6. He Pengqi, Liang Hantian, Liu Zhao. Risk analysis and detection practice of offshore wind and submarine cables [J] Wind energy, 2023, (04): 94-97.
7. Manacorda G , Miniati M , Simi A ,et al.Development of a bore-head GPR for Horizontal Directional Drilling (HDD) equipment[J].IEEE, 2014.
8. Hobohm S .The Horizontal Direction Drilling Technique at DN 500[J].Gwf, 2015, 156(s1spec.):37-43.
9. Winiowski R , Opata P , Orowicz G .Numerical Methods for Optimization of the Horizontal Directional Drilling (HDD) Well Path Trajectory[J].Energies, 2020, 13(15):3806.
10. Olumoko F T , Ossia C V .Stress Analysis of Buried Pipeline Installed by Horizontal Directional Drilling Using ANSYS Finite Element Software[J].World Journal of Engineering and Technology, 2019, 07(3):365-378.