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Numerical Simulation Study on The Degree of Submarine Cable Protection by Riprap Protection Layer Against Anchor

Zhiyuan Cheng*, Zhonggui Zhang[a] and Qiong Nie[b]

School of architecture and materials engineering, Hubei University of Education, Wuhan, China

*Corresponding author e-mail: chengzhiyuan2008@163.com, [a]252850690@qq.com, [b]491947848@qq.com

Abstract. Based on the discrete element theory, the rockfill-anchor-cable discrete element model was built on the PFC^{3D} simulation platform. Combined with the engineering practice, numerical simulation of the penetration process of anchor into the submarine cable riprap protection layer was carried out, the relationship between force and displacement and the sidewall pressure of the submarine cable under the anchor partial penetration were obtained, and the anti-anchor damage ability of the submarine cable was evaluated quantitatively. The results show that the resistance force of the riprap to the anchor increases gradually with the increase of anchor invasive displacement, and eventually stabilize, which reflects the forming, developing, rupturing and restructuring process of the physical chain of the ripped-rock. Furthermore, the riprap protection layer has a significant protective effect on the submarine cable.

1. Introduction

With the rapid development of global economy and technology, submarine cable is more and more applied to communication and power transmission across the sea and river. British Telecom laid the world's first international commercial cable in the English Channel In 1850, since then, dozens of Such long-distance submarine cable appeared in the world in more than 100 years [1]. With the improvement of our inter-island electricity network, the increase needs of communication, and the rapid development of international information exchange, choosing the submarine cable as electricity and communication transmission medium across the sea or river has become a necessity. In recent years, submarine cables damaged by anchorages are accident-prone, and the safe operation becomes a grave threat, IEEE submarine cable laying specification listed anchor-caused fault as the biggest man-made disasters [2, 3]. In order to prevent the direct damage of the anchor on the submarine cable, we usually take different protection measures according to different conditions of the seabed, such as casing protection, blunt buried protection, the riprap protection, et al [4]. If the seabed on the channel line is hard, The general preferred riprap protection scheme. However, submarine cable covered with riprap protection layer also will be affected by the anchor. So far, research in the field of submarine cable laying focused on the selection of cable type, route planning, construction method etc, and the research on submarine cable protection only limited to the bare condition. However, the quantitative research on submarine cable protected by riprap is basic or blank. Therefore, this paper will do the

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numerical simulation analysis of the relationship between force and displacement of riprap protection layer under the local penetration of anchor, quantitative assessment anti-anchor damage ability of the riprap protection layer, and explore a practical way of quantitative analysis for the security of submarine cable covered with riprap

2. Numerical simulation method

The riprap protection layer is rockfill, it is collection consist of a certain gradation of rock particles. Unlike continuous media materials, it has unique mechanical properties [5, 6]:

(1) The shear strength of rockfill depends on the coefficient of friction between the particles,and it is proportional to the pressure within a certain range;

(2) Because there are a lot of porosity within the rockfill, it will expand or contract under the action of shear stress;

(3) The rockfill will produce elastic strain and the plastic strain under external loads,this is because the bite role between particles is not strong in the low pressure environment,so it produces sliding and dislocation.

The rockfill exhibit some unique mechanical properties as a result of the interaction between the particles [7]. The contact force between particles will change with the accumulation form of rockfil. Under the action of load, particles may appear sliding, extrusion and rolling, so that within the rockfill particles rearrange and the rockfill produce macroscopic deformation. Therefore, we must combine microscopic structure and macroscopic mechanical in the study of the mechanical properties of the rockfill, and consider the links between them [8]. So, this article will apply the Discrete Element Method (DEM), simulatie the penetration process of anchor into the riprap protection layer based on the DEM analysis platform PFC^{3D}.

3. Discrete Element Model

When using DEM to study the mechanical properties of granular media, distribution of the particles can be seen as random. Due to the random variables are mostly used random number representation, this requires to produce uniform distribution of random numbers [9]. In order to produce uniform distribution of discrete particle combination in computer, the Monte Carlo method can be introduced. Monte Carlo method is a numerical calculation method based on probability and statistical theory, it has obvious advantages in solving the problems of stochastic and deterministic: the convergence rate has nothing to do with the dimension, there is little effect by the geometric conditions, and it has the ability to handle continuous problems and ability to deal directly with the randomness [10].

3.1. Riprap Model

In pellet stack algorithm aspect, this article will use particle size expansion method: first, establish the boundary consist of wall unit, and generate particles according to the smaller radius range in border randomly. Then, expand the grain to the required radius for implementation of particle dense extrusion; At last, remove the wall unit boundary, through the calculation the stress releases, and the rockfill will achieve natural accumulation condition, as shown in Figure.1:

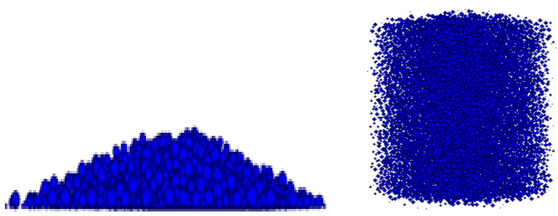

Figure. 1 Cross section and plan of rockfill.

The computational efficiency of DEM is embodied in the two processes: contact detection and the calculation of the overlap between particles. For 3D spherical particles, calculation of these two processes is very simple. But For particles of other shapes, calculation of the two processes become much more complex which result in lower computational efficiency. But in nature, the shape of the particles is non-spherical in most cases, such as the riprap of submarine cables [11]. in order to be closer to the actual situation, this article will use the tetrahedral particles to simulate the actual particle shape.

A simple and effective method to simulate non-spherical particles is the way of the atomic aggregate into molecular [12]: getting several smaller particles together with rigid connection into the block needed. within the same block, particle contact is negligible, and the algorithm of connection of the block and the surrounding particles is the same with spherical particles. This article used an alternative method, that was generating rockfill by spherical particle first, and then combining four spherical particles into a tetrahedron.

Because of the large particle size, the ankylosis role with the particle don't be considered in this article. The contact model between particles adopt Hertz contacts model. As a result of the low movement velocity of the particles and small viscosity coefficient of sea water, local damping was not considered. A large amount of particulate matter system example by SUN Qicheng and Liu Jiangguo show that the damping ratio is about 0.05~0.1, in this article,viscous damping ratio is 0.1.

3.2. Submarine cable model

Because there is no Continuous media unit to describe the submarine cable in PFC^{3D}, spherical particles of parallel combination were used to simulate submarine cable approximately in this article. Due to the stiffness of the adhesive material, force and moment will come into being owing to the relative displacement at the contact point, and their value depends on the Normal and tangential stress, that is why the spherical particles of parallel combination can simulate the submarine cable approximately. A list of particles contact with each other was generated and the radius of particle is the same as submarine cables. The normal and tangential stiffness of the parallel bond normal were obtained in accordance with the equivalent elastic disc. Figure.2 shows the submarine cable model in PFC^{3D}:

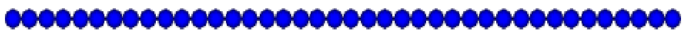

Figure. 2 Submarine cable model

3.3. Anchor model

PFC^{3D} cannot directly generate the object of complex shape,therefore,it use the method of atoms into molecules in this article:first,generate wall unit boundary according to the anchor of the shape,and generate smaller particles in the space surrounded by the boundary;Then,enlarge the particle diameter until close contact between the particles,and get all the particles generated together into a rigid body.Figure.3 shows the anchor model in PFC^{3D}:

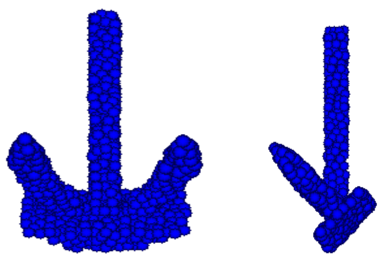

Figure. 3 Anchor model

4. Engineering Example

4.1. Project overview

Taking the Qiongzhou Strait 500KV submarine cable riprap protection project as the research object, which across the Qiongzhou Strait from Guangdong Province to Hainan Province, the total length is about 31km.In this paper, we choose the anchor force at 50% specified length of the rope [13]: the horizontal load on the anchor is 17.031*KN* and no vertical load, the anchor is Spike Anchor. The parameter of riprap and cable is as following:

Table. 1 Riprap parameters

density	Modulus of elasticity	Poisson's ratio	Coefficient of friction
2650kg/m^3	70GPa	0.18	0.35

Table. 2 Cable parameters

Cable diameter	Cable weight in air	Cable weight under water	Maximum allowable sidewall pressure	Equivalent elastic modulus	Poisson's ratio
139mm	48kg/m	32kg/m	17kN/m	50GPa	0.3

Riprap protection program is using Dynamic Positioning method,throw rocks above the cable,the thickness of rockfill is at least 1 meter.The shape and size of the rockfill is as following [14]:

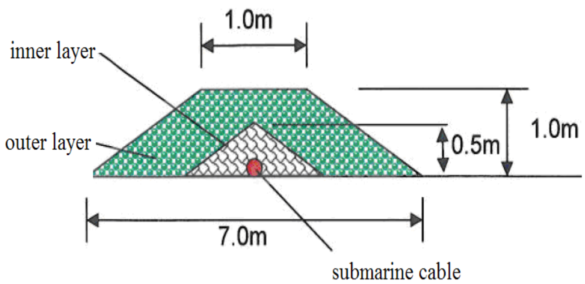

Figure. 4 The shape and size of the rockfill

The inner layer of the rockfill use the stone of 1~5 inches to prevent cables from being damaged, and the thickness is 0.5m above the sea-bed;The outside layer use the stone of 2~8 inches to ensure the stability of the rockfill.

The calculate model of the rockfill against anchor is as following:

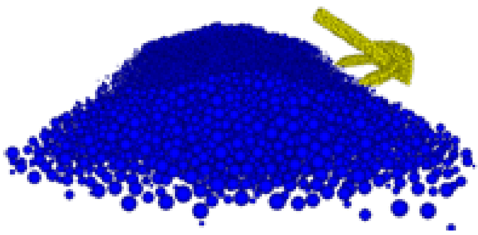

Figure.5 Model of the rockfill against anchor

4.2. Simulation results and analysis

When the anchor penetrates from the side of the rockfill inside the protective layer under the traction of the chain,the internal particles mutually staggere and rearrang so as to produce adverse effect to the submarine cables. What's more, the anchor may pierce through the riprap protection layer and hook the submarine cable directly, which causes the riprap protection layer expiration. By monitoring the the relationship between resistance force and the intrusion displacement and the sidewall pressure of submarine cable, we can analysis the special mechanics characteristic of the riprap protection layer when dredging anchor.The relationship between resistance force and the intrusion displacement can be obtained by PFC^{3D} as follows:

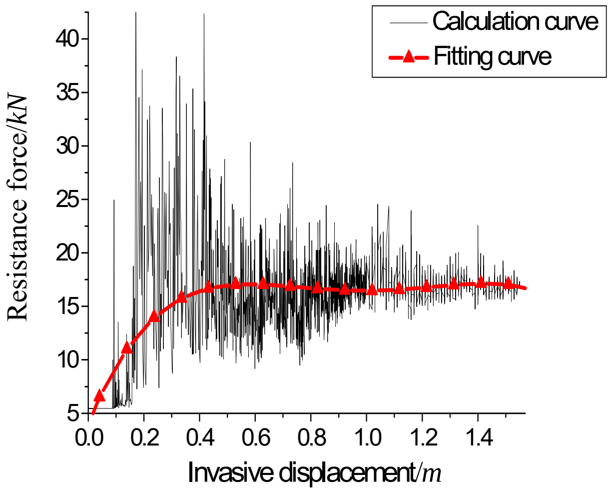

Figure.6 The relationship between resistance force and the invasive displacement

Figure.6 shows that the resistance force gradually increases at first, then fluctuates around the horizontal load(17.031*kN*) of the anchor, and gradually stabilizes at last. The development of the resistance force can be divided into two phases: The first phase is the formation and development of force chain. In this phase, the rockfill is extruded densely with the movement of the anchor, and the force chain in the rockfill starts to form and develop. Thus, the resistance force increases with the increase of invading displacement of the anchor. At the same time, the resistance force has large fluctuations for the redistribution of the particle system; The second phase is the break and reconstruction of force chain. When the force chain is sufficiently developed to resist the anchor caused force, the force exerted on the particles end of the force chain is very small, so the particles basically intact that they can be regard as been restrained. Because the particles are loosely packed that the lateral pressure is not big. when the resistance force develops to a certain extent, the force chain will fracture, then the resistance force will decrease in a sudden and then new force chain will restructuring. Therefore,the value of the resistance force will fluctuate around the value of external load. Throungh the simulation, we can also get the relationship between invasive displacement and the sidewall pressure at the most unfavorable position, as follows:

Figure.7 shows that the sidewall pressure of the submarine cable maintains small at the beginning, and basicly were not affected by the influence of the anchor until the invasive displacement increased to 0.25*m*.Then the sidewall pressure reaches the maximum value(5.83*KN/m*).In the whole process, the anchor doesn't hook the submarine cable directly, and the sidewall ressure of the submarine cable has not reached limits(17*KN/m*) which effectively protect the submarine cables.

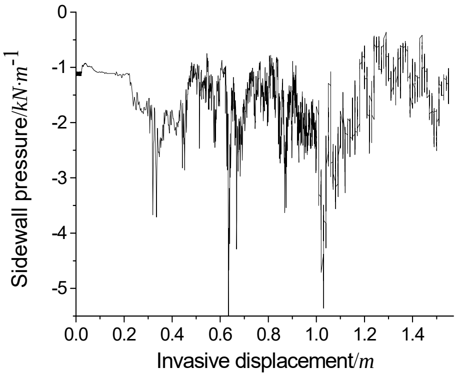

Figure.7 The relationship between sidewall pressure and the invasive displacement

5. Conclusion

Discrete Element Method is able to effectively simulate the special mechanical properties of the riprap protection layer during the local lateral penetration by anchor, and can intuitively descrip the development trend of the force chain inside the riprap protection layer, so it can provide design basis for submarine cable protection by riprap protection layer against anchor.

Acknowledgments

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