Research on simulation of anchor concrete frame beam reinforcement in slope

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Abstract. The anchor concrete frame beam is a kind of slope protection structure. Based on the project of a road cutting slope from Havelian to Thakot highway in China–Pakistan Economic Corridor, the reinforced effect of anchor concrete frame beam is studied by using the strength reduction finite element method. The safety coefficients are obtained from the stability analysis of slopes with different coefficients in similar geo-environmental settings. The results show that the anchor concrete frame beam can decrease the horizontal displacement significantly and increase the slope stability. The slope stability reduces as the slope coefficient increases in the same engineering settings. The results can provide reference for the design and construction in the project of high road cutting slope.

1. Introduction

The anchor concrete frame beam, as a kind of light-weight geotechnical support structure, plays a role in slope protection and ensure the overall beauty of the slope. As it is convenient to construct and flexible to design, this kind of structure has become one of the most widely used direct protection methods for road slope engineering [1] [2] [3]. In the analysis of the force mechanism of the frame beam, Liu Xiaoli et al [4] based on the linear elasticity winker foundation model, used the finite element method of the bar system to simulate the frame beam. As this method is very limited in mathematical calculation according to the elasticity theory, the problem of vertical and horizontal coordination deformation of the frame beam cannot be solved. And then, Liu Xiaopeng [5] used the 3D simulation software Ansys to carry out three-dimensional numerical analysis on frame beam slope of the actual engineering, and analyzed the force mode of the frame beam in the reinforcement slope. The limit equilibrium method is used mostly to evaluate the slope stability of frame beam reinforcement. This method is to analyze the stability of the slope after strengthening the slope from the static balance, which cannot reflect the deformation of the slope body, and because the force exerted on the frame beam has a three-dimensional space characteristic, it is difficult to effectively evaluate the reinforcement effect of the concrete frame beam by simply using the limit equilibrium method. As a result, the finite element strength reduction method is used to analyze the different gradings by combining the actual project of the high-speed slope of the highway project from the Havelian to Thakot section of the China–Pakistan Economic Corridor. The stability safety factor of the slope engineering and the force characteristics of the frame beam in the case of series, the calculation results have certain guiding significance for the engineering and its design optimization.
2. Introduction of anchor concrete frame beam

The anchor concrete frame beam structure combines the plane frame and the anchor rod. Through the combination of anchor rod and plane frame with rock and soil mass of slope, the supporting structure is formed to bear the landslide thrust and keep the slope in a stable state. The concrete frame beam is cross-linked by the beam and the longitudinal beam to form an integral frame structure. The anchor is anchored at the intersection of the frame beam and the longitudinal beam at one end, and anchored to the stable formation inside the slope at the other end (as shown in Figure 1). The anchor rod is a flexible force-bearing rod. Only it is combined with the rock and soil body can it form a force system under the coordinated deformation of the frame beam. So, the anchor rod, the frame beam and the rock and soil body of slope these three together to form a retaining system and play a protective role.

3. Calculation principle of slope stability strength reduction method

There are two main types of slope stability analysis methods, one is the limit equilibrium method, and the other is the strength reduction method. The stress characteristics of the anchor frame beam have obvious three-dimensional effect, and the strength reduction method can be used to analyze the overall deformation of the slope. The strength reduction method is to reduce the shear strength until the calculation cannot converges, and consider the stage without convergence as the damage, and the maximum strength reduction rate of the stage is taken as the minimum safety factor of the slope. When the safety factor is calculated by the strength reduction method, it is considered that the elastic modulus E and the Poisson's ratio \( \mu \) of the slope are constant, and the cohesive force \( C \) and the internal friction angle \( \phi \) are gradually reduced in the following manner until the divergence is calculated, and the divergence is \( Fs \) is used as the minimum safety factor. The safety factor is calculated as follows:

\[
F_s = \frac{\tau}{\tau_i}; \quad \text{Where} \quad \tau \text{ is the shear strength of the slope, and } \tau_i \text{ is the shear stress on the sliding surface.}
\]

\[
\tau = c + \sigma_n \tan \phi, \quad \tau_i = C_f + \sigma_n \tan \phi_f.
\]

\[
c_f = \frac{c}{SRF}; \quad \phi_f = \tan^{-1} \left( \frac{\tan \phi}{SRF} \right); \quad \text{Where } SRF \text{ is the strength reduction factor}
\]

4. Engineering case analysis

4.1. Overview of Highway Engineering of China-Brazil Economic Corridor

The Highway between the Haveli and Thakot sections of the China–Pakistan Economic Corridor has a total length of 19.419 km. This section is a combination of the gentle slope at moderately low mountain and the river valley. The terrain is high in the west and low in the east. According to the topographic map and cross section, the difference of the ground height within the excavation range of the deep excavation is 65.60m. The stratum structure of the slope area is simple, and the mountain slope rock has been exposed, covered with breccia and macadam locally and sporadically, and the
underlying bedrock is Precambrian phyllites, mainly is strong weathered phyllite, which is gray, cryptocrystalline structure, thousand-piece structure, joint fissure development, rock mass fracture, core breccia-gravel-like, and its physical and mechanical parameters are shown in Table 1. The bolt frame beam slope protection is adopted, and the coefficient excavation is carried out. Figure 2 is a layout diagram of the sash frame beam of the slope section of a certain mileage section. Frame beam design: Grid spacing 3.0m*3.0m is adopted for protection. The vertical rib width of the frame beam is 20cm, and the width of the transverse rib is 20cm, and the thickness of the beam ribs is 25cm. On both the upper and lower sides use two φ12 steel bars as the main ribs of the steel bar, and hooping with φ8 steel bar in 30cm spacing. Every 4 vertical ribs (12m) of grid slope protection are set with 2cm deformation joints, and each joint is filled with asphalt-soaked wood or asphalt of 2cm thick. The cross section of the frame beam is shown in Figure 3.

Table 1. Physical and mechanical parameters of soil.

| dry density $\rho_d$ /g·cm$^{-3}$ | saturated density $\rho_s$ /g·cm$^{-3}$ | cohesive force (KPa) | internal friction angle ($\phi$) |
|----------------------------------|---------------------------------------|----------------------|-------------------------------|
| 2.5                              | 2.55                                  | 15                   | 28                            |

![Fig 2. Elevation of slope of a certain mileage.](image)

![Fig 3. Layout diagram of frame girders.](image)
4.2. Calculation model
This project has characteristics of long lines, high and low terrain, and different slope heights. If each section is calculated, it will take a long time and the calculation amount is large, and the excavation of slopes of different heights adopts the method of laying slope ratio 1:1 and slope height 10m to arrange the frame girders. In the calculation, the safety factors of slopes with different slope relief series are calculated firstly, and then the corresponding safety factors of slopes with different mileage can be found after the slope height corresponds to the slope coefficient value. This method provides a fast and effective analysis method for studying the overall stability of slopes with different regions in similar sites. This method can be extended to other similar slope projects, providing an effective theoretical basis for practical engineering. The slope is 65.60m high and the slope height is 18.2–65.60m. The simulated slope coefficient is divided into 2 slopes, 3 slopes, 4 slopes, 5 slopes and 6 slopes. The calculation model constitutive model adopts Mohr-Coulomb. The model, frame beam and anchor are elastic constitutive and beam element simulation. The finite element mesh model of each grading series is shown.

4.3. Analysis of stability results of slopes with different slope coefficients
When using the finite element strength reduction method for slope stability analysis, the criterion of instability is determined by numerical calculation without convergence; when it is not converged, the strength reduction coefficient is the safety factor of slope stability. Figure 5 shows the overall equivalent plastic strain cloud of the 3D model slope without convergence under different grading series conditions. In the figure, the plastic zone of the sliding zone of the slope extends from the top of the slope to the foot of the slope, and the plastic shear strain area is critically penetrated. According to this, the safety factor of each slope is judged.
Fig 5. Equivalent plastic strain cloud maps of different levels of the slope

When the calculation of the slope of each level does not converge (determined to be unstable), Table 2 shows the corresponding strength reduction factor, the safety factor, and the relationship between the number of slope stages and the safety factor is shown in Figure 6. The calculation results show that the safety factor of all levels of slopes meets the requirements after the frame beam reinforcement. The reinforcement method of the frame beam is simple and effective. At the same time, with the larger the slope coefficient is, the safety factor is gradually reduced. When reaching the 6 slopes, the safety factor is 1.2, the slope coefficient continues to increase, and the frame beam reinforcement method is adopted, and the safety factor will not reach the specification. Claim. In view of the close proximity of the geotechnical parameters of the China–Pakistan Economic Corridor Highway Project, slopes of height below 60m can be carried out by frame beam reinforcement, and other effective and reasonable reinforcement methods are required. According to the slope coefficient, the safety factor of different height slopes is evaluated, which is a simple and effective calculation method for projects with similar line lengths.

Table 2. Safety factors of stability of different levels of the slope.

| Levels of the slope | Safety factors | Stability of the slope |
|--------------------|----------------|-----------------------|
| 2                  | 2.525          | stable                |
| 3                  | 1.85           | stable                |
| 4                  | 1.475          | stable                |
| 5                  | 1.35           | stable                |
| 6                  | 1.2            | stable                |

Fig 6. Curve of safety coefficient and slope relief series.

5. Conclusion

In view of the wide application of concrete girders in practical engineering, combined with the three-dimensional finite element model, the strength reduction method is adopted and each slope section is classified according to the slope coefficient. The stability safety coefficients of several slopes are calculated separately. Generally speaking, the larger the slope coefficient is, the lower the
safety factor is. In the actual project, the safety factor of different slope height is evaluated according to the slope coefficient, which is a simple and effective calculation method for the project with a similar length.

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