Influences Analysis of Dynamic Response for Slope Supported by Frame with Anchors under Different Anchor Intervals

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Abstract. This article based on the practical engineering in the northwest loess area in China, considered the interaction and collaborative work of frame-anchor-soil, with the help of the finite element software ADINA, established a 3D finite element model of the frame prestressed anchor supporting slope system under earthquake action. In the model, the soil was simulated by elastic-plastic model, and a bilinear elastic model was used to simulate the anchor, friction-element was used to describe the interaction between soil and frame (beams, columns and retaining plate), the frame is simulated by a bilinear elastic-plastic model. By inputting bidirectional seismic waves, the dynamic response of the supporting system under different horizontal and vertical spacing of anchors was compared and analyzed. Finally, obtained the influence law of different anchor spacing on the slope seismic response.

Keywords: Frame with anchors; supporting slope; seismic action; dynamic response; anchor spacing.

1. Introduction

With the development and construction of the western part of China, a large number of roads, railways, urban structures and other infrastructure facilities have to be built in the loess region in the northwest of China, so there are a large number of slope projects [1-4]. Earthquakes are very harmful to slopes. In order to ensure the normal operation of the road and the stability of people's life, it is necessary to select a reasonable form of support structure to support and reinforce these slopes [5-6]. As a new type of flexible support structure, frame with pre-stressed anchors has been more and more widely used and the effect is remarkable [7-12]. However, it is difficult to systematically study the supporting parameters of the flexible support slope with frame with pre-stressed anchors under the earthquake. Many studies used the finite element numerical method to solve the problem in slope engineering [13]. Simulating the engineering and determining the qualitative relationship among the parameters of the supporting system and study the influence of various parameters on the support of seismic response of the slope. It is significance to the design of the slope supported by frame with pre-stressed anchors in loess region.

The paper based on the actual project in northwest loess region. The influence of different anchor spacing on the slope system is analyzed with the help of the numerical analysis software ADINA. Considering the interaction and collaborative work of frame-anchor-soil, establishing the 3D finite...
element model of the frame anchor supporting slope system under the earthquake. In the model, an elastoplastic model is used to simulate the soil mass. The bilinear linear elastic model is used to simulate the anchor. The contact element is used to simulate the relationship between the soil mass and the frame (beam, column and retaining plate). The frame is simulated by bilinear elastic model. This paper mainly studies the effects of different horizontal and vertical anchor spacing on the seismic response of slope displacement peak, acceleration peak, anchor axial force and earth pressure peak.

2. Project Summary
In a loess slope engineering, the slope height is 12m, the angle between the slope and the horizontal plane is 80° and the safety coefficient is 1.3. The seismic fortification intensity of the project is 8 degrees and the peak acceleration of earthquake is 0.30g. The soil parameters of the slope are shown in table 1. The section size of frame beam and column is 400mm×400mm and the thickness of retaining plate is 150mm. The design parameters of C20-grade concrete anchor are shown in table 2.

### Table 1. Soil parameters of the slope.

| Cohesive force (kPa) | Angle of internal friction (°) | Severe (kN·m⁻³) | Ultimate friction (kPa) |
|----------------------|-------------------------------|------------------|-------------------------|
| 18                   | 25                            | 16.4             | 50                      |

### Table 2. Anchor design parameters.

| The layer number of anchor | Anchor solid diameter (mm) | Steel bar diameter (mm) | Free length (m) | Length of anchorage section (m) | Total anchor length (m) |
|---------------------------|---------------------------|-------------------------|-----------------|-------------------------------|------------------------|
| 1                         | 150                       | 28                      | 6               | 10                            | 16                     |
| 2                         | 150                       | 28                      | 5               | 10                            | 15                     |
| 3                         | 150                       | 28                      | 5               | 9                             | 14                     |
| 4                         | 150                       | 28                      | 4               | 8                             | 12                     |
| 5                         | 150                       | 28                      | 4               | 7                             | 11                     |
| 6                         | 150                       | 28                      | 4               | 5                             | 9                      |

3. Seismic Wave Selection
In this paper, the dynamic analysis is based on the initial stress state of the slope supported by the frame with pre-stressed anchors. The influence of deformation and other factors on the static force of the frame with pre-stressed anchor support structure is ignored. The seismic action refers to the horizontal and vertical seismic action of the EL Centro seismic wave, the finite element model is the X axis and Z axis, as shown in figure 1.

Figure 1. EL-Centro oscillogram.
4. Establishing the Numerical Finite Element Analysis Model
In the model, 100kN prestress is applied to all anchors. In order to minimize the impact of the boundary on the seismic response, a range of 4-10 times the depth of the slope is taken as the calculation area [14]. For this reason, the numerical model takes 5 times of slope height as the lateral boundary.

![Figure 2. The finite element calculation model.](image)

(a) Frame-anchor layout (b) Retaining plate model

![Figure 3. Layout diagram of the supporting structure.](image)

5. The Influence of Anchor Spacing on Earthquake Response
It has been found from a large number of practical projects that the anchor spacing has a great influence on the static stability of the slope, the displacement of the slope, the axial force of the anchor and the magnitude of the earth pressure. The horizontal anchor spacing under the static action is more obvious than the vertical one [3]. While under the action of earthquake, there are few researches and analyses on the influence of anchor spacing on the peak of slope displacement, peak of acceleration, peak of axial force and peak of earth pressure in each row of anchor. In this paper, a software ADIAN is introduced to simulate this problem. Figure 4 ~ 7 show the influence of anchor horizontal spacing on seismic response, which can be divided into three working conditions, namely, the horizontal spacing is 2.0m, 2.5m and 3.0m. Figure 8 ~ 11 show the influence of vertical spacing of anchor on the seismic response, which can be divided into three working conditions, namely, the vertical spacing is...
2.0m, 2.5m and 3.0m. It can be found from the figure that, under the action of earthquake, the peak of slope displacement and peak of acceleration and peak of axial force and peak of earth pressure in each row of anchor all increase with the increase of the spacing both in the horizontal and vertical directions, and the influence of the horizontal spacing is more obvious than the vertical spacing.

### 5.1 The Influence of Anchor Horizontal Spacing on Earthquake Response

#### Figure 4. Effect of the displacement peak on the slope about horizontal spacing.

#### Figure 5. Effect of the acceleration peak on the slope about horizontal spacing.

#### Figure 6. Effect of the axial force of each layer anchor about horizontal spacing.

#### Figure 7. Effect of the soil pressure peak about horizontal spacing.
5.2 The Effect of Anchor Vertical Spacing on Seismic Response

Figure 8. Effect of the displacement peak on the slope about vertical spacing.

Figure 9. Effect of the acceleration peak on the slope about vertical spacing.

Figure 10. Effect of the axial force of each layer anchor about vertical spacing.

Figure 11. Effect of the soil pressure peak about vertical spacing.

6. Conclusion
Through a project example, the seismic response of slope supported by frame structure with prestressed anchors under the different anchor horizontal spacing and the vertical spacing is analysed. From what has been discussed above, the conclusion as follows. On the one hand, under the seismic action, the peak of slope displacement, peak of acceleration, peak of each row of anchor axial force, and peak of earth pressure increase with the increase of the horizontal spacing and the vertical spacing. On the other hand, the influence of the horizontal spacing is more obvious than the vertical spacing.

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