1 Introduction

Landslides are a common and second most devastating disaster after earthquakes in terms of degree of damage (Yan et al., 1989). Therefore, research study on the early warning and forecasting of landslide has been undertaken since the 1960s. The current forecast system is based on the verification of prediction focused on the following: method of mechanism analysis, method of landslide deformation precursor phenomenon based on experience, statistical mathematical modeling method, integrated multi-parameter prediction method, and method based on nonlinear science. Considering that the evolution process of landslide consists of deformation, development, maturity, and destruction, Yan (1995) used the Verhulst biological growth model, which is one of the most typical prediction models to describe and predict landslides successfully. Li (1996) used the Verhulst inverse function model, another common prediction model, to fit and describe the slope deformation characteristics under the analysis of slope deformation and failure mechanism. Sun et al. (1993) established the Pearl biological growth model, which is promising but lacks tests for landslide prediction. Alternatively, Saito (1965; 1969) attributed the development of landslide to unstable flow stage, constant flow of viscoplastic phase, and accelerated phase, which was supported by experiments and analyses of practical experience. As the landslides on Oigawa railway, Cairn Tunnel, and ZongGu trunk were successfully predicted, this theory creates a landslide forecast precedent. However, the time of occurrence of slope failure, which is associated with the steady-state rate, is not applicable in the creep range. Therefore, this paper establishes a logarithm landslide forecasting model based on the three periods of slope creep theory and combines it with the definition of asymptotic lines to make accurate landslide prediction.

2 Slope creep theory

The process of landslide deformation and failure process is essentially a process of creep deformation of rock mass. Slope creep is defined as a “slow, more or less continuous deformation or flow of excavated and natural slopes involving rock, soil, ice or combination materials which take places under gravity and external loadings” (Emery, 1979). Rock mass deformation studies show that under continuous function of load, deformation increases with time and show the characteristics of a three-stage evolution (Crosta, 2003). Many instances of landslide monitoring data show that under the action of load, slope rock mass deformation evolution has a similar three-stage evolution curve. Phase I is an initial deformation stage, phase II is a constant deformation stage, and phase III is an accelerated deformation stage.

When a slope enters the accelerated deformation stage until it is completely damaged, its deformation changes dramatically (Ter-Stepanian, 1963; Fukuzono, 1985; Voight, 1988). The displacement-time curve forms an exponential curve according to the definition of an asymptotic line. When point M along the curve is infinitely far away from the origin and the distance of the straight line is infinitely close to zero, the line is called the asymptote of the curve. Likewise, for the deformation-time curve, if the deformation becomes infinite in a short period, a massive slide will take place at this time. Therefore, the focus is to establish a model function with an asymptotic line according to the monitoring displacement-time curve, make a dynamic fitting, and adjust the model parameters with real-time monitoring data, thus determining the asymptotic line. In this case, the prediction of the destruction of a slope can be relatively accurate.

3 Logarithmic prediction model

The dynamic fitting for this model combined with monitoring data is not in linear fitting, but in non-linear least squares fitting with Levenberg-Marquardt (LM) algorithm (Lourakis, 2005).
Table 1, the fitting results of each measuring point

<table>
<thead>
<tr>
<th>Measuring point</th>
<th>Model parameters</th>
<th>Fitting coefficient</th>
<th>average residual error</th>
<th>Asymptote value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD2</td>
<td>0.014</td>
<td>0.026</td>
<td>0.994</td>
<td>13.949</td>
</tr>
<tr>
<td>SD6</td>
<td>0.013</td>
<td>0.014</td>
<td>0.997</td>
<td>12.908</td>
</tr>
<tr>
<td>SD7</td>
<td>0.014</td>
<td>0.008</td>
<td>0.995</td>
<td>86.903</td>
</tr>
</tbody>
</table>

The model function is as given in Eq. 1

\[ \Delta = \frac{-\ln|1-p_0 t|}{p_1} \] ................ (1)

Where \( t \) is monitoring time in days, \( \Delta \) is monitoring displacement in millimeters and \( p_0, p_1 \) are model parameters, which may change with the monitoring data.

4 Instance verification

The Chaancun landslide is situated at the center of Dalian Xicheng International tourism business district, close to the Lushun middle highway from section 9km+200m to 9km+700m, in Dalian City (China). The exact location is 121°26¢07.48² to 121°26¢46.91²E and 38°56¢15.20² to 38°56¢42.28²N. The total landslide area is about 21 million square meters.

The forecasts were selected at three monitoring points for fitting the calculation: upper, middle, and lower edges of the sliding body, as shown in Fig. 1.

The forecasts were selected at three monitoring points for fitting the calculation: upper, middle, and lower edges of the sliding body, as shown in Fig. 1.

Fig. 2 shows that displacement of the measurement points increases, stabilizes, and increases again with the time. The tertiary period plays a key role in landslide prediction. According to landslide creep theory and real-monitoring displacement, the third stage of landslide can be set, and the parameters of logarithmic prediction model can be calculated using the Levenberg-Marquardt (LM) method. The fitting results are shown in Table 1.

Fig. 2. Displacement-time curve of the measuring points SD2, SD6, SD7

References


