LANDSLIDES FORECASTING ANALYSIS BY DISPLACEMENT TIME SERIES

Centro di Ricerca CERI
Previsione, Prevenzione e Controllo dei Rischi Geologici
www.ceri.uniroma1.it

Facoltà di Scienze Matematiche, Fisiche e Naturali

Master di II livello in ANALISI E MITIGAZIONE DEL RISCHIO IDROGEOLOGICO

a.a. 2011-2012
OUTLINE

- INTRODUCTION
- METHOD
- RESULTS
- CONCLUSIONS
INTRODUCTION

INTERNSHIP TUTOR:

DOTT. PAOLO MAZZANTI
Chief Executive Officer and co-founder

NHAZCA s.r.l. Internship
INTRODUCTION

INVERSE VELOCITY ANALYSIS OF HISTORICAL LANDSLIDES: FORECASTING LANDSLIDE’S TIME TO FAILURE

\[ R = H \cdot E \cdot V \]
INTRODUCTION

The internship was divided in the following steps:

1. Search of data about pre-failure displacement of historical landslides.
2. Realization of a database of historical landslides from literature.
3. Digitalization of the selected deformation-time diagrams.
5. Comparison of the inverse-velocity method results with the real data.
METHOD

FORECASTING LANDSLIDE TIME TO FAILURE: INVERSE VELOCITY THEORY

TERTIARY CREEP THEORY

- BRITTLE BEHAVIOR
- CONSTANT LOAD
METHOD

FORECASTING LANDSLIDE TIME TO FAILURE: INVERSE VELOCITY THEORY

FUKUZONO INVERSE VELOCITY METHOD

\[ a = A v^\alpha \]

\[ \frac{1}{v} = \left( A(\alpha - 1) \cdot (t_r - t) \right) \left( \frac{1}{\alpha - 1} \right) \]

INTEGRATION

\[ \int \frac{1}{v} \, dt = \int \left( A(\alpha - 1) \cdot (t_r - t) \right) \left( \frac{1}{\alpha - 1} \right) \, dt \]

Failure
METHOD

FORECASTING LANDSLIDE TIME TO FAILURE: INVERSE VELOCITY THEORY

VOIGHT VELOCITY METHOD

\[ a = A v^\alpha \]

\[ \frac{1}{\text{velocity}} \]

INTEGRATION

\[ v_r = \left[ A(\alpha - 1)(t_r - t) + (v)^{(1-\alpha)} \right]^{(1-\alpha)} \]
# METHOD

## HISTORICAL LANDSLIDES DATABASE

<table>
<thead>
<tr>
<th>ID</th>
<th>NAME</th>
<th>LOCATION</th>
<th>FAILURE YEAR</th>
<th>GENERAL GEOLOGY (material)</th>
<th>VEGETATED</th>
<th>MECHANISM</th>
<th>VOLUME (m³)</th>
<th>AVERAGE PRE-FAILURE SLOPE GRADIENT (deg)</th>
<th>NATURAL OR MAN-MADE</th>
<th>TRIGGER</th>
<th>TYPE OF MONITORING</th>
<th>MONITORING DURATION (days)</th>
<th>AVERAGE VELOCITY</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Selborne slope cutting</td>
<td>England</td>
<td>1989</td>
<td>Soil</td>
<td>No</td>
<td>rototranslational</td>
<td>18413</td>
<td>49</td>
<td>man-made</td>
<td>groundwater</td>
<td>Inclinometers</td>
<td>400</td>
<td>0.25 mm/day</td>
<td>Petley et al., 2002</td>
</tr>
<tr>
<td>2</td>
<td>Tessina</td>
<td>Italy</td>
<td>2002</td>
<td>Soil</td>
<td>-</td>
<td>rototranslational</td>
<td>5x10⁵</td>
<td>22</td>
<td>natural</td>
<td>groundwater</td>
<td>Extensometers</td>
<td>1825</td>
<td>90 mm/day</td>
<td>Petley et al., 2004</td>
</tr>
<tr>
<td>3</td>
<td>La Clapierê</td>
<td>France</td>
<td>1987</td>
<td>Rock</td>
<td>yes</td>
<td>complex</td>
<td>5 x 10⁶</td>
<td>22</td>
<td>natural</td>
<td>water and snow</td>
<td>Distancemeter, benchmarks</td>
<td>1825</td>
<td>30 mm/day</td>
<td>Sornette et al., 2004</td>
</tr>
<tr>
<td>4</td>
<td>Valpola</td>
<td>Italy</td>
<td>1987</td>
<td>Rock</td>
<td>yes</td>
<td>rockavalanche</td>
<td>35 x 10⁵</td>
<td>-</td>
<td>natural</td>
<td>water</td>
<td>Surface survey</td>
<td>58</td>
<td>20 mm/day</td>
<td>Borsetto et al., 1991</td>
</tr>
<tr>
<td>5</td>
<td>Ruinon</td>
<td>Italy</td>
<td>2001</td>
<td>Rock</td>
<td>yes</td>
<td>rototranslational</td>
<td>13 x 10⁶</td>
<td>-</td>
<td>natural</td>
<td>water</td>
<td>Surface survey</td>
<td>1460</td>
<td>4 mm/day</td>
<td>Crosta and Agliardi</td>
</tr>
<tr>
<td>6</td>
<td>Monte Beni</td>
<td>Italy</td>
<td>2002</td>
<td>Rock</td>
<td>no</td>
<td>rotational</td>
<td>50 x 10⁵</td>
<td>44</td>
<td>natural and man-made</td>
<td>water and snow</td>
<td>Surface survey</td>
<td>240</td>
<td>6 mm/day</td>
<td>Gigli et al., 2011</td>
</tr>
<tr>
<td>7</td>
<td>Randa</td>
<td>Switzerland</td>
<td>1991</td>
<td>Rock</td>
<td>no</td>
<td>rockfall</td>
<td>30 x 10⁶</td>
<td>29</td>
<td>natural</td>
<td>-</td>
<td>Extensometers</td>
<td>3650</td>
<td>0.07 mm/day</td>
<td>Jaboyedoff et al., 1998</td>
</tr>
<tr>
<td>8</td>
<td>Dosan line</td>
<td>Japan</td>
<td>1962</td>
<td>Rock</td>
<td>-</td>
<td>-</td>
<td>60x10⁴</td>
<td>-</td>
<td>man-made</td>
<td>-</td>
<td>Surface survey</td>
<td>3</td>
<td>-</td>
<td>Saito et al., 1999</td>
</tr>
<tr>
<td>9</td>
<td>Vajont</td>
<td>Italy</td>
<td>1963</td>
<td>Rock</td>
<td>yes</td>
<td>rock-earth slip</td>
<td>260 x 10⁴</td>
<td>25</td>
<td>natural and man-made</td>
<td>groundwater</td>
<td>Benchmark</td>
<td>70</td>
<td>43 mm/day</td>
<td>Sornette et al., 2003</td>
</tr>
</tbody>
</table>
METHOD

DIGITIZING OF THE SELECTED HISTORICAL LANDSLIDES
METHOD

DIGITIZING OF THE SELECTED HISTORICAL LANDSLIDES
METHOD

DIGITIZING OF THE SELECTED HISTORICAL LANDSLIDES
METHOD

NORMALIZATION OF THE SELECTED TIME SERIES

NORMALIZED TIME SERIES

FORMULA:
\[ Z = \frac{(Y - \bar{Y})}{S} \]
METHOD

TERTIARY CREEP: VELOCITY AND ACCELERATION PLOT
METHOD

TERTIARY CREEP: VELOCITY AND ACCELERATION PLOT
METHOD

TERTIARY CREEP: VELOCITY AND ACCELERATION PLOT
METHOD

CONSTANTS CALCULATION: A & ALPHAN

\[ a = A v^\alpha \]

LINEARIZATION

\[ \log a = \log A + \alpha \log v \]
METHOD

CONSTANTS CALCULATION: A & ALPHA

\[ a = Av^\alpha \]  

LINEARIZATION \[ \log a = \log A + \alpha \log v \]

SELBORNE TIME SERIES
VELOCITY-ACCELERATION LINEAR REGRESSION
METHOD

CONSTANTS CALCULATION: A & ALPHA

\[ a = A v^\alpha \]

\[ \log a = \log A + \alpha \log v \]

MONTE BENI TIME SERIES

INVERSE VELOCITY ANALYSIS OF HISTORICAL LANDSLIDES

01/03/2014

NHAZCA s.r.l. Internship
METHOD

FUKUZONO AND VOIGHT ANALYSIS
METHOD

FUKUZONO AND VOIGHT ANALYSIS
METHOD

FUKUZONO AND VOIGHT ANALYSIS
## RESULTS

<table>
<thead>
<tr>
<th>LANDSLIDE</th>
<th>A</th>
<th>ALPHA (α)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vajont</td>
<td>0,00005</td>
<td>2,60</td>
</tr>
<tr>
<td>Monte Beni</td>
<td>0,00007</td>
<td>2,34</td>
</tr>
<tr>
<td>La Clapiere</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Randa</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Selborne</td>
<td>7,1(10^{-9})</td>
<td>4,72</td>
</tr>
<tr>
<td>Valpola</td>
<td>2,7(10^{-9})</td>
<td>5,20</td>
</tr>
<tr>
<td>Tessina</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dosan Line</td>
<td>0,0011</td>
<td>2,38</td>
</tr>
<tr>
<td>Bohemia</td>
<td>0,0095</td>
<td>1,67</td>
</tr>
<tr>
<td>Braced up</td>
<td>0,00045</td>
<td>3,33</td>
</tr>
<tr>
<td>Tabakayama</td>
<td>0,000053</td>
<td>2,68</td>
</tr>
<tr>
<td>La mure</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Oiwaga</td>
<td>0,0018</td>
<td>2,69</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Landslide</th>
<th>Actual time to failure (day)</th>
<th>FUKUZONO Calculated time to failure (day)</th>
<th>VOIGHT Calculated time to failure (day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vajont</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Monte Beni</td>
<td>258</td>
<td>260</td>
<td>260</td>
</tr>
<tr>
<td>La Clapiere</td>
<td>4880</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Randa</td>
<td>1188</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Selborne</td>
<td>600</td>
<td>610</td>
<td>605</td>
</tr>
<tr>
<td>Valpola</td>
<td>62</td>
<td>61</td>
<td>61</td>
</tr>
<tr>
<td>Tessina</td>
<td>2078</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dosan Line</td>
<td>62</td>
<td>66</td>
<td>62</td>
</tr>
<tr>
<td>Bohemia</td>
<td>159</td>
<td>166</td>
<td>166</td>
</tr>
<tr>
<td>Braced up</td>
<td>1875</td>
<td>1870</td>
<td>1870</td>
</tr>
<tr>
<td>Tabakayama</td>
<td>87</td>
<td>90</td>
<td>88</td>
</tr>
<tr>
<td>La Mure</td>
<td>39</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Oiwaga</td>
<td>74</td>
<td>79</td>
<td>77</td>
</tr>
</tbody>
</table>
CONCLUSIONS

After analyzing all the series we can conclude that:

•“Time to failure” analysis is limited just to landslides which present a tertiary creep deformation.

•The “graphical technique” is most straightforward.

•Failure forecasting relies on the identification of consistent trends.

•It is advisable to use their own data magnitude for the analysis (in terms of precision).

•Monitoring must be continued as long as possible prior to failure.

•The result must be constantly reevaluated and the best-fit functions must be revised in view of the latest data.
THANK YOU FOR YOUR ATTENTION