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SNOW AVALANCHE,  
LANDSLIDE, DEBRIS FLOW  
PREDICTION AND CONTROL**

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MOVEMENT, PRECIPITATION AND GROUNDWATER FLUCTUATION  
AT THE CONDON CREEK LANDSLIDE, OREGON, U.S.A.

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**Summary;** The Condon Creek landslide in western Oregon moves repeatedly during the rainy season. Observations characterize this feature as a precipitation-induced landslide. A groundwater simulation model is used to predict initiation and movement during the rainy season.

1. INTRODUCTION

Precipitation and resulting groundwater accumulation are major causes of landslides. The actual effect of precipitation on landslide movement is not well known because few studies have been conducted. In western Oregon, the rainy season lasts from October through March and contributes approximately 80 % of the total annual precipitation. Most landslides occur during this time. The Condon Creek landslide, described here, is a typical precipitation-induced slide that has been observed by Forest Service for several years. Observations of precipitation, movement and groundwater level indicate repetitive landslide movement triggered by a precipitation threshold. A simulation model based on daily precipitation data is used to estimate groundwater fluctuation and provides a basis for predicting landslide movement.

2. LOCATION AND FEATURE

The Condon Creek landslide is located along the north bank of Condon Creek in the Siuslaw National Forest, about 18km north-east of Florence, Oregon near the Pacific Ocean (Fig. 1). The landslide is approximately 5.4 hectares in area. The head scarp of the Condon Creek landslide consists of two distinct semicircular scarps separated by a region that appears to be

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presently inactive (Fig. 2). In this paper, the left section (west) of the landslide is studied. This landslide is composed mainly of Eocene sandstone and intercalated thin mudstone layers. The slip surface is along the dip slope in the Flournoy Formation; the slide is a translational type, with the failure zone parallel to the bedding. Average gradient is about 5 degrees. The depth of the landslide is about 5 m in the middle part of the slope. Originally the slope was covered with old Western hemlock and Douglas-fir, but trees were removed in March, 1987 in order to study the influence of trees on landslide movement. Dendrochronological studies (Graham, 1985) indicated three periods of very active movement: 1957-58, 1964-65, 1970-73.



Fig. 1 Location of the Condon Creek Landslide

### 3. LANDSLIDE MONITORING

Daily precipitation, surface displacement and groundwater level were monitored. Precipitation and surface displacement were monitored from water year(WY) 1985 (Oct.1, 1984- Sep. 30, 1985) to WY 1990. Groundwater level was observed during WY 1990. Precipitation data was collected at the Mapleton station, 13 km southeast of the Condon Creek landslide from WY 1985 to WY 1988; Thompson station, 18 km east of the

Table 1 Data on precipitation and movement

(mm)

| WY                                             | 1985                  | 1986             | 1987            | 1988                    | 1989           | 1990*           |
|------------------------------------------------|-----------------------|------------------|-----------------|-------------------------|----------------|-----------------|
| Precipitation (a year)                         | 2131                  | 2400             | 2278            | 2212                    | 2365           | -----           |
| Precipitation(Oct.-Mar.)                       | 1689                  | 1966             | 1717            | 1750                    | 1934           | 1920            |
| Movement (a year)                              | 41                    | 221              | 23              | 52                      | 82             | 176             |
| Maximum of Monthly Movement                    | (Nov.)<br>25          | (Feb.)<br>202    | (Nov.)<br>19    | (Jan.)<br>24            | (Jan.)<br>59   | (Feb.)<br>128   |
| Monthly Precipitation of Max. Monthly Movement | (Nov.)<br>663         | (Feb.)<br>663    | (Nov.)<br>457   | (Jan.)<br>455           | (Jan.)<br>357  | (Feb.)<br>502   |
| Maximum of Monthly Precipitation               | (Nov.)<br>663         | (Feb.)<br>663    | (Jan.)<br>467   | (Dec.)<br>640           | (Nov.)<br>604  | (Jan.)<br>659   |
| Maximum of Daily Precipitation                 | (Nov. 11. & 27)<br>74 | (Feb. 22)<br>114 | (Nov. 26)<br>76 | (Jan. 9 & Dec. 9)<br>97 | (Jan. 9)<br>88 | (Feb. 9)<br>102 |

\* : October 1. 1989 - March 31. 1990

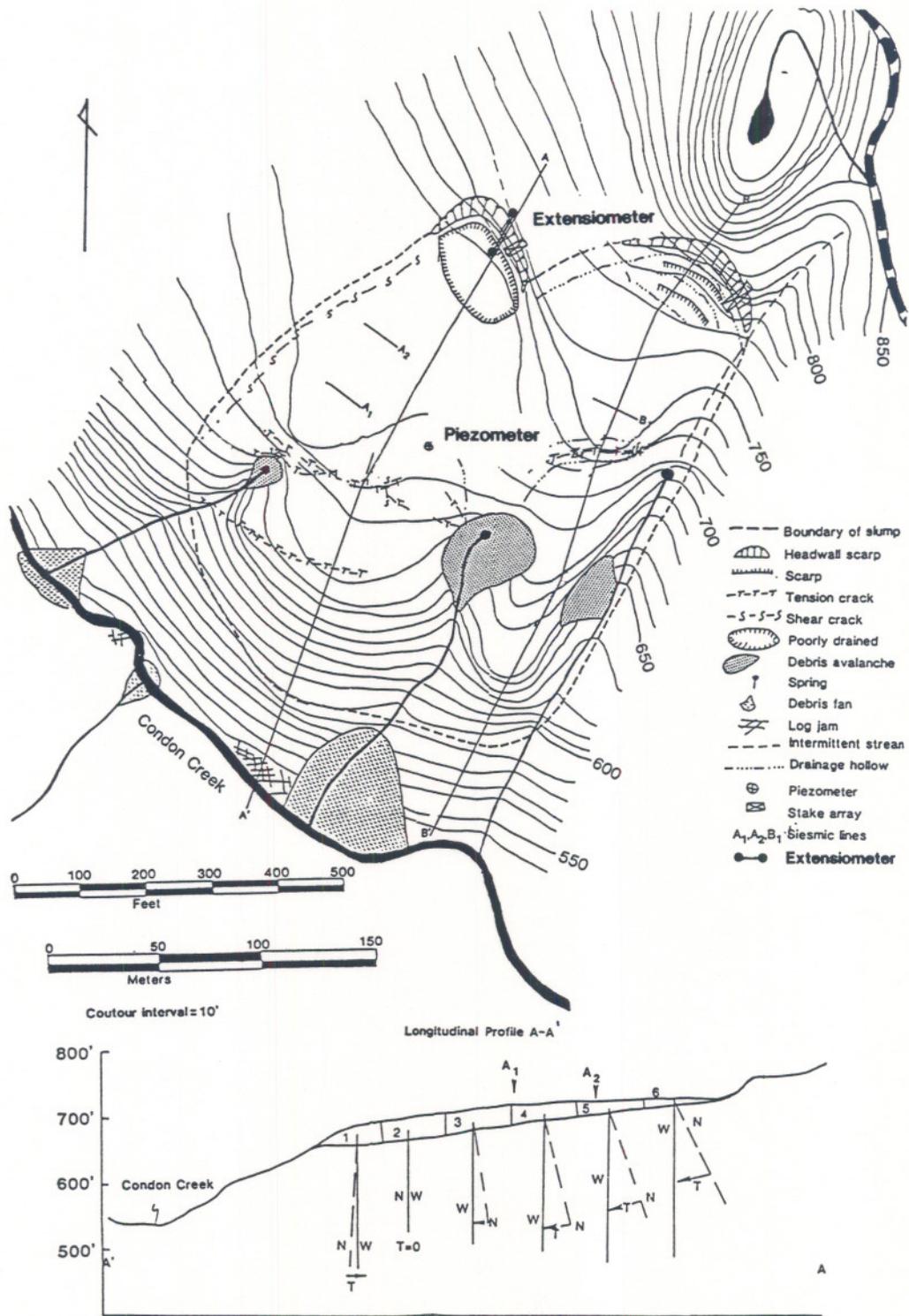


Fig.2 Topographic map of the Condon Creek landslide (After Graham, 1985)

landslide was used in WY 1989 because the Mapleton station did not work well. In WY 1990, a raingauge was set up in the landslide area and observed. Surface displacement at the main scarp was monitored by an extensiometer installed across tension cracks at the boundary of the active area and recorded in an analog chart-recorder. The measurement error of extensiometer due to the daily range of wire extension and contraction is within about 0.5mm. Groundwater level was measured by recording a piezometer. The piezometer (transducer type) for the measurement of groundwater level was set 5m deep (close to the slip surface) in the middle of slope (Fig. 2). The transducer receives input of 5 volts from the recorder and returns a percentage of that voltage to the recorder. The percentage of voltage is regulated by the amount of pressure to which the transducer is subjected by the water above it in the well. The voltage is converted to a digital value and stored in a memory module. The memory module is read and analyzed in a disk drive computer.

#### 4. MOVEMENT AND PRECIPITATION

##### 4.1 Precipitation and seasonal movement

The total annual precipitation ranges from 2130 mm to 2400 mm. A total amount of rainy season precipitation (October to March) ranges from 1689mm to 1966mm. Precipitation during

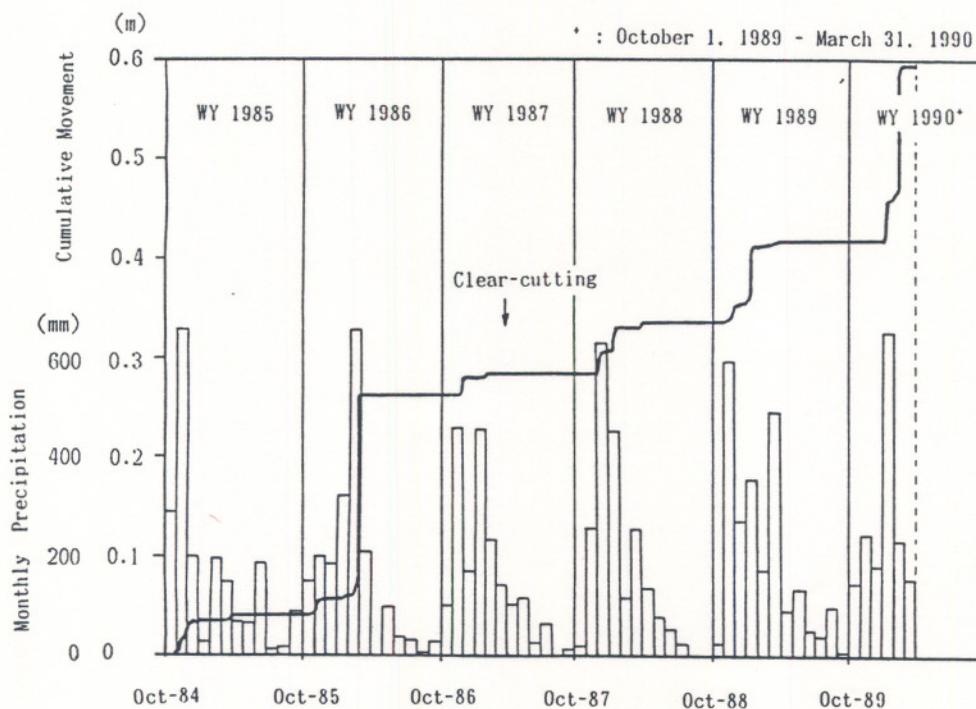


Fig.3 Cumulative movement and monthly precipitation

the rainy season is approximately 80 % of the annual total precipitation. The greatest recorded monthly rainfall was 663 mm (November, 1984 and February, 1985). More than 200 mm per month is seldom recorded in the dry season. The annual cumulative displacement ranges from 2.3 cm to 22.1 cm (Table 1).

Figure 3 shows cumulative landslide movement and monthly precipitation for six years (WY 1985 - WY 1990). Movements of the Condon Creek landslide are seasonal, beginning in September or October, and continuing until March or April. This landslide is especially in responsive to high monthly precipitation. Drastic displacement occurred twice: February 1986 and February 1990. These are before and after the clear-cutting in the area. Both displacements were associated with high precipitation (> 600mm per month). Cumulative movement during the 3 years before clear-cutting (28.5cm) was almost the same as that after clear-cutting (30.1cm). According to these data, the effect of trees on this landslide movement is not significant. Figure 4 shows the relationship between a total precipitation and a total movement during the rainy season. Movement is initiated with a total wet season precipitation of more than 1600 mm and increases rapidly when the value of total wet season precipitation exceeds 1900mm. The relationship between precipitation and movement in this landslide is expressed by Equation (1):

$$\log Y = 2.75 \times 10^{-3} X - 4.155 \quad (1)$$

where X is total amount of precipitation in the rainy season (half a year) and Y is displacement (cm); the coefficient of correlation is 0.895. Kronfellner-Kraus(1980) indicated a similar relationship between the precipitation of ten months from November through August and movement in a landslide creep site in rock, Austria.

#### 4.2 Short-term precipitation and movement

Figure 5 shows the relationship between three-day precipitation and the total movement of three day periods. Movement is noted two days after the initiation of precipitation. This means there is a two day time lag due to

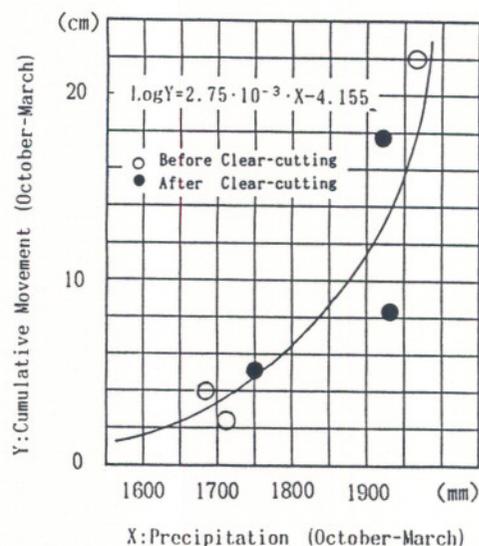


Fig.4 Cumulative movement and precipitation from October to March

infiltration time. Almost 50 mm of precipitation in a three-day period is required to initiate the landslide and the movement increases exponentially with higher precipitation. The effect of trees on this landslide movement due to short-term precipitation is not significant. One case of landslide movement with < 50 mm of three-day precipitation was observed. This was during a period of high antecedent moisture.

### 5. GROUNDWATER LEVEL AND MOVEMENT VELOCITY

The relationship between groundwater level and surface displacement is shown in Fig. 6. The Condon Creek landslide moves when the groundwater level at the middle of the slide rises 2.5m or more above the slip surface (5m deep). The movement velocity is also proportional to groundwater level. Detection of this threshold is useful in the predicting landslide initiation. About 50mm of precipitation in 3-days (previously explained as threshold to initiate landslide movement) is required to raise the groundwater level to 2.5 m. A simulation of groundwater fluctuation is attempted in the next section.

### 6. GROUNDWATER FLUCTUATION AND ITS SIMULATION

Figure 7a shows daily precipitation, landslide movement and groundwater fluctuation from October 1, 1989 to March 31, 1990. Movement occurred in January and February during heavy precipitation. Groundwater levels during early December to early January were not measured due to recorder failure. Thus, the relationship between movement and groundwater level in January is

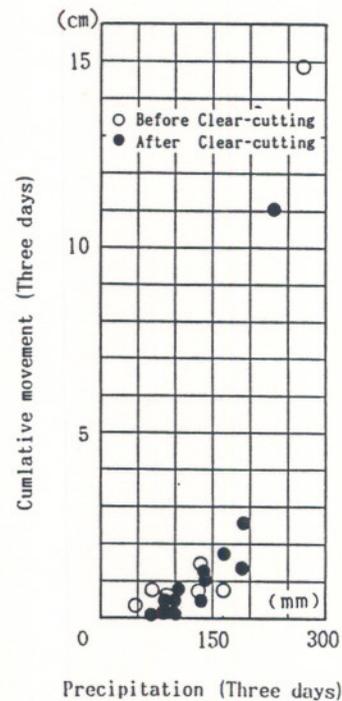


Fig.5 Three days' movement and precipitation

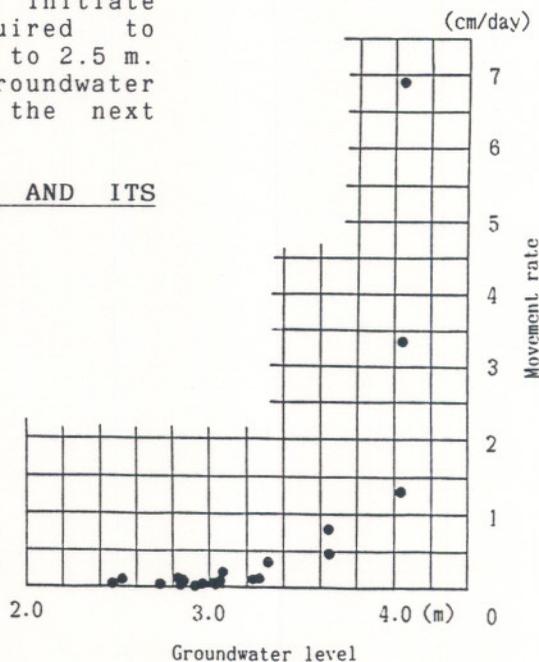


Fig.6 Movement rate and groundwater level in WY 1990

uncertain. Missing data were simulated, based on daily precipitation. A model called the " tank model " (Sugawara et al, 1986) is generally used for the flood analysis. As shown in Fig. 7b, the tank model used has two outlets in the side wall and one outlet in the bottom. Precipitation is introduced into the tank and the some water partly drains through the bottom outlet and some through the side wall outlets. The sum of the outputs through the side wall outlet forms the discharge and the sum of outlet through the bottom is underground infiltration. The remainder is stored as groundwater. The parameters of each outlet are found by trial and error. The relationship between the run-off, Y, and the storage amount of the tank is not linear. The run-off increases greatly when storage increases. Therefore, the ratio between the run-off and infiltration, I, is also not constant, but increases with increased storage. Here we focus the groundwater level in the slope. The level, X, in the tank indicates groundwater level in Fig. 7a.

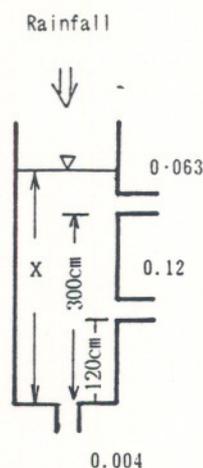


Fig.7b  
Simulating model  
for groundwater  
fluctuation

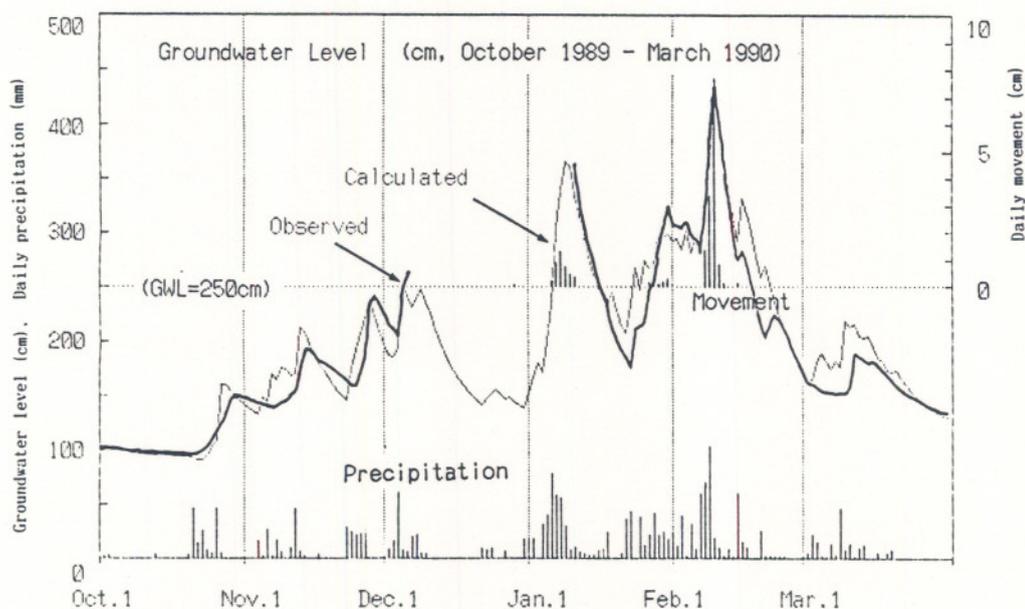


Fig.7a Groundwater fluctuation (calculated and observed), daily movement and daily precipitation in WY 1990

In this calculation, initial loss for the dry layer in early October is 90 mm of precipitation. Effective void ratios of dry and wet layers are 0.12 and 0.08. Evapotranspiration is neglected in this case.

Results obtained are in agreement with the results of the field observations, as shown in Fig. 7a. In Fig. 7a, a broken line shows calculated groundwater level, a bold line indicates observed level, histograms at the bottom show daily precipitation and those on the dotted line show surface movements. The movements during the period (January) of missing data are approximated when the estimated groundwater level is over 2.5m from the slip surface. This coincides with the critical value of groundwater needed to initiate the movement (Fig. 6).

## 7. CONCLUSION

The Condon Creek landslide is a typical, precipitation-induced landslide. This landslide moves only in the rainy season. Intensive precipitation is required for landslide initiation. This precipitation causes groundwater accumulation in the slope and thus instability of the landslide. Antecedent precipitation may permit initiation under lower precipitation levels. The application of a tank model to simulate groundwater from daily precipitation is useful to determine whether or not a landslide moves and for estimation of displacement during a precipitation event or the rainy season.

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