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Possible Vapor Lock Generation Near a Sliding Surface as a Mechanism of Huge Earthquake Landslides

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Abstract

The Iwate-Miyagi Nairiku earthquake in 2008 (M7.2) caused the Aratozawa landslide which have a huge earthquake landslide exceeding 900 m in width, 1,300 m in length and 100 m in depth. Although the average slope of the main sliding surface of this landslide was remarkably gentle (about 2°), the landslide body moved about 350 m. In addition, although the moving distance was large, the main landslide body reportedly experienced minimal damage except at the edges. The Higashi Takezawa landslide caused by the Chuetsu earthquake in 2004 (M6.8) is a similar example. In that case, although the landslide body moved about 100 m, the main moving body retained its original form for most of its part (Nakamura 2009).

In this study, we researched why the erarthquake landslides move long distances despite the gentleness of the slope and why the sliding bodies caused by the earthquake landslides minimally damaged although the moving distances were large. The research was conducted by the transdusing law of conservation of energy and the modeling by using actual mesured values of the Aratozawa earthquake landslide. We concluded that the ground water temperature near slip surface of the earthquake landslide exceeds the vaporization temperature by frictional heat of moving masses and it make the water vapor. The water and vapor near slip surface behave as shock absorber to downward pressure and the sliding energy of moving masses. As a result, landslide movement becomes easy, which can reduce the damage of the moving body. We named this phenomena "Vapor lock phenomena in earthquake landslides".

Keywords

Vapor lock • Landslides • Earthquake

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Model Methodology of Analyzing

According to the law of conservation of energy, it is possible to make the hypothesis that all frictional energy can be converted into thermal energy, Q, in closed system. In this study, all frictional energy mean the work of moving masses, W, which slide along the direction of main sliding surface of the landslide. Thus, next three formulas can be true.

$$W = N \tan \phi \, x \quad (1)$$

$$Q = m C \Delta T \quad (2)$$

$$W = Q \quad (3)$$

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Equation 1 shows the work of moving masses which slide along the direction of main sliding surface of the landslide. This is the product of acting force, $N \tan\phi$, and relative displacement, x, of bedrock and moving masses of landslide. N is perpendicular stress and ϕ is an internal friction angle. m in (2) is weight of layer V, which is holding water and the water could rise in the temperature. ΔT is the amount of rise in the temperature. C is specific feet. W can transduce displacement of moving mass on a slope with Enoki's model (2007) when the bedrock got strong seismic shocks. Enoki suggests that coseismic behavior of rigid-plastic solid can be modeled by using the relationship of inertial force and continuity condition of acceleration by d'Alembert's principle. Soil is frictional material in this model (Fig. 1).

In this study, we use this model to examine the coseismic behavior of moving mass. In $N \geqq 0$, bedrock and moving masses slide together without separating or making shear layer between bedrock and moving masses. It is when absolute value of shear force T is less than maximum shear resistance, $Smax$. Moving masses slide downwards when absolute value, T, which is acting downwards is more than $Smax$. On the other hand, absolute value, T, which is acting upward is more than $Smax$ when moving masses move upward on a slope.

$$Smax = |N \tan\phi + c/\tan\theta| \quad (4)$$

In (4), c is cohesion and θ is slope gradient. Only shear force, T, transmits from bedrock to soil masses when moving masses is sliding. T is maximum frictional resistance in this time. Seismic acceleration in bedrock showsαv andαh. One in moving masses shows $\alpha' v$ and $\alpha' h$. In relative motion, we write,

$$\alpha v \neq \alpha' v, \quad \alpha h \neq \alpha' h \quad (5)$$

$\alpha' v$ and $\alpha' h$ are calculated by these continuity condition of acceleration. As a result, we can calculate how much relative acceleration, $\Delta\alpha\theta$, increase when soil masses slide downwards on a slope. In addition, moving distance, x, relating to frictional mortion can be found by integrating time, dt, twice. Therefore, amount of rise in temperature, ΔT, is given by obtaining m and C in shear layer by use of (1).

Model Examination by Using the Results of the Aratozawa Landslide Survey

The Amount of Relative Displacement, *x*, and the Work, *w*

From the results of Aratozawa landslides survey, the set values of model slope were 100 m in height, 2° in gradient and 70 m in head of water. Physical values and condition to conduct the examination are shown in Fig. 2.

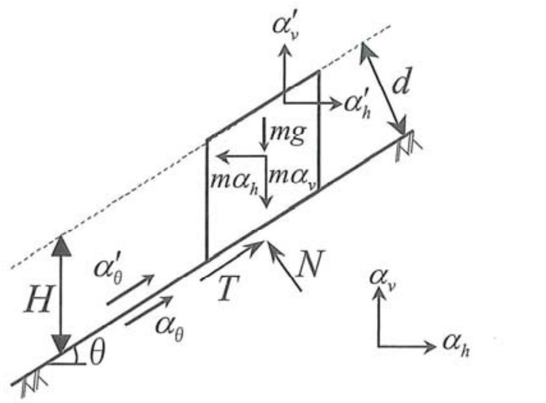

Fig. 1 Seismic response modeling of soil masses on infinitely long slope (Enoki 2007)

Data of strong motion measured by seismometers was used for analysis. The seismometers were buried in a basic bedrock inspection corridor of Aratozawa dam. In this examination, the maximum component of sliding soil masses on a slope divided into horizontal component, αh, and vertical component, αv. $\alpha\theta$ of Fig. 1 is the energy converted the traveling seismic acceleration through bedrock. Similarly, $\alpha'\theta$ of Fig. 1 is the energy converted the traveling seismic acceleration through moving masses. Both of them are upward positive power. From the results of calculations, moving masses were sliding together with bedrock until 12.65 s. However, moving masses started gradually separating from bedrock after that. The cumulative amount of relative displacement was 4 cm between 15 s and 16 s. Ultimately, the total amount of relative displacement during earthquake reached 5.1 cm. The work, W, of this displacement can be found of (1) which is the multiplication of perpendicular stress, N, and relative displacement, x. As a result of the calculation, the answer, W, was 1,589,590 J ($=\text{kgf}\cdot\text{m}^2/\text{s}^2$).

Phase Transition and Heat Requirement, *Q*

In this analysis, 5 mm in depth of deformation layer, V, near slip surface, 0.1 in effective porosity, 1.7 g/cm^3 in density of bedrock, ρ, and 0.8 J/g·°C in Specific heat of soil fraction, Cb were hypothesized as physical value. 4.178 J/g· °C was applied to the calculation as specific heat of water, Cw, when ground water temperature was 15°C. Head of water at slip surface, V, is 70 m. This was determined by the result of water level observation at field works. In this case, the saturated water vapor pressure is approximately 8 atm. Thus, boiling point of water at slip surface becomes approximately 170°C by the equation of state for international studies (IAPWS-95). In this case, the ground water near slip surface can boil when deformation layer at slip surface, V, got over 155°C in heat. It means that liquid phase can be

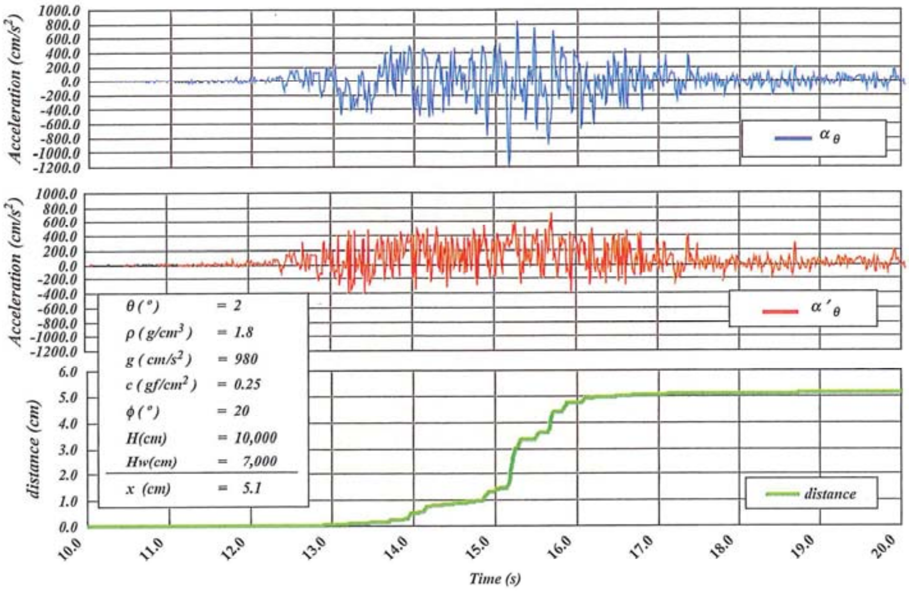

Fig. 2 Amount of relative displacement and seismic response of soil masses on slope

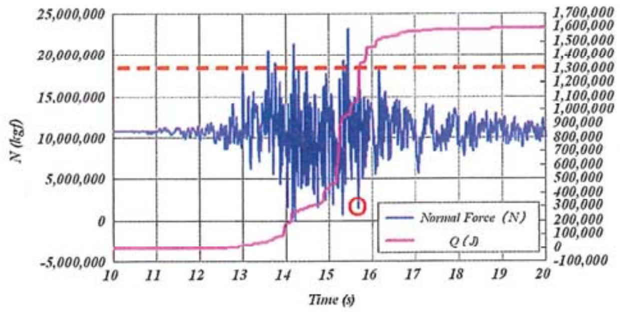

Fig. 3 Change of normal stress, N

changed to gas-liquid phase mixed state. In addition, heat quantity, Q, to make the ground water near slip surface vapor can be found from (2). The answer is 1,272,395 J. The ground water deformation layer V near slip surface can boil with this heat quantity, because the work, W, at Aratozawa landslides which was calculated by (1) in a previous chapter was 1,589,590 J. This value is over the heat quantity, Q, which is possible value causing vapor generation.

Vapor Lock Phenomena in Earthquake Landslides

We suggest the following possibility and hypothesis. The work that happened at the bottom of sliding soil masses by earthquake changes frictional heat. This heat energy makes the ground water temperature up and vaporize the water. In other words, the ground water temperature near slip surface exceeds the vaporization temperature by soil mass moving and it make the water vapor. Schematic diagram of this hypothesis shows Fig. 4. This phenomenon is rapid change in state within 2 s as shown in Fig. 3.

We estimate that water and vapor are mixing in the interspace between moving masses and bedrock in the early state of this phenomenon. Incidentally, the vapor lock is the phenomenon that foot brakes went out caused by the vapor generation in a hydraulic brake as a transmission when foot brakes heated up. Pressure from brake pedal transmits to a brake shoe because liquid is hardly compressed in a hydraulic brake system. However, the pressure from brake pedal can not be transmitted to a brake shoe because bobbles are easily compressed after brake fluid became liquid-bobble mixed state caused by evaporation of brake fluid in parts by heat. We hypothecate that such vapor rock phenomenon happen near slip surface of landslide. As soon as W increased over Q at layer V holding ground water near slip surface, babbles generated in layer V. As a result, the downward pressure from soil masses to bedrock is absorbed by the compaction property of bobbles. Therefore, the pressure does not transmit to bedrock easily. In addition, the product of the pressure and the volume of gas is equal by Boyle's law at isothermal condition. After friction layer near slip surface became liquid – gas mixture, it behave as shock absorber when moving masses slide on rugged slip surfaces (Fig. 4). As a result, the damage of moving masses becomes extremely small. We hypothecate that W exceed Q, the moment when downward pressure rapidly decreases by upward action of seismic acceleration to soil masses, and babbles generate

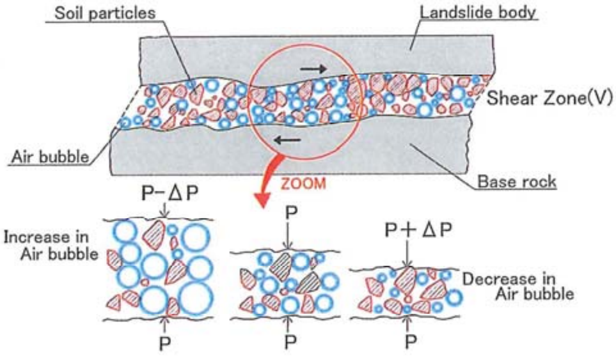

Fig. 4 Conceptual diagram of Vapour lock

(red circle on Fig. 3). At the moment, the phase transition to babble explodes and it cause that the speed of displacement acceleration increases at once. It can make moving masses sliding smoothly just like a hovercraft's sailing. In such situation, it can be possible that moving masses slide long distance at gentle slopes.

Conclusion

In this research, we examined thc possibility of vapor lock generation near a sliding surface as one of the mechanisms that generate a huge earthquake landslide in which the landslide body suffers little damage. When a strong earthquake occurs, the frictional heat resulting from the relative displacement near a slip surface increases the groundwater temperature. The pressure change near a sliding surfacc could change the phase of the hot groundwater, resulting in a simultaneous vapor lock state. As a result, landslide movement becomes easy, which can reduce the damage of the moving body.

Further Work

It is important to verify the vapor lock phenomena in earthquake landslides.

Necessary temperature is 170°C to cause gas-liquid phase transition. If shear layer was heated to 170°C, crystallized Calcite as a geothermometer could be found near heated slip surface. The amount of calcite may be little, because landslide happens in short time. For this reason, it might be difficult to find calcite by X-ray diffraction. However, microscopic observation has possibility to find it. Furthermore, it is significant to clarify the impact of gas bubbles on shear strength.

By adding a heat-generating device in a shearing tester, it make possible to investigate what gas bubbles effect shear strength. It is valuable and necessary to test.

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