Examination regarding the design method of a protective barrier for debris flow

R. Sawada
Railway Technical Research Institute, Japan

Abstract

When designing a protective barrier in order to protect a railway from debris flow, the debris flow evaluates the effect which it has on a protective barrier, and examines a wall and basic structure.

In this case, if debris flow can evaluate the influence which it has on a protective barrier as an external force like earth pressure, the design method of a retaining wall can be applied and a protective barrier can be designed.

Then, ground displacement caused by liquefaction referred to the valuation method of external force exerted on a structure. In addition, the debris flow examines how to evaluate the influence which it has on a protective barrier as an external force.

As a result, the debris flow was considered as viscous fluid and the external force which acts on a protective barrier has been presumed by asking for the viscous coefficient and drift velocity of the debris flow. Moreover, it was shown that applying the design method of a retaining wall and the design of a protective barrier is attained.

Keywords: incomplete debris flow, viscous fluid, deterrence pile.

1 Introduction

In Japan in recent years, generating of a landslide disaster represented by the debris flow resulting from a rainy season or local severe rain by a typhoon has occurred frequently. For this reason, in Japan, erosion control enterprise is promoted as a national policy.

A railway in Japan has many routes also on a mountain slope, and an original countermeasure against an earth-and-sand disaster may be needed.

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Here, the earth-and-sand disaster assumed on a railway line is the operation stop by many earth-and-sand inflows onto the track by an incomplete debris flow. Moreover, early restoration will become difficult once damage occurs. For this reason, it is possible to install the deterrence pile and protective barrier for preventing earth-and-sand inflow onto a track as a countermeasure original with a railway, as shown in Fig. 1 on the railway.

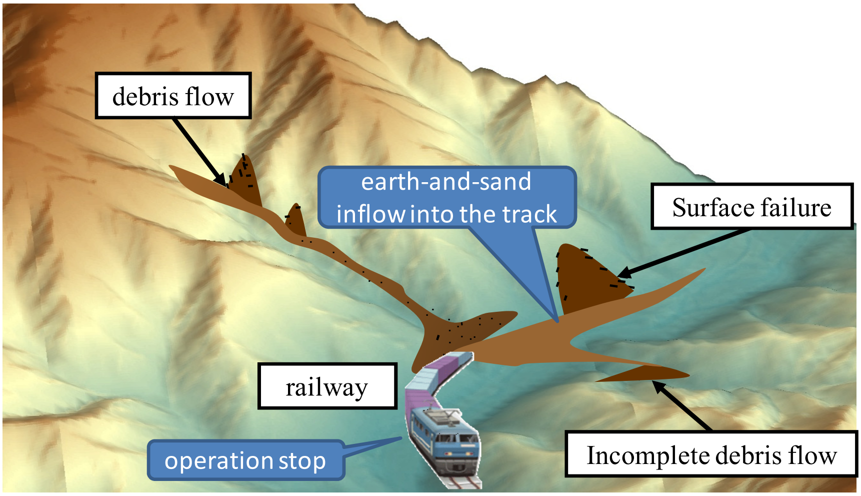

Figure 1: The example of the landslide disaster on a railway.

Therefore, this research considered the design of a countermeasure method to an incomplete debris flow, having assumed the incomplete debris flow to be fluid, in order to establish the design method of a deterrence pile or a protective barrier for an incomplete debris flow.

2 Presumption of the drag force to the structure by an incomplete debris flow

If incomplete debris flow can evaluate the influence, which it has on a structure as action external force like earth pressure, with the application of the design approach of a foundation structure or a retaining structure, the design of the countermeasure method by the deterrence pile or a protective barrier will be attained. Here, since it is the phenomenon of rainwater and groundwater mixing incomplete debris flow with soil, and flowing as one, it is conceivable that the action is fluid-like. As conditions, which take into consideration the phenomenon in which the soil carries out an action in fluid to the design of a structure, it has influence of lateral flow during the liquefaction in the case of an earthquake.

Then, it referred to the method of evaluating the influence, which lateral flow during the liquefaction in the case of an earthquake has on a structure, and examined how to evaluate the influence which incomplete debris flow has to a structure as action external force.

Lateral flow during liquefaction is a phenomenon in which the soil which excess pore water pressure rose and changed into the liquefaction state flows several meters horizontally. Therefore, in the design of the structure installed in the soil where lateral flow is assumed, drag force is presumed assuming the liquefied ground to be viscous fluid, and the method of making this drag force act on a structure as external force from the soil is proposed [1].

Therefore, in this research, the incomplete debris flow was assumed to be viscous fluid, and the same view as lateral flow during liquefaction was applied.

2.1 Fluid character of an incomplete debris flow

If it is assumed from the generating mechanism of an incomplete debris flow, it will be presumable that uniform accelerated motion of the incomplete debris flow is carried out. Thus, it is thought that the rheology character of the fluid in which fluid movement is uniform accelerated motion can be taken into consideration as pseudoplastic fluid, as shown in Fig. 2.

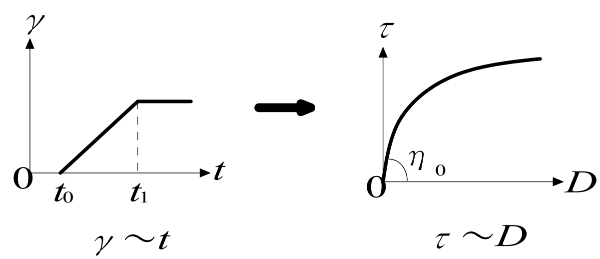

Figure 2: The rheology action of pseudoplastic fluid.

Then, viscous fluid character was considered as shown in Fig. 3. As for this idea, when the fluid between two layers, where only minute distance left deformation, shear stress occurs. Movement of the fluid in this case is given with the rheology equation shown in eqn. (1) [2].

$$\tau = KD^{n} \tag{1}$$

where τ is shear stress (N/cm^2), D is shear velocity (1/sec), K is pseudoplastic viscosity (N· sec^n/cm^2), and n is structure viscosity index.

Next, in the central part of the flow of an incomplete debris flow, the relation between shear stress and shear velocity was taken into consideration about the minute element of the soil of Fig. 3. In this case, the calculation of the shear velocity in the central part of a flow can assume distribution of the vertical direction of velocity of flowing fluid to be distribution of cosine curve, and can presume it by using the velocity of flowing fluid of ground surface.

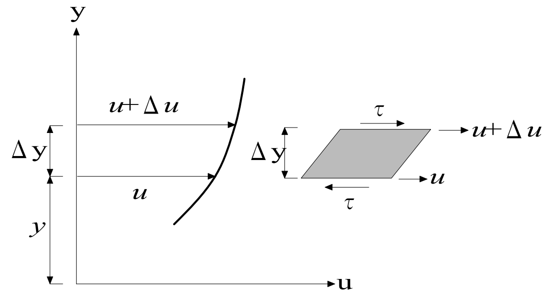

Figure 3: Character of viscous fluid.

Moreover, the shear stress in a minute element is the inertial force of an incomplete debris flow, as shown in Fig. 4, and it can be calculated using eqn. (2) using acceleration in the case of ground surface flows [3]. In this case, as for the incomplete debris flow assumed to be a rigid body, change of the vertical direction of acceleration is taken into consideration. Therefore, vertical direction of deformation of the ground is taken into consideration for convenience.

$$\tau = \gamma_d \frac{\gamma z}{g} \alpha_{\max} \qquad (2)$$
$$\gamma_d = 1 - 0.00015z$$

where τ is shear stress (N/cm^2), γ is unit volume weight of soil (N/cm^3), z is depth (cm), $\alpha_{\max}$ is maximum acceleration of ground (gal), and g is acceleration of gravity (gal).

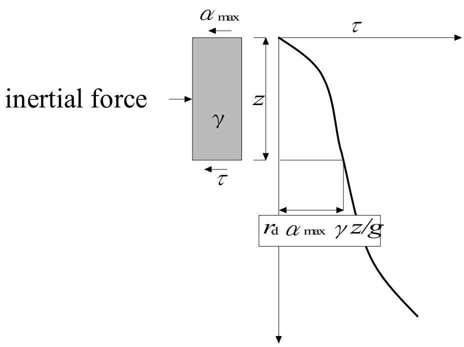

Figure 4: Vertical distribution of shear stress.

Therefore, it becomes possible to obtain the coefficient of viscosity of an incomplete debris flow, and the relation of shear velocity from eqn. (1) using the shear stress and velocity of flowing fluid of ground surface which were calculated with the application of the above-mentioned view (refer to Fig. 5).

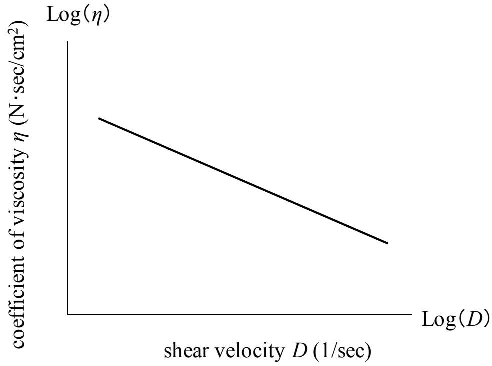

Figure 5: The outline of the relation between a coefficient of viscosity and shear velocity.

2.2 Examination of drag force

If the coefficient of viscosity and velocity of flowing fluid of an incomplete debris flow are known, when an incomplete debris flow is approximated as pseudoplastic fluid, the drag force which an incomplete debris flow exerts on a structure can be calculated. In this case, in calculation of drag force, it took into consideration that the design of the structure was based on the static analyzing method. Therefore, the equivalent linearizing method, as shown in Fig. 6, was applied, and it was decided to calculate drag force using an apparent coefficient of viscosity. That is, the coefficient of viscosity, which can be found from the shear stress and shear velocity in a certain time was taken into consideration as an apparent coefficient of viscosity.

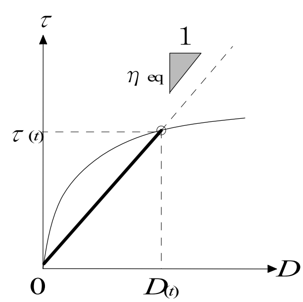

Figure 6: An apparent coefficient of viscosity.

In this case, since a coefficient of viscosity is taken into consideration for linear for convenience, drag force is calculated from the Navier-Stokes equations.

Here, drag force is realized in the balance of the inertial term, the viscous term, and the pressure term from the Navier-Stokes equation. Moreover, the contribution grade of an inertia term and a viscous term is defined by Reynolds number. That is, only in consideration of a viscous term and a pressure term, if the Reynolds number is small, if large, only an inertia term and a pressure term will be considered.

Here, the Reynolds number is given by eqn. (3) [4].

$$R_e = \frac{\gamma}{g}\frac{uL}{\eta} \tag{3}$$

where R_e is Reynolds number, γ is unit volume weight of soil (N/cm^3), u is velocity of flowing fluid (cm/sec), η is coefficient of viscosity (N･ sec/cm^2), and L is representation length (it is a diameter in the case of a pillar) (cm).

Here, the drag force, which acts on the deterrence pile (pillar) in the flow of the pseudoplastic fluid taken into consideration by the apparent viscous coefficient, is presumed from the approximate solution of Navier-Stokes equations.

An approximate solution has the approximation Stokes which disregards an inertial term, and the approximation Oseen which approximates an inertial term for linear. Although approximation Stokes gives the solution right about the problem of a ball, not having a solution is known when considering the flow of the circumference of a pillar. This is for reaching by the flow of the circumference of a pillar to the place, which the influence of viscous left.

The Reynolds number becomes large and it becomes impossible therefore, to disregard an inertial term at the distant place. Therefore, in this research, we thought that the fluid load exerted on a deterrence pile was expressed by the flow of the circumference of a pillar, and decided to presume an approximate solution from the approximation Oseen in consideration of linearization of the inertial term of the Navier-Stokes equations.

The drag coefficient of the pillar by approximation Oseen is given by eqn. (4) [5].

$$C_D = \frac{8\pi}{R_e}\frac{1}{T+\frac{1}{2}} \times \left[1 - \frac{R_e^{\,2}}{32}\left(T + \frac{5}{16}\frac{1}{T+\frac{1}{2}}\right) + \cdots\right] \tag{4}$$

$$T = \ln\left(\frac{8}{R_e}\right) - \gamma$$

where R_e is Reynolds number, γ is Euler's constant (= 0.5772).

Therefore, the drag force per unit length is given by eqn. (5).

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$$F = C_D A \frac{\gamma}{g} \frac{u^2}{2} \tag{5}$$

where F is drag force per unit length (N/cm), A is stress area of deterrence pile (cm^2), γ is unit volume weight of soil (N/cm^3), u is velocity of flowing fluid (cm/sec), C_D is drag coefficient, and g is acceleration of gravity (gal) .

Therefore, the drag force of the incomplete debris flow can be calculated from eqn. (5) by calculating a drag coefficient from eqn. (4) using the Reynolds number of the ground obtained by eqn. (3).

3 Safety assessment of the structure to an incomplete debris flow

For the foregoing paragraph, the incomplete debris flow was assumed to be pseudoplastic fluid, and how to presume the external force which acts to a structure was shown.

The safety of the structure to incomplete debris flow is confirmed from the section force which occurs by drag force, and the proof stress of a structure.

Then, the drag force by an incomplete debris flow was statically taken into consideration triggered by the simplicity of numerical computation.

In this case, the section force which occurs from eqn. (6a) to a deterrence pile is calculated. Here, it is necessary to take into consideration the force proportional to the coefficient of viscosity depending on the relative velocity of the ground and a deterrence pile.

However, under the present circumstances, it is difficult to take the displacement rate of a deterrence pile into consideration in static analysis.

Therefore, as shown in eqn. (6b), the force of the difference of the drag force by an incomplete debris flow and the reaction force depending on deformation of a deterrence pile was taken into consideration. The section force of a deterrence pile occurs according to this relative force. That is, the response of the deterrence pile decided to evaluate by beam theory on elastic foundation. Only presumption of external force shall be taken into consideration in fluid. Here, a coefficient of subgrade reaction is calculated by eqn. (7). However, it is necessary to presume the elastic shear modulus of the soil under flow and to calculate the coefficient of subgrade reaction under flow.

$$EI \frac{d^4 y}{dx^4} = F - \eta \dot{v}_p \tag{6a}$$

$$EI \frac{d^4 y}{dx^4} = F - k_h D y \tag{6b}$$

where EI is the rigidity of deterrence pile ($N \cdot cm^2$), η is coefficient of viscosity ($N \cdot sec/cm^2$), v_p is displacement velocity of deterrence pile, k_h is coefficient of subgrade reaction (N/cm^3), y is displacement of deterrence pile (cm), D is diameter of pile (cm), and F is drag force (N/cm).

$$k_h = 0.2[2G(1+\nu)]D^{-3/4} \tag{7}$$

where k_h is coefficient of subgrade reaction (N/cm^3), G is elastic shear modulus (N/cm^2), ν is Poisson's ratio (=0.5), and D is diameter of pile (cm).

In addition, about distribution of the depth direction of drag force, it was considered as the distribution of cosine curve as well as the former.

The outline of a numerical computation model is shown in Fig. 7.

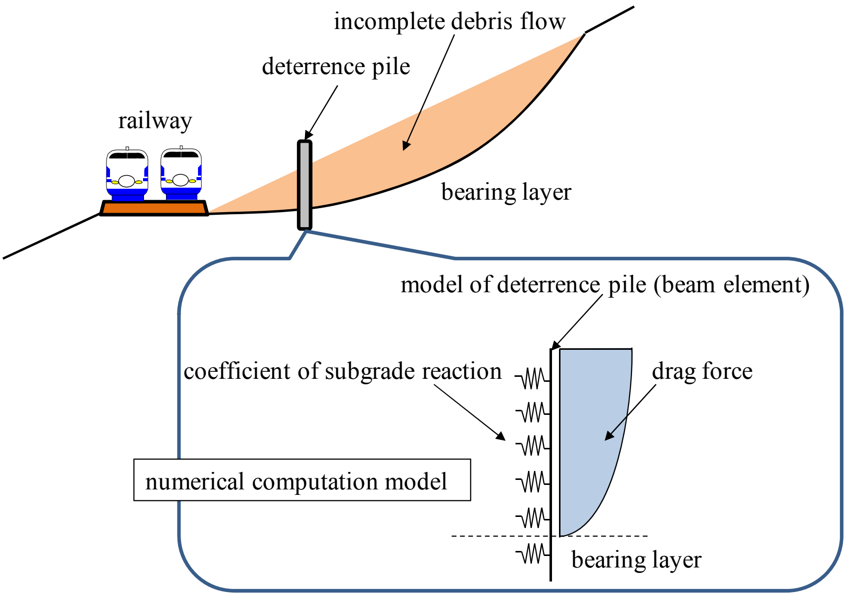

Figure 7: The outline of a numerical computation model (deterrence pile).

Moreover, examination of the protective barrier applied the same method as the case of a deterrence pile. However, since a protective barrier is hard, it is assumable that deformation of a structure is small. Therefore, as shown in Fig. 8, the bearing capacity in the conditions used as the rigid body and the section force of the wall in the conditions used as the cantilever fixed to the foundation are evaluated to the drag force by an incomplete debris flow.

4 Conclusion

The method of evaluating the external force of acting on a structure in consideration of incomplete debris flow as viscous fluid, as drag force was proposed. The valuation method applied the method of evaluating the external force by lateral flow during liquefaction.

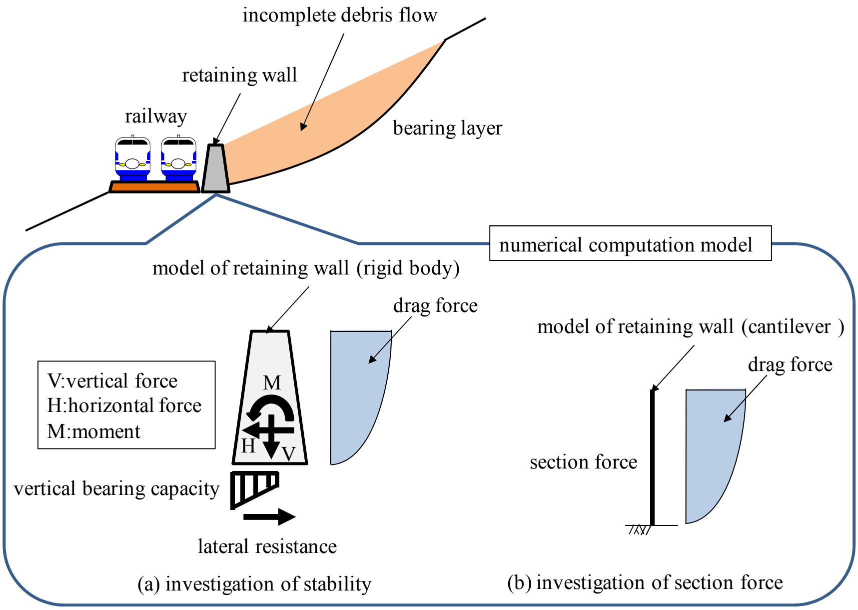

Figure 8: The outline of a numerical computation model (retaining wall).

By this proposal, we could attain the design of a countermeasure to the landslide disaster of a railway wayside and examination of the efficient countermeasure.

In this research, since the incomplete debris flow was assumed to be viscous fluid, if a coefficient of viscosity and velocity of flowing fluid are known, presumption of external force will be attained simply. It is considered by the past damage example and the target conditions of a place for the anticipation of velocity of flowing fluid to be possible. Moreover, a coefficient of viscosity can be referred to the coefficient of viscosity of the liquefied ground shown from past research.

Furthermore, proposed design calculation is a method by beam theory on elastic foundation, and in order to use the coefficient of subgrade reaction which can be found from a SPT-N value, it is an advantage that complicated investigation is not needed.

However, the coefficient of viscosity of an incomplete debris flow changes with soils. Therefore, it is necessary to investigate the coefficient of viscosity according to the soil. Moreover, there is a difference according to geographical feature conditions, etc. also regarding the shear velocity of the ground.

Therefore, it is required to increase the presumed accuracy of these values in order to evaluate drag force correctly. It becomes a subject to raise such presumed accuracy from now on.

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