Slope Failures and Subsurface Water Flow in Reclaimed Farm Lands

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Introduction

Mountaineous lands occupy more than 70% of Japanese land and most of them are sloping areas.[1] This means that more than 70% of rain falls on sloping areas, and part of it soaks into the slopes and the remains flow down the slope surfaces. About 28% of cultivated lands, whose total area is 5,470,000 ha, are on the slopes in Japan.

Recently, expansion of cultivated lands in Japan is confined mainly to such sloping areas, and most land reclamations in the sloping areas have been carried out through a great amount of soil banking and cutting, which we call "improved-yamanari-reclamation." Although those reclamations have been improved with the development of construction equipments and operation controls, effects of such a great amount of banking and cutting on subsurface water flow, surface runoff, soil erosion, slope stability and soil fertility are still vague.

This paper describes the relation between land reclamations and slope failures under heavy rainfalls, and subsurface water flow in model slopes of reclaimed farm lands.

Land reclamation and slope failures[2]

Many slope failures occurred in the reclaimed farm lands in Shikoku district, southwest part of Japan, under heavy rainfalls in 1972 and 1976. All the slope failures in Mitoyo county, north part of Shikoku district, were classified into 3 types as shown in Fig. 1. Type 1 is a large scale disaster in which a great amount of soil slides down the slope.

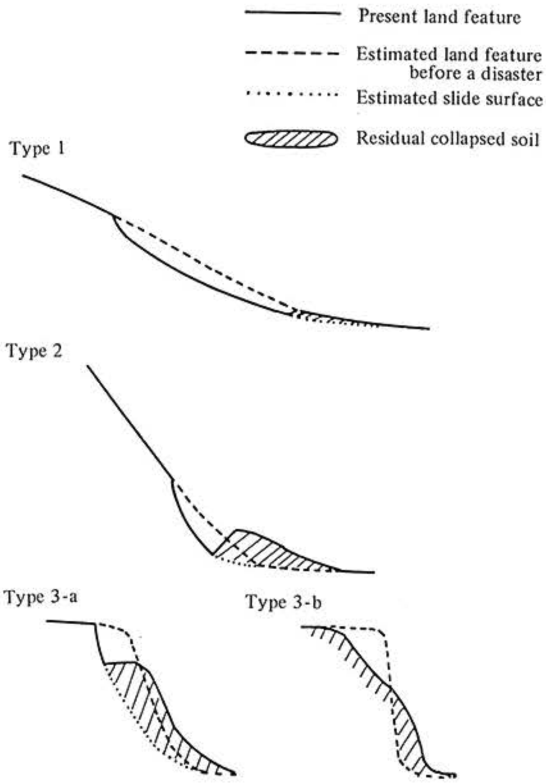

Fig. 1. Three types of slope failures in Mitoyo county
Type 1: Large scale slope failure
Type 2: Collapse of foot of a large slope
Type 3-a: Slide down of top of a small slope
Type 3-b: Fall down of top of a small slope

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Type 2 is a middle scale disaster in which the foot of large slope falls down. Type 3 are small scale disasters in which the top of slope slides down or falls down.

At the same time, those slope failures were classified according to the antecedent construction methods, i.e., improved-yamanari-reclamation, sloping-reclamation, yamanari-reclamation and terracing-reclamation. Improved-yamanari-reclamation is the reclamation in which the original rolling topography is changed to the gentle and wide slopes through a great amount of soil banking and cutting, which is required to use large machines in such sloped fields. Sloping-reclamation is the reclamation in which the natural slopes are arranged for planting, and the operating roads are constructed through soil cutting and banking. Yamanari-reclamation is the reclamation in which natural slopes are used as far as possible for both fields and operating roads. Terracing-reclamation is the reclamation in which flat fields are constructed through soil cutting and banking. Note that above-listed reclamations are ordered according to the amount of soil cutting and banking required for completing the constructions, except terracing reclamation.

Table 1 shows the matrix of the numbers of all slope failures in Mitoyo county classified by the types of slope failures and the antecedent construction methods. The matrix shows that there exists an obvious relation between the types of slope failures and the antecedent construction methods of the farm lands, that is, the more the quantity of soil cutting and banking during the antecedent construction, the larger scale collapses occurred. Terracing-reclamation looks very safe but this method is rarely adopted in recent projects of land reclamation.

Improved-yamanari-reclamation is preferred because it changes complex topography of mountaineous areas into gentle and wide farm lands which above all is desirable for mechanization of agriculture in such sloping areas. On the other hand, as shown in Table 1, this type of reclamation seems to have some unstability under a heavy rain.

Table 1. The matrix of the number of slope failures in Mitoyo county

Kinds of reclamation	Types of slope failures		
	Type 1	Type 2	Type 3
Improved-yamanari	24	0	0
Sloping	19	15	0
Yamanari	8	14	12
Terracing	0	3	0
Total	52	32	12

Table 2. Outlines of 6 cases of large scale disasters

Cases	Slope angle	Volume of fallen soils			Estimated weight of fallen soils
		Length	Width	Depth	
A	16°	52 m	40 m	9.5 m	11000 t
B	22	106	25	5.9	7400
C	16	98	45	4.6	7300
D	18	60	22	4.4	3100
E	15	55	26	3.9	2900
F	16	—	—	—	—

Field investigation of large scale disasters[2)]

Six cases were selected to investigate elaborately the actual conditions of large scale disasters in Mitoyo county. All of them were Unshu mandarin fields. Table 2 shows the outlines of these cases in terms of slope angles, sizes and masses of soils fell down.

All cases selected were made of banked soil and inclined at angles of 15 to 22°. In addition, there were 3 layers in all the cases, namely banked soil layer, plant layer* and subsoil layer which had been formed during the antecedent reclamation. The slidesurfaces were found to be almost corresponding to plant layers which had large pores, big permeabilities and small bulk densities.

Fig. 2 shows the schematic three-phase distribution in the vicinity of the sandwiched plant layer. The average bulk density and

* Plant layer is composed of vegetation existed on land surface before the reclamation. Land under the vegetation is referred to subsoil layer after the reclamation in this paper.

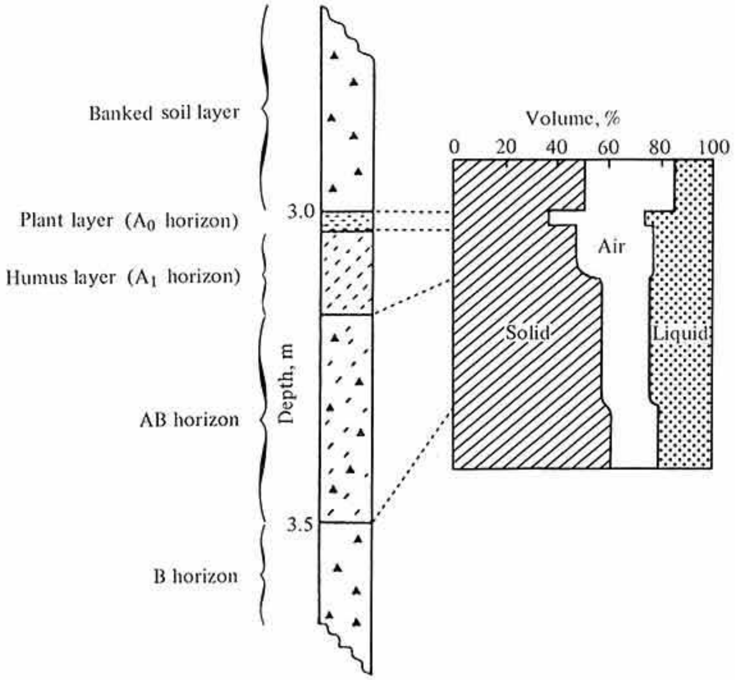

Fig. 2. Schematic three-phase distribution in the vicinity of a sandwiched plant layer

the average hydraulic conductivity of plant layers were 0.66 g/cm^3 and 0.41 cm/sec respectively, while those of banked soils were 1.33 g/cm^3 and 0.016 cm/sec respectively and those of subsoils were 1.47 g/cm^3 and 0.019 cm/sec respectively.

As a matter of course, the existence of such plant layers under banked soils is suspected to have important relation to the large scale disasters in improved-yamanari-reclamation. An experimental study was considered to be the best way to evaluate effects of the plant layer on subsurface water flow and large scale slope failures.

Model experiment of subsurface water flow

1) *Infiltration*[3,4]

Fig. 3 shows an example of experimental device which is constructed of a rain simulator and a 50 × 50 × 140 cm soil container of which front panel was made of clear acrylic board. As a model of a plant layer in the reclaimed farm land, a 3 cm thick air dried gravel layer was sandwiched between air dried Masa sandy loam soils. Using a gravel layer was more convenient to repeat the experiments many times without disturbing the physical conditions of water flow rather than using the plant layer itself. The hydraulic conductivity of gravel and Masa sandy loam were 0.91 cm/sec and 0.0028 cm/sec respectively.

Visual wetting fronts at every 10 min were traced directly on the acrylic board during a constant rain, then the board was photographed. The waving curves in Fig. 3 are the wetting front under 14.4 mm/hr rain for 210 min. It is clearly recognized in Fig. 3 that after almost uniform advancement of the wetting front, it stopped at the interface between the top soil layer and the second gravel layer. Uranine yellow powder, used as a tracer of infiltrated water, also showed the stop of vertical downward water movement at the interface and the occurance of the lateral water flow along the interface. The thick-

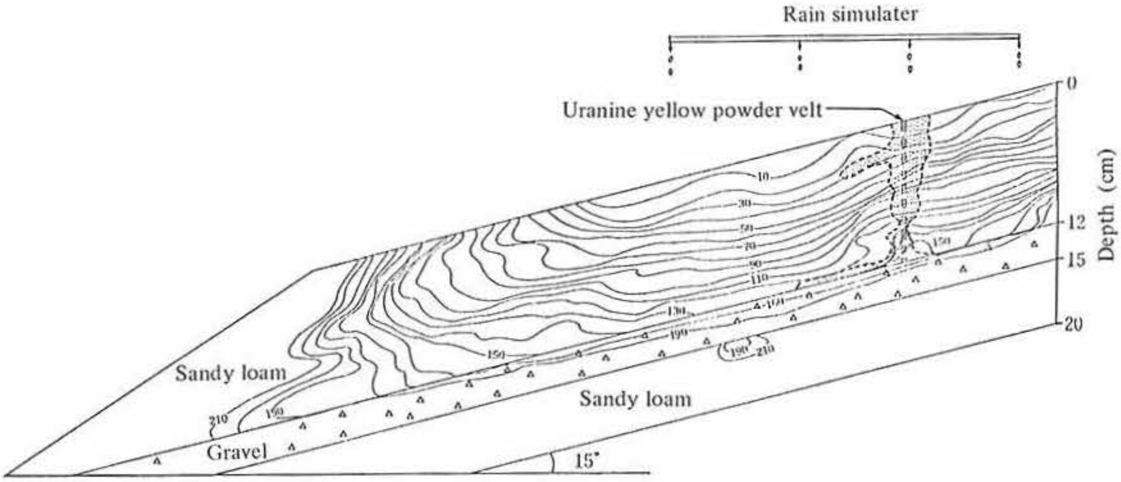

Fig. 3. Wetting front advancement in a model slope during 210 min artificial rainfall Numbers indicate the time from the start in minutes. The shadowed area indicates the spread of the uranine solution conveyed by infiltrated water.

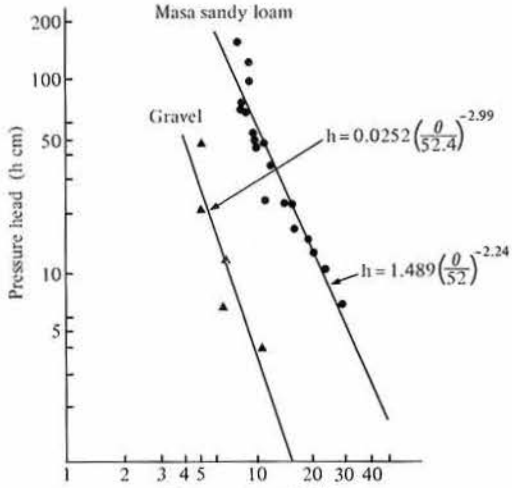

Fig. 4. Soil water characteristic curves in sorption of Masa sandy loam and gravel
The relations between θ and h were derived from the least squares method.

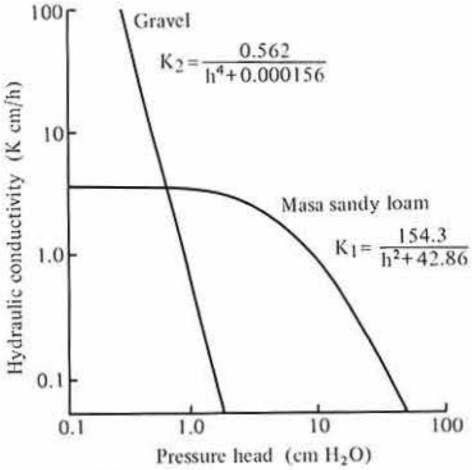

Fig. 5. Hydraulic conductivity of Masa sandy loam and gravel obtained by the steady evaporation method

ness of lateral water flow was estimated to be less than 1 cm.

The effects of the slope angle, thickness of the top soil layer, initial water content and rain intensity on the behavior of the wetting front were elaborately investigated, and such a stop of the wetting front was concluded to be general in those sandwiched soil layers.

2) Steady percolation[5] *and drainage*

The water content distribution and lateral water flux during a steady rain percolation were predicted theoretically. Fig. 4 shows the soil water characteristic curves of Masa sandy loam and gravel. Fig. 5 shows hydraulic conductivities versus pressure heads of them. Using these values, distributions of pressure head, water content and lateral water flux were estimated theoretically. Fig. 6 shows the results for the sandwiched slope,

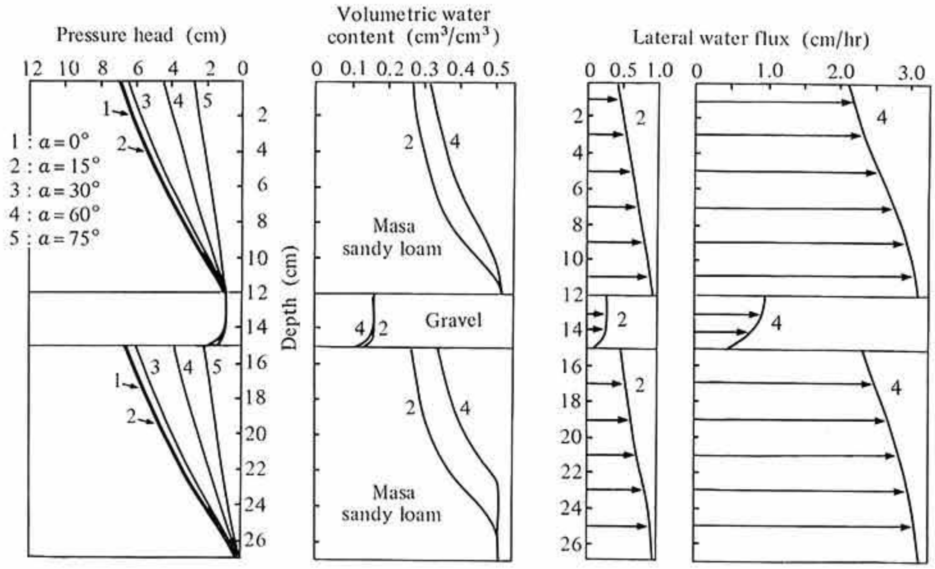

Fig. 6. Estimated distributions of pressure heads, volumetric water contents and lateral water fluxes under a steady rainfall of 11.4 mm/hr
α is the slope angle.

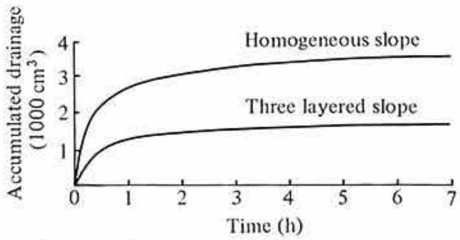

Fig. 7. The change of the accumulated drainage from the homogeneous and the three layered slopes after a steady rain fall of 55 mm/h
The angles of both slopes are 15°.

namely, the top soil layer, the gravel layer and the subsoil layer, under a steady rain. Obviously, the sandwiched gravel layer contained much less water than Masa sandy loam and had the role to promote lateral flux in the top soil layer.

Fig. 7 shows a comparison of the accumulated drainage from a homogeneous model slope and from a 3 layered model slope. It is clear that the accumulated drainage is less from the latter slope than that from the former slope. These experimental results mean that the sandwiched gravel layer disturbed the prompt discharge of water from the top soil layer in the same manner as observed during infiltration and steady percolation.

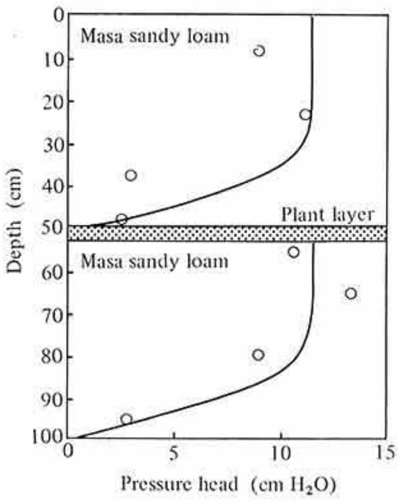

Fig. 8. The experimental (dots) and the theoretical (solid lines) pressure head distributions under a steady rain fall of 20 mm/h
The angle of the slope is 15°.

3) Verification of experimental results

At the last of all the experiments, a 20 × 100 × 160 cm model slope was used to verify the above mentioned experimental results using the actual plant layer instead of the gravel layer. It was proved that all the results obtained from gravel model experiments were true for the sandwiched plant layer. Fig. 8 shows the theoretical and the experimental distribution of pressure head during a steady rain of 20 mm/h in a slope, whose angle is 15 degree, which sandwiches a plant layer between Masa sandy loams. The experimental distribution of pressure head was well predicted theoretically.

Conclusion

From the view point of subsurface water flow during rainfalls, the sandwiched plant layer, which was formed during reclamation, was revealed to play complicated roles depending upon the circumstances of soil and moisture. The sandwiched plant layer disturbed subsurface water flow during infiltration, steady percolation and drainage. The next question is how it will function when the ground water level is forced to arise. Although the answer is beyond this paper, such a sandwiched plant layer will have a very important role in ground water flow.

In improved-yamanari-reclamation, the plant layer under banked soil is hardly removed due to an increase of construction cost. Since this method of reclamation is prevailing in Japan, it is believed that a further study is necessary to evaluate the role of such plant layers on subsurface water flow and on slope stability as well.

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