CORRELATION OF EROSION RATES WITH THE STRENGTH OF HIGH ERODIBLE VOLCANIC ASH SANDY SOIL

Islam Awad Student Member, Institute of Environmental Systems, Kyushu University.
Noriyuki Yasufuku Member, Institute of Environmental Systems, Kyushu University.
Hidetoshi Ochiai Member, Institute of Environmental Systems, Kyushu University.

1. Introduction

Overland flow erosion is frequently observed for the volcanic ash sandy soil named as Shirasu located in south western Japan. This paper presents a primary study to predict the rate of soil loss by overflow erosion (E_r) and its relation with the peak compressive strength (q_u). Series of physical models tests were performed on different samples of Shirasu soils reinforced by chemical additives such as calcium hydroxide and calcium oxide. The primary results reinforced the need to account for spatial variability of parameters such as the degree of compaction, water content and particles grading to make realistic predictions of soil loss through erosion by overland flow. The influence of spatial trend in the mean behavior of the critical flow velocities and soil erodibility is also shown to have a significant impact on soil erosion. Several researches were conducted to monitor the riverbanks failures [1]. Hanson[2] carried out a channel erosion study of two compacted soils as well as Sheikh et al[3] measured the erosion rate of compacted Na-montmorillonite soils. For the previous studies, the following equation was proposed to describe erosion rate and its relation with the critical shear stress:

$$E_r = \alpha\,(\tau-\tau_c)^{\gamma} \qquad (1)$$

Where E_r is the erosion rate per unit time per unit area (m^3/sec/m), τ is the actual shear stress, τ_c is the critical shear stress and (α, γ) are the variable measured factors from laboratory tests experimental model.

Erosion rates had been often linked with the shear stress applied on the soil surface. Moreover, the current study has an objective to understand more the effect of soil mechanical properties such as the peak compressive strength (q_u) on the hydraulic erosion index such as erosion rates. In this study, the above mentioned relationship is experimentally investigated.

2. Physical model test procedure and sample used

The erosion experimental apparatus flume was using acrylic plates materials. *Figure 1* shows a schematic view of the channel. A sample box hole with the dimensions (100 cm x 10 cm x 20 cm) was created at 147 cm upstream from the outlet, where a compacted soil sample was set.

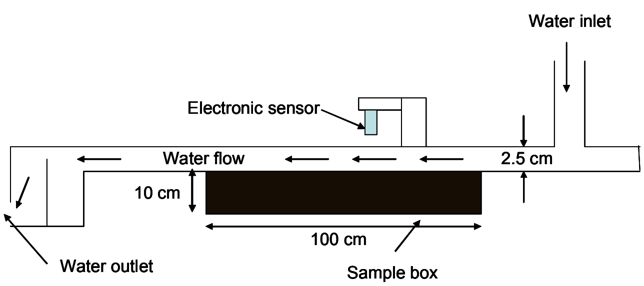

Figure 1. Experimental apparatus profile view

A water tank with 1.2 m3 volume was then set on a frame above the inlet of the flume to maintain a constant head and regulate the flow velocity during the test. On the other hand, a barrel to receive the water passing the apparatus outlet was set at the end to collect the water and by using a pump, the water was driven back to the upper water tank. A mobile electronic sensor was installed above the soil sample box to measure the surface level variations before and after the flow. The results were then transmitted to a data logger to transfer the level surveys in installments.

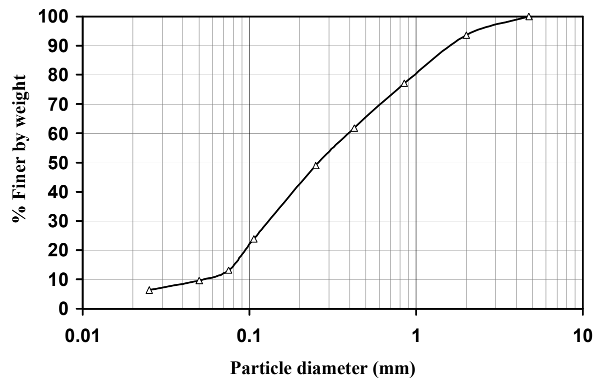

Figure 2. Grain size distribution curve for Shirasu soil specimen

The material used in the erosion tests was the volcanic ash sandy soil (Shirasu soil) taken from Kagoshima prefecture. The maximum grain size distribution for the soil sample placed in the sample box of the apparatus was 4 mm. The uniformity of this sample was 5 (*Figure 2*). The maximum dry density was 1248 kg/cm^3. The optimum water content obtained was 20%. In most of cases, a type of chemical additive was added by variable dosage for the unit dry weight whether it was calcium oxide or calcium hydroxide. To make soil specimen, the sample was compacted using a wooden compactor cylinder of 19 cm in length and 4 cm in diameter until reaching the required compaction degree and then to have a 10 cm thick homogenous compacted layer. The compaction was carried out in order to reach the maximum dry density at the water optimum value in predetermined calibrated manner.

3. Experimental cases

A series of experiments was carried out to investigate the effect of erosion on different compaction degrees (cases 1 to 3). On the other hand, another type of experiments was to investigate the influence of the different dosages and types of chemical additives on the erosion rate which is corresponding to cases 4 to 18. The tests conditions and results are summarized in Table 1. The specimens for cases 1 to 3 were compacted in the apparatus with different compaction layers for each case, in order to obtain different compaction degrees of 0.8, 0.9 and 0.93 of the maximum dry density at the optimum water content mentioned before. The calcium hydroxide dosages of 1%, 2% and 3% were added to the Shirasu soils specimens and cured for 1, 7, 14 days respectively which represent cases 4 to 12. The calcium oxide dosages of 1% and 3% were added to the Shirasu soils specimens and cured for 1, 7, 14 days which represent cases 13 to 18.

4. Results and discussions

The influence of compaction degree on erosion of soils was investigated. Comparing cases 1 to 3, the results obtained show that higher compressive strengths and less erosion rates were found with the higher compaction degree (Table 1.). The higher critical velocities were obtained with the higher degree of compaction and compressive strength. Uniaxial compression tests were carried out for samples of Shirasu soils (for 0.9 compaction degree) with different cases (cases 4 to 18). The mechanical analysis for the specimens shows a higher compressive strength after any case of curing days (1, 7, 14 days) for Ca $(OH)_2$ than CaO for different doses but relatively the calcium hydroxide gave higher values (*Figure 3*).

Table 1 Specimen properties, tests conditions and results.

	Case No.	Compaction degree	Water content	Dry density	Critical velocity	Eroded volume	Erosion rate	Chemical additive	Dose percentage	Curing days	Peak compressive strength (qu)
		%	%	g/cm^3	cm/s	cm^3	cm^3/s				KN/m^2
Series I	1	0.8	18.9	1.02	18	48.1700	0.0268	…….	…….	1	7
	2	0.9	18.9	1.11	23	23.5700	0.0131	…….	…….	1	17
	3	0.93	18.8	1.14	25	19.5600	0.0109	…….	…….	1	21
Series II	4	0.89	20.3	1.1	25	32.9800	0.0137	$Ca(OH)_2$	1%	1	34.24
	5	0.91	19.6	1.12	25	24.4980	0.0102	$Ca(OH)_2$	1%	7	51.50
	6	0.9	20	1.11	26	18.3012	0.0076	$Ca(OH)_2$	1%	14	55.17
Series III	7	0.9	20.1	1.11	27	29.8870	0.0125	$Ca(OH)_2$	2%	1	43.37
	8	0.9	19.2	1.11	28	18.3135	0.0076	$Ca(OH)_2$	2%	7	53.29
	9	0.91	20.6	1.12	28	15.3237	0.0064	$Ca(OH)_2$	2%	14	78.55
Series IV	10	0.9	19.8	1.11	29	19.2080	0.0080	$Ca(OH)_2$	3%	1	45.61
	11	0.89	19.9	1.1	30	11.9140	0.0050	$Ca(OH)_2$	3%	7	73.46
	12	0.9	19.7	1.11	30	11.0680	0.0046	$Ca(OH)_2$	3%	14	101.44
Series V	13	0.88	20.3	1.09	22	33.3863	0.0139	CaO	1%	1	21.22
	14	0.9	19.8	1.11	23	25.9892	0.0108	CaO	1%	7	29.31
	15	0.92	20.1	1.13	23	25.7078	0.0107	CaO	1%	14	32.14
Series VI	16	0.91	20	1.12	25	31.8348	0.0133	CaO	3%	1	30.72
	17	0.9	19.2	1.11	25	27.7356	0.0116	CaO	3%	7	38.26
	18	0.9	20.2	1.11	26	16.8097	0.0070	CaO	3%	14	40.2

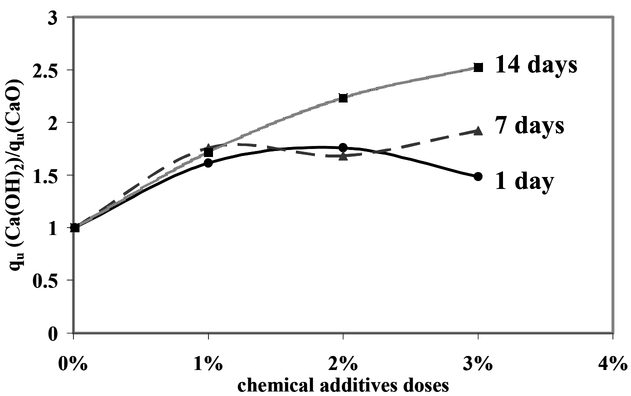

Figure 3. Comparison between the peak compressive strength for every dose of Shirasu soil with both kinds of the chemical additives (the calcium oxide and the calcium hydroxide)

The erosion rates obtained (Table 1) were defined by monitoring the final survey after the test completion for each case, and then by dividing the volume eroded by the elapsed time, the erosion rates could be then obtained. It is shown in Table 1 for the case of calcium oxide that a higher dose could lead to a better soil resistance against erosion and less erosion rates obtained. That trend is strongly shown for the case of calcium hydroxide as less erosion rates are obtained so far as in *Figure 4*.

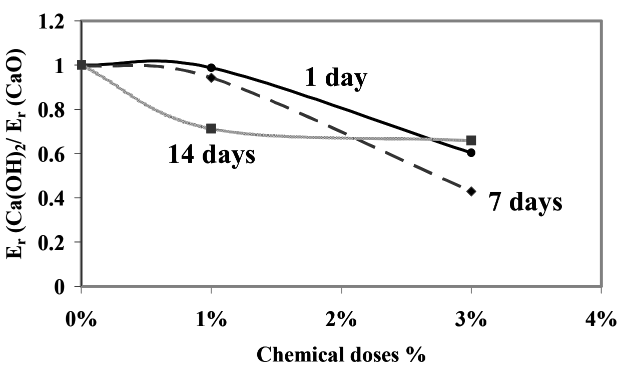

Figure 4. Comparison between the erosion rates for every dose of the volcanic ash sandy soil with both kinds of the chemical additives (the calcium hydroxide and the calcium oxide)

A correlated relationship between the erosion rates and the peak compressive strength was drawn in *Figure 5* to show the possibility to prove that hypothesis. From the experimental results shown at that figure, the erosion rates can be described by the following empirical equation (correlation factor $R^2 = 0.80$).

$$E_r = 0.087\, q_u^{-0.6} \qquad (2)$$

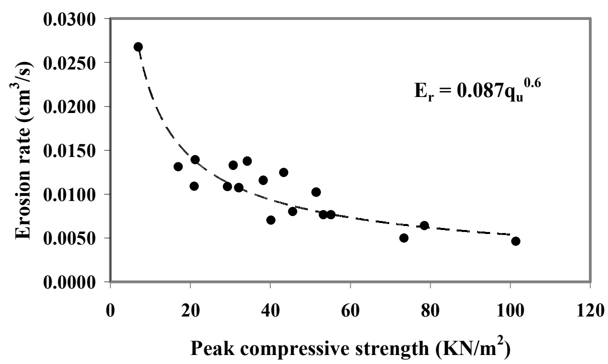

Figure 5. Correlation of peak compressive strengths and erosion rates

5. Conclusions and recommendations

The following are the clarified considerations: First, the erosion rates of soil specimens improved by higher percentages of chemical doses decreased when the water flow velocities exerted on the specimens are constants. This consideration is notably found for the calcium hydroxide than the calcium oxide. Second, the critical flow velocities of the soil specimens are higher when exerted on high compacted soils rather than less compacted ones. Finally, we can observe that the peak compressive strengths increase with higher doses of chemical additives. These considerations provide important findings to analyze flow erosion from a geotechnical point of view and to facilitate field measurement erosion prediction.

References

1) I.Awad, N.Yasufuku and H.Ochiai; Erodibility of Unsaturated Volcanic Ash sandy soils related to degree of compaction, Proceedings of the 3rd Asian conference on unsaturated soils, Nanjing, China, April 21-23, pp. 169-174, (2007).

2) G. J. Hanson; channel erosion study of two compacted soils, Transactions of the ASAE, Vol.32, No.3, pp296-305, (1988).

3) A. Shaikh, Ruff J. F. and S. R. Abt; Erosion rate of compacted Na-montmorillonite soils, Journal of geotechnical Engineering, Vol. 114, No.3, pp.127-131, (1990).