Compaction Requirements for Fill Slopes

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Site development in Hong Kong has involved large-scale cuttings and fill construction and, until quite recently, the steep and high fill slopes were formed by end-tipping of the borrow material with no compaction on the slopes or within the main body of the fill. Although the loose fill may be stable when dry as formed, it may not continue to be dry during the rainy season when direct infiltration of rain water and concentration of run-off water on the slopes can result in saturation of the surficial few metres of fill. This saturation reduces the soil strength through reduction in pore-water suction and hence can lead to a shallow failure of the slope.

If the fill were sufficiently dense prior to saturation, the soil would tend to increase in volume during deformation and the failure would take the form of a debris slump coming to rest at the foot of the slope. If the fill were loose, however, the soil would tend to decrease in volume or even collapse, causing a rapid rise in pore-water pressure and consequent liquefaction, with the end-result that the failure produces a mud-avalanche travelling at great speed well beyond the foot of the slope.

The disastrous consequences of such mud-avalanches are well known. At Sau Mau Ping, 71 people were killed in June 1972 and 18 killed in August 1976; elsewhere, the property damage and disruption to roads and services has been extremely high.

Complete prevention of failures in fill slopes or in cuttings can never be guaranteed except at prohibitive cost, but amelioration of the consequences of a failure can be achieved at a reasonable cost. In particular, the potential collapse of soil structure leading to a mud-avalanche can be eliminated by compacting the fill to a state such that volume expansion occurs on shearing rather than volume contraction.

Using bulk samples of typical fill material, the critical densities at which no volume change occurred during deformation were determined. Since critical density can vary considerably with soil grading, the results were standardised in terms of the Relative Compaction Factor, which is the ratio of dry density to the maximum dry density measured by the Standard Compaction Test.

TEST RESULTS

The main sources for fill in Hong Kong are residual decomposed granite, a silty sand; the more completely decomposed 'red earth' decomposed granite, a clayey sand; and decomposed rhyolite, a sandy silt to clayey silt. Three bulk samples of decomposed granite, two samples of red earth, and two samples of decomposed rhyolite, having the gradings shown in Figure 1, were tested at initial states varying from loose to dense.

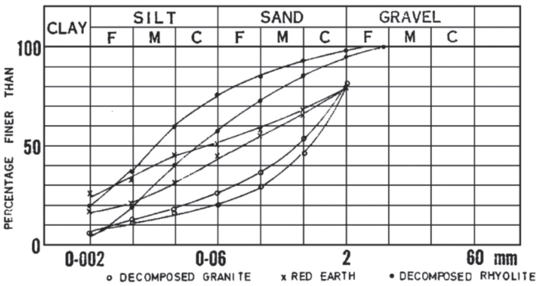

Figure 1.

The most dangerous portions of a fill alone with regard to potential collapse are the surficial zones extending a few metres below the surface, where the over-burden pressures are small. For convenience in dealing with loose soil at low confining pressures, the shear-box test was used with normal pressures of 25, 50 and 75 kPa, corresponding roughly to fill thicknesses of 1, 2 and 3 m. Specimens were prepared in the shear-box by hand-ramming to the required density, and were then soaked in water to simulate the effects of infiltration and afterwards sheared at strain-rates slow enough to allow unrestricted volume change.

Figure 2 illustrates typical load and volume change results during shear deformation for the three soil types. From these results the critical dry density at which shearing occurs at constant volume was found by interpolation. For a particular soil the critical dry density increases slightly with increasing normal pressure, as could be expected, and ranges from 1.41 to 1.78 Mg/m^3 depending on soil type. Standardising these results by dividing the critical density by

Table 1. Critical relative compaction factor (percent)

	Soil Type	Decomposed Granite			Red Earth		Decomposed Rhyolite	
	Sample No.	1	2	3	4	5	6	7
Normal Pressure (kPa)	25	88	87	88	94	97	93	94
	50	91	92	94	99	101	95	98
	75	92	94	94	104	107	100	105

Standard Compaction maximum dry density leads to the values of Critical Relative Compaction Factor shown in Table 1.

Hence, for decomposed granite a Relative Compaction Factor in the range of 90 to 95% could be sufficient to prevent the possibility of a structural collapse. For comparison, Relative Compaction Factors as low as 70% were measured at Sau Mau Ping after the 1976 failure. For the red earth and decomposed rhyolite, Relative Compaction Factors in the range of 95 to 105% would be sufficient to ensure no structural collapse.

The strength results from the tests are illustrated in Figure 3, which shows the cohesion intercept c and angle of shearing resistance ø for fully drained soaked conditions as a function of Relative Compaction Factor for three of the soil samples. The increasing strength resulting from adequate compaction (Relative Compaction Factor greater than the critical) is clearly shown. For the decomposed granite and red earth, the cohesion intercept is negligibly small at densities less than the critical but is significantly non-zero (greater than 5 kPa) at densities greater than the critical because of the pre-compression from compaction. For the decomposed rhyolite, the cohesion intercept is appreciable (greater than 10 kPa) even at low densities although the angle of shearing resistance is fairly small.

A moderate cohesion intercept value of the order of 5 kPa could generally be sufficient to prevent shallow slope failures from occurring in fill even though the slope angle may be greater than the angle of

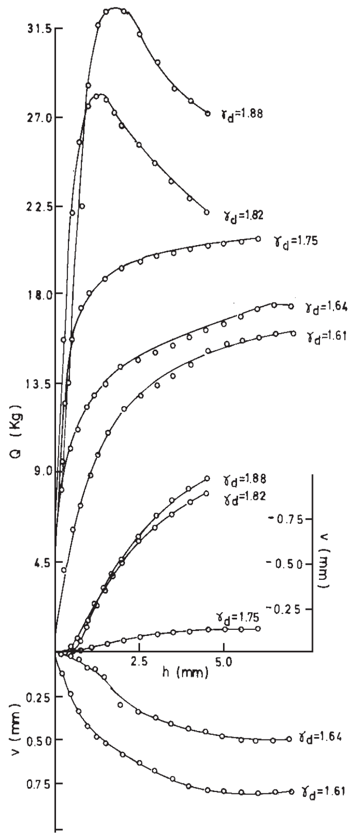

Figure 2a. Decomposed granite

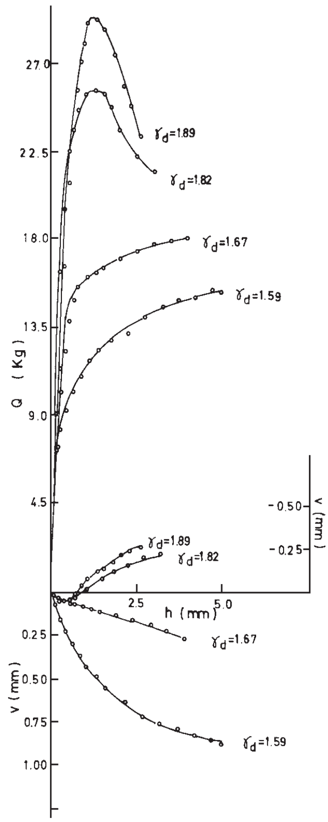

Figure 2b. Red earth

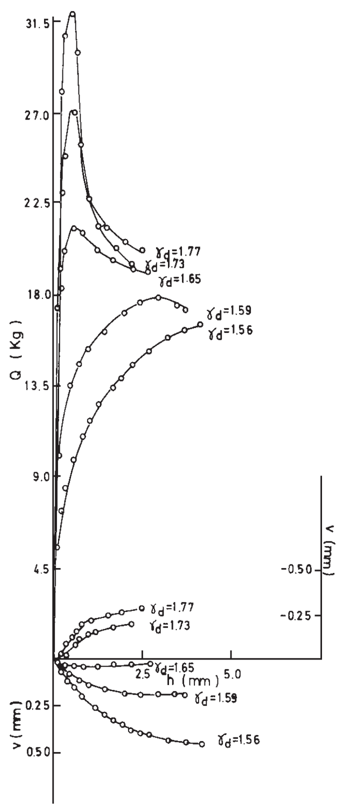

Figure 2c. Decomposed rhyolite

shearing resistance. On this strength basis a Relative Compaction Factor of about 90% would be satisfactory for the decomposed granite and the decomposed rhyolite but a value of above 100% would be necessary for the red earth.

DISCUSSION

The need for adequate compaction of fill slopes has been made abundantly clear by the occurrence of disastrous mud avalanches in the past. From the results presented here for typical soils encountered in Hong Kong the necessary amount of compaction to eliminate any possibility of structural collapse can be seen to be quite modest.

For decomposed granite, the most common source of fill, a Relative Compaction Factor of 90 to 95% is all that is necessary while for red earth and decomposed rhyolite a rather higher range of 95 to 105% is necessary, but relative compaction can be achieved using normal compaction plant with no difficulty. Site control to ensure that the desired compaction is in fact being achieved is, of course, essential since the standard of comparison - the maximum dry density - is a very variable quantity. Figure 4 shows the range in Standard Compaction maximum dry density and optimum water content for a variety of soil samples to illustrate the necessity of control testing. Although the results cluster around the 5% air voids curve, the range in actual maximum dry density is considerable. For decomposed granite the range is from about 1.55 t/m^3 to 1.95 t/m^3, for decomposed rhyolite from about 1.35 t/m^3 to 1.8 t/m^3.

The critical density, at which no contraction occurs, is a conservative value to prevent mud avalanches, since at slightly lower densities there would be only a small volume decrease but no sudden structural collapse. It is thus not strictly necessary that the fill should be entirely denser than the critical value and occasional control test densities somewhat lower than critical are tolerable. Provided that good site control on compaction is in operation, then it would be reasonable to aim for an average site density equal to the critical with an allowable proportion of 5% of the fill less than, say, 90% of critical. In terms of Relative Compaction Factors, a suitable specification could thus be

	Minimum site average	95% of volume greater than
Decomposed Granite	95%	85%
Decomposed Rhyolite, Red Earth	105%	95%

ACKNOWLEDGEMENTS

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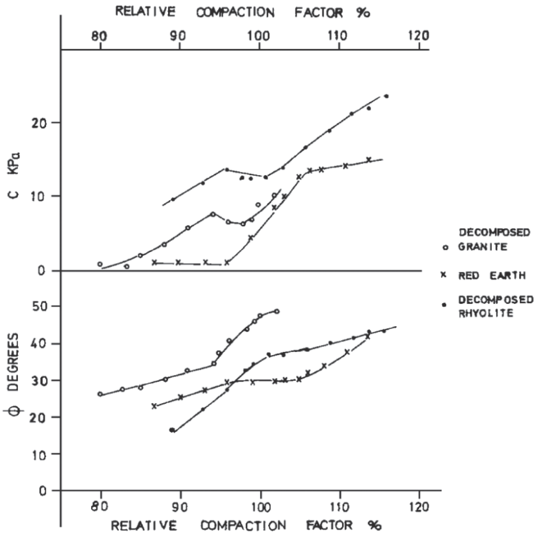

Figure 3.

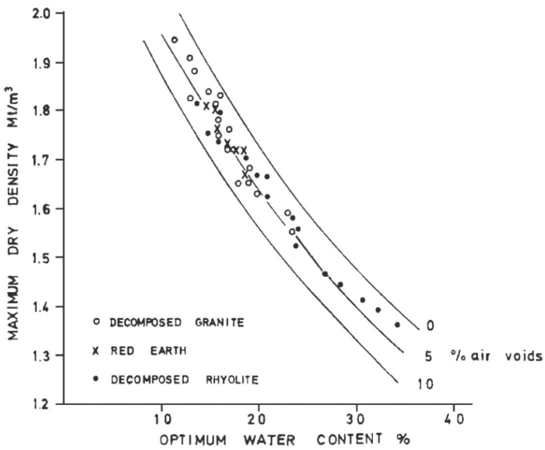

Figure 4.