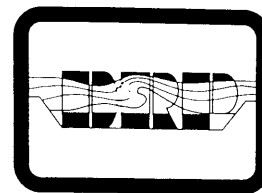# Dredging Research
Technical Notes

Degradation of Hydraulically Transported Clay Balls

Purpose

This technical note presents results obtained from tests conducted on synthesized clay balls and on clay balls from Mobile Ship Channel subjected to a simulated environment similar to hydraulic transport conditions. Work was conducted under Dredging Research Program (DRP) Technical Area 2, Material Properties Related to Navigation and Dredging. Based on these results, empirical relationships between degradation rate and the clay's plasticity and density (or stiffness), as well as the balls' average transport (drag) velocity, are established. More detailed test procedures and results are given by Leshchinsky, Richter, and Fowler (1992a,b).

Background

Degradation resistance of hydraulically transported clay balls varies widely. Friable clays slurrify rapidly after being excavated by the cutterhead (Figure 1). Stiff or highly plastic clays may deform into a ball shape (Figure 2). This phenomenon may or may not be beneficial, depending on the application. For example, if a dike is to be constructed using hydraulic fill, clay balling, especially out of stiff clay, is desirable since construction is then feasible (Figure 3). Conversely, clay balls slow down the transport process; that is, the volume of solids in water may decrease by an order of magnitude typically from about 50 percent to about 5 percent. In extreme cases, clay balls may clog the dredge pipeline. Consequently, knowledge of degradation resistance of dredged clay balls is necessary to predict the transporting difficulty and, possibly, to plan the dredged material containment. Even the selection of a cutterhead may be related to the degradation rate; that is, it can be selected so as to produce the proper initial ball size.

A pressurized clay ball tumbler has been designed and constructed at the U.S. Army Engineer Waterways Experiment Station. This device is currently being used in tests simulating conditions in the dredge pipe, to quantify clay ball degradation during transport. Similarly, an upflow tube has been constructed to investigate the erosive effect of slurry flow past a clay ball. It will

Figure 1. Slurrified clay at the Gaillard Island disposal
site (Mobile District)
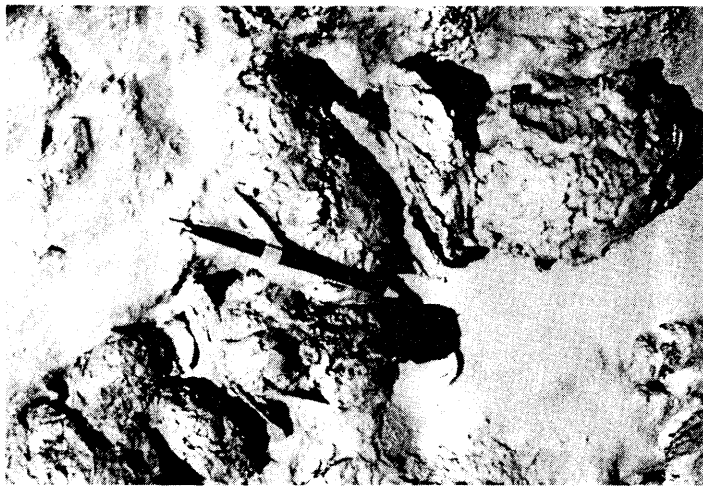
a. Soft but highly plastic clay

b. Stiff clay

Figure 2. Clay balls

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Figure 3. Stiff clay balls used to construct a steep dike

be possible to simulate different velocities and slurry characteristics in these two laboratory devices.

Additionally, to achieve actual field calibration of degradation, a piping system has been constructed. This system will be placed on a 30-in. dredge pipe to introduce clay balls into the dredge pipe flow of maintenance material. The clay balls will be recovered as they leave the dredge pipe, and the damage will be quantified in terms of mass and volume lost during passage.

Additional Information

This technical note was written by Dr. Dov Leshchinsky, University of Delaware; Mr. Stephen D. Richter, Century Engineering, Inc., of Dover, Delaware; and Dr. Jack Fowler and Mr. Paul Gilbert, U.S. Army Engineer Waterways Experiment Station (WES). For additional information, contact Dr. Fowler, (601) 634-2703, or the manager of the Dredging Research Program, Mr. E. Clark McNair, Jr., (601) 634-2070. Further information on the pressurized clay ball tumbler designed and constructed at WES can be obtained from Mr. Gilbert, (601) 634-2797.
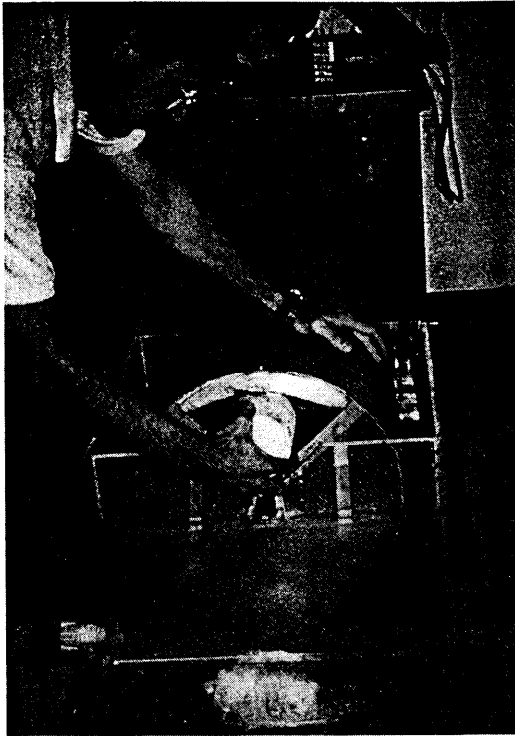
Testing Apparatus

When transported hydraulically, clay lumps are dragged slowly over the bottom of the dredge pipe while slurrified portions flow rapidly above as a suspension. To simulate the interaction between a clay lump, the pipe, and the fluid turbulence, the apparatus shown in Figure 4 was assembled. Generally, it resembles the device reported by Lord and Isaac (1988). The interaction simulation device consists of a sheet metal drum (40 cm in diameter and in length) with screened ends. The inner wall of the drum was lined with a fine sandpaper. The drum was suspended in an acrylic plastic container that was filled with clear water, thereby submerging half the drum. A clay lump was inserted through an opening in the screen (Figure 4a). A variable-speed electric motor, engaged to the drum through a shaft, spun the drum (Figure 4b). The drum was rotated, for each specimen, at a constant speed up to a selected time. After the selected exposure time to agitation had elapsed, the motor was stopped and the specimen's intact portion removed (Figure 4c). This portion was then oven-dried and weighed (Figure 5) to determine the degradation (that is, the percent, by weight, of material that had slurrified) because of exposure to the simulated hydraulic transport environment.

Tests were conducted at three distinctive tangential velocities of the drum: 0.75, 1.5, and 2.25 m/sec. These velocities are assumed to signify the average relative velocities between the slowly dragged clay lumps and the dredge pipe. However, in the tests, the drum (that is, analog to the pipe) moves relative to the lumps.

Clay Specimens

Clay lumps were prepared by mixing kaolinite and bentonite. By varying the proportion of the components, synthesized clays possessing a wide range of plasticity could be tested. Tests indicated that beyond 10 percent bentonite in the mixture, the clay lumps exhibited insignificant degradation under the simulated hydraulic conditions. Hence, the relevant range of bentonite in mixture was limited to 10 percent. Figure 6 shows the Atterberg limits as a function of bentonite in mixture. The liquid limit (LL) signifies the water content at which the clay turns into a heavy liquid (that is, slurrifies); the plastic limit (PL) indicates the water content at which the clay turns from a semisolid into a plastic material. The plasticity index (PI) is defined as PI = LL - PL and signifies the range of moisture content in which the clay keeps its integrity as a plastic lump. In their natural state, nearly all dredged clays possess water content, ω_n, equal to or greater than the plastic limit (that is, $\omega_n \geq$ PL). Subsequently, PI is the practical and maximal range of water content before slurrification occurs (that is, before the water content increases above LL), thus making it reasonable to seek a correlation between degradation and the plasticity index.

a. Placement of clay lump
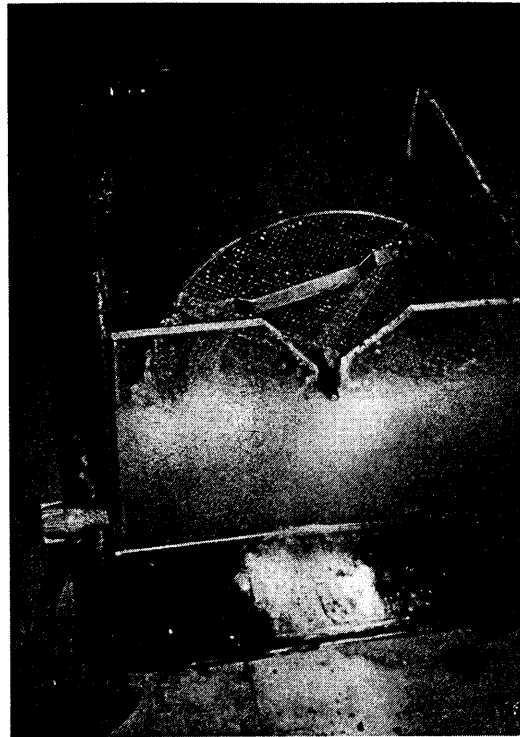
b. Test in progress

c. Removal of intact lump
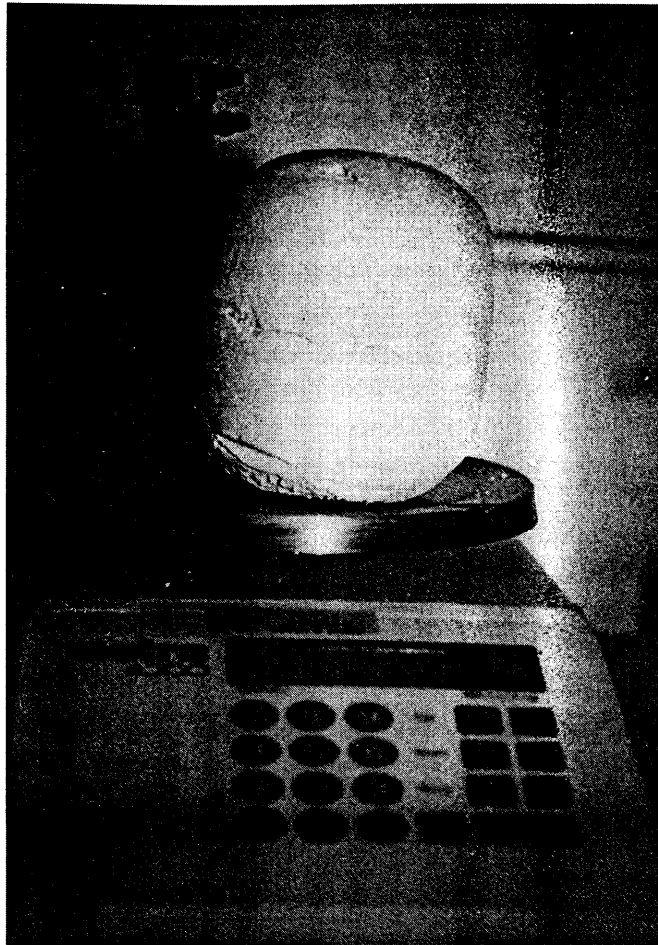
Figure 4. Testing apparatus
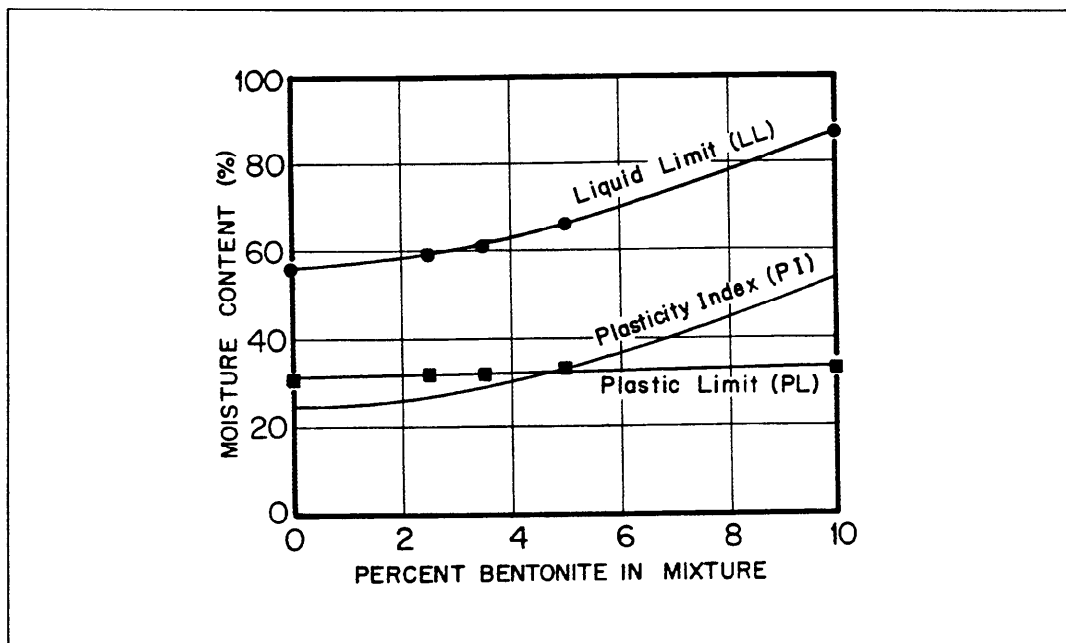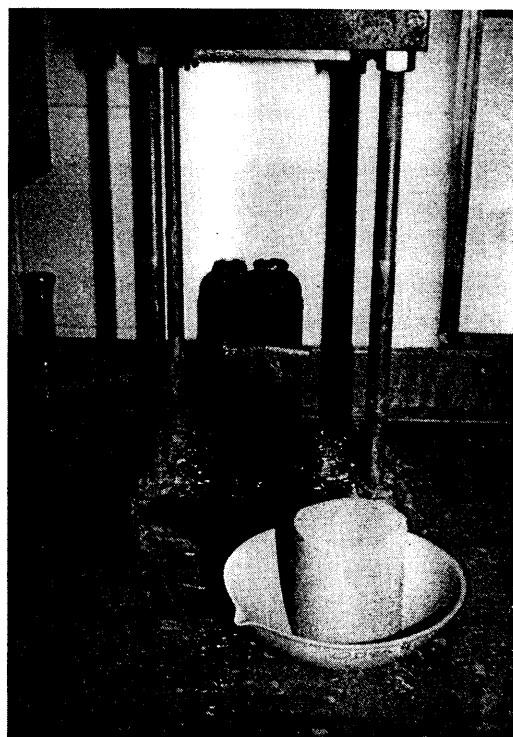
Figure 5. Oven-dried intact lump

Figure 6. Atterberg limits versus bentonite in mixture

Based on the standard Proctor test, it was determined that the maximum dry density varies between 14.0 and 13.7 kN/cu m, for 0 percent and 10 percent bentonite in the mixture, respectively. The corresponding optimal moisture content varied between 29 and 31 percent. At its maximum density, the synthesized clay can be classified as "stiff." At 80 percent of its maximum density, the clay can be categorized as "soft." Also, for submerged soils, the density (or stiffness) is directly related to the voids ratio of the material, or alternatively, to the natural water content, ω_n, of the clay. Subsequently, it seems reasonable to seek a correlation between degradation and stiffness (or initial density of clay lumps). Hence, tests were conducted on specimens at three initial dry densities: 80, 90, and 100 percent of the maximum Proctor value. These percentages are termed "relative compaction," R_c (that is, R_c = 80, 90, and 100 percent).

Specimens were prepared as follows. The bentonite and kaolinite mixture was proportioned to produce the desired PI. Water was added to yield the Proctor's optimal moisture content. The wet mixture was then statically compacted in a Proctor mold (4-in. diameter and 4.5-in. height; Figure 7a), using a hydraulic jack, to a desired dry density (that is, to R_c = 80, 90, or 100 percent). The specimen extruded from the mold (Figure 7b) was then used as the synthesized clay lump possessing a prescribed PI and R_c.
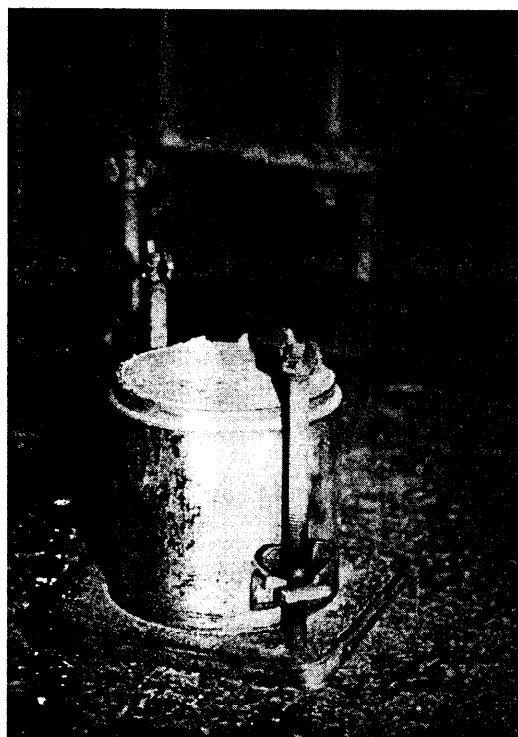
a. Compacted in Proctor mold   b. Extruded specimen

Figure 7. Specimen

Results

   Figure 8 shows the typical appearance of oven-dried specimens after being
subjected to drum agitation. Note that these specimens turned into clay
lumps. Results of one set of tests (out of 12 sets) are presented in Figure 9.
Figure 9 illustrates the data on specimens having a plasticity index, PI, of
25 percent agitated at a drum tangential velocity, v_t, of 2.25 m/sec (note that
v_t presumably signifies the relative velocity between the dragged lump and
the dredge pipe). The "remaining intact material" represents the dry weight
of the intact portion of the specimen after agitation divided by its initial dry
weight. A straight-line fitting for the data points seems reasonable. The
slope of the fitted line signifies the rate of lump degradation as a function of
R_c, PI, and v_t. This rate may be an important design parameter, allowing
one, for example, to assess the lump size at the end of the dredgeline.

   The fitted slopes for all test results, similar to Figure 9, were plotted in Fig-
ures 10a, b, and c versus the transport velocity and as a function of plasticity
and compactness. Once the validity of the simulated tests is verified, these
figures can be considered as design charts. One can then estimate from Fig-
ure 10 the required transport rate of cut lumps, in a given pipe, so as to at-
tain a certain production (that is, excavation) rate while achieving the con-
struction objectives (that is, while considering the dredged material end of the
dredging activity). This estimation can be accomplished based on easily char-
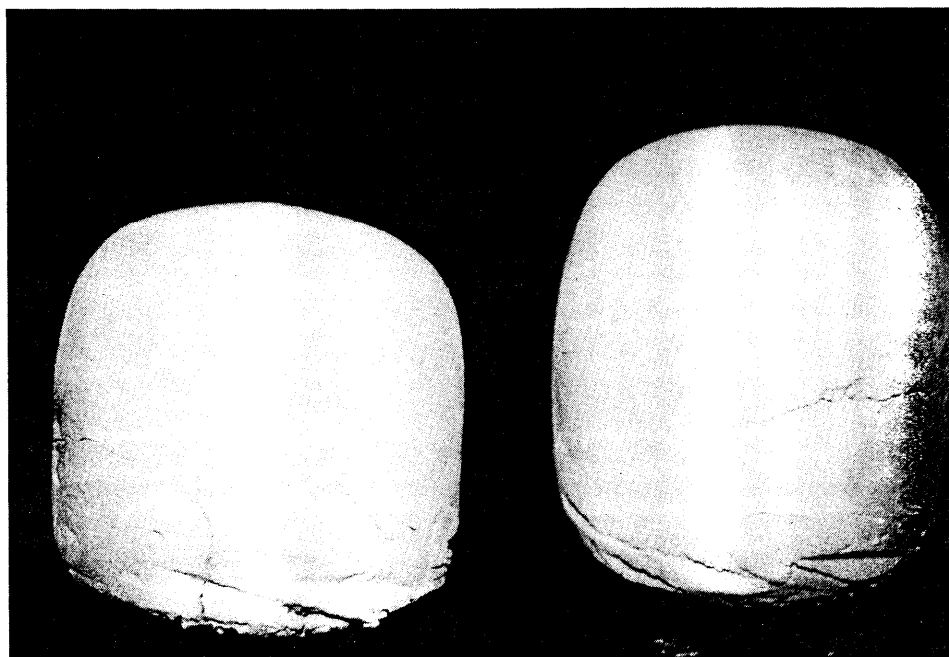acterized in situ properties: plasticity (PI) and compactness (R_c).

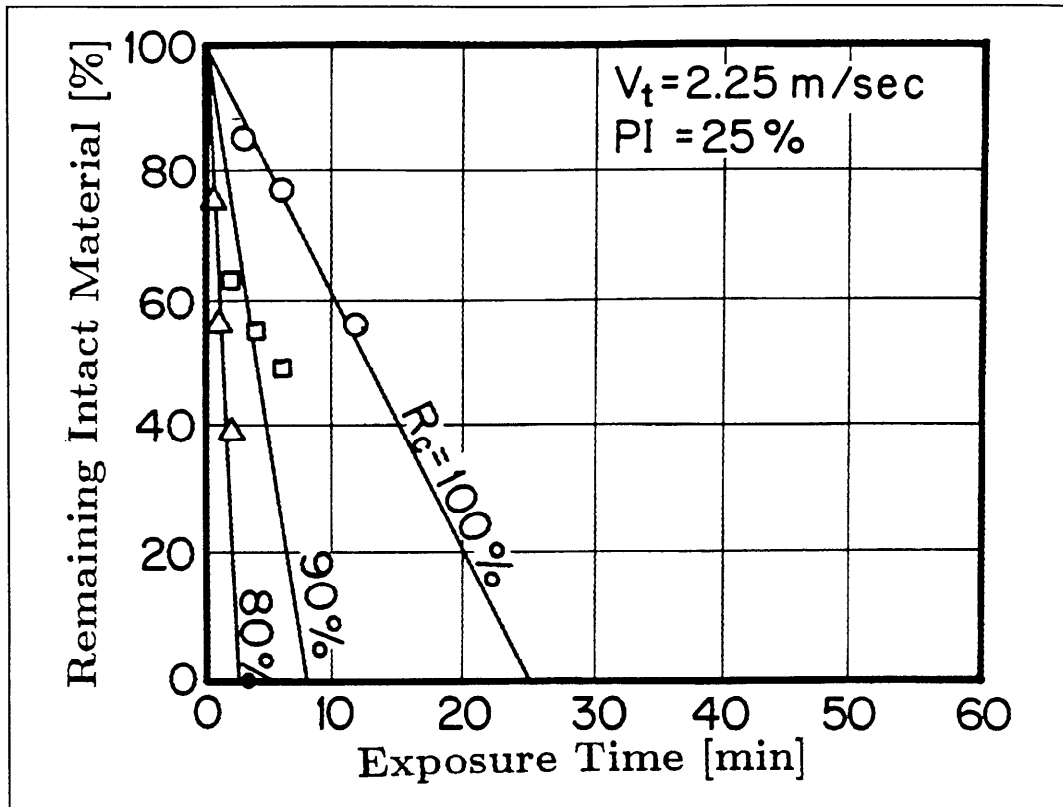Figure 8.   Typical appearance of specimens that turned into clay balls

Figure 9. Typical test results (PI = 25 percent and v_t = 2.25 m/sec)

Figure 10 shows that decreasing PI or increasing v_t may significantly increase the rate of degradation. At low density (soft clay), plasticity plays a major role. At high density (stiff clay), however, the rate of degradation is virtually independent of plasticity as long as PI ≥ 25 percent.

Conclusions

The results obtained from tests on synthesized clay specimens, conducted in a simulated hydraulic transport environment, show that plasticity and density (or stiffness) have significant effects on the lumps' rate of degradation. For very dense material, the degradation rate was found to be negligible at any plasticity index greater than 25 percent. Rates of degradation for highly to moderately dense clays, having plasticity indices between 25 and 35 percent, are rather slow. As the plasticity index increases above 35 percent, the degradation rate rapidly becomes negligible.

The test results indicate the likelihood of clay balls formation, that is, when the clay lumps will exhibit little degradation/slurrification. For example, if the criterion for clay balls formation is a degradation rate of 5 percent per minute (that is, at this rate a clay ball of a specified size will be delivered at the end of a given dredge pipe), then Figure 10a indicates that at v_t = 1 m/sec the PI must exceed 30 percent for soft clay. Increasing the transport velocity

a. Soft clay (density = 80 percent of maximum value)

b. Medium clay (density = 90 percent of maximum value)

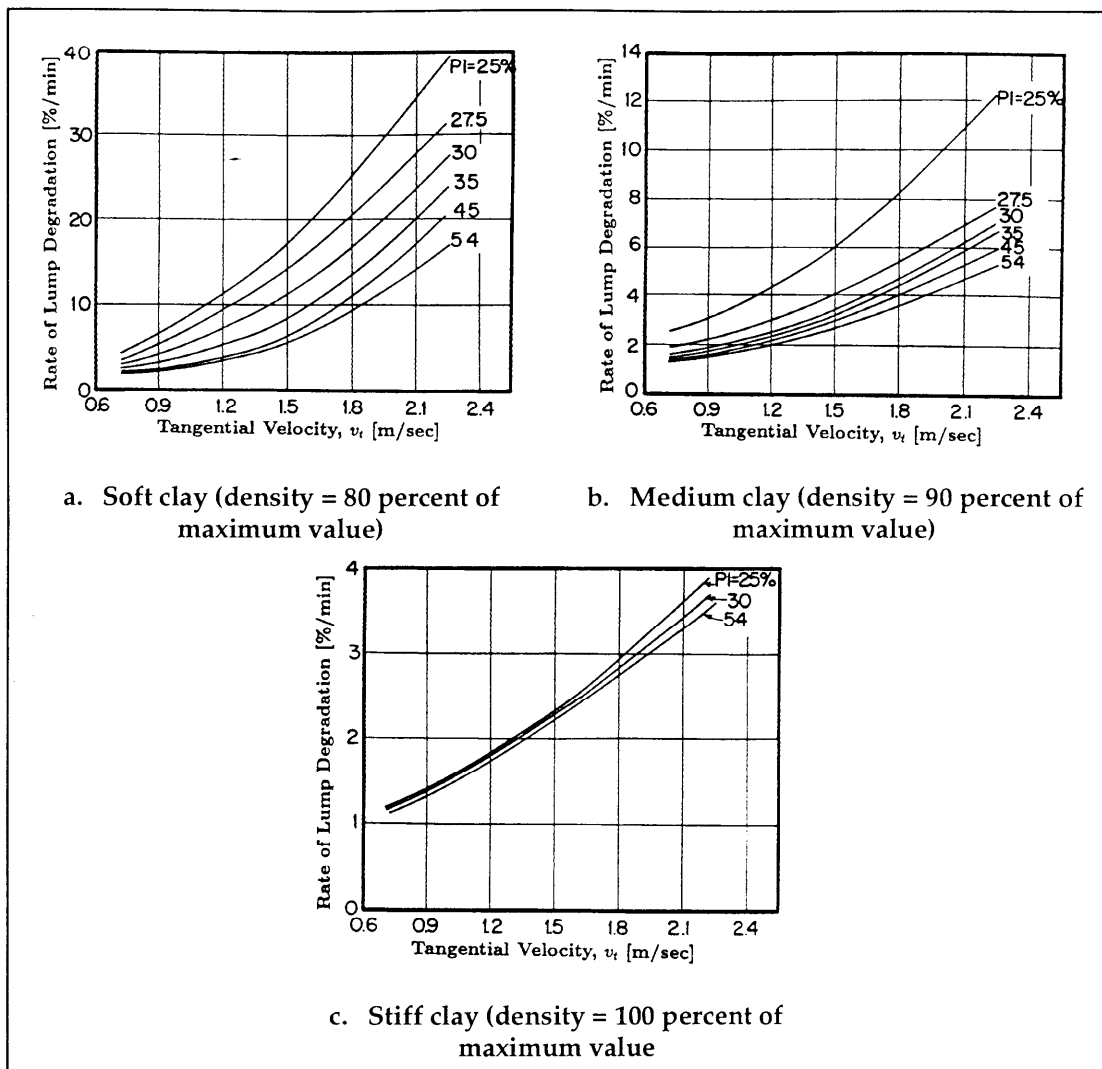c. Stiff clay (density = 100 percent of maximum value

Figure 10. Proposed design charts

will require a higher PI. Figure 10a also implies that an increase of PI from 25 to 35 percent drastically decreases the degradation rate. Figure 10c indicates that for PI > 25 percent, clay balls are likely to develop in stiff clay. This supplements the information provided previously by Verbeek (1984) about the formation of clay balls.

References

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Lord, E.R.F. and Isaac, B.A.A. 1988. "Geotechnical Investigation of Dredged Overburden at the Syncrude Oil Sand Mine in Northern Alberta, Canada," *Canadian Geotechnical Journal*, Vol 25, No. 1, pp 132-153.

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