Geotechnical Properties and Flow Behavior of Coal Refuse under Static and Impact Loading

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Project Description and Objectives: Millions of tons of coal waste are produced every year and stored in coal waste slurry impoundments. Since impounded slurried waste has high water content and low shear strength, an inadequately designed or constructed impounding structure is susceptible to the flow failure via a breach of its embankment following static or impact (e.g. blast-induced) loading. In other cases a flow failure may occur in the form of a breakthrough into an adjacent or subjacent underground mine. Both types of failure endanger public safety and health, property, and natural ecosystems. They may result from several factors including poor embankment construction or a weak barrier between an impoundment basin and an underground mine. They always result from impounded slurry that remains flowable because of insufficient consolidation to resist the effects of static or dynamic forces. Before this study there has been no comprehensive work on the geotechnical and rheological properties of impounded coal waste slurry, and the mechanisms that cause and sustain slurry flow. This project studied the geotechnical properties and flow behavior of coal waste slurry under static and impact loading. The influence of important parameters such as water content, particle size distribution, viscosity, and magnitude of static and impact loading on the material's flowability was investigated.

Applicability to Mining and Reclamation: The results of this study provide a better understanding of coal waste slurry flowability and consequent failure potential of coal waste impoundments. It is concluded that using liquid limit as the maximum allowable water content is an appropriate, conservative option for preventing flow failure during the construction and expansion of an impounding facility. In addition, the construction of slurry cells in place of large impounding structures was found to be an effective countermeasure to flow-failure potential.

Methodology: The geotechnical properties and flow behavior of impounded coal refuse under static and impact loading was assessed by using a range of standard laboratory tests, and small-scale model and centrifuge model experiments. The centrifuge model was used to measure slurry flow characteristics under loads equivalent to those imposed on slurry at depth in a typical impoundment. All of the tests followed ASTM standards or common practices used in geotechnical engineering. The amount of the sampled slurry available allowed multiple runs of many of the tests to check for repeatability. The tests and experiments were conducted on coal waste slurry samples collected at two coal preparation plants, one each in Kentucky and West Virginia.

Highlights: Important conclusions of the study include the following:

1) Geotechnical properties of the coal waste slurry such as particle size distribution, specific gravity, compressibility, consolidation parameters, permeability, liquid and plastic limits, in-situ water content, shear strength, and viscosity play important roles in the flow characteristics of coal waster slurry. Of particular interest in this study was the liquid limit of the samples, which was 38.1 and 42.5 for the KY and WV samples, respectively.

2) Velocity and travel distance of coal waste slurry flow decreased as the water content and applied shear stress (controlled in the models by slope angle) were reduced. Flow did not occur at water contents slightly higher than the liquid limit.

3) By comparing the results of the small scale model test and centrifuge test, it was found that the increase of mass or volume of slurry sample increased flow velocity. However, the influence of mass was less important than that of water content.

4) Slurry flow was not triggered by impact loading until compressive strain exceeded 1%. When the flow started, the solid sample changed into a very thick and viscous fluid. The effect of impact loading became insignificant as the water content was reduced a level slightly higher than the liquid limit. Coal waste slurry with a water content below liquid limit should have sufficient resistance to impact disturbance.

5) The advantage of slurry cells is related to the dikes of coarse refuse separating them, i.e. their great stiffness and geotechnical strength, high permeability, and ability to engender speedy dissipation of pore water pressure within the slurried fine refuse. No flow was observed when slurry cell samples were subjected to a compressive strain as high as 10% generated by impact loading. The measured pore water pressure indicated that the slurry did not liquefy. The pore water pressures recorded were much less than those measured in experiments without slurry cells.

Results and Findings: A few of the findings from the study include the following:

The flow characteristics of the coal waste slurry samples were greatly dependent on water content and shear stress (Figure 1). Shear stress was controlled in the model tests by the slope angle over which the flow was directed. Flow did not occur at water contents slightly higher than the liquid limit.

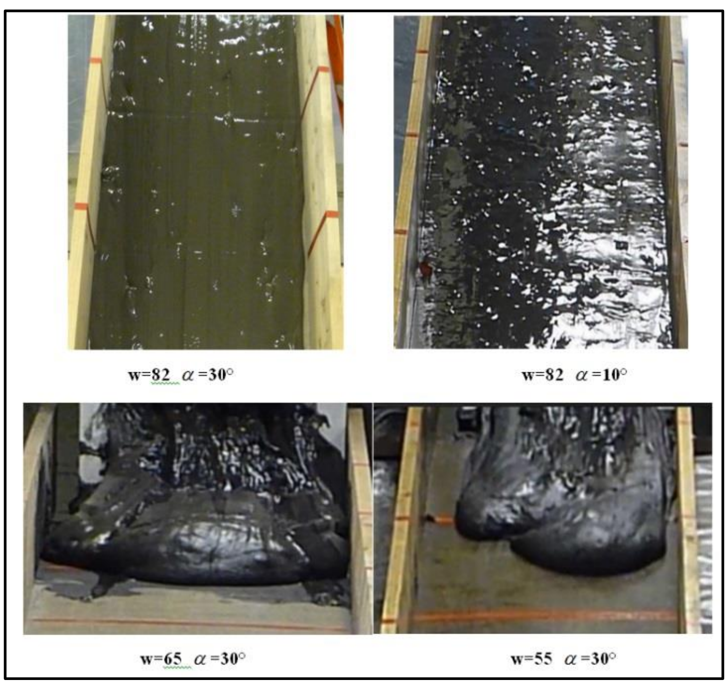

Figure 1: Flows of the WV sample at different water contents (w) and slope angles (α).

The threshold water content for flow initiation under impact loading (Figure 2) was slightly below the threshold under static loading.

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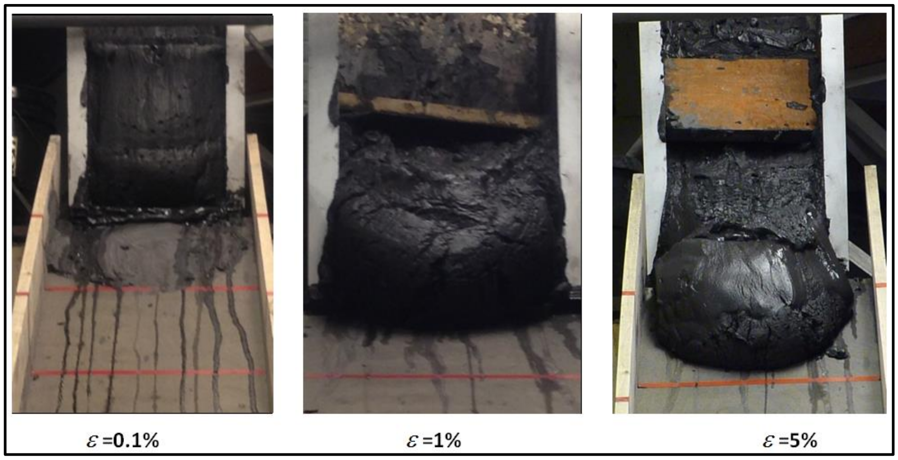

Figure 2: Results of impact loading tests (at different strains ε) on KY sample under different compressive strains (α =30°, w=48%)

At sufficiently high water content impact loading caused a buildup of excess pore pressure in the slurry up to the point where liquefaction could have occurred (Figure 3).

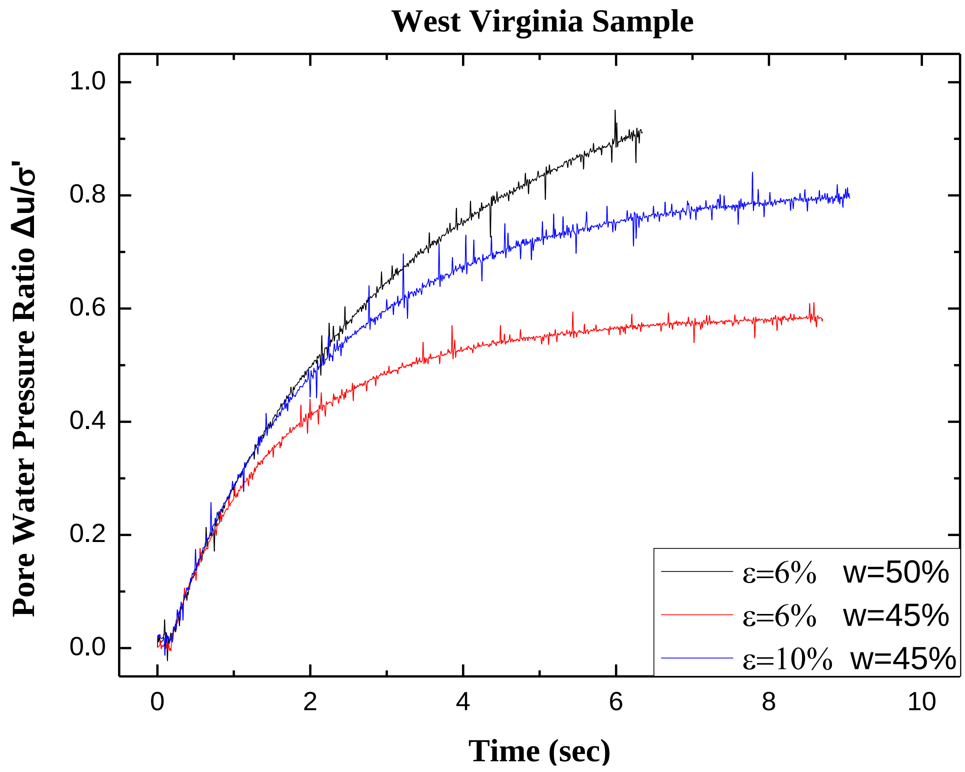

Figure 3: Recorded pore water pressures under impact loading.

The use of slurry cells significantly reduced the excess pore pressure generated under impact loading (Figure 4).

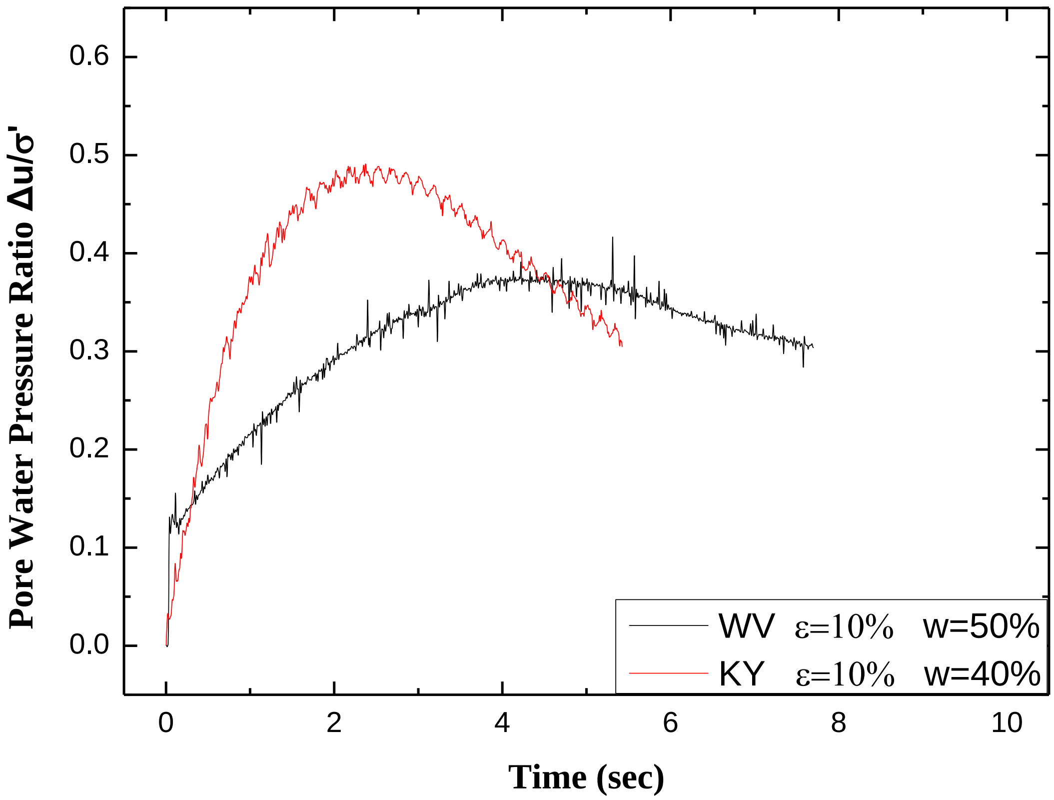

Figure 4: Recorded pore water pressures in slurry cells under impact loading.

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