Investigation of Headcut Erosion in Cohesive Soils

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Abstract—Headcut, known as knickpoint migration too, is developed due to sudden change in channel bed followed by bed scour and erosion which progressing upstream. The results are the downstream morphological change and transporting massive sediment to the downstream reservoir. Most of the past studies focus on non-cohesive soils, although many problems occur because of cohesive soils. In this study, 10 different samples of cohesive soils in long term consolidation with different composition of silt and clay were tested under different circumstances of waterfall height and flow velocity to investigate the neck migration rate and the sediment yield. Tests were continued to reach a constant migration rate. One of the effective phenomena in all tests was tensional cracks on soil surface. The size and number of these cracks have inverse relation with percent of clay. Because of these cracks, massive erosion occurs at the beginning of all tests. By reducing percent of clay, headcut, waterfall height and sediment yield were increased and by reducing waterfall height and flow velocity these parameters were reduced. In lower percent of clay, headcut erosion will occur quickly with more slants. Caving phenomenon was not observed in any tests and massive erosion rate was more quickly.

Keywords: cohesive soil, headcut erosion, river, sediment
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INTRODUCTION

Headcuts are step-changes in bed surface elevation where intense, localized erosion takes place [1, 4]. These step-changes may be as little as few centimeters to as much as a few meters in height. Head cutting may developed due to both natural and man induced reasons [5]. Earthquake, tectonic processes, piping, change in river sediment due to flood or draught are among the natural factors and change in flow regime due to dams or urbanization and change in base levels due to river mining are among human impact which may result in headcutting. The process of headcutting causes to both soil loss and sediment production in a variety of environments, contributing to as much as 94% of river sediment yield [14]. The sediment production from process of headcutting is 50 times more important than surface erosion so that the problems [22]. Generally, the more cohesive the valley alluvium, the more likely it is that the headcut will remain vertical as it moves backward [27]. There are generally four mechanisms of mass failure observed at knickpoints [7]: (1) Undercutting that leads to cantilever toppling; (2) Undercutting that leads to tensile failure and toppling; (3) Undercutting that leads to shear fail-

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Bryan [2] demonstrated the link between headcut formation, flow concentration, and rill incision in cohesive materials. Bryan suggested that supercritical flow was a necessary precursor for headcut development and that once formed headcuts displayed a complex evolutionary history during migration. Robinson and Hanson [17–19] investigated the migration characteristics and failure mechanics of pre-formed headcuts in cohesive materials, and examined the roles of stratigraphy, overfall height, flow discharge, and backwater level in headcut migration. Robinson and Hanson highlighted the significant impact that material characteristics and especially soil water content have on sediment erodibility and rates of headcut migration. According to the shape of the erosion, two categories of headcut can be distinguished: single-step and multi-step headcuts and according to the erodibility of headcut foundation two categories can be distinguished: non-erodible and erodible foundation [28]. Parker [13] considered effect of urbanization on headcut migration and investigated the total amount of agricultural land in the watershed decreased by 37.91% and the impervious area increased by 20.30%.

Bottom sediments are accumulators and transformers of the substances entering water bodies; they take an active part in general system [26].

In general, headcut erosion is important in two regards: (1) there has been little research on this topic and there is little information about it; (2) Sediment yield in this erosion is much more than surface erosion [11], which is highly important for the reservoirs of constructed dams, soil loss, and sedimentation in rivers.

The objective of this experimental research is to consider the migration rate and sediment yield as well as the extent of headcutting erosion in cohesive soils (with a different composition of silt and clay) for different waterfall heights and flow velocity under long-term pre-saturated natural consolidation conditions.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

Layout of the Flume

The tests were performed in a re-circulating flume in the experiment Lab of Water Research Institute, Tehran, Iran. The flume has a dimension of $12 \times 0.45 \times 0.6$ m (length × width × height). Figure 1 shows sketch of the flume system.

Observational interval in all tests had a dimension of $3 \times 0.45 \times 0.6$ m (length × width × height). Waterfall upstream length for all tests is 1.6 m with no slope (smooth surface) but waterfall height is different.

Experimental Procedure

Initial tests were performed to determine the hydraulic conditions (depth, velocity and discharge) to be applied for occurrence of headcut in our tests. Moreover, to conduct the headcut erosion tests on the samples, it was necessary to take measures to prepare