EXPERIMENTAL INVESTIGATION ON OVERTOPPING AND INUNDATION HYDRODYNAMICS AROUND AN OPEN DIKE WITH RIPARIAN FOREST

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1. INTRODUCTION

Many dikes have been built by humans or formed naturally along the rivers. River dikes are considered as defense structures and constructed to prevent flooding of valleys and confine the flow of the river for higher and faster flow. Discontinuous dikes are traditional flood mitigation strategies, employing along the lower and middle reaches of river basins. This river embankment consists of unique series of dikes with openings left along the embankment. (Kawanaka et al . 2007). During a flood event, water inundates to flood plains through discontinuous parts of the embankment and retained there until water level drops then returns. Therefore, it delays and reduces the flood peak in the main channel. Discontinuous dikes (Kasumi levee) in the Tokigawa River in Saitama Prefecture are shown in Fig. 1(a). As most of the embankments are not designed to be overtopped, hence they are vulnerable and sensitive to overtopping flow. The problem of river embankment failures by overtopping has always been of great importance because of their disastrous effects to cause widespread inundation and catastrophic damages on properties. Recently in 2019, a levee breaching was occurred near to riparian forest upstream of the open dikes in Tokigawa River during the typhoon Hagibis. Therefore, levee overtopping is a significant issue that needs to be addressed. The objective of this research was to experimentally evaluate the flow hydrodynamics around open dike with riparian forest in the river.

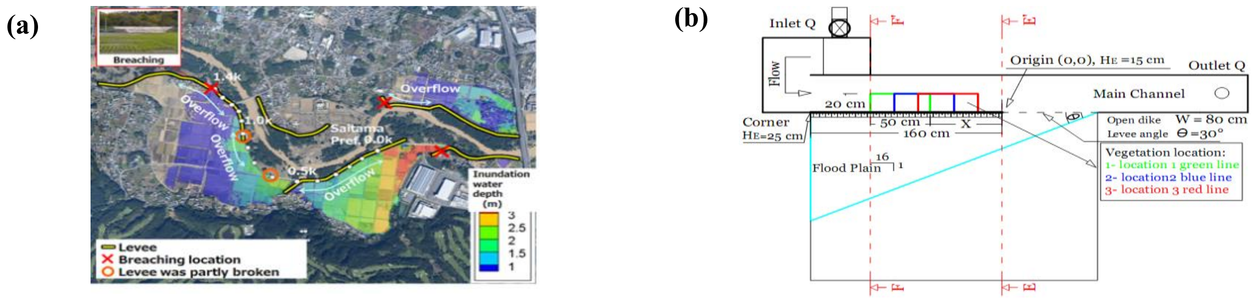

Fig. 1: (a) Damaged situation of Kasumi levee system in the Tokigawa River. (b) Laboratory experiment set up

2. METHODOLOGY

The experiments were conducted using a rectangular cross-sectional flume channel with 400 cm long, 40 cm wide, and 40 cm height on the left-hand side wall and a variable height (H_E) between 15 cm to 25 cm on the right-hand side. At the origin point (open dike area) h =15 cm and h = 25cm in upstream corner of flood plain at a distance of 160 cm from the origin point as in Fig. 1(b). The slope of channel bed is 1:400 and the slope of flood plain is 1:16. Experiments were conducted for three different steady flow rates (Q) which were estimated for three different initial flow depths with open dike but without (VM) (h_0). i.e., $h_{0,1}$= 10cm, $h_{0,2}$ = 14cm, and $h_{0,3}$ = 18.5 cm. The embankment model (EM) on the channel right bank consisted of an open dike model having an opening width (W) of 80 cm as in Fig. 1(b). The height of the flood plain bed (H_{FP}) at the open dike area was 10 cm and the angle of open levee to the main channel was selected generally as 30° . The vegetation model (VM) contained circular wooden cylinders with 4mm diameter and the density of VM was defined according to G/d ratio (Takemura & Tanaka, 2007). Here G is the clear spacing between vegetation cylinders and d is the diameter of cylinders. The VM consisted of three densities. i.e., sparse (G/d = 2.3), intermediate (G/d = 1.09), and dense (G/d =0.25). Length and the width of the VM were selected generally as 50 cm and 20 cm respectively. The downstream boundary of VM was located at x distance from the origin point as in Fig. 1(b). The location of VM changed, such that at the location 1, X = 60 cm, location 2, X = 40 cm and location 3, X = 20 cm.

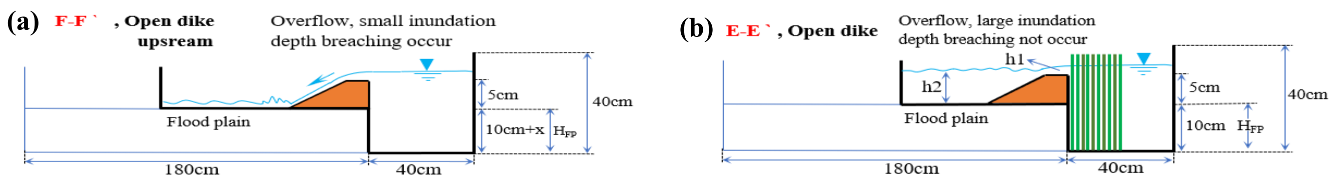

Fig. 2: (a) Overtopping at section F-F’. (b) Cross section at starting point of open dike

Keywords: open levee, weak location of levee , backwater rise by vegetation, Overtopping flow , water cushion.
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3. RESULTS AND DISCUSSION

Flow conditions (h_0) in no vegetation case, at $h_{0,1,}$ water depth is below the flood plain level near the open dike area. At $h_{0,2}$ and $h_{0,3}$ channel water depth is higher than flood plain level. After introducing the VM, overtopping flow from EM occurred only for the maximum flow depth $h_{0,3}$ = 18.5 cm. Therefore, results for maximum initial flow conditions were taken for the discussion. The water depths along the embankment and the height of the embankment are shown as a normalized parameter H_{ND}. Here, $H_{ND} = h/h_0$ or H_E/h_0, where h is water depth along the embankment, H_E is the height of the embankment and h_0 is the corresponding no vegetation case water depth. Further, the non-dimensional distance (L_{ND}) to the downstream boundary of the VM from the starting point of open dike also discussed. Here, $L_{ND} = x/W$. At location 1, 2 and 3, the corresponding L_{ND} values are 0.75, 0.5 and 0.25 respectively.

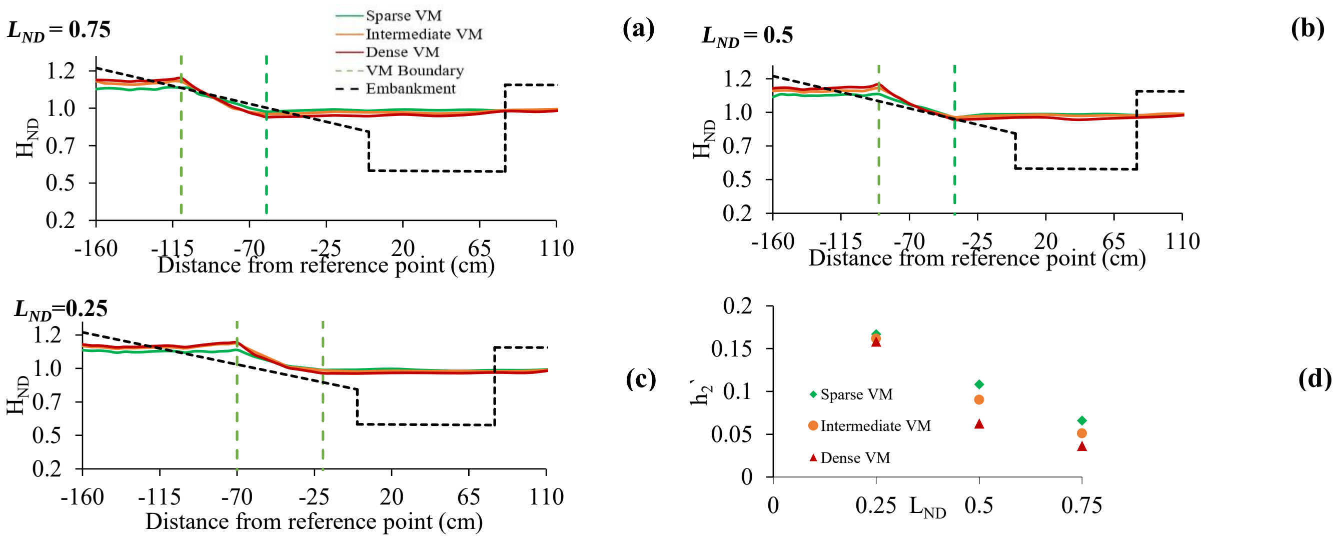

Fig. 3: (a) Normalized water depths in channel (H_{ND}) for L_{ND} = 0.75, (b) L_{ND} = 0.5, (c) L_{ND} = 0.25 and (d) Normalized flood plain water depth (h_2') for overtopping cases.

According to the Fig. 3, water overtop the embankment model (EM), for all the vegetation conditions and L_{ND} cases except for sparse VM at L_{ND} = 0.75. The maximum water depths are observed by the dense VM at its frontal face for all the L_{ND} cases. However, due to the slope of the EM, the overtopping depth (h_1) and the overtopping location varied with L_{ND}. As per Fig.3(a), when L_{ND} = 0.75, overtopping occurs in front of vegetation, however it doesn't overflow from EM at downstream side in vegetated zone. It overtops again in the downstream of VM. However, Fig.3(b) and Fig.3(c) show that after overtopping occurred at the upstream, it continues to the downstream. When the forest condition is dense, the inundation depth (h_2) of the flood plain is decreased. This is because the backwater-rise upstream of vegetation decreases the water depth at the open-dike part and flood plain water depth is affected by the backwater rise from the open-dike part. For EM overtopping cases, the lowest water depth inside the flood plain is observed by the dense VM for L_{ND} = 0.75 and 0.5 cases. However, for L_{ND} = 0.25, there isn't significant difference of h_2 compared to vegetation conditions. Since the EM has a slope, the inundation depth was normalized as h_2'where, $h_2' = h_2/H_E$. As per the Fig. 3(d), for all the overtopping cases, the lowest $h_2' \approx 0.036$ is given by the dense VM at L_{ND} = 0.75 and the highest $h_2' \approx 0.167$ is given by the sparse VM at L_{ND} = 0.25. Therefore, water cushion phenomenon with greater magnitude can be observed for all the VM conditions at L_{ND} = 0.25, discouraging the erosion of the embankment toe. In contrast, lowered water cushion body observed for L_{ND} = 0.5 and 0.75 can increase the erosion with changing the vegetation condition from sparse to dense respectively. In actual situation (1.4k in Fig.1a), levee breaching could be occurred where water cushion effect was less, and overtopping water depth was large according to the riparian vegetation condition and levee height undulation.

4. CONCLUSION

When the vegetation exists in the vicinity of the open dike, the breaching risk to the embankment is minimum regardless of the forest patch density, due to the formation of the high magnitude of water cushion body. Having a dense forest patch upstream of the open dike can increase the erosion of levee in a flood event by overtopping where lowered water cushion body is formed. The critical distance to the downstream of the vegetation patch can be estimated as 0.75 times the open dike width with the setting conditions of hydraulic condition. More study is needed because the river and floodplain slope can affect the critical distance.

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