STUDY OF LEVEE CREST UNDULATIONS ON SCOUR CHARACTERISTICS AFTER LEVEE OVERTOPPING UNDER DIFFERENT FLOW CONDITIONS

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1. INTRODUCTION:

Levee failure may be precipitated by structural failure, under seepage, piping, surface erosion, and/or overtopping scour. Levee scour by overtopping has recently been the subject of research projects; including laboratory tests, real-situation field tests, and numerical simulations. Levee structures are one of the primary sources of coastal flood protection used throughout the world. Levee overtopping is a root component that can lead to levee breaching and eventual failure. Sediment scour around protective coastal structures is the primary component that attributes to the weakening of that structure, and sometimes failure over time. Scour among various types of obstructions is a widely researched topic, with some of the first studies of scouring, at piers and spur-dikes. Scour geometry varies according to the intensity of the waves both in the absence of and in the presence of a storm surge. Other parameters include the structure's height, emerged length of the structure, the flow depth, and the sediment characteristics. Most of the studies were conducted 2D previously. Some researchers conducted 3D experiments but from field studies it is observed that levee crest is not flat as in previous studies (Afreen,2015) Therefore, objective of current study is to investigate the effect of levee crust undulations on scour patterns and scour characteristics and to draw some relationships between non-dimensional parameters.

2. EXPERIMENTAL SETUP AND METHODOLOGY

For determination of equilibrium scour pattern following Hydraulic, geometric and sediment parameters were considered during dimensional analysis as from eq(1).

$$S = f(d_{bank}, V, W_h, \rho, \nu, g, W_{bank}, h_{bank}, \lambda l, \lambda h, i, d_{50}, \rho_s) \ldots (1)$$

For three dimensional experiments, wooden levees were constructed in the experiment flume (3m length, 4m width and 0.5m height). Fig.1 shows the schematic diagram of the experimental setup. At the landside 1V:3H levee slope is maintained and constant levee height of 6cm is kept during the experiments. The physical model was run for overtopping widths (W_{bank} in Fig.2) of 40 and 80cm. overtopping depth is kept from 1cm to 5cm.Three real type of levee crest undulations were created as shown in Fig 2. Type1 (8cm wavelength), type2 (16cm wavelength) and Type3(24cm wavelength). Total 36 experiments were conducted as results shown in Table1 and 2. The d_{bank} at the top of the levee was measured by a point gauge. Medium grain size (d_{50}) of 4.5mm (suitable for clear water scour conditions) was placed over an area of 2m at landside of levee with 25cm of thickness.

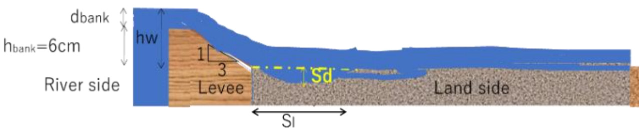

Fig.1 schematic diagram of experimental setup

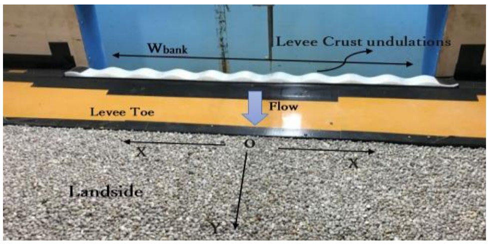

Fig.2.Experimental Setup

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For all the 3D experimental cases, equilibrium scour profile was achieved after duration of 60 minutes from the start of the overtopping. Soil surface profile was measured by point gauge and scour profile photos were taken after 60 minutes of overflow for all the cases. The center point of the levee toe (Point “O” in Fig.2) is considered as origin. Scour profile data for X and Y directions were taken.

3. RESULTS AND DISCUSSIONS

(i) Scour profiles for 40cm and 80cm overtopping widths and overtopping depth for 1cm to 2cm.

Fig.3 (a), (b), and Fig.4 (a) and (b) represents the contour maps for scour profiles at the downstream of the levee considering W_{bank} (40, and 80cm) at equilibrium condition for 1cm and 2cm overtopping height (d_{bank}) respectively for all the four cases with varying crest wavelengths. For 1cm overtopping depth multiple scour holes (Type4-MT) along transverse direction were formed for both 40cm and 80cm overtopping widths. Double scour hole in Transverse direction (Type-2-DT) for 40cm W_{bank} and 2cm of d_{bank} was formed. In the contour plots, dark shades represent scoured regions and white color indicates accretion areas. Scour pattern is like flat condition cases for both overtopping widths.

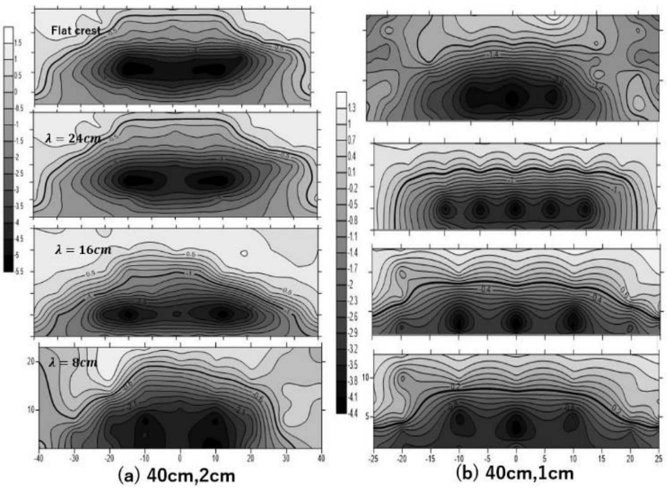


Fig.3 Scour profiles for Flat case, Type I Type II and Type III Crest undulations, **(a)**40cm of W_{bank} and 2cm of d_{bank} (**b)** 40cm of W_{bank} and 1cm of d_{bank}

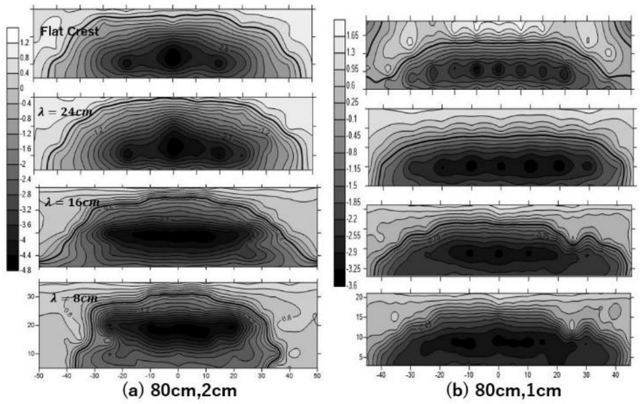


Fig.4 Scour profiles for Flat case, Type I Type II and Type III Crest undulations, **(a)** 80cm W_{bank} and 2cm d_{bank} **(b)** 80cm W_{bank} and 1cm d_{bank}

(ii) Effect of crest undulations on Scour characteristics

20 experiments (5 experiments for each case) were performed with overtopping width of 80cm (table1) and 16 experiments were performed with overtopping width of 40cm (table2) with overtopping depth from 1 to 5cm having 6cm constant height of bank. Energy head, scour dimensions and scour pattern has been presented below in tabular form.

Table 1, 2, Maximum scour dimensions, scour pattern, Energy head at levee crest and at levee toe just before HJ (E2) and F_r for W_{bank} = 80cm and different d_{bank} conditions considering 3D.

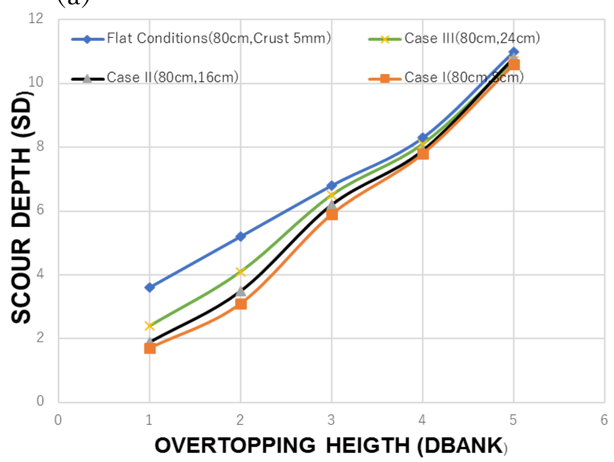
Exp case	Exp setup	h_{bank} (cm)	W_{bank} (cm)	d_{bank} (cm)	Energy head, E (cm)	F_r	*Sd*	*Sw*	*Sl*	Scour Pattern
Flat Condition										
1	3D	6	80	1	7.5	1.8	2.8	86	16	4-MT
2	3D	6	80	2	9	2.8	4.8	102	30	3-DL
3	3D	6	80	3	10.5	3.6	6.8	122	43	5-MTDL
4	3D	6	80	4	12	3.8	8.3	125	57	5-MTDL
5	3D	6	80	5	13.5	4.1	11	130	65	5-MTDL
Case III(24cm)										
6	3D	6	80	1	7.5	1.7	2.4	82	17	4-MT
7	3D	6	80	2	9	2.7	4.1	105	31	3-DL
8	3D	6	80	3	10.5	3.6	6.5	125	42	5-MTDL
9	3D	6	80	4	12	3.8	8.1	127	53	5-MTDL
10	3D	6	80	5	13.5	4.1	10.7	131	63	5-MTDL
Case II(16cm)										
11	3D	6	80	1	7.5	1.3	1.9	88	15	4-MT
12	3D	6	80	2	9	2.4	3.5	98	32	3-DL
13	3D	6	80	3	10.5	3.6	6.2	115	46	5-MTDL
14	3D	6	80	4	12	3.8	7.9	128	50	5-MTDL
15	3D	6	80	5	13.5	4.1	10.8	130	72	5-MTDL
Case I(8cm)										
16	3D	6	80	1	7.5	1.2	1.7	92	13	4-MT
17	3D	6	80	2	9	2.3	3.1	109	33	3-DL
18	3D	6	80	3	10.5	3.6	5.9	110	44	5-MTDL
19	3D	6	80	4	12	3.8	7.8	120	47	5-MTDL
20	3D	6	80	5	13.5	4.1	10.6	125	70	5-MTDL

Exp case	Exp setup	h_{bank} (cm)	W_{bank} (cm)	d_{bank} (cm)	Energy head, E (cm)	F_r	Wd	Sd	Sw	Sl	E2	%Loss	Scour Pattern
Flat Condition													
21	3D	6	40	1	7.5	1.4	53	4.4	33	7	1.32	82	4-MT
22	3D	6	40	2	9	2.8	69	5.5	61	24	3.44	62	2-DT
23	3D	6	40	3	10.5	3.9	75	7.2	74	45	6.80	35	3-DL
24	3D	6	40	4	12			11.9	81	54.5			3-DL
25	3D	6	40	5	13.5			13.8	89	74.5			3-DL
Case III(24cm)													
26	3D	6	40	1	7.5	1.4	53	4	33	6.8	1.32	82	4-MT
27	3D	6	40	2	9	2.7	69	5.5	60	23.5	3.38	62	2-DT
28	3D	6	40	3	10.5	3.9	75	7	73.5	45	6.80	35	3-DL
Case II(16cm)													
29	3D	6	40	1	7.5	1.2	55	2.5	34	6.5	1.2	83	4-MT
30	3D	6	40	2	9	2.7	72	4	61	23	3.2	64	2-DT
31	3D	6	40	3	10.5	3.9	75	6.8	73.5	45	6.8	35	3-DL
Case I(8cm)													
32	3D	6	40	1	7.5	1.2	57	1.8	35	6	1.2	84	4-MT
33	3D	6	40	2	9	2.6	74	3.6	63	21	3.1	66	2-DT
34	3D	6	40	3	10.5	3.9	76	6.5	73	45	6.8	35	3-DL
35	3D	6	40	4	12			11.7	82	55			3-DL
36	3D	6	40	5	13.5			13.7	90	75			3-DL

S_d: Maximum scour depth, S_w: Maximum scour width, S_l: Maximum scour length, 2DT: Double scour holes at the transverse direction, 3-DL: Double scour holes at the longitudinal direction,4MT: Multiple scour holes in transverse direction, 5-MTDL: Multiple scour holes in both directions. h_{bank}: Levee height, W_{bank}: Overtopping width, d_{bank}: Overtopping height

Scour dimensions were compared with flat conditions when there are no undulations on levee crest. Fig.5 (a) and (b) shows that scour depth is increasing with increase in overtopping depth. Scour pattern is similar in all cases with flat condition case only difference occurs in scour dimensions with low flood case (1cm and 2cm), but almost same results with flat conditions when high flood (3 to 5 cm overtopping depth) conditions.

(a)



(b)

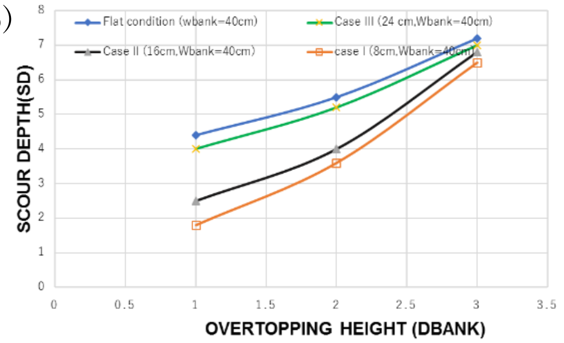


Fig.5: (a) Relationship between scour depth and overtopping height for 80cm overtopping width (b) for 40cm overtopping width

For low overtopping depth there is about 2 to 4 % of energy dissipation from levee crest to levee toe just before hydraulic jump with levee crest undulations. It was also observed that multiple strip flow occurs for 2cm d_{bank} and 8cm crest wavelength instead of single layer flow in flat case.

(iii) Sensitivity check for levee crest undulations wavelength and wave height

Fig.6 shows the effect of levee crust undulations on scour patterns. For overtopping depth of 1cm and 2cm scour ratio is away from 1, it means undulations are more sensitive for low flood case for high flood case scour ratio is very close to 1 that shows results are almost constant with undulation case and without undulation case.

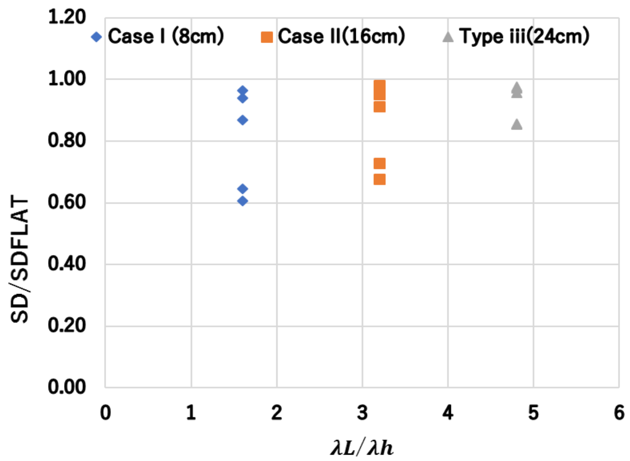


Fig.6: Sensitivity of $\lambda L/\lambda h$ for W_{bank}=80cm

(iv) Post tsunami survey and vulnerability of different scour patterns

Fig.7 shows result of post tsunami survey that was conducted for preliminary assessment of energy head and overtopping width of bank. When low energy head and medium overtopping width Type 4-MT scour pattern occurs and with medium to high energy head and high overtopping width Type5-MTML pattern occurs. From this survey we can assess which type of pattern will occur.

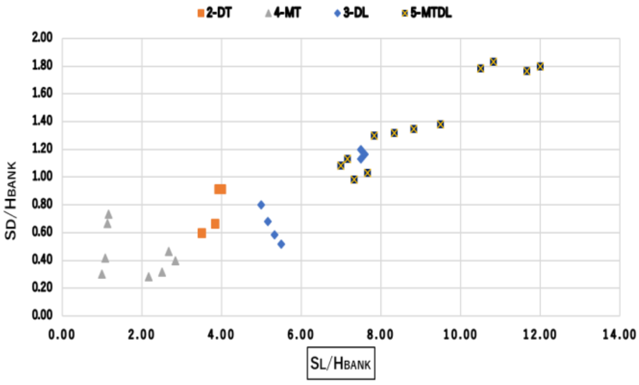


Fig.7. Scour pattern observed during a post tsunami survey

Impact of different scour patterns on levee structure and d/s property was analyzed from Fig 8. When scour depth is higher and scour length is less it means deeper scour hole is formed near levee toe. Type 2-DT and Type-4MT are dangerous for levee structure and its stability as they form near the levee toe whereas Type-3DL and Type5- MTML are dangerous both for levee stability and d/s property because these holes extend is transverse as well as in longitudinal direction. These results can be utilized for study of levee design and its stability using different hydraulic and geometric parameters.

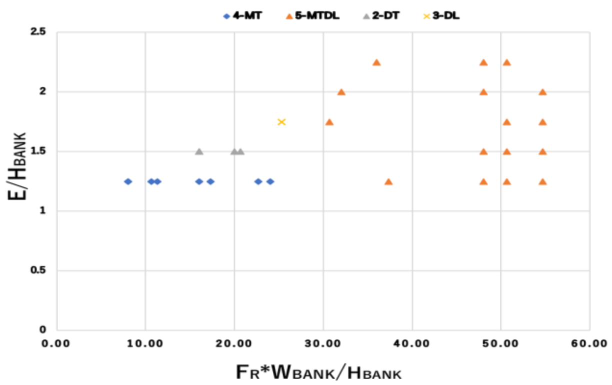


Fig.8: Relationship among different scour patterns considering important non-dimensional parameters

4. CONCLUSION:

Three dimensional experiments have been conducted to investigate the effect of levee crest undulations on scour patterns due to hydraulic and geometric parameters variation. From analysis of 3D experimental data, it is evident that for crest undulations with low flood cases (1cm and 2cm overtopping flow) scour depth decreases with decrease of wavelength of levee crest undulations. For high flood cases (3 to 5cm overflows) crest undulations effect is negligible, energy dissipation due to crest undulations in case of low overtopping depths which is negligible with high over flows. It was observed that undulations have no effect on scour pattern as scour profiles are same with without crest undulations. From post tsunami survey it was concluded that Type 4-MT and Type 2-DT scour patterns are in transverse direction which forms very close to levee toe that's why these patterns are dangerous for levee structure and its stability, whereas Type 3-DL and Type 5-MTML patterns form longitudinally as well as transverse direction, so these are dangerous for both property on landside (when a big city is very close to levee) and for levee structure.

ACKNOWLEDGEMENT: This work was supported by JSPS KAKENHI Grant Number 17H04936.

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