EVALUATING TOE EROSION AND STREAMBANK STABILITY WITH BSTEM MODEL FOR YONABA CREEK

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Abstract- Streams and rivers has a majority of sediment from streambank erosion. By using Bank Stability and Toe Erosion Model (BSTEM), toe erosion and streambank stability analysis is performed for Yonaba Creek. For that study two different streambanks (left and right sides) evaluated considering two different flow and two different tension crack.The purpose of this paper is to indicate the application of BSTEM as a valid model for observing and quantifying the streambank condition for a restoration process and evaluate the effects of different flow depth and tension crack on stream stability.

I. INTRODUCTION

Streams and rivers have a big majority of the sediment load from streambank erosion.Streams can be seen in different shapes in time due to the effect of the erosion. As it changes, sediment is transported and deposited. The stream can achieve a stable shape over time with minor changes in erosion and sedimentation.In fact, sediment loads and streambank stability have been major concerns for decades and abundant money has been spent on stream bank stabilization (Lavendel, 2002; Bernhardt et al., 2005). Streambank models are using to validate the bank stability and demonstrating ways for bank stabilization. One of the most commonly used and most advanced streambank stability models is the Bank Stability and Toe Erosion Model (BSTEM), developed by the National Sedimentation Laboratory in Oxford, Mississippi, USA. From the first version BSTEM has developed in each version and now the most current model is BSTEM 5.4. The most current public model isBSTEM version 5.4 which is based on two different module.Bank stability module and toe erosion module are components of BSTEM. BSTEM Calculates a safety factor (FOS) to evaluate bank stability. Fluvial erosion is the main element of estimating bank undercutting for toe erosion component.

BSTEM model has different tabs which are introduction tab, technical background tab, model use tab, geometry input tab, bank material tab, bank vegetation and protection tab, bank model output tab, toe model output tab and unit converter tab. First step to start using model is entering geometry information into the “Input Geometry” tab which contain fields for bank geometry, bank layer thickness, and channel-flow parameters. Five layers can be defined with layer thickness information. Soil parameters for each layers can be defined by user with the soil type or input user defined values. Channel flow parameters are reach length, reach slope, elevation of flow, and duration of flow. This tab also contains calculations for estimating τc based on particle diameter and estimating κ based on τc (Hanson and Simon, 2001). The “Bank Model Output” tab gives an opportunity to user to define a water table depth below bank top. Also own pore pressure can be defined by user. After running bank stability model, the outputs are including safety factor, shear emergency elevation, shear surface angle used, and geometry. Factor of safety is the main control point to observe if failure may occur. Bank is defined as ‘stable’ when factor of safety is greater than 1.30. Banks with a Fs value of 1.0 and 1.3 are called ‘conditional stable’.A new bank geometry is determined if bank failure occur, factor of safety is smaller than the value of 1.00. Users have an opportunity to export new (failed) bank profile into model. The other evaluation that can be done by using BSTEM is toe-erosion model. User can get useful output from this tab such as average applied boundary shear stress, maximum lateral retreat, eroded bank area, eroded bank toe area, eroded bed area, eroded total area and new geometry. User can export new (eroded) profile into model as in bank stability model. BSTEM also has a bank vegetation and protection tab which gives an opportunity to observe the effects of bank top vegetation on bank stability using root-reinforcement model. The output of this tab is added cohesion due to roots. The purpose of this paper is to indicate the application of BSTEM as a valid model for observing and quantifying the streambank conditionfor a restoration process. Yonaba Creek will be evaluated with BSTEM model with two different flow rates and two different tension crack.

II. FIELD INFORMATION

Yonaba Creek, MS, a representative stream segment located at the northern headwaters area of the Town Creek Watershed (Ramirez-Avila et al, 2010). The creek has a drainage area of 74.20 square miles. USGS Website has field and laboratory water quality samples data available. Latitude of stream is 34°20'25", and longitude of stream is 88°44'45". Information for Yonaba Creek is maintained by USGS Mississippi water science Center. This creek is evaluated by John J. Ramirez-Avila by subdividing the 270 m reach to eight transects and surveyed from February 2009 to March 2010.

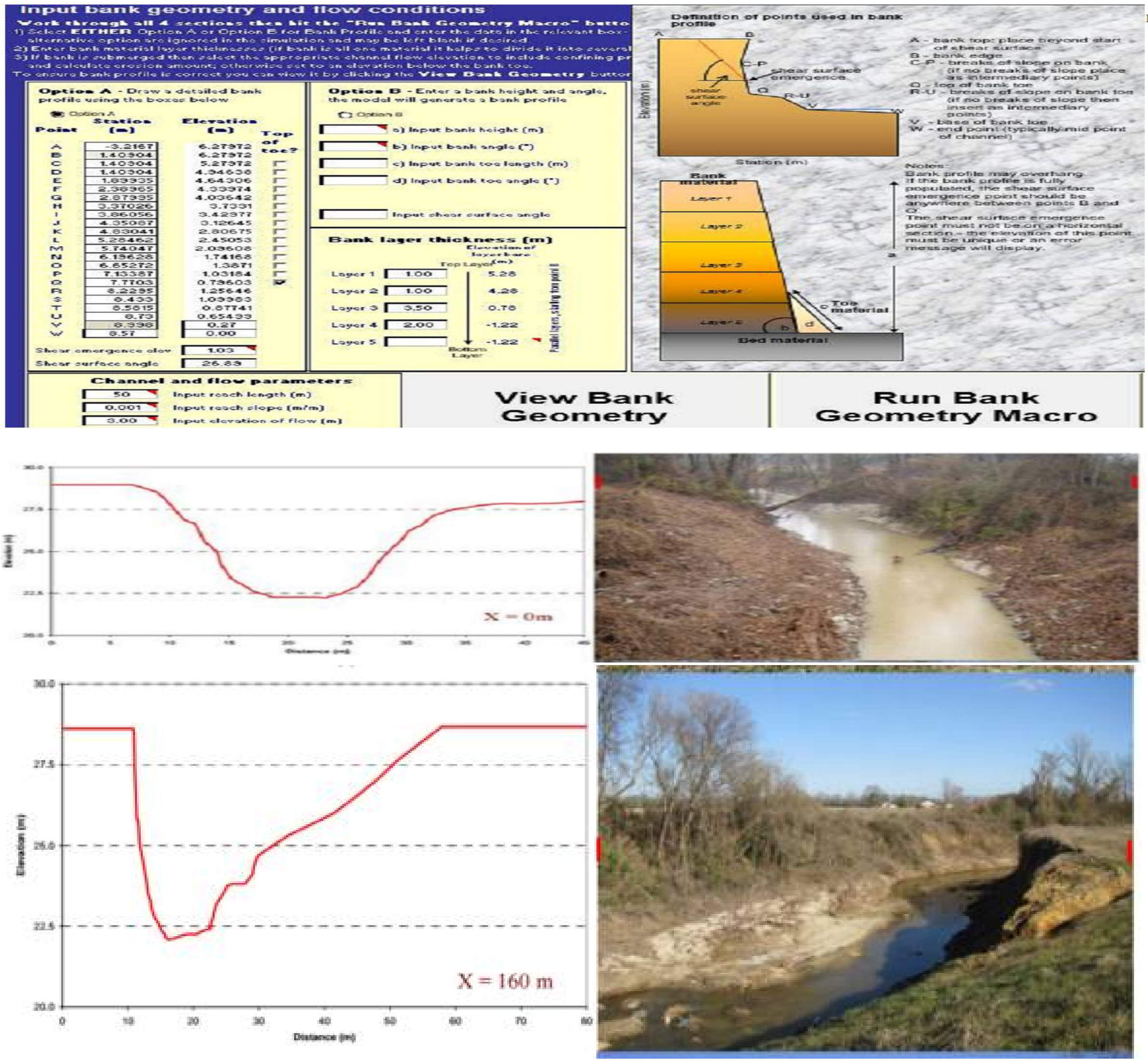


Figure 1. Cross sections geometry input (adapted from Ramirez-Avila,2010)

III. INPUT DATA

Two different streambanks which are streambank x=0 m and x=160 m are evaluated for both left and right sides. Geometry data was obtained from previous research done by Ramirez-Avila, 2010. Reach slope was entered to the model as 0.001.

Two different flow depths were 2.00m and 3.00m for 12 hours flow duration.

For streambank instability inputs water table depths was defined 4m and two different tension crack were0m and 1.5 m.

The field observation and particle size analysis results for the streambanks material allows defining representative streambank profiles, including the 85m segment with rip rap protection(Ramirez-Avila et al, 2010). Following table includes the representative streambank profiles information.

BSTEM Model was used with following steps.

- Model was run the toe- erosion model and data is exported to the model.
- Bank geometry macro is run and clicked on run bank stability model.
- If a bank failure occurs, data is saved, new geometry is exported, and then toe erosion is evaluated.
- If a bank failure does not occur, geometry has not been exported and toe erosion model is evaluated.Considerations:
- If no failure is observed the analysis is finished after 5 toe erosion iterations.
- After an instability event occurs (FS<1), the analysis is ended if the FS is higher than 1.1.

Cross section	Layer depth (m)	τ_c (Pa)	k_d ($cm^3 N^{-1} s^{-1}$)	% Sand	% Silt	% Clay	Bulk density ($Mg\ m^{-3}$)	Density ($kg\ m^{-3}$)	Friction Angle (ϕ')	Suction Angle (ϕ^b)
1	0 - 4	4.22	4.08	67.08	14.18	18.84	1.47	2.22	31	17
	4 - 6.5	7.44	1.69	56.65	23.62	19.73	1.42	1.88	31	17
	6.5 - 20	0.39	5.93	70.84	16.25	12.91	1.54	2.31	31	15
2 (Rip Rap)	0 - 20			0	0	0	2.08	2.5	45	
Left streambank: 3, 6	0 - 1	1.91	1.49	73.10	19.21	7.69	1.69	2.4	32	17
	1 - 2	0.5	6.09	75.54	12.04	12.42	1.56	2.40	27	12
	2 - 5.5	0.5	9.86	73.66	12.72	13.62	1.54	2.31	27	11.5
	5.5 - 20	0.39	5.93	70.84	16.25	12.91	1.54	2.31	31	15
Right streambank: 3, 4, 5, 6	0 - 9	2.00	9.86	73.66	12.72	13.62	1.54	2.31	27	11.5
	9 - 20	0.39	5.93	70.84	16.25	12.91	1.54	2.31	31	15
Left streambank: 4 (Levee)	0 - 3	0.14	24.09	89.31	5.49	5.2	1.69	2.40	30	20
	3 - 6.2	0.14	24.09	84.86	7.21	7.93	1.63	2.30	30	20
	6.2 - 20	0.39	5.93	70.84	16.25	12.91	1.54	2.31	31	15
Left streambank: 5 (Pipe outlet on levee)	0 - 1.5	0.14	24.09	89.31	5.49	5.2	1.69	2.40	30	20
	1.5 - 2.0	0.14	24.09	84.86	7.21	7.93	1.63	2.30	30	20
	2.0 - 6.25	0.14	24.09	84.86	7.21	7.93	1.63	2.30	15	10
	6.25 - 20	0.39	5.93	70.84	16.25	12.91	1.54	2.31	31	15
Left streambank: 7, 8	0 - 5.0	0.5	9.86	73.66	12.72	13.62	1.54	2.31	27	11.5
	5.0 - 6.5	2.00	9.86	73.66	12.72	13.62	1.54	2.31	27	11.5
	6.5 - 20	0.39	5.93	70.84	16.25	12.91	1.54	2.31	31	15
Right side: 7,8	0 - 9	1.46	1.56	73.66	12.72	13.62	1.68	2.4	30	17
	9 - 20	0.39	5.93	70.84	16.25	12.91	1.54	2.31	31	15
Streambed		18.3	6.20	93.78	5.09	1.13		2.65		

Figure 2 Streambank material stratigraphy of seven representative streambank profiles and streambed of the Yonaba Creek (obtained from Ramirez-Avila, 2010)

4. RESULTS AND DISCUSSION

BSTEM calculation shows that the most critical scenario for the analysis is on streambank x= 160m and left side, flow depth is 3m and tension crack is 1.5m. Factor of safety was calculated for each streambank and each condition. Only streambank x=160m left side determined as unstable while other three streambank are stable or conditionally stable. Flow rate effects can be observe significantly from the results than obtained from BSTEM calculation. The table below is the results of toe-erosion model for streambank 6 (x=160m), left side, flow rates are 2m and 3m, tension crack is 1.5 m.

Flow Depth(m)	Flow Duration(hr)	tension crack(m)	Applied Shear Stress(Pa)	Max Lateral Retreat(m)	Bank Eroded Area(m2)	Bank Toe Eroded Area(m2)	Bed Eroded Area(m2)	Total Eroded Area(m2)
3	12	0	30.68	15.607	0.159	0.022	0.013	0.194
3	12	0	41.72	17.707	0.241	0.03	0.019	0.29
3	12	0	8.51	13.712	0.082	0.012	0.019	0.113
3	12	0	8.57	4.504	0.103	0.004	0.013	0.12
3	12	0	8.86	4.788	0.111	0.013	0.004	0.129
3	12	0	8.66	4.746	0.113	0.013	0.005	0.131
3	12	0	8.9	5.1	0.122	0.014	0.005	0.14
3	12	0	9.13	5.601	0.13	0.014	0.005	0.149
3	12	0	9.3	6.029	0.14	0.014	0.005	0.159
			TOTAL:	77.794	1.201	0.136	0.088	1.425

Table 1 Streambank 6, left Toe-erosion Model Output

Flow Depth(m)	Flow Duration(hour)	tension crack(m)	Applied Shear Stress(Pa)	Max Lateral Retreat(m)	Bank Eroded Area(m2)	Bank Toe Eroded Area(m2)	Bed Eroded Area(m2)	Total Eroded Area(m2)
3	12	1.5	30.68	15.607	0.159	0.022	0.013	0.194
3	12	1.5	29.48	11.415	0.27	0.027	0.015	0.312
3	12	1.5	8.44	14.161	0.083	0.011	0.019	0.113
3	12	1.5	8.52	4.499	0.106	0.011	0.004	0.121
3	12	1.5	8.78	4.765	0.115	0.011	0.004	0.13
3	12	1.5	9.63	3.897	0.151	0.011	0.004	0.167
3	12	1.5	9.9	4.009	0.162	0.012	0.005	0.178
3	12	1.5	10.12	3.994	0.173	0.013	0.005	0.191
3	12	1.5	10.31	4.251	0.184	0.014	0.005	0.203
3	12	1.5	10.47	4.585	0.198	0.017	0.005	0.22
			TOTAL:	71.183	1.601	0.149	0.079	1.829

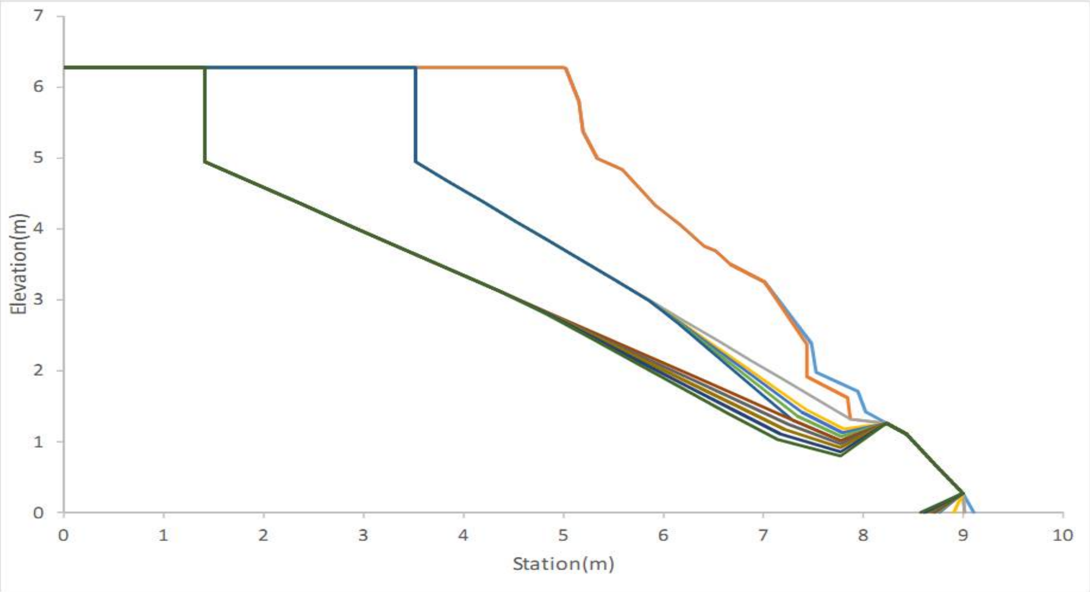
Table 2 Streambank 6, left Toe-erosion Model Output

Tension crack effect is observed from results. When tension crack is increased from 0m to 1.5 m total maximum lateral retreat increases about 6.5m. Additional tension crack makes the streambank less stable which means reduces the factor of safety and causes more toe erosion.

Factor of safety values were obtained for each case scenario and determined that streambank 6, left side has a FoS= 0.85 (unstable) after five iterate runs with a FoS= 1.15(conditionally stable). The observed scenario again has a flow depth is equal to 3m and tension crack is 1.5m. The model predicted new geometry data after failure occur. Geometry data was saved to a file to observe from the first condition and to the last condition after bank obtains the stability after failure. Iterate runs were continued until streambank gains stability with five consecutives FoS>1.50. Three different failures were seen during the modelling. All geometry data was represented in a graph to see the failure of the streambank.

Bank and bank toe protection was applied by choosing live fascine. When the root-reinforcement model is run the model requires to enter maximum rooting depth value which is determined as 1m. Gamma Grass, Eastern was selected and specified the plant age as 2 years. Also, percent contribution to assemble was specified as %100.

Toe protection model gave an additional cohesion due to roots 5.5 Pa. The bank stability model was run. New safety factor with that protection is 1.11(conditionally stable). It was 0.94(unstable) before root reinforcement.



Graph 1Streambank 6 left side geometry for, flow depth=3m, tension crack=1.5m after failure occur.

CONCLUSION

The Yonaba Creek was evaluated to see the effects of high and low tension cracks and flow depths. The streambank has a sandy material. Four streambanks were examined and one of them was not stable. The most significant retreat occurs with high flow rate and bigger tension crack. BSTEM Model is a very useful tool to examine toe erosion and streambank stability. Also user can observe the streambank responses to a root reinforcement model. This study shows effects of flow rate and tension crack changes on lateral retreat and bank stability. Also the worst case scenario was evaluated after root reinforcement and result shows stream may obtain more stability with root reinforcement. As seen from results vegetation has a big importance for streambank stability and should be taken into any restoration projects.

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