Hydraulic Evaluation and Determination of Requirements for Overtopping of Earth Non-Overflow Embankments

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Introduction:

A hydraulic evaluation of the requiremnts for non-overtopping of earth non-overflow embankments was accomplished. The purpose of this study is to develop information to develop a plan of action prior to the 1998 spring runoff.

References and Experience:

The evaluation at this time considers the technical information and procedures used for the Waterways Experiment Station June 1964 Technical Report 2-650, entitled *"Stability of Riprap and Discharge Characteristics, Overflow Embankments, Arkansas River, Arkansas."* It also considers the experience of the Rock Island District with the 1993 flood event, the St. Paul District's experience with the Lock and Dam No. 3 spot dikes and the St. Paul District's experience with the Environmental Management Program earth embankments.

A. WES Technical Report 2-650: Figure 1 is a plot of approach energy elevation versus tailwater elevation based on Waterways Experiment Station Technical Report 2-650. Even though this plot was developed for embankments protected with riprap to determine stability, the same type of plots for earth embankments provides insight with regard to the stability. The riprap gradations used in the physical model tests are presented in Table 1.

Table 1

Riprap Gradations used in "*Waterways Experiment Station June 1964 Technical Report 2-650* "*Stability of Riprap and Discharge Characteristics, Overflow Embankments, Arkansas River, A*									
Percent Lighter	**Gradation A**		**Gradation A_1**		**Gradation B**		**Gradation C**		
	Diameter in inches	Weight (pounds)	Diameter in inches	Weight (pounds)	Diameter in inches	Weight (pounds)	Diameter in inches	Weight (pounds)	D in
100	37.50	2620	24.00	687	16.00	204	16.00	204	
50	16.20	211	15.80	196	6.90	16	5.30	7.40	
15	8.00	25	8.00	25	3.50	2	1.60	0.20	

Table 2

Evaluation of Performance of Mississippi River Locks and Dams Earth Dams without erosion protection in the Rock Island District during the 1993 Flood Event.			
L&D	Applicable	Comment	Conclusion
11	NO	Earth dam does not have erosion protection for overtopping. The 1993 high water of 611.2 was less than the crest elevation of 613.5.	No conclusion can be reached at this site.
12	NO	Earth dam does not have erosion protection for overtopping. The 1993 high water of 602.2 was less than the crest elevation of 604.0.	No conclusion can be reached at this site.
13	NO	Earth dam does not have erosion protection for overtopping. The 1993 high water of 591.4 was less than the crest elevation of 592.0.	No conclusion can be reached at this site.
14	NO	Embankment at this site is protected with with 3.0 feet of rock and sheet pile to the crest elevation.	No conclusion can be reached at this site.
15	NO	No earth dam at this site.	No conclusion can be reached at this site.
16	NO	Earth dam is protected with riprap for overtopping.	No conclusion can be reached at this site.

17	NO	Earth dam is protected with riprap for overtopping.	No conclusion can be reached at this site.
18	YES	Earth dam does not have erosion protection for overtopping. The 1993 high water of 540.9 exceeded the crest elevation of 537.0 by 3.9 feet. The headloss at the peak was 0.8 feet. The non-overflow earth dam is about 3210 feet long with a height of 24 feet. A crest elevation of 537.0 feet corresponds to about a 2 percent chance flood frequency.	The only earth non-overflow embankment overtopped in 1993 in the Rock Island District was at L&D 18. This earth section runs parallel with the river. It sustained some minor damage with a section at the upper end that was approximately 100 feet long and 5 to 6 feet deep. This loss had no impact on the navigation pool and was repaired shortly after the flood.
19	NO	No earth dam at this site.	No conclusion can be reached at this site.
20	NO	No earth dam at this site.	No conclusion can be reached at this site.
21	NO	Embankment at this site is protected with rock, sheet pile and concrete	No conclusion can be reached at this site.
22	NO	No earth dam at this site.	No conclusion can be reached at this site.

B. Locks and Dams No. 11-22. Information was obtained from the Rock Island District with regard to experience with the 1993 flood event. The following paragraphs discuss the available information from the 1993 flood event:

1. **General**. Table 2 summarizes the evaluation of the performance of the earth non-overflow embankments in the Rock Island District. In summary, Lock and Dam No. 18 is the only site which is applicable for this evaluation. The earth non-overflow embankments in the reach from Lock and Dam No. 11 through 13 were not overtopped. For the reach from Lock and Dam No. 14 through 22, the embankments, with the exception of Lock and Dam 18, are either fortified with erosion protection or a earth non-overflow embankment is not part of the project.

2. **Lock and Dam 18**. The following is a summary of the information available for Lock and Dam No. 18:

1. Gage Related Information- is summarized on Figure 2 and Figure 3.
2. Water Surface Profiles - are shown on Figure 4 and Figure 5.
3. Plots of Head Differential, Stage and Discharge for the

   1993 flood are shown on Figure 6.

4. Plot of Head and Tailwater relative to the crest elevation of the earth non-overflow embankment is shown on Figure 7.

5. Plot of Head versus tailwater elevation relative to the crest for the daily values when the non-overflow embankment was overtopped is shown on Figure 8.

c. **Locks and Dams 2 and 4-10**. Information is not available for overtopping of non-overflow embankments at L&D Nos.2 and 4-10 since the procedure in the past has been to prevent overtopping.

d. **Lock and Dam No. 3 spot dikes**. The St. Paul District has considerable experience with the Lock and Dam No. 3 project where earth embankments are overtopped about 15 percent of the time based on a duration curve. Figure 1 is a plot of approach energy elevation versus tailwater elevation using WES TR 2-650 procedures. The plot shows gradations tested in the physical model study in addition to plots of observed approach energy versus tailwater elevations for the period from 1959-1996. This plot was developed for the design condition which considers the total headloss at one embankment. Currently, there are three embankments in series that are overtopped with most of the headloss occurring at the downstream embankment. From Figure 1, it can be seen that:

1. **Asymptote-** A line with the approach energy elevation equal to the tailwater elevation forms an asymptote for the data.

2. **1993 barge accident-** The conditions that existed at the time of the accident created the plot that goes through the critical point with an approach energy of 4.1 and a tailwater of -.8 feet. For this condition, the downstream rock and earth embankment sustained considerable damage. The embankment in the breach area was totally eroded. In addition, scour continued to create a scour hole with a depth about 30 feet below the normal water level for the Mississippi River at that location. WES TR-2-650 indicates that for the head-tailwater condition experienced, even the heavier gradation A_1 would be unstable. This is consistent with what was observed in the field.

3. **Tailwater=2.0-** For this tailwater condition, most of the data for Lock and Dam No. 3 falls between the approach energy elevation of 2.2 through 2.7 with one event at 3.5 feet. For the downstream embankment, the approach energy elevation would be on the order of 2.1 through 2.6 assuming that most of the headloss is at that embankment as was the case in 1993. From the experience with the downstream embankment or spot dike system, a approach energy elevation in the range of 2.1 - 2.6 can cause considerable damage to an earth embankment.

4. **Other Tailwater Conditions-** For other tailwater conditions, similar conclusions can be drawn. The only difference is that the relative relationship to the approach energy elevation is shifted.

e. **Environmental Management Program-** Embankment overtopping experiences associated with habitat projects summarized below are from Jon Hendrickson’s 29 December 1997 Memorandum for Record, subject:"Embankment Overtopping Experiences Associated With Habitat Projects":

1. The following tables document conditions and effects of habitat project earth embankment overtopping during floods. Earth embankments constructed as part of habitat projects take on several forms including islands, closures structures, and dikes. Most of these projects have been constructed as part of the Upper Mississippi River Environmental Management Program (EMP).

Table 3

Pool 4, Peterson Lake Sand Closure	Construction Year	Overtopping Depth (feet)	Head Differential (feet)	Vegetative Stabilization	Scour Depth (feet below average water surface)
	1995	4 ft in 1996	0 to 0.5	Poor	4 to 15
Discussion: The three sand closure structures at the upstream end of the lake completely eroded away. In addition, scour occurred so that the post-flood channel depths at all three closures increased. This scour was most significant at channel 3 where a 15-foot scour hole developed in what had been a 5-foot deep channel.					

Table 4

Pool 5, Sand Run Closures, Weaver Bottoms	Construction Year	Overtopping Depth (feet)	Head Differential (feet)	Vegetative Stabilization	Scour Depth (feet below average water surface)
	1986	3 feet in 1993 2 feet in 1994 4 feet in 1997	0 to 0.5	Good	No Scour, Structure was Stable
Discussion: Because of the relatively small head differential and the good vegetation cover, these structures were stable during the floods.					

Table 5

Pool 5, MN-14 Closures, Weaver Bottoms.	Construction Year	Overtopping Depth (feet)	Head Differential (feet)	Vegetative Stabilization	Scour Depth (feet below average water surface)
	1987	3 feet in 1993 2 feet in 1994 4 feet in 1997	0.5 to 1.0	Variable	Up to 10 feet
Discussion: Vegetative stabilization on the structure was variable. In the areas where vegetation was sparse, significant erosion occurred, with up to 10 foot deep scour holes forming. In areas where good vegetative cover had been established, no erosion occurred. The perimeter of this structure had been stabilized with riprap, and this undoubtedly acted as a hard point, reducing structure erosion.					

Table 6

Pool 5, Spring Lake Peninsula	Construction Year	Overtopping Depth (feet)	Head Differential (feet)	Vegetative Stabilization	Scour Depth (feet below average water surface)
	1994	2 feet in 1997	0 to 0.5	Good	No Scour,Structure was Stable
Discussion: Because of the relatively small head differential and the good vegetation cover, this structure was stable during the floods. Some erosion did occur on a road adjacent to and lower than the structure. The overtopping depth on the road was 4 feet.					

Table 7

Pool 8 Islands	Construction Year	Overtopping Depth (feet)	Head Differential(feet)	Vegetative Stabilization	Scour Depth (feet below average water surface)
	1992	1 foot in 1993 2 feet in 1997	0.0 to 0.5	Poor in 1993 Good in 1997	No Scour, Structure was Stable
Discussion: In 1993, the project was less than a year old and vegetation had been planted on the island less than a month before the flood hit. Based on field reconnaissance during the flood, it was apparent that the short grasses that had become established were helping prevent erosion. In addition, the top of the island was constructed of a mixture of sand, silt, and clay which had some cohesiveness that helped prevent erosion. In 1997, vegetation was well established and no erosion occurred.					

Table 8

Pool 9, Lansing Big Lake Closures	Construction Year	Overtopping Depth (feet)	Head Differential (feet)	Vegetative Stabilization	Scour Depth (feet below average water surface)
	1994	2 feet in 1995 4 feet in 1996 8 feet in 1997	0 to 0.5	Poor in 1996 Variable 1997	See discussion below.
Discussion: Some structure erosion occurred in 1995, but most occurred in 1996. In almost all cases the structures, which consisted of a granular fill core with a topsoil cap, eroded down to the preproject ground surface and then stopped. In some cases more significant erosion was observed near trees which had been left near the structures. This was repaired in 1996 with rock structures. No significant damage occurred in 1997. Because of the floodplain forest canopy, grassy vegetation has been slow to become established on the earth structures.					

2. A number of earth structures constructed as part of habitat projects have been overtopped during recent floods on the Mississippi River. The use of rock for embankment stabilization is usually minimized on these types of projects, partly because engineers can assume a higher level of risk, and partly because the natural resource agencies have discouraged the use of rock in the past. Instead, vegetative stabilization has been relied on. Three important factors: overtopping depth, head differential, and vegetative stabilization affect structure erosion or scour. Of these three factors, vegetative stabilization appears to be most strongly correlated with the occurrence of erosion. If there was good vegetation established on the structures, they were stable. If vegetation was poor or variable, problems occurred.

There is obviously a relationship between scour and head loss (See Waterways Experiment Station Technical Report 2-650, Stability of Riprap and Discharge Characteristics, Overflow Embankments, Arkansas River, Arkansas). A rigorous analysis of this relationship based on experiences at habitat projects isn't possible because of the lack of precise information on head loss. The only situation where a head loss of greater than 0.5 feet occurred on one of the habitat structures is at MN-14, the outlet from Weaver Bottoms. Significant erosion occurred here in 1993 because of this situation. However, vegetation establishment on the structure was also important since areas that had sparse vegetation eroded, while areas that were well vegetated suffered little damage.

Overtopping depth is most significant during the initial stages of inundation. Rarely does damage occur if the overtopping depth is less than half a foot. As depths increase over the structure, hydraulic/tractive forces increase also, increasing the potential for erosion. One positive aspect of deep inundation is that wave action doesn't cause structure erosion.

3. Habitat project design is an adaptive process, that must rely heavily on past experiences. Based on the information presented above, two guidelines can be established which can be used on future projects. These guidelines aren't set in stone and should continue to evolve bases on new information.

Guideline 1 - Establish grassy and woody vegetation on earth structures as soon as possible. Based on observations of the Pool 8 Islands during the 1993 flood, even recently established vegetation helps to stabilize structures. Woody vegetation is desirable since it is persistent, and will help structure stability during Spring floods when grasses are dormant.

Guideline 2 - If the head differential across the structure exceeds 0.5 feet, rock should be used to stabilize the structure.

3. Approach Energy versus tailwater- Figure 9 is a plot of approach energy versus tailwater for the Lock and Dam No. 18 earth embankment with the 1993 flood event. Figure 10 shows plots for the category 3 projects as defined in paragraph 4. Figure 11 shows the category 4 projects as defined in paragraph 5.

4. Classification of earth embankments- For the purpose of this evaluation, a classification system is proposed in Table 9.

Table 9

Classification of earth embankments subjected to overtopping			
Category	Headloss Range(ft)	Minimum W50 Stone (lbs)	Description
1	0.0-0.2	1 or vegetation	Category 1 earth embankments or levees are defined as those embankments subjected to overtopping with an approach energy versus tailwater relationship that equates to a headloss less than 0.2 foot. Embankments or levees in this category are not likely to sustain significant damage if overtopped. With a tailwater of 4.0 feet, extrapolating the available data from *TR2-650* indicates that a W_{50} stone size on the order of 2.9 inches or a 1 pound stone would be required to resist the erosion with an approach energy of 4.2 feet for the upper limit of headloss for this category. The W_{50} size for category 1 ranges from 0 to 1 pound.

2	0.2-0.5	2 or vegetation	Category 2 earth embankments or levees are defined as those embankments or levees subjected to overtopping with an approach energy versus tailwater relationship that equates to a headloss in the range of 0.2 feet to 0.5 feet. Earth embankments or levees in this category are in a transition between a low risk of sustaining significant damage to a high risk of sustaining significant damage if overtopped. Vegetation and/or materials of which the earth embankment or levee are constructed impact the risk of significant damage. With a tailwater of 4.0 feet, extrapolating the available data from *TR2-650* indicates that a W_{50} stone size on the order of 3.2 inches or a 2 pound stone would be required to resist the erosion with an approach energy of 4.5 feet for the upper limit of headloss in this category. From this information, it can be seen that going from a headloss of .2 feet to .5 feet, will result in twice the stone weight required for the W_{50} size. The W_{50} size for category 2 ranges from 1 to 2 pounds.
3	0.5-2.0	7	Category 3 embankments are defined as those earth embankments subjected to overtopping with an approach energy versus tailwater relationship that equates to a headloss greater than 0.5 feet and less than 2 feet. Earth embankments or levees in this category would have a high risk of erosion.With a tailwater of 4.0 feet, extrapolating the available data from TR2-650 indicates that a W_{50} stone size on the order of 5.3 inches or a 7 pound stone would be required to resist the erosion with an approach energy of 6.0 feet for the upper limit of headloss in this category. The W_{50} size for category 3 ranges from 2 to 7 pounds.

4	2.0-3.0	210	Category 4 embankments are defined as those earth embankments subjected to overtopping with an approach energy versus tailwater relationship that equates to a headloss greater than 2 feet and less than 3 feet. Earth embankments or levees in this category would have a high risk of erosion. With a tailwater of 4.0 feet, extrapolating the available data from *TR2-650* indicates that a W_{50} stone size on the order of 16.2 inches or a 210 pound stone would be required to resist the erosion with an approach energy of 6.0 feet for the upper limit of headloss in this category. The W_{50} size for category 4 ranges from 7 to 210 pounds.
5	> 3.0	> 210 or concrete	Category 5 embankments are defined as those earth embankments subjected to overtopping with an approach energy versus tailwater relationship that equates to a headloss greater than 3 feet. Earth embankments or levees in this category would have an extremely high risk of erosion.With a tailwater of 4.0 feet, extrapolating the available data from *TR2-650* indicates that a W_{50} stone size greater than 210 pounds would be required to resist the erosion with an approach energy of 7.0 feet for the upper limit of headloss in this category. Because of the large stone size requirements for this category, a concrete structure may be more feasible than providing riprap for erosion protection.

5. Verification of Classification System- The verification of the classification system used for this evaluation is presented in **Table 10**.

Table 10

Verification of the Classification System for Earth Embankments subject to Overtopping				
Project	Headloss in Feet	Category	Verifies Category Performance	Discussion
Pool 4- Peterson Lake Sand Closure	0.0-0.5	1 or 2	Yes	This project is most likely in category 2. Poor vegetation contributed to the erosion observed.

Pool 5- Sand Run Closures at Weaver Bottoms	0.0-0.2	1	Yes	Hydraulic information is not sufficient to determine whether this project should be in category 1 or 2. However, no scour was observed which fit with the definitions of category 1 or 2.
Pool 5- MN-14 Closures at Weaver Bottoms	0.5-1.0	3	Yes	Scour occurred to a depth 10 feet below the average water surface elevation.
Pool 5- Spring Lake Peninsula	0.0-0.2	1	Yes	Scour was not a problem.
Pool 8 Islands	0.2-0.5	2	Yes	Scour was not a problem.
Pool 9- Lansing Big Lake Closures	0.2-0.5	2	Yes	Erosion and scour occurred.
Lock and Dam No. 3 Upper- Corps Spot Dike System	<.2	1	Yes	Generally, erosion from overtopping is not a significant problem for the upper Corps Spot Dike System as long as the lower spot dike system is not breached.
Lock and Dam No. 3 Intermediate Spot Dike System	<.2	1	Yes	Generally, erosion from overtopping is not a significant problem for the Intermediate Spot Dike System as long as the lower spot dike system is not breached.
Lock and Dam No. 3 Lower Spot Dike System	0.5 Normal 4.8 Barge Accident	3 Normal 5 Barge Accident	Yes	Erosion has been a major problem for the lower spot dike system for normal conditions and an extreme problem for the barge accident scenario.

Lock and Dam 18	0.8-1.4[1]	3	Yes	At Lock and Dam No. 18, the cost of repair was minor. However, the fact that breaching occurred to a depth of 5-6 feet demonstrates that breaching is a serious consideration. At Lock and Dam 18, additional information is needed with regard to the materials used to construct the embankment to gain further insight. Since the embankment was overtopped during the month of July, any vegetation would have had enough time to be well established prior to overtopping. A spring runoff event would occur before any vegetation would be established and, therefore, have a higher rate of erosion

[1] Water surface profile for the 0.2 percent change event indicates that at the upstream end of the levee at river mile 411.5, the elevations are about 0.1-0.2 feet higher than the elevations at the dam which is at river mile 411.0. Therefore, in 1993, the head differential at the upstream end of the levee could have been on the order of 1.0 to 1.6 feet.

6. Application of Classification System- The application of the classification system used for this evaluation is presented in Table 11.

Table 11

Application of Classification System to Locks and Dams 2-10 on the Mississippi River within the St. Paul District			
Project	Headloss in Feet	Category	Discussion and Consequence of Overtopping
Lock and Dam No. 2 Earth Embankment	0.8-2.3(1969)	3 normal 4 (1969)	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching.

Lock and Dam No. 3 Earth Embankment-MN (Not Spot Dikes)	0.5	3	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching.
Lock and Dam No. 4 Earth Embankment	0.7	3	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching.
Lock and Dam No. 5 Earth Embankment	2.4 Upstream 0.9 Downstream	4	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching. In 1997, field surveys indicated that the pool was 1.5 feet higher at the upstream end of the embankment.
Lock and Dam No. 5A Earth Embankment	0.7 Upstream 0.5 Downstream	3	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching. In 1997, field surveys indicated that the pool was 0.2 feet higher at the upstream end of the embankment.
Lock and Dam No. 6 Earth Embankment	1.6	3	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching.
Lock and Dam No. 7 Earth Embankment	0.8	3	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching.
Lock and Dam No. 8 Earth Embankment	1.2 Upstream 0.7 Downstream	3	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching. In 1997, field surveys indicated that the pool was 0.5 feet higher at the upstream end of the embankment.
Lock and Dam No. 9 Earth Embankment	0.7	3	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching.

Lock and Dam No. 10 Earth Embankment	0.6	3	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching.

[1] Source: USAED-St Paul Water Control Web Server; historic water surface profile tabulation for 1952, 1965, 1967, 1969 and 1993 events.

Table 12

Rank of Locks and Dams 2-10 on the Mississippi River within the St. Paul District considering risk			
Project	Headloss in Feet	Category/Rank[1]	Discussion and Consequence of Overtopping
Lock and Dam No. 5 Earth Embankment	2.4 Upstream 0.9 Downstream	4/1	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching. In 1997, field surveys indicated that the pool was 1.5 feet higher at the upstream end of the embankment.
Lock and Dam No. 2 Earth Embankment	0.8-2.3(1969)	3 normal 4/2 (1969)	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching.
Lock and Dam No. 6 Earth Embankment	1.6	3/3	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching.
Lock and Dam No. 8 Earth Embankment	1.2 Upstream 0.7 Downstream	3/4	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching. In 1997, field surveys indicated that the pool was 0.5 feet higher at the upstream end of the embankment.
Lock and Dam No. 7 Earth Embankment	0.8	3/5	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching.

Lock and Dam No. 9 Earth Embankment	0.7	3/6	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching.
Lock and Dam No. 4 Earth Embankment	0.7	3/7	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching.
Lock and Dam No. 5A Earth Embankment	0.7 Upstream 0.5 Downstream	3/8	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching. In 1997, field surveys indicated that the pool was 0.2 feet higher at the upstream end of the embankment.
Lock and Dam No. 10 Earth Embankment	0.6	3/9	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching.
Lock and Dam No. 3 Earth Embankment-MN (Not Spot Dikes)	0.5	3/10	If overtopped by a spring flood, the earth embankment is likely to sustain considerable erosion and possible breaching.

[1]Rank is from the highest risk(Rank of 1) to the lowest risk embankment(Rank of 10) based on the headloss expected. This ranking could change if the materials of the embankment are taken into consideration.

7. Conclusion. The conclusion reached at this time is that the earth non-overflow embankments will have a significant risk of incurring considerable damage if overtopped. The rate of erosion depending on the headloss, the embankment materials and the vegetation providing erosion protection. In the St. Paul District, Lock and Dam No. 5 would have the greatest risk of breaching as shown in Table 12 not taking into account any geotechnical considerations. When the geotechnical considerations are taken into account, another table can be developed taking into account both the hydraulic and geotechnical factors.

8. Options: At this time, the recommended plan has not been determined since the determination of the recommended plan will need to involve input from other disciplines in the District. However, some options available are discussed below:

- **Do nothing-** This is currently the selected option in the Rock Island District for the earth non-overflow embankments. The advantages and disadvantages for this alternative are as follows:

  - **Advantages-** This is the least cost alternative initially.

  - **Disadvantages-** No assurance can be made with regard to the stability of the earth embankment with regard to erosion. It is likely that erosion will occur. Based on the experience with other projects as presented in paragraph 2, it can be seen that there is a significant risk that the earth embankments will breach. Once a breach is initiated, the general tendency is for the flow to increase through the breach causing higher and higher scouring velocities with additional erosion occurring. This process was demonstrated during 1993 for the earth dike between Gantenbein Lake and the Mississippi River where a breach formed. Once the dike was breached, the scour accelerated in a 1-2 day time period to the point where a 30 foot scour hole formed where the embankment once existed.

- **Raise non-overflow embankments.** The advantages and disadvantages for this alternative are as follows:

  - **Advantages-** This alternative will prevent damages to the earth non-overflow embankments.

  - **Disadvantages-** This alternative requires a substantial effort making it quite costly.

- **Provide erosion protection-** The advantages and disadvantages for this alternative are as follows:

  - **Advantages-** This alternative will prevent damages to the earth non-overflow embankments. The costs for this alternative could be relatively low when compared to raising the embankment. It appears that a minimal riprap layer thickness with a filter material would be adequate to prevent erosion for most sites based on the category determination shown in Table 11 and the requirements for specific categories shown in Table 9. This would be needed on the crest and only the upper portion of the embankment from the crest to a point 5 to 10 feet below the crest on the downstream slope. The exceptions to the minimal requirements would be Lock and Dam No. 5 and, possibly, Lock and Dam No. 2 depending on which design condition is used.

  - **Disadvantages-** This alternative minimizes the disadvantages.

- **Combination of Options A, B and/or C.-** The advantages and disadvantages for this alternative are as follows:

  - **Advantages-** This alternative will prevent damages to the earth non-overflow embankments. It also allows for an overall optimization of the alternatives.

  - **Disadvantages-** This alternative minimizes the disadvantages.

/signed/
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Figure 1

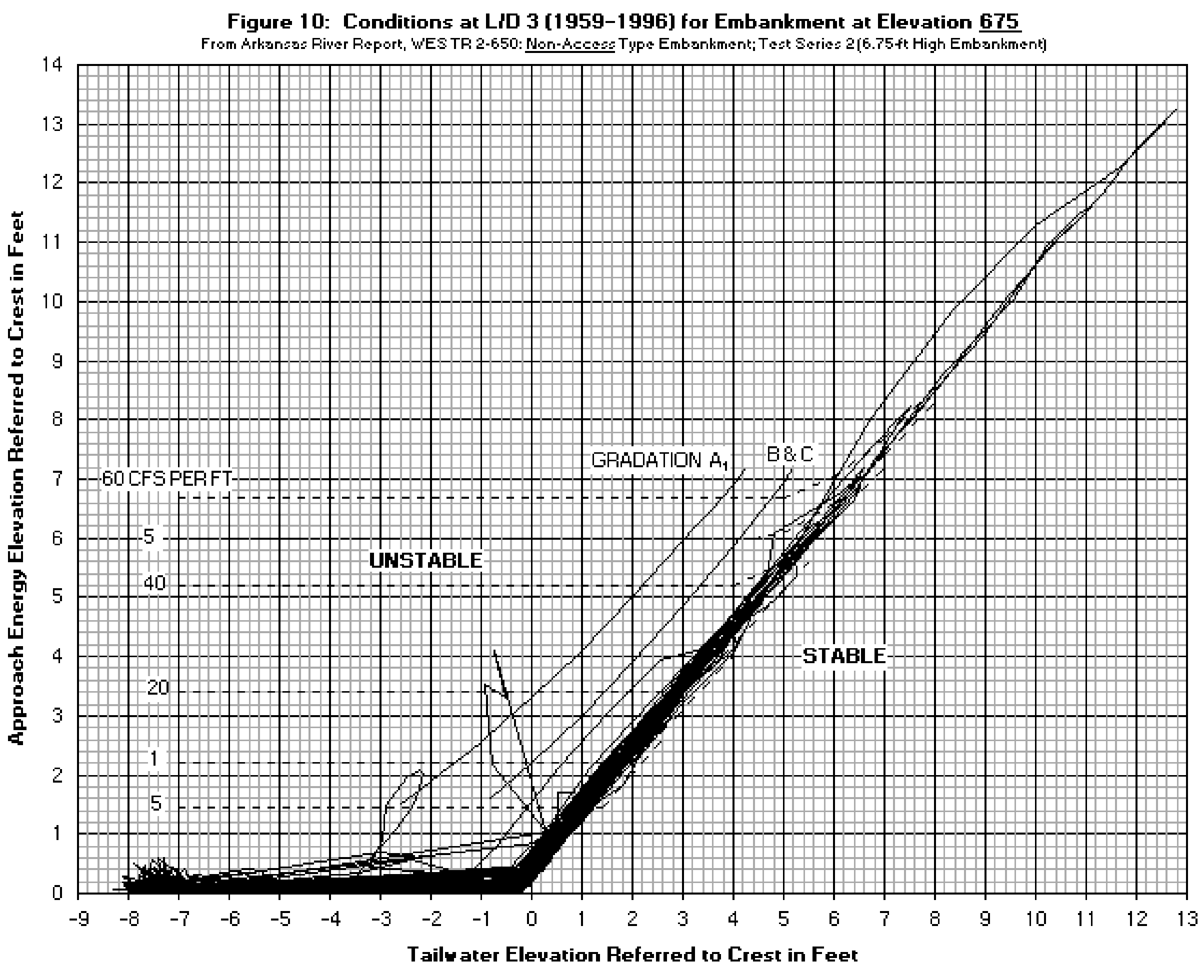


Figure 2 **Figure 3**

Gage Related Information	
MI18 - L&D 18 OMNI data	
Stream	Mississippi River
Gage Zero	518.52 feet MSL (1912)
Flood Stage	10.00 feet
Record Stage	21.54 Date 07-10-93
Location	Lat 40-53-07 Long 91-01-21
Drainage Area	113,600 square miles
River Mile	410.5
Location of Gage	Lock and Dam 18 Gladstone, IL.

Gage Related Information	
GLDI2- L&D 18 near Gladstone, Il	
Stream	Mississippi River
Gage Zero	518.52 feet MSL (1912)
Flood Stage	10.00 feet
Record Stage	21.54 Date 07-10-93
Location	Lat 40-53-07 Long 91-01-21
Drainage Area	113,600 square miles
River Mile	410.5
Location of Gage	Lock and Dam 18 Gladstone, IL.

Figure 4

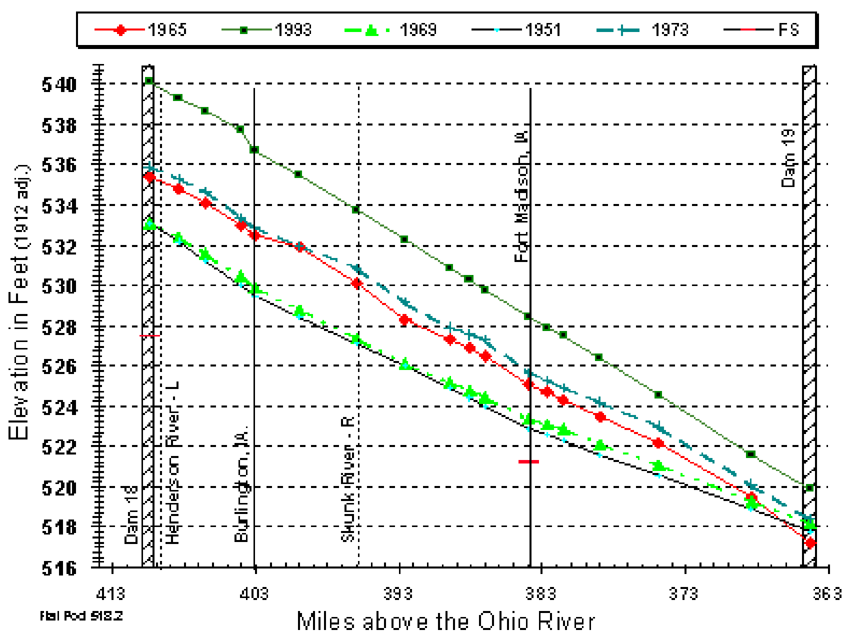


Figure 5

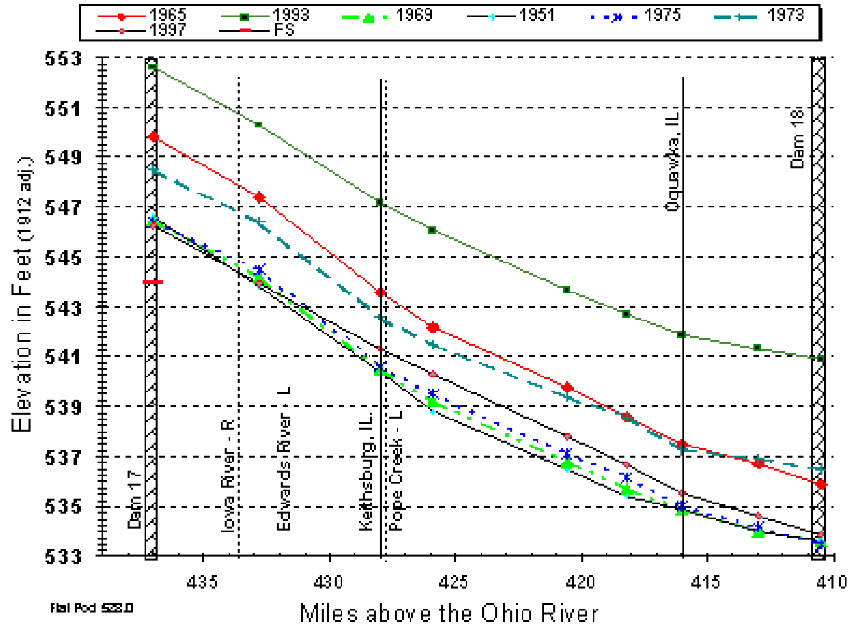


Figure 6

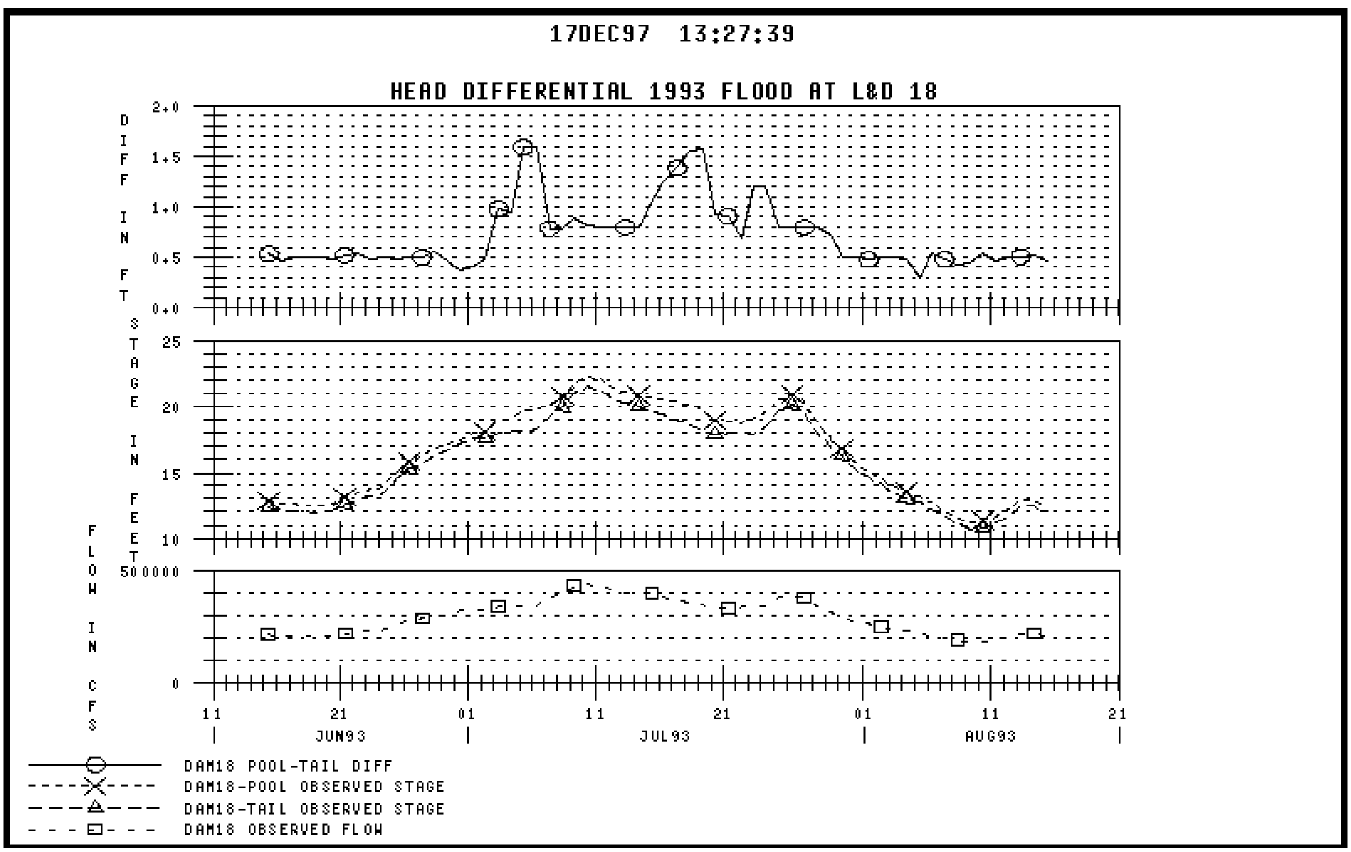


Figure 7

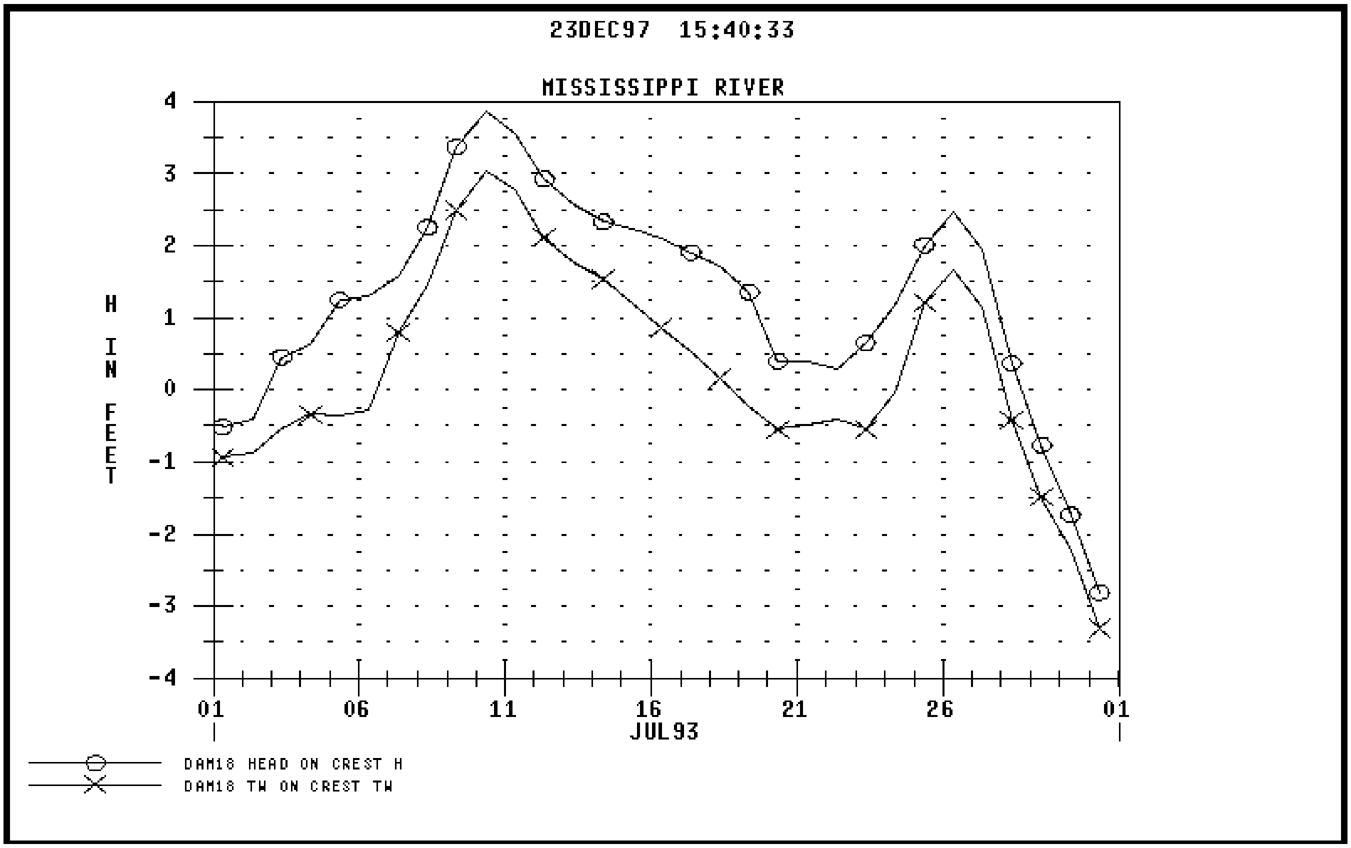
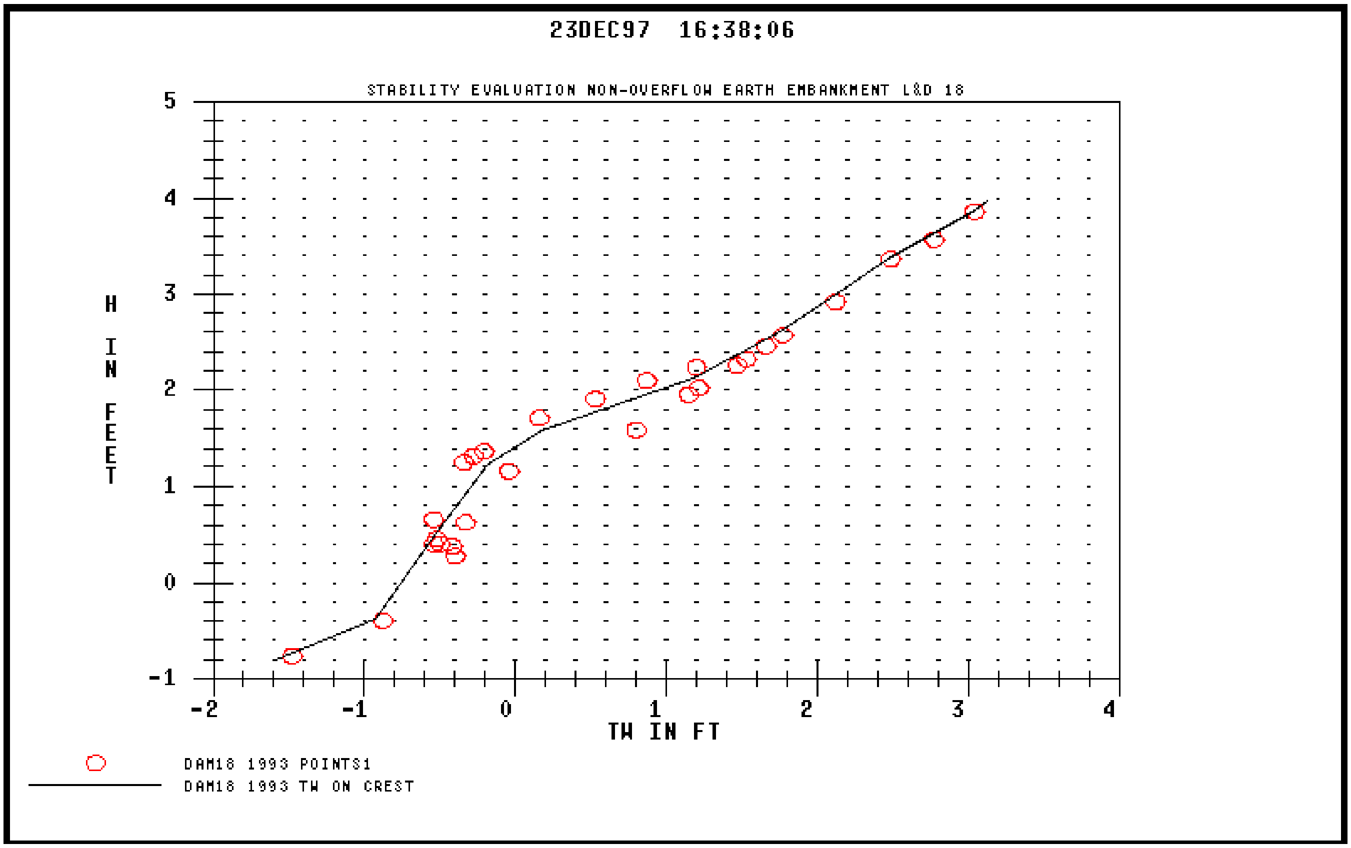
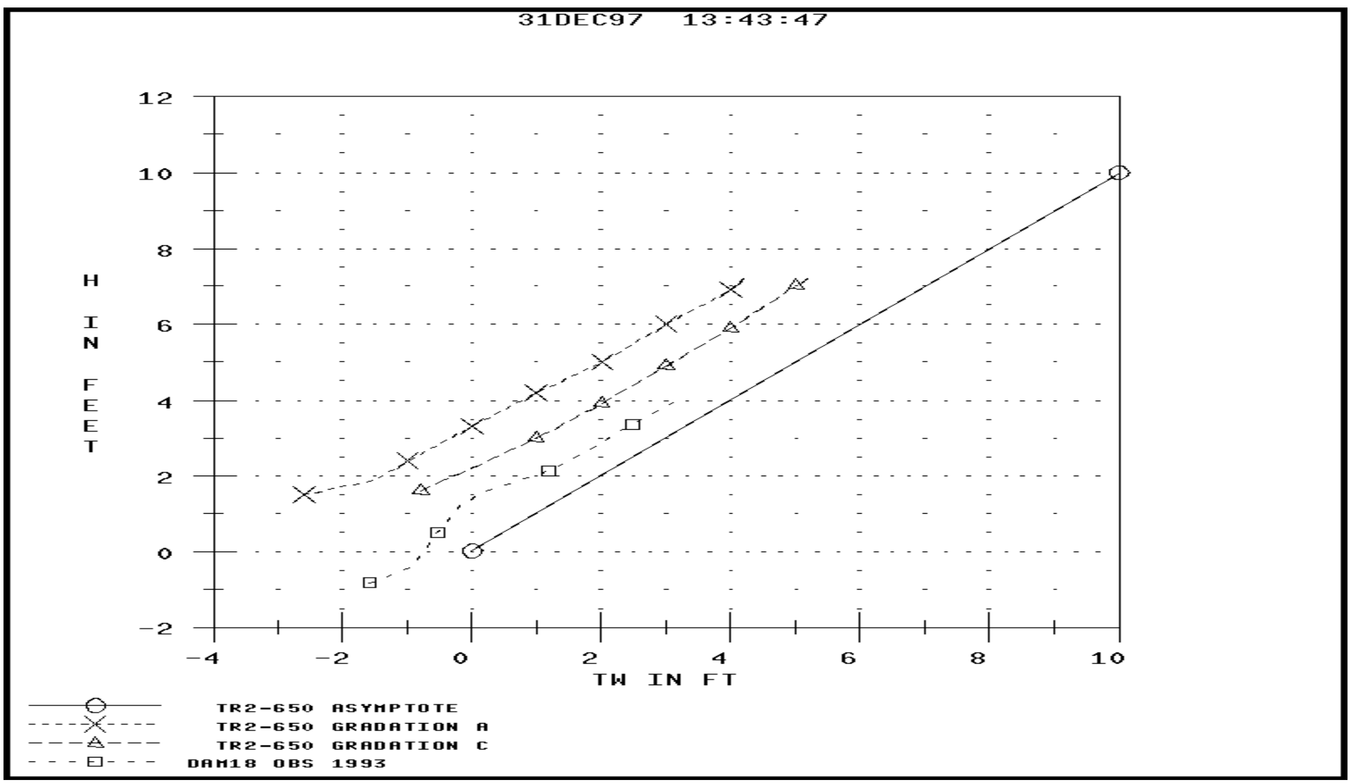

23DEC97 15:40:33
MISSISSIPPI RIVER
H IN FEET
4
3
2
1
0
-1
-2
-3
-4
01
06
11
16
21
26
01
JUL93
DAM18 HEAD ON CREST H
DAM18 TW ON CREST TW

Figure 8



23DEC97 16:38:06
STABILITY EVALUATION NON-OVERFLOW EARTH EMBANKMENT L&D 18
H IN FEET
TW IN FT
DAM18 1993 POINTS1
DAM18 1993 TW ON CREST

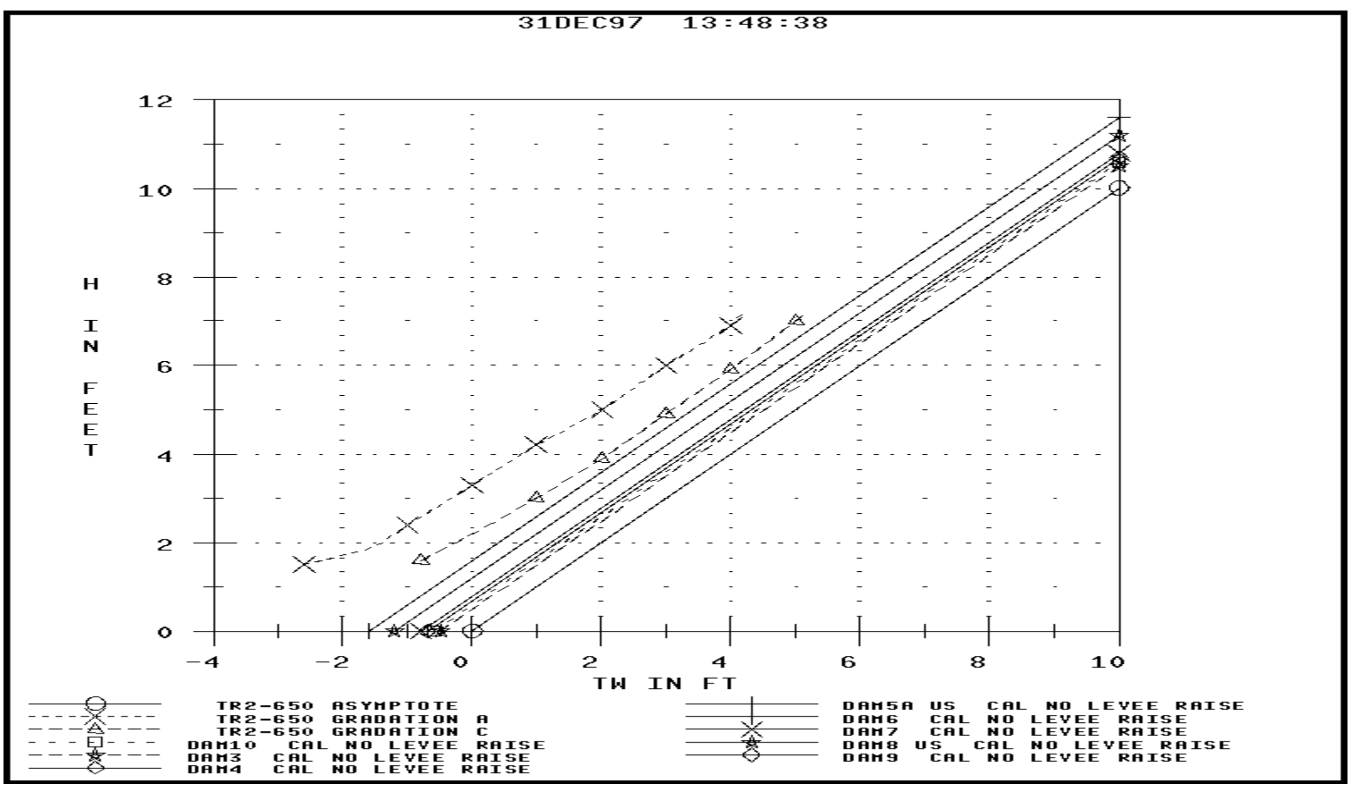
Figure 9



31DEC97 13:43:47
H IN FEET
TW IN FT
TR2-650 ASYMPTOTE
TR2-650 GRADATION A
TR2-650 GRADATION C
DAM18 OBS 1993


TR2-650 GRADATION A
TR2-650 GRADATION C
DAM18 OBS 1993

Figure 10


31DEC97 13:48:38
H IN FEET
12
10
8
6
4
2
0
-4
-2
0
2
4
6
8
10
TW IN FT
TR2-650 ASYMPTOTE
TR2-650 GRADATION A
TR2-650 GRADATION C
DAM10 CAL NO LEVEE RAISE
DAM3 CAL NO LEVEE RAISE
DAM4 CAL NO LEVEE RAISE
DAM5A US CAL NO LEVEE RAISE
DAM6 CAL NO LEVEE RAISE
DAM7 CAL NO LEVEE RAISE
DAM8 US CAL NO LEVEE RAISE
DAM9 CAL NO LEVEE RAISE

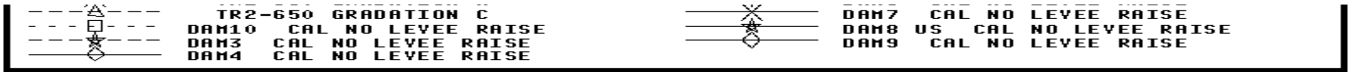
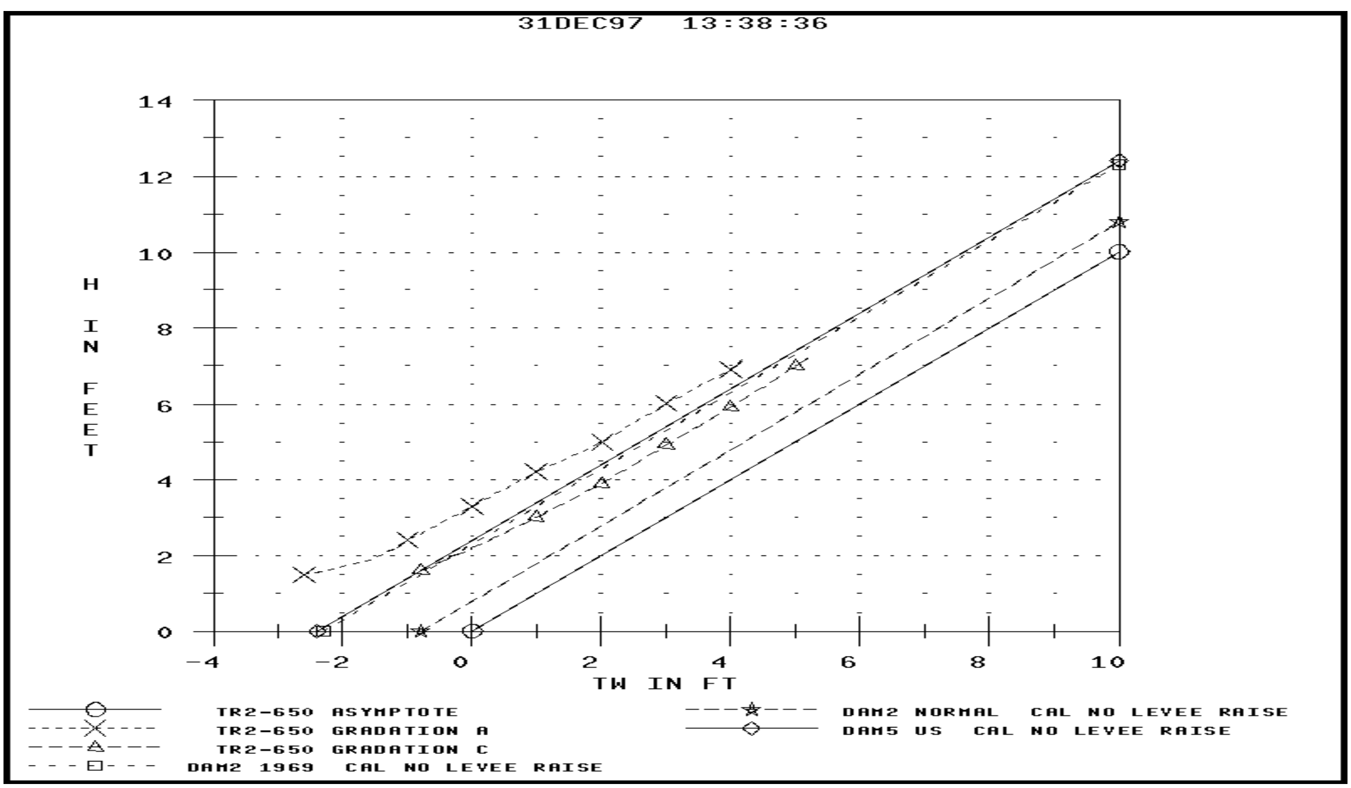

TR2-650 GRADATION C
DAM10 CAL NO LEVEE RAISE
DAM3 CAL NO LEVEE RAISE
DAM4 CAL NO LEVEE RAISE
DAM7 CAL NO LEVEE RAISE
DAM8 US CAL NO LEVEE RAISE
DAM9 CAL NO LEVEE RAISE

Figure 11


31DEC97 13:38:36
H IN FEET
TW IN FT
TR2-650 ASYMPTOTE
TR2-650 GRADATION A
TR2-650 GRADATION C
DAM2 1969 CAL NO LEVEE RAISE
DAM2 NORMAL CAL NO LEVEE RAISE
DAM5 US CAL NO LEVEE RAISE

For further information, contact: Stuart Dobberpuhl, P.E.