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Engineering and Design
OVERTOPPING OF FLOOD CONTROL LEVEES AND FLOODWALLS

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Engineer Technical
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1. Purpose. This letter provides a report describing suggested design assumptions and procedures when considering the potential flood overtopping of levees and floodwalls.

2. Applicability. This letter applies to all HQUSACE/OCE field operating activities (FOAs) responsible for planning, design, construction, and operation and maintenance of civil works projects.

3. Discussion. The attached paper was originally presented at the ASCE Hydraulics Division Specialty Conference, "Water for Resource Development", held in Coeur d' Alene, Idaho, on August 14-17, 1984. The paper is published in the proceedings of that conference. As per ER 1110-2-1405, paragraph 6h(6), all project designs containing levees and/or floodwalls should be examined for overtopping risks. In the many cases where overtopping would be potentially hazardous, the enclosed information will aid engineers in minimizing this hazard.

FOR THE COMMANDER:

Encl

WILLIAM N. McCORMICK, Jr.
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Directorate of Engineering and
Construction

OVERTOPPING OF FLOOD CONTROL LEVEES AND FLOODWALLS

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ABSTRACT: The risk of overtopping can be significant for flood control levees or floodwalls, and the consequences can be costly and potentially catastrophic. Designs using superiority can force initial overtopping in the least hazardous location. Water surface profiles above the design profile need examining to apply superiority. Documenting overtopping consequences in the protected area is helpful for a flood hazard plan. A local flood warning system can be beneficial to the plan.

Introduction.

Levees and floodwalls are flood control structures meant to keep flood waters out of a floodplain area. These structures have upper limits beyond which larger floods cannot be controlled. This limit is often referred to as the level of protection that the structure provides to the floodplain area. Since the structure will experience bigger floods that will overtop and flood the interior, overtopping becomes a design concern. The rate of failure of a levee or floodwall is difficult to predict with sudden failure a possibility. Sudden failure in an urban setting could cause a catastrophe. The solution for these problems is proper design to control overtopping location and thus minimize failure and safety concerns.

Flood overtopping of a structure into a previously protected area is a risk inherit in any levee or floodwall project. This risk varies with the level of protection afforded by the structure. Risk can still be significant even for areas with protection from rare floods. The following table illustrates the overtopping potential during the typical 100 year economic life of a levee or floodwall, references 1 & 7.

ANNUAL FLOOD LEVEL		RISK IN PERCENT OF "N OR MORE" EVENTS EXCEEDING A GIVEN ANNUAL FLOOD LEVEL IN 100 YEARS				
EXCEEDANCE INTERVAL IN YEARS	EXCEEDANCE FREQUENCY IN PERCENT	N=1	N=2	N=3	N=4	N=5
500	0.2	18	2	Nil	Nil	Nil
100	1.0	63	26	8	2	Nil
25	4.0	98	91	77	57	37
5	20.0	100	100	100	100	100

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A good overtopping design can:

- Force overtopping in a selected reach, with the following benefits:
  - Controls the initial overtopping to reduce the impact of sudden overtopping failure.
  - Provides an initial cushion of water in interior areas to lessen overtopping impacts in other levee reaches.
  - Reduces the chance of overtopping in less desirable areas.
- Reduce project maintenance and replacement costs.

No overtopping design can prevent overtopping.

Two Types of Overtopping Design.

Two design types can be used to control initial overtopping. An obvious one is the use of different levee heights relative to the design water surface from reach to reach to force overtopping in a desired location. The other design uses notches, openings, or weirs in the structure. The inverts for these features are in the freeboard of the structure, i.e. above the design flood stage but below the neighboring top of levee. Examples are railroad or road openings and rock weirs. There is a logical paradox associated with the notch concept. Levee freeboard is designed to take care of the "unknowns" in the design process: to pass the design flood if it is higher, from unknown or unpredictable causes, than previously determined. A notch in this freeboard might be a cause of overtopping flow which otherwise might have safely passed down the channel, if only the notch had been the same height as the rest of the levee. Never-the-less, this type of design is frequently used to achieve other design goals.

Design Goals.

For initial overtopping, the overriding concern is choosing the least hazardous location for initial inundation of the interior. A least hazardous location could be a golf course, an oxbow lake, a ponding area, the least developed area, or a downstream reach. In some cases, overtopping may be partially controlled in open spaces or by routing to ponding areas. In other situations internal dikes or high ground may control overtopping volumes. Control of development for the above examples thru acquisition of real estate interests is an important part of a project. This real estate control serves two purposes - first, to minimize safety concerns for buildings adjacent to initial and more frequent overflow areas, and second, to allow control of development into the future so that the overtopping design is not compromised.

The level of protection can sway the design emphasis for overtopping. A 20 percent chance annual flood level of protection should have many overtoppings in 100 years. Prudent design would minimize the cost of maintenance or major replacement for the structure due to repetitive overtoppings. In contrast, a 0.2 percent chance annual flood level of protection may have high levees in an urban setting, causing community dangers from overtopping. The emphasis for this design would stress safety and prevention of a catastrophe.

Superiority in overtopping is a concept dealing with adjacent levees or levee reaches designed to overtop one before the other, references 3, 5 & 6. Superiority may simply mean providing higher levees at all points except where initial overtopping is desired. A more complex example involves two separate levees across the river from one another; one protecting highly urbanized areas, the other mostly agricultural area, but both having similar levee elevations. Value judgements could be made to allow overtopping of the agricultural before the urban. The urban area thus would get wet last and possibly would obtain a higher level of protection in the process, due to the volume of water going over the other levee and not into river level increases. Another concept is chain failure of adjoining but independent levees. Failure of one may rupture the next and the next. Superiority can be used to reduce this potential. A similar idea concerns flank or tie-back levees along tributaries to the river. The hydrology for the tributary may provide higher water surface profiles than the river. In addition the tributary may be flashy with short warning times and potential dangers from quick overtopping. Safety may be a concern and superiority along the tributary reaches over the other reaches is appropriate.

Design goals provide the strategies to help configure the levee or floodwall and provide special considerations for the overall scheme of protection. However, water surface elevations or profiles are usually the dominant concern in overtopping design. The computation of these profiles needs special attention.

Water Surface Profiles.

Once a water surface profile for the design discharge is determined, a minimum freeboard distance above this water surface is determined and typically added to the design water surface profile. There is a tendency by hydraulic engineers at this point in the analysis to declare their work at an end and proclaim the minimum freeboard profile, profile M, as the levee crest profile. This is usually a mistake. Water surface profiles for flows only slightly above the design discharge can do surprising things. In a recent Corps of Engineers flood control project, a water surface profile for a flood 2 feet above the design discharge profile at the downstream end of the levee, resulted in this same flood profile increasing to 10 feet above the design profile at the upstream end. If the project had been designed with a constant 3-foot freeboard, a flood only slightly above the design flood would have overtopped the levee at the upstream end, flowed at high velocity thru the town, filled the area inside the levee like a bathtub, and run over the top of the downstream portion of the levee from the inside out.

The following procedure will generally prevent the above hazard from becoming reality. Having located the least hazardous area for overtopping, a series of water surface profiles (profiles A1, A2, ...AX, ...AY) above the design discharge is computed. One of these profiles, profile AX, will just touch profile M. If this point on profile M coincides with the desired overtopping reach and all other points along profile M are above profile AX, then profile M (the constant minimum freeboard profile) is set as the levee crest.

A more likely outcome is that profile AX will first touch profile M in a reach other than the most desirable overtopping area. In this case, additional profiles with increasing discharges are considered until a profile AY crosses profile M in the reach of least hazardous overtopping. The portion of profile AY above profile M represents a putative levee crest profile which is at exactly the same level as an incipient overtopping flood. Levee superiority is now added to the portion of profile AY above profile M. This allows initial overflow only at the intersection of profiles AY and M, the least hazardous reach. The added superiority should not be in the form of abrupt jumps in levee height (which would tend to make local residents uneasy), but should be gradual increases. As flood stages increase, the length of levee being overtopped should gradually increase; and after initial overtopping, the head differential across the levee crest should be small. Finally, for reaches of profile AY below profile M, profile M should be used as the levee crest.

After all of this the work should still continue. Knowing the impacts of overtopping are as important as the control of overtopping. People protected by the structures need to know about any potential dangers or maintenance and repair requirements. This knowledge can be used effectively in responding to overtopping problems.

Overtopping Impacts and Responses.

The primary emphasis in an impact evaluation should be the description and quantification of dangerous overtopping inundation scenarios. After this, hydrologic and other data should be quantified to meet the concerns of the individual protected area. An example: in an urban setting the duration of inundation may be important for health reasons but in a agricultural area for economic reasons. The following data may be needed to quantify overtopping impacts:

- rate of rise of infrequent floods causing overtopping
- warning time after a flood is recognized as having overtopping potential
- linear extent of initial overtopping along levee or floodwall
- volume of overtopping and subsequent interior depths and areal extent of inundation
- routing or movement of interior inundation with potential velocities

- duration of inundation, which may be a function of the interior flood control features, reference 4
- potential damage to levee, floodwalls or other structures or facilities
- potential crippling or loss of critical public services such as electricity, water, hospitals, fire and police assistance, access along public roads, etc.

All of this information can be used to develop a flood hazard plan to respond to potential flooding of the interior protected area. Any response can be aided by additional warning time. Local flood warning systems can help in determining the maximum water surface and the timing of a current flood situation, reference 2. Developing and institutionalizing a response plan with a flood warning system can significantly lessen the dangers and damage associated with overtopping of flood protection structures.

Summary.

The safety of any levee or floodwall can be increased with proper design of flood overtopping locations. The intelligent understanding of overtopping impacts can aid in planning for the hazard. A local flood warning system coupled with a flood hazard response plan can lessen the adverse impacts of overtopping.

APPENDIX - References

1. "Guidelines for Determining Flood Flow Frequency," Bulletin 17B, Revised Sep 81, Editorial Corrections Mar 82, Interagency Advisory Committee on Water Data, Hydrology Subcommittee, USGS, Appendix 10.

2. "Local Flood Warning Systems," draft copy, Interagency Advisory Committee on Water Data, Hydrology Subcommitte, USGS.

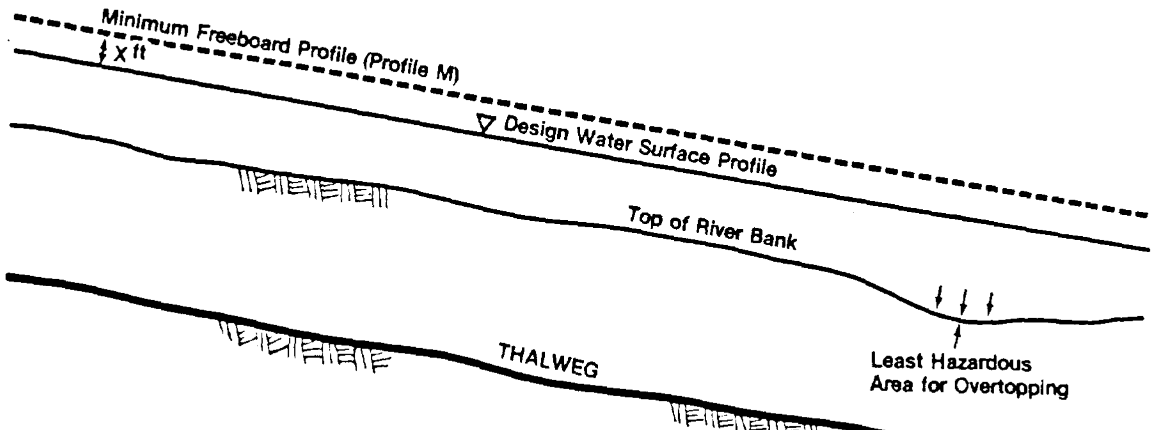
3. U.S. Army, Corps of Engineers, Civil Works Engineer Bulletin 54-14, 1954, "Improvements in Design and Construction Practices in Civil Works", pp 2-4.

4. U.S. Army Corps of Engineers, Engineer Circular 1110-2-247, 1983, Draft Engineer Manual entitled "Hydrologic Analysis of Interior Areas."

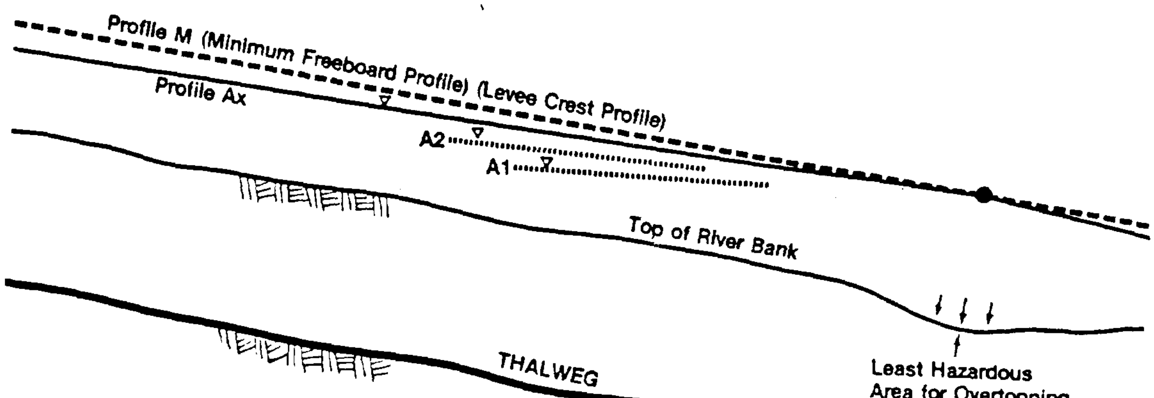
5. U.S. Army Corps of Engineers, Engineer Manual 1110-2-1601, 1970, "Hydraulic Design for Local Flood Protection Projects."

6. U.S. Army, Corps of Engineers, Engineer Regulation 1110-2-1405, 1982, "Hydraulic Design for Local Flood Protection Projects."

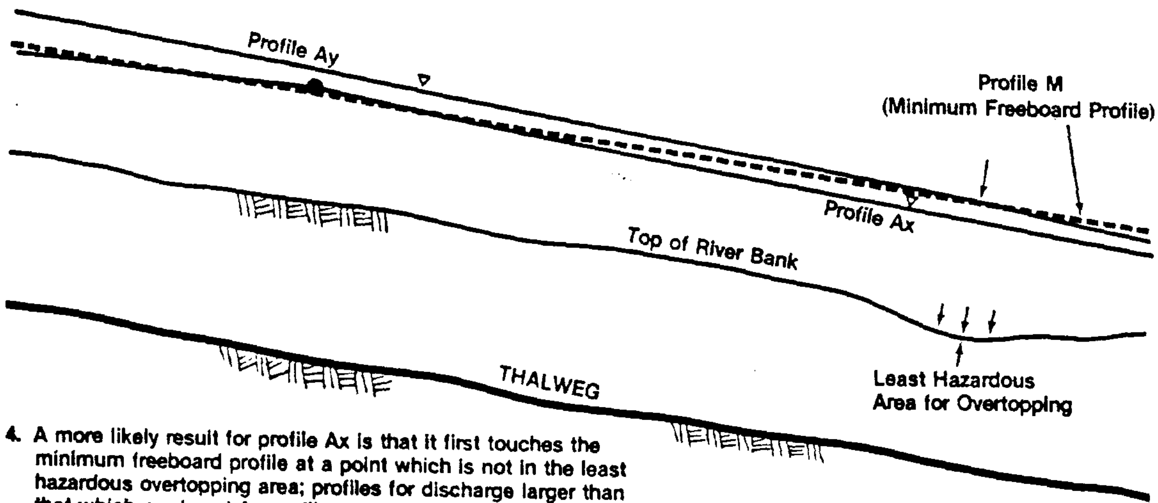
7. U.S. Army, Corps of Engineers, Engineer Technical Letter 1110-2-274, 1982, "Flood Risk Analysis."



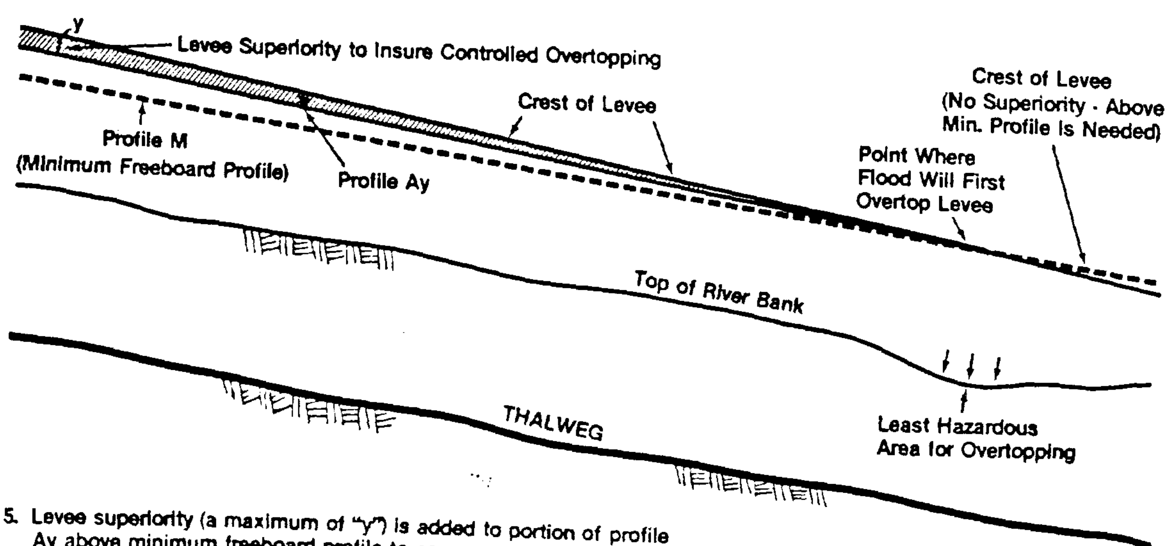
1. Minimum freeboard (x feet) for project or reach is determined and added to the water surface profile for the design flood.
2. Least hazardous area for overtopping is located.



3. Profiles A_1, A_1,··· Ax are computed for a discharge larger than design discharge. A relatively unlikely result is that profile Ax just touches the minimum freeboard profile at the point of least hazardous overtopping; the minimum freeboard profile can then be used as the levee crest profile.



4. A more likely result for profile Ax is that it first touches the minimum freeboard profile at a point which is not in the least hazardous overtopping area; profiles for discharge larger than that which produced Ax profile are computed until Profile Ay crosses minimum freeboard profile at least hazardous point.



5. Levee superiority (a maximum of "y") is added to portion of profile Ay above minimum freeboard profile to assure overtopping first at least hazardous area.