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Technical Letter
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1 May 2005

Engineering and Design
DESIGN GUIDANCE FOR LEVEE UNDERSEEPAGE

1. Purpose. The purpose of this document is to provide interim guidance for design of levees to minimize the adverse effects of levee underseepage. This ETL recommends exit gradients and associated minimum acceptable factors of safety. Use of this guidance should minimize emergence of adverse levee underseepage and initiation of sand boils along flood-control levees with a landside top stratum. EM 1110-2-1913, *Design and Construction of Levees*, currently contains design recommendations for levee seepage control. Except for the changes recommended in this ETL, all other definitions, design equations and procedures recommended in EM 1110-2-1913 should be followed. Where changes are recommended, the specific EM reference is noted in brackets. Currently, EM 1110-2-1913 is in the process of being updated to incorporate these recommendations and other changes. This ETL will be rescinded when the EM is revised.

2. Applicability. This ETL applies to USACE commands having civil works responsibilities.

3. Distribution Statement. Approved for public release; distribution is unlimited.

4. References.

a. EM 1110-2-1913, Design and Construction of Levees.

b. Biedenharn, D. G., and Tracy, F. T. 2000. Finite Element Method Package for Solving Steady-State Seepage Problems, Technical Report TL-87-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

c. Brizendine, A. L., Taylor, H. M., Jr., and Gabr, M. A. 1995. LEVSEEP: Analysis Software for Levee Underseepage and Rehabilitation, Technical Report GL-95-10, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

d. Engineering Computer Graphics Laboratory. 1996. FastSEEP Automated Seepage Analysis Reference Manual, Brigham Young University, Provo, UT.

e. Gabr, M. A., Taylor, H. M., Jr., Brizendine, A. L., and Wolff, T. F. 1995. LEVEEMSU: Analysis Software for Levee Underseepage and Rehabilitation, Technical Report GL-95-9, U.S. Army Engineer Waterway Experiment Station, Vicksburg, MS.

f. Hess, J. R. and Sills, G. L. 2004. A Review of Corps of Engineers Levee Seepage Practices in the Central California Flood Control System, Working Rivers- Balanced Resource Management 24th Annual USSD Conference, St. Louis, MO, April 2004.

g. Knowles, V. R. 1992. Applications of the Finite Element Seepage Analysis Corps Program CSEEP (X8202), Technical Report ITL-92-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

h. Tracy, F. T. 1994. Seepage Package, CSEEP Micro Version, X8202, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

i. U.S. Army Engineer Waterways Experiment Station. 1956. Investigation of Underseepage and Its Control, Lower Mississippi River Levees, Technical Memorandum No. TM-3-424, 2 Vols., U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

j. USACE. 2003. Recommendations For Seepage Design Criteria, Evaluation and Design Practices, Report prepared for the Sacramento District, 15 July 2003.

k. Wolff, T. F. 1989. LEVEEMSU: A Software Package Designed for Levee Underseepage Analysis, Technical Report GL-89-13, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

5. Background. [Appendix C-1]

a. Empirical Performance Data Base. One of the more important contributions to underseepage design criteria was the work presented in TM 3-424, “Investigation of Underseepage and Its Control, Lower Mississippi River Levees,” U.S. Army Engineer Waterways Experiment Station, 1956. The purpose of TM 3-424 was (1) to develop a better understanding of the phenomena of seepage beneath levees and of the factors that influence underseepage, (2) to obtain information that would make possible a rational analysis of underseepage, and (3) to study various means of underseepage control and develop formulas and criteria for their design. The relationship, shown in Figure 1, between severity of seepage and upward gradient through the top stratum at the levee toe was established for 16 sites along the Lower Mississippi River during the 1950 flood.

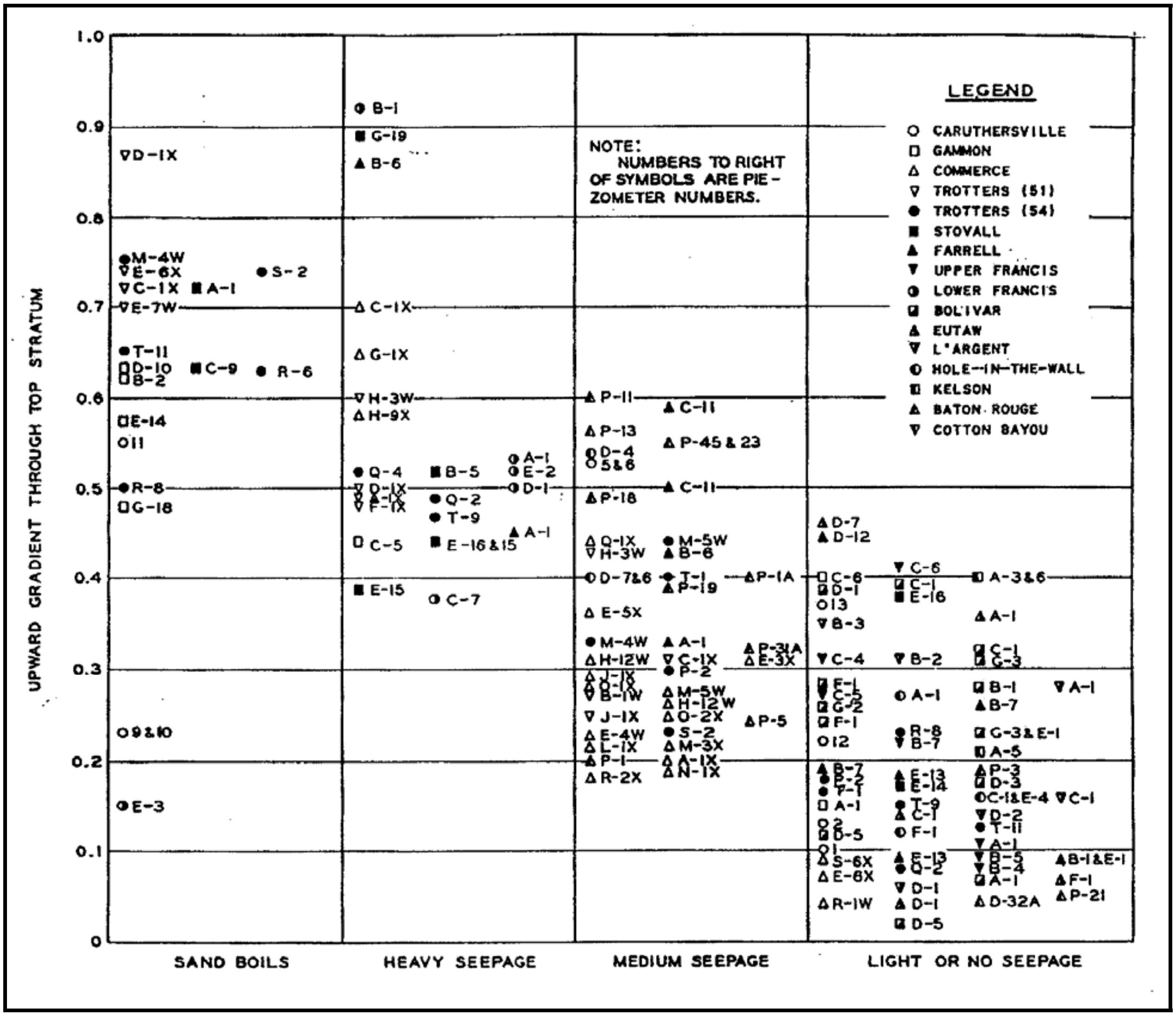

Figure 1. Severity of seepage as related to upward gradient through top stratum (from U.S. Army Engineer Waterways Experiment Station 1956, Vol. 1, Figure 47, p. 272)

The observed data recorded within this figure have been reproduced and discussed in numerous reports since its original publication. From this figure, the 1956 report also reported that the following general trend shown in Table 1 could be assumed.

Table 1. Exit Gradient vs. Seepage Condition Trends

Exit Gradient, i	Seepage Condition
0 to 0.5	Light/no seepage
0.2 to 0.6	Medium seepage
0.4 to 0.7	Heavy seepage
0.5 to 0.8	Sand boils

The above data would appear to indicate that the gradient required to cause sand boils varies considerably, and sand boils might even occur at an exit gradient of 0.5. However, the 1956 report explains these data as follows:

> *"…the gradient required to cause sand boils varies considerably at the different sites, and relatively low gradients were recorded near some sand boil areas. This may be due to the fact that at sites where sand boils developed previous to the 1950 high water, only fairly low excess head may have been required to reactivate boils in 1950 and, as a relief of pressure occurs at the boil, readings of Piezometers near the boil may be somewhat lower than those farther from the boil."*

This explanation has been overlooked in most reports. It is mathematically impossible to have a first time sand boil in the top stratum with a saturated unit weight above 110 lb per cubic foot and with an exit gradient less than 0.8.

b. History of Levee Seepage Design Guidance. Detailed design guidance for underseepage design is presented in EM 1110-2-1913, *Design and Construction of Levees*. This guidance is based on methods and equations presented in TM 3-424. These equations assume that the foundation materials consisted of two soil layers, each of uniform thickness with horizontal boundaries, a semi-pervious *top stratum* (blanket of silt or clay) with thickness z and a *pervious substratum* (sands and gravels) with thickness d. Also, they assume that flow in the top blanket is vertical and flow in the pervious substratum is horizontal. These assumptions are reasonable if the horizontal permeability of the pervious substratum is at least ten times the vertical permeability of the top blanket.

TM 3-424 presented methods and equations to be used in design of seepage control measures. It recommended that seepage berms be designed by the following method:

> *"Seepage berms should have a width and a thickness such that i through the top stratum and berm at the landside toe of the levee will not exceed 0.5, and at the berm toe will not exceed 0.75 to 0.80. However, seepage berms need not have a*

> *width exceeding 300 to 400 feet depending on soil conditions and height of levee."*

The Corps used these design criteria until 1962. In 1962 the now Mississippi Valley Division office undertook a Staff Study to review design criteria for landside seepage berms for the Mississippi River levees. USACE Mississippi Valley Division (1962) reported that the reason for this study was as follows:

> "*During the May 1962 Mississippi River Commission (MRC) high water inspection trip, local interests stated that seepage berms constructed in the past few years are very thin and that larger berms may be required to adequately protect the levee. The MRC agreed to reconsider the adequacy of its berm design criteria." Discussions within the Staff Study stated: "Recently constructed seepage berms are relatively thin and wide and have been designed in a rational method."* It then noted that if the intent was to increase the thickness of the berm, the increase in thickness could be accomplished by requiring a lower i to be used at the toe of the levee. (Note: In 1962 USACE design was in accordance with TM 3-424 that prescribed designing to an i of 0.5.)

Hess and Sills (2004) reported that the 1962 Staff Study recommended that the design requirements be changed from what was presented in TM 3-424 to what is currently listed in EM 1110-2-1913 [Appendix C-3b1]. These current requirements apply to all projects, existing and new construction. If the computed upward gradient through the blanket at the landside toe of the levee is greater than 0.8, a seepage berm should be designed with an allowable upward gradient of 0.3 through the blanket and berm at the landside toe of the levee (approximately equivalent to a factor of safety of 2.8 at the 0.3 gradient). A lower factor of safety could be used if there were sufficient soil data and past performance information to justify it. The berm width would be designed to lead to an allowable upward gradient of 0.8 at the berm toe, with a maximum width of 300 to 400 feet.

If the computed upward gradient through the blanket at the landside toe was between 0.5 and 0.8, then a minimum berm with a width of 150 feet and a thickness ranging from 5 feet at the levee toe and 2 feet at the berm crown should be constructed [Sections 3 and Appendix C-3b2]. If the computed gradient was less than 0.5, but there was a history or an expectation of severe seepage, then the minimum seepage berm should be constructed (EM 1110-2-1913). It is implied that if the computed upward gradient through the blanket at the landside toe of the levee was less than 0.5, and there was no history of seepage distress, then no remediation would be required.

6. Recommended Design Guidance. Deviation from the following design guidance is acceptable when based and documented on sound engineering judgment and experience. This guidance was developed primarily from the work performed by the USACE Sacramento levee seepage Task Force. Most of this guidance was included in a report to USACE Sacramento

(USACE 2003). The Task Force was chaired by George L. Sills, P.E.; and included Dr. Leslie F. Harder, Jr., P.E.; Dr. Thomas F. Wolff, P.E.; Christopher B. Groves, P.E.; Dr. Mosaid Al-Hussaini, P.E.; and Dr. J. Michael Duncan, P.E. John R. Hess, P.E. was the Task Force Project Manager.

a. A high emphasis should be placed on gathering data from levee performance during previous floods. This information should be used to plan exploration programs and past performance data should be used to calibrate the results of seepage models. Past flood performance should also be used as part of the engineering judgment in the final determination of the adequacy of existing and future seepage control measures [Sections 2-1 and Appendix C-2].

b. An extensive subsurface geotechnical investigation along the levee systems should be conducted and supplemented with geophysical investigation techniques as appropriate. A minimum target level of subsurface explorations should be a series of explorations approximately every 1,000 feet, consisting of an exploration at the riverside toe, at the landside toe, and a deep exploration at the levee crest. It is strongly recommended to use site appropriate geophysical procedures to interpolate between borings, to guide additional borings in anomalous areas, and as a basis to avoid unneeded borings [Sections 2-9 and 2-10].

c. Piezometers should be installed to monitor and learn from flood events along selected portions of the levee system. This information should be used to adjust computer models of the area where appropriate [Section 2-9].

d. The allowable factor of safety for use in evaluations and/or design of seepage control measures should correspond to an exit gradient at the toe of the levee of $i = 0.5$. In general, this would provide a factor of safety of about 1.6. This change will standardize all levee seepage requirements to one exit gradient of 0.5. Landside drainage ditches (along the toe of the levee), seepage berms, and relief wells should all be designed to the same exit gradient of 0.5. However, to design to a 0.5 gradient, the engineer **must** also incorporate the following: [Appendix C-3b (1)].

(1) There must be an adequate amount of subsurface exploration, as outlined above, which would have at least three borings/soundings (one on the riverside, through the levee, and one landside) every one thousand feet. This is intended to represent a minimum level of required effort. In highly urbanized areas where the hazard level is high, or areas of complex geology, there should be a greater number of explorations in order to minimize uncertainties and overall risk.

(2) Past flood histories should be reviewed and seepage information used to correct computer models so that they better predict true behavior. Notwithstanding the results of the

computer models, seepage control measures should be implemented for any levee area that has previously sustained significant seepage distress.

(3) Seepage control measures should be maintainable to assure that they will perform as designed. Districts, sponsors, etc., should be committed to regular inspections and sponsors must adhere to prescribed operation and maintenance of the underseepage control measures, particularly for relief wells. All responsible groups must control activities and development within the critical zone of the levee that would impact the effectiveness of the underseepage control measures.

(4) For all systems, where observation of levee performance is hindered, and especially for high intensity use areas (i.e., cornfields next to levees, basements, pools, etc.), the engineer must consider the implications of flood fighting. A plan to accomplish this flood fighting should be developed. In these areas, more geotechnical data must be obtained and the flood-fighting plan must be known in advance. Designing to a lower i in these areas will not completely insure against failure of the system.

(5) The saturated unit weights of the "*in situ*" landside blanket soils must be at or above 110 lb per cubic foot.

e. When current design computations require construction of a minimum berm, the minimum berm width should be changed to 4 X the height of the levee unless engineering judgment dictates a more conservative berm. If a more conservative berm is used, the width should not exceed 150 feet. This would be a change from the current USACE recommended minimum berm width of 150 feet [Appendix C-3b (2) and (3)] regardless of levee height.

f. The thickness of a berm should only be increased to cover the amount needed for shrinkage and consolidation of the foundation. This overbuild should be calculated or estimated based on past performance. (Note: The current requirement to overbuild 25 percent [Appendix C-3b (1) and (5)] to allow for shrinkage, foundation settlement, and variation in design factors does not increase the critical factor of safety at that location. The critical factor of safety is always located at the toe of a design berm. Any variations in design assumptions will also lower this factor of safety, thereby making any added material to the berm unnecessary.)

g. As stated in TM 3-424, *"In order for a semipervious berm to function as intended, it must have a permeability equal to or greater than that of the underlying top stratum and must not be appreciably thicker than the computed thickness. On the basis of values of kbl obtained at the piezometer sites (Table 38), it appears that a berm must be constructed of silty sand or fine sand to be classified as semipervious."* Therefore, care must be taken to insure proper material is used in the construction of a berm if it is designed using the assumption that the berm is "semipervious." Berms to be constructed as "semipervious" must be constructed with silty sands or fine sands and be designed using the semipervious suite of equations [Section 5.4b (2)].

h. USACE levee guidance is under review. Currently EM guidance sets the recommended acceptable range of a berm’s width between 300 and 400 feet [Appendix C-3b (4)]. If design requirements determine that a berm’s width should exceed 300 to 400 feet, current design guidance recommends that the berm’s width be reduced arbitrarily to remain within the range of 300 to 400 feet. This situation results in a hydraulic gradient exceeding 0.8 at the berm toe. Limiting the width of large berms, to the range of 300 to 400 feet, is based on the assumption that a sand boil 300 to 400 feet from the levee will not threaten the levee. Consequently, as we have designed larger berms and then reduced the design to these arbitrary widths, we now have berms in our levee systems with factors of safety values less than 1.0 at the toe of the berms. Depending on how much the berm width was reduced, this factor of safety can be much less than 1.0. This means sand boils will form at the toe of the berm during floods. We now know that when sand boils move material, with repeated floods the cumulative effect of this movement of material will threaten the levee. Studies are currently being performed to determine an appropriate factor of safety at the berm toe. In the interim, it is recommended that whenever a berm’s width is reduced, the factor of safety at the toe should be recalculated. Great caution and good engineering judgment should be used for recommended seepage remediation in these reaches.

7. Computer Programs to Use for Seepage Analysis [Section 5.4d]. Blanket theory should be adequate for most all-general levee underseepage analysis, where substrata are known with reasonable detail and a transformed blanket layer can be developed with reliability. Blanket theory works fine for a simple model. If the model becomes more complicated and the potential construction costs justify, the more complicated computer analysis may be the appropriate tool. A 2-D analysis can be helpful where the substrata system is more complex. A more complicated 3-D type analysis is almost never justified. It is more important to obtain more subsurface data to better depict the subsurface conditions. When the subsurface conditions are understood, the best modeling method can be selected.

a. Listed below are a few of the computer programs that can be used to perform these analyses. (These programs are listed in EM 1110-2-1913; however, additional usage information has been added.)

(1) If the soil profile can be idealized with a top blanket of uniform thickness overlying a foundation layer of uniform thickness and seepage flow is assumed to be horizontal in the foundation and vertical in the blanket, then simple blanket theory equations can be used. Computer programs like LEVSEEP (Brizendine, Taylor, and Gabr 1995) or LEVEEMSU (Wolff 1989; Gabr, Taylor, Brizendine, and Wolff 1995) could also be used. LEVSEEP would be simpler to use.

(2) If the soil profile is characterized by a top blanket and two foundation layers of uniform thickness, and seepage flow is assumed to be horizontal in the foundation, horizontal and vertical

in the transition layer, and vertical in the blanket, then LEVEEMSU or the finite element method (CSEEP) could be used (Biedenharn and Tracy 1987; Knowles 1992; Tracy 1994; Brizendine, Taylor and Gabr 1995). LEVEEMSU would be simpler to use.

b. If the idealized soil profile is complicated and irregular boundary conditions exist, analytical procedures may no longer provide accurate results and graphical or numerical models are applicable. A number of finite element and finite difference programs are available to evaluate complex models. The finite element program CSEEP (Tracy 1994) is available to all field offices. When using CSEEP it is recommended that FastSEEP, a graphical pre- and post-processor, be used for mesh generation, assuming boundary conditions and soil properties, and viewing results (Engineering Computer Graphics Laboratory 1996).

FOR THE COMMANDER:

DONALD L. BASHAM, P. E.
Chief, Engineering and Construction
Directorate of Civil Works