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Subject: Revision and Clarification of EM 1110-2-2100 and EM 1110-2-2502

Applicability: Guidance

1. Purpose: This bulletin transmits specified revision and clarification of guidance for the design of concrete hydraulic structures. Guidance pertains to hydraulic loads and load cases for critical and normal structures; the determination of applied loads associated with the stability and structural design of concrete hydraulic structures; seepage effects on lateral earth pressures; and bearing capacity of soil founded walls.

2. References:

EM 1110-1-1905, Engineering and Design: Bearing Capacity of Soils

http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-1-1905.pdf

EM 1110-2-2100, Engineering and Design: Stability Analysis of Concrete Structures

http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-2100.pdf

EM 1110-2-2502, Engineering and Design: Retaining and Flood Walls

http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-2502.pdf

ITL-91-1, Users Guide: Computer Program for Design and Analysis of Sheet-Pile Walls by Classical Methods (CWALSHT) Including Rowe's Moment Reduction

<http://acwc.sdp.sirsi.net/client/search/asset/1033743>

Cedergren, H. R. (1977). Seepage, Drainage and Flow Nets, second edition, John Wiley & Sons, Inc., New York, NY.

Clough, G. W. and Duncan, J. M. (1991). Earth pressures, chapter in Foundation Engineering Handbook, 2nd edition, edited by Hsai-Yang Fang, van Nostrand Reinhold, New York, NY, pp. 223-235.

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Ebeling, R. M., Fong, M. T., and White, B. C. (2014). Analysis of a Flood Plain I-Wall Embedded in Horizontally Stratified Soil Layers During Flood Events Using Corps_I-Wall Version 1.0, U.S. Army Engineer Research and Development Center, ERDC Technical Report ITL-14, Vicksburg, MS.

3. Background: The publication of EM 1110-2-2100 superseded portions of the guidance presented in EM 1110-2-2502. The relationship between EM 1110-2-2100 and EM 1110-2-2502 is not explicit and has caused confusion for designers. This ECB addresses some of the ambiguities and lack of complete guidance in EM 1110-2-2100 for design of flood and retaining walls. It also updates some of the minimum requirements in EM 1110-2-2100.

4. Attachment A provides updated guidance for EM 1110-2-2100. Attachment B presents detailed guidance and clarification for the design of retaining and flood walls.

5. Distribution: Unlimited.

6. The points of contact for this ECB are Richard Ludwitzke, CECW-CE, 202-761-1580 and David Sullivan, CELRH-DSPC-GE, 304-399-5721.

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Attachment A
Guidance Revisions for EM 1110-2-2100

1. Load condition categories: The following table replaces EM 1110-2-2100, Table 3-1, and provides criteria for critical structures.

Table 1 (EM 1110-2-2100, Table 3-1) Load Condition Probabilities

Load Condition Categories	Annual Probability (p)	Return Period (t_r)
Usual	Greater than or equal to 0.10	Less than or equal to 10 years
Unusual (normal structures)	Less than 0.10 but greater than or equal to 0.0033	Greater than 10 years but less than or equal to 300 years
Unusual (critical structures)	Less than 0.10 but greater than or equal to 0.00133	Greater than 10 years but less than or equal to 750 years
Extreme (normal structures)	Less than 0.0033	Greater than 300 years
Extreme (critical structures)	Less than 0.00133	Greater than 750 years

2. Bearing Capacity of Soil Founded Structures. EM 1110-2-2100 references EM 1110-1-1905 for bearing capacity requirements of soils. EM 1110-2-1905, Table 1-2 and Table 4-8, present typical factors of safety and presumptive allowable bearing pressures for spread footings but does not contain specific factors of safety for hydraulic structures. The following table provides minimum factors of safety for bearing capacity for soil founded structures covered under EM 1110-2-2100, for all site information categories, and replaces the allowable bearing pressure increases for unusual and extreme loads presented in paragraphs 3-10 and 3-12g.

Table 2 Bearing Capacity Minimum Factors of Safety

<i>Load Condition Categories</i>			
Structure Designation	Usual	Unusual	Extreme*
Critical	3.5	3.0	2.0
Normal	3.0	2.0	>1.0

*For seismic conditions the factor of safety shall be >1.0 for MCE loading of critical structures and MDE loading of normal structures.

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The factors of safety for normal structures in the table were derived from the Table 4-1 of EM 1110-2-2502. The factors of safety for critical structures in the table were derived from the Tables 4-2 and 4-3 of EM 1110-2-2502.

Attachment B
Clarifications

1. Guidance provided by Chapter 4 of EM 1110-2-2502 has been superseded by Chapters 2 and 3 and Appendix B of EM 1110-2-2100.
2. Water Surface Elevation Confidence Level. Hydraulic engineers often develop water surface elevations of specific annual chance of exceedance events with different confidence levels (i.e. 50%, 90% and 95% confidence level) during the planning and design process of flood risk reduction projects. Paragraph 4-3(a) of EM 1110-2-2100 indicates that for stability analysis, structural engineers require median (50% confidence) water level. All stability and structural design and evaluation of hydraulic structures shall be performed using median water levels.
3. Forces on Walls. Guidance in Chapter 3 of EM 1110-2-2502 has been superseded by EM 1110-2-2100. Lateral earth pressures and forces shall be computed in accordance with Chapter 5 of EM 1110-2-2100. Lateral soil forces for all failure modes are calculated using the minimum required factor of safety against sliding to obtain the developed soil strength parameters ϕ_d and c_d , as defined by paragraph 5-2.b of EM 1110-2-2100.
4. Resisting Side Lateral Earth Pressure. In paragraph 5-3.e of 1110-2-2100 resisting side earth pressure is computed by passive earth pressure equations using developed soil shear strength. For certain load cases, the resisting side force computed with a passive pressure coefficient may be higher than the driving side forces. In these cases the engineer shall adjust resisting side forces to not exceed driving side forces and ensure the wall is in static equilibrium.
5. Effective Earth Pressures When Steady State Seepage is Present. EM 1110-2-2100 currently provides limited guidance on calculation of earth pressures when steady state seepage is present. Under differing load conditions walls may experience water pressures associated with:
 - no water (i.e. groundwater levels below wall)
 - hydrostatic
 - transient (not considered in this bulletin)
 - steady state

Existing closed form solutions for the calculation of lateral earth pressures in EM 1110-2-2100 are based on effective stress, hydrostatic conditions and do not account for seepage forces. These seepage forces increase effective soil stress and frictional soil strength on the high head side of walls and decrease effective soil stress and frictional soil strength on the low head side. A practical approach to incorporate seepage body forces into these earth pressure equations in an effective stress analysis is to change the buoyant unit weight of soil. For example, simplified steady state flow conditions (with homogenous, isotropic permeability) are commonly used in wall stability analyses and approximated by the line-of-seepage method (Ebeling, et.al, 2014)

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where the seepage gradient is constant in the soil on both sides of the wall. Under this approach, the effect of seepage is to alter the effective unit weight of water in the region of flow to:

$$\text{High head side (vertical flow downward): } \gamma_{we} = \gamma_w(1 - i)$$

$$\text{Low head side (vertical flow upward): } \gamma_{we} = \gamma_w(1 + i)$$

(From ITL-91-1)

Where:

γ_{we} = effective unit weight of water

γ_w = unit weight of water

i = seepage gradient (a positive number computed as the change in total head divided by the length along a path of seepage)

For soils below the water levels on driving and resisting side of the wall the effective unit weight of soil is used in place of the buoyant unit weight in the EM 1110-2-2100 wedge equations and is found by subtracting the effective unit weight of water as illustrated in Figures 1 and 2 and the following equation:

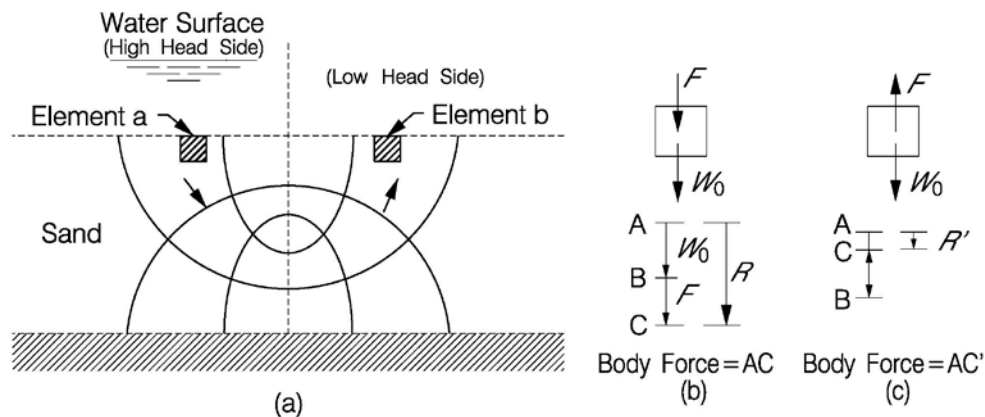


Figure 1. Seepage force effects (after Cedergren (1977)). (a) Flow net for a sheet pile wall. (b) Seepage force combines with effective weight on element a to increase the body force vector AC. (c) Seepage force reduces effective weight on element b to reduce the body force vector AC.

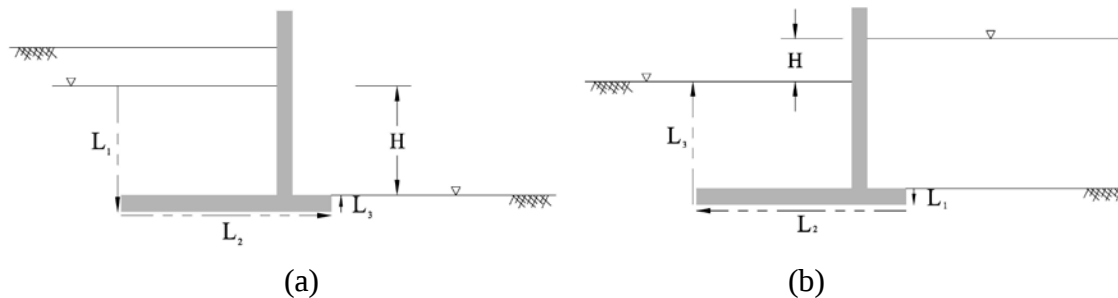


Figure 2. Seepage paths for gradient determination. H =change in total head and (seepage) path length $L=L_1+L_2+L_3$. (a) Retaining wall with high head on the “retained” side of the wall. (b) Flood wall with high head on the “wet” side of the wall. Observe these vectors denote the direction of seepage.

$$\gamma_{se} = \gamma_s - \gamma_{we}$$

Where:

γ_s = saturated unit weight of soil

γ_{se} = effective unit weight of soil

Note that in the case of no seepage, $i=0$, and γ_{se} equals the buoyant unit weight of soil. It is cautioned that the effective unit weight of soil approach discussed in this section is not for use in a total stress analysis.

6. Multilayer soils and Irregular Ground Surface. Situations with multilayer soils and irregular ground surface are not covered in EM 1110-2-2100. Approximate solutions can be found in paragraph 3-13 of EM 1110-2-2502 for more complex profiles than can be calculated by the equations in EM 1110-2-2100. More precise results can be obtained by using CTWALL, CWALSHT, and commercially available slope stability analysis programs. It is important to compare results from computer programs with hand calculations of simple profiles to verify the user is using the correct approach to determine earth pressures. Similarly, when a complex profile requires the use of a computer program, a simplified version of the profile should be evaluated with either charts or earth pressure equations for comparison purposes.

7. Compaction earth forces may be important for rigid concrete walls founded on rock, where the system does not allow movement to relieve them. The critical failure mode in this situation is concrete strength, as the stability failure modes allow relaxation of the compaction pressures as movement occurs. Paragraph 3.17 of EM 1110-2-2502 provides information on earth compaction pressures that includes a referenced procedure to adjust active earth pressures to include these pressures. Appendix J of EM 1110-2-2502 provides a modification of this procedure for walls designed for at-rest conditions. Since EM 1110-2-2502 was published, additional research has been performed on compaction induced pressures. Clough and Duncan (1991) provide a practical

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computational procedure based on that research to estimate compaction induced earth pressures behind an unyielding wall.

8. In addition to the section on earth pressures due to compaction, other portions of the Clough and Duncan (1991) earth pressures chapter may prove valuable to engineers estimating earth pressures for design.