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Engineer Technical  
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Engineering and Design  
STABILITY CRITERIA FOR EXISTING CONCRETE  
NAVIGATION STRUCTURES ON ROCK FOUNDATIONS

1. Purpose. The purpose of this letter is to provide interim criteria and procedures for analyzing and for improving the stability of existing concrete navigation structures on rock foundations. Concrete navigation structures include lock walls, lock chambers, and approach walls.

2. Applicability. This letter is applicable to all field operating activities having responsibilities for the design and construction of civil works projects.

3. References. See Enclosure 3.

4. Background. Past practice has been to use the same stability criteria for designing new structures and for reviewing existing structures. Most of the existing structures, although not meeting the referenced stability criteria (ref. 5, 6, 7 & 8), have performed satisfactorily for many years. It may not be necessary to improve the structure's stability to satisfy the referenced criteria when the remaining life of the structure is relatively short or when there are no indications of any stability problem. Relaxation to the referenced criteria have been granted on a case by case basis. A research investigation, as a part of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Program (ref. 9), was undertaken to study the stability of the existing concrete structures. The preliminary results of the REMR research and the experience from recent rehabilitation projects are included in this ETL. Revisions will be made as the additional results from REMR research and other sources become available.

5. Procedures. The following procedures shall be used in the evaluation of current stability conditions and in the determination of necessary corrective measures. They should be considered as guides and are not intended to replace engineering judgement by the engineers responsible for the project. The stability condition should be reviewed when there are significant changes in the loading conditions, severe damage due to accident,

aging or deterioration, discovery of structural deficiencies, revision of stability criteria to become more conservative, or when required by ER 1110-2-100 (Ref. 2). The phases listed below shall be followed in sequence until the prescribed conditions are satisfied. The procedures are illustrated with a flow chart in Enclosure 1.

a. PHASE I, Preliminary Analyses and Evaluation. Preliminary analyses should be performed based upon available data and actual conditions of the structure. Before performing the analysis, collect and review all the available data and information for the structure including geologic and foundation data, design plans, as-built plans, periodic inspection reports, damage reports, repair and maintenance records, plans of previous modifications to the structure, measurements of movement, instrumentation data, and other pertinent information. It may be necessary for the engineer to inspect and examine the existing structure to assess its condition. Friction between the backfill and wall or on a plane within the backfill may be considered in the stability analyses of existing structures. Recent REMR research indicated that neglecting wall friction or shear force in the backfill is unnecessarily conservative (ref.9). Preliminary results indicates that no more than 50% of the shear force maybe considered effective in resisting overturning and sliding. Calculation of shear force on the assumed shear plane maybe found in most soil mechanics text books such as in Chapter 10, ref. 13. If the results of the analyses indicate that the structure satisfies the referenced stability criteria, no further investigation is needed. Otherwise, list all the possible remedial schemes and prepare the preliminary cost estimate for each scheme. ER 1130-2-417 (ref. 4) should be followed if applicable.

b. PHASE II, Study, Investigation, and Comprehensive Analyses. When the preliminary analyses indicate that the structure does not meet the referenced criteria, a meeting should be arranged to decide on plans for the proposed comprehensive analyses, and to define the extent of the sampling and testing program, the remedial schemes to be studied, the extent of the parametric study, and the proposed schedule. This meeting should include representatives from the district, division, CEEC-E, and CECW-O. The meeting will facilitate the design effort and should obviate the need for major revisions or additional studies when the results are submitted for review and approval. The parametric study should be performed to determine the effect of each parameter on the structural stability. The parameters to be studied should include, but not be limited to, unit weight of concrete, ground water levels, uplift pressures, and shear strength parameters of the backfill material, rock or soil

foundation, and structure-foundation interface. The maximum variation of each parameter should be considered in determining its effect. An exploration, sampling, testing, and instrumentation program should be developed, if needed, to determine the magnitude and the reasonable range of variation for the parameters which have significant effects on the stability of the structure as determined by the parametric study. The division laboratory should be used to the maximum extent practicable to perform the testing in accordance with ER 1110-1-8100 (ref. 1). Comprehensive stability analyses should be performed using the material properties obtained from the sampling and testing program and procedures from referenced guidances plus the use of shear friction as discussed in paragraph 5.a. Lateral earth pressure may be reduced to the active state except when very loose or expansive material was used for the backfill. Preliminary results from REMR research indicate that the lateral earth pressure can be greatly reduced from the at-rest pressure with very small wall movement ratio (ref. 9). Since the wall must translate and/or rotate prior to failure, an active condition is justified in the analyses for structures with dense and stiff backfill. Smaller reduction should be used for other types of backfill (p.380, ref. 10). The amount of reduction of lateral earth pressure should be determined after careful evaluation of data from field investigations and material testing. Three dimensional modeling should be performed to achieve a more accurate prediction of the structural behavior when required (ref. 12). No remedial measures are required if the referenced criteria are satisfied.

c. PHASE III, Deviation from Referenced Criteria. If the structure still cannot meet the referenced criteria, deviation may be considered. Since the purpose of incorporating a factor of safety in structural design is to provide a reserved capacity with respect to failure, a lower factor of safety may be justified in the analysis of existing structures if a higher degree of confidence in the values of the critical parameters can be achieved from the field investigation. Table 1 lists the minimum stability criteria for the analysis of existing structures. If analysis indicates safety factors are above the values listed in Table 1, the stability of the structure may be acceptable without remedial measures. The request for deviation from the referenced criteria shall be submitted to CEEC-E for approval with the following documentation:

(1) Comprehensive stability analyses and cost estimates for all schemes of remedial measures.

(2) Past performance of the structure, including instrumentation data and description of the structure condition such as cracking, spalling, displacements, etc.

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- (3) The anticipated remaining life of the structure.
- (4) A description of consequences in case of failure.

TABLE 1  
MINIMUM STABILITY CRITERIA FOR  
EXISTING NAVIGATION STRUCTURES

CASES	NORMAL COND.	MAINT. COND.	SEISMIC COND.
% COMP. AREA/ BASE AREA	75%	50%	RESULTANT WITHIN BASE
F.S.--SLIDING	1.60	1.25	1.10

NOTE: Maximum base pressure shall not exceed the allowable unit bearing capacity of the foundation material in all cases.

6. Stability Requirements For Remedial Measure. The reduction of lateral pressure and introduction of shear friction as listed in paragraph 5.a and 5.b and the relaxation of design criteria in Table 1 shall not be used in the design of remedial measures such as prestressed and non-prestressed anchors. The remedial measure shall be designed to meet the referenced stability criteria. In unusual cases where this is not practical, the allowed minimum stability criteria shall be determined at a meeting with the district, division, CEEC-E, and CECW-O. Construction plans, specifications, and cost estimate for the proposed remedial measures should be developed in accordance with ER 1110-2-1200 (ref. 3).

7. Prestressed Anchors. Prestressed anchors may be used to stabilize the existing walls, foundation slabs, and concrete monoliths. They are effective in improving the safety factors against overturning, sliding, and uplift. The number, orientation, and capacity of anchors used should be based on engineering considerations and stability requirements. The existing concrete and structure should be checked for its adequacy to withstand the sustained load at the anchorage points. Anchors installed in aggressive environments should be provided with double corrosion protection. Design, installation, and testing of anchors and anchorages should be in accordance with reference 11. Allowable bond stress used to determine the length of embedment between grout and rock should not be more than 50 percent of the ultimate bond stress determined by tests. The

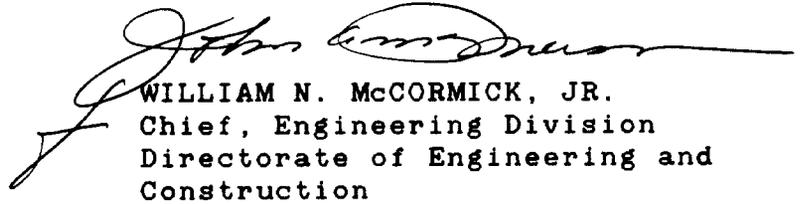
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values of bond strength in paragraph 4.3.2.6 of reference 11 may be used in lieu of tests during the design, but the design value should be verified by tests before or during construction. In addition to the first three anchors, a minimum of five percent of the anchors, but not less than two anchors, selected by the engineer, shall be performance tested.

8. Non-prestressed Anchors. Non-prestressed anchors shall not be used if other options are feasible. The effectiveness of this system is questionable and undependable due to the movement required to activate the anchor force. Therefore, the system should not be considered as effective in improving the safety factor for the structure's stability. They may be used as the last resort to prevent any possibility of catastrophic failure. The location, design, and installation of the anchors may follow the guidance provided in Enclosure 2. Bond strength used in calculating embedment length shall be verified by pull out tests in the field or laboratory.

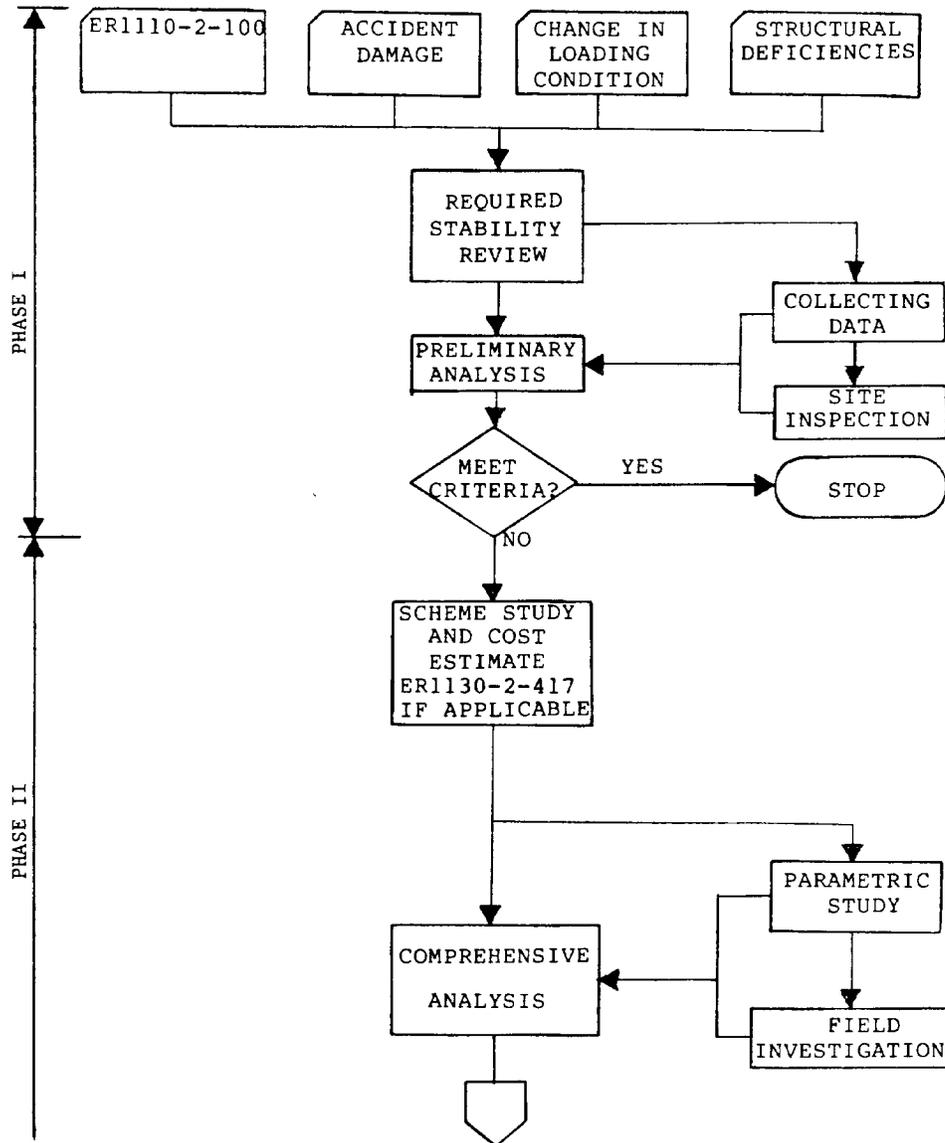
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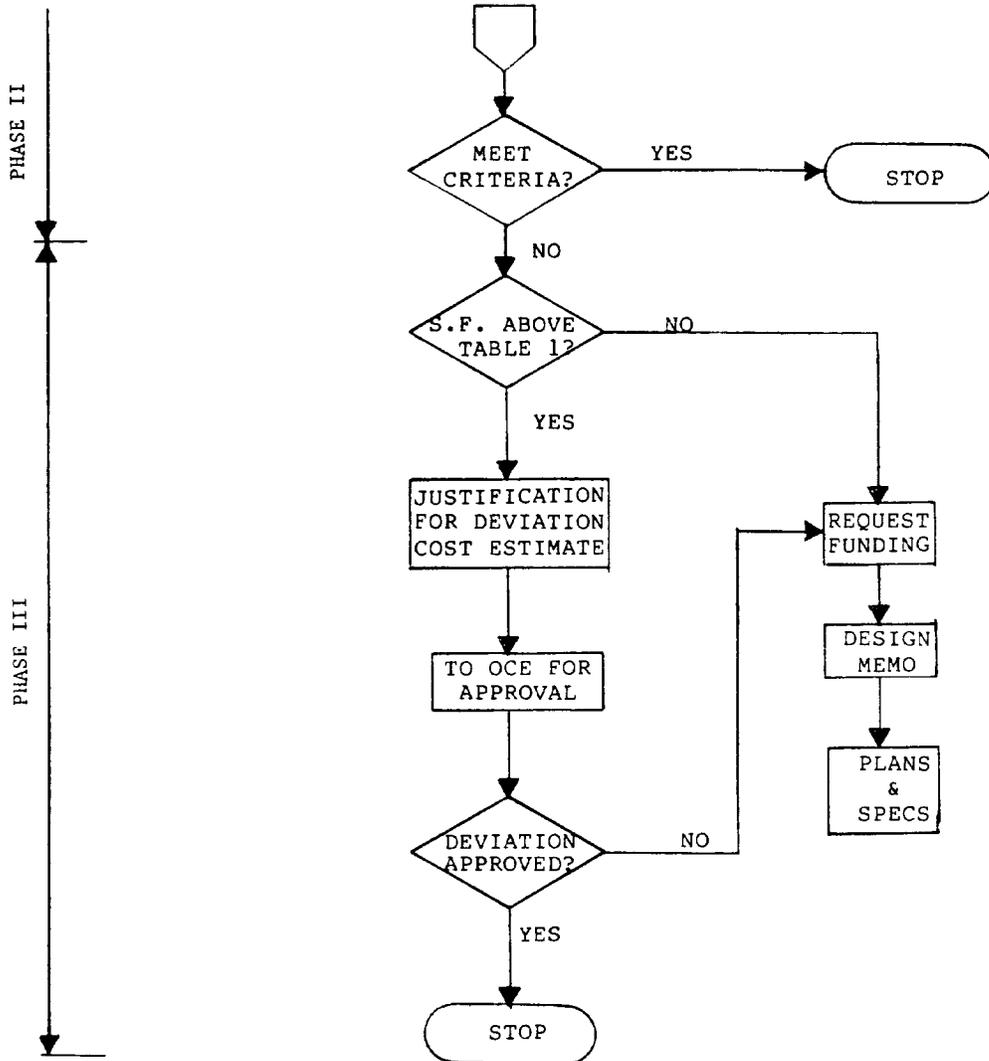
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### Sequence of Stability Evaluation for Existing Structures





Guidance for the Design, Installation,  
and Testing of Non-prestressed Anchors

1. General. Non-prestressed anchors are installed similar to prestressed anchors except no post-tensioning is applied and anchors are grouted full length. They do not physically impart an immediate active force to the structure. The anchor force will be activated only when the structure moves. Therefore, it is desirable that these anchors be installed with the minimum lateral loads on the structure, thereby activating the anchor force partially under the normal load and minimizing the movement of the structure beyond its normal position when the anchor force is fully activated.

Non-prestressed anchors should be considered as a temporary measure. If the remaining or extended life of the structure is anticipated to exceed ten years, other options or total replacement should be considered.

2. Method of Analysis. The method of analysis and loading conditions for determining overturning and sliding stability should be in accordance with applicable references in Inclosure 3 and the guidance provided herewith. Due to uncertainties in structural behavior and lack of research in this area, shear friction under the footing or dowel action of the anchors should not be included in calculating the sliding resistance.

3. Type and Material. Most anchors used in this system are reinforcing steel bars. Other materials and shapes are also allowed if they are more economical. Mechanical connectors should be avoided whenever possible since they will complicate installation and increase overall costs. The bars should be anchored in the foundation and concrete structure using a portland cement grout or epoxy resin. The bond force of the grout or resin should be sufficient to support the ultimate force of the bar used.

4. Design Considerations. Due to the lack of a positive downward force from non-prestressed anchors, cracks under the footing will likely be created when activating the anchor force. These cracks will change the seepage pattern and redistribute the uplift pressure under the foundation. To be conservative, it is assumed that the cracks will penetrate to the point where the compression zone ends assuming there is no anchor force. The following guidelines are provided in designing non-prestressed anchor system:

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a. Allowable Design Strength

High strength bar	ASTM A722, Type II	$P_{all} = 0.60 P_{ult}$
Reinforcing bars	ASTM A615, Grade 60	$P_{all} = 0.80 f_y * A_b$

Where

$P_{all}$  = Allowable anchor force, lb  
 $P_{ult}$  = Ultimate tensile force guaranteed by manufacturer, lb  
 ( $f_u * A_b$ )  
 $f_y$  = Yield strength of bar, psi  
 $A_b$  = Area of bar, in<sup>2</sup>  
 $f_b$  = Ultimate strength of bar, psi

b. Embedment Lengths within structure. Usually, the bond between grout and concrete is stronger than the bond between bar and grout. In case the bond strength between grout and concrete is suspect due to the condition of the existing structure, a field test should be performed to determine the actual bond strength. The embedment length of anchor bar within the concrete structure should be computed with the following equation:

$$L = \frac{P_{all}}{\pi d_b f_{ba}} \quad (2-1)$$

Where

$L$  = Embedment length, in  
 $d_b$  = Diameter of the bar, in.  
 $f_{ba}$  = Allowable bond stress, normally equal to  $0.25 f_{bu}$ , psi.  
 $f_{bu}$  = Ultimate bond stress between bar and grout or between concrete and grout, whichever is less, psi.

The value of  $f_{bu}$  should be determined from tests. In lieu of test,  $f_{bu}$  may be conservatively assumed as  $6\sqrt{f_c'}$  where  $f_c'$  is the strength of concrete or grout.

c. Embedment lengths within foundation. The largest value of  $L$  in (1), (2), and (3) below should be used as the embedment length within the rock foundation.

(1) Bond Between Bar and Grout

$$L = \frac{P_{all}}{\pi d_b f_{ba}} \quad (2-2)$$

## (2) Bond between grout and rock

$$L = \frac{P_{all}}{\pi d_h f_{ca}} \quad (2-3)$$

Where

$d_h$  = Diameter of drilled hole, in.

$f_{ca}$  = Allowable bond stress equal to  $0.25f_{cu}$ , psi.

$f_{cu}$  = Ultimate bond strength between grout and rock, or  $c$ , whichever is less, psi.

$c$  = Cross bed shear value in rock in the direction of pullout, psi.

The value of  $f_{cu}$  should be determined from field tests. In lieu of test, table in Paragraph 4.3.2.6 in reference 11 may be used during the design. However, this value shall be verified in the field before installation. In case of multi-layer rock foundation, the total bond should be the summation of the bond of each individual layer. In weak rock foundation, underream bell may be considered to increase the pullout resistance in which case,  $d_h$  in Equation 2-3 shall be replaced by  $0.66d_R$  where  $d_R$  is the diameter of the underream bell.

(3) Rock mass shear failure. Normally, rock mass failure will not govern the design. In case of weak or cracked rock foundation or shallow anchors (less than 10') where this type of failure is deemed possible, a rational analysis shall be performed to ensure the adequate embedment length. Parameters used in the analysis should be based upon field and laboratory tests. In lieu of a more detailed analysis, a failure surface in the shape of a cone with 30 degree tip angle may be assumed for each anchor. Consider only the weight of the rock within the cone in computing the resistance capacity of the anchorage. In case of closely spaced anchors, resistance capacity should be multiplied by a factor of  $(2s/L)$ , but not more than 1.0, where  $s$  is the spacing of anchors and  $L$  is the embedment length.

5. Construction Guidance. The design engineer should specify the diameter, depth and alignment tolerance for the anchor hole. Drilling, testing for watertightness, and insertion and grouting of anchor should follow the requirements in reference 11. Normally, anchor holes should not be closer than five feet center to center or within two feet of an expansion joint or face of the structure. In case a weak layer of rock material is encountered in the foundation, consideration should be given to staggering the anchor depths to avoid laminar failure. The contract documents should include an installation and monitoring procedures to insert the anchor to the proper depth and to keep the bar centered in the hole. After the anchor installation,

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grouting can be accomplished by either a gravity or pressure method. Resin anchors, if used, should meet the requirements in paragraph 4.4 of reference 11. The choice of grouting methods should be based on an evaluation of the site foundation data, anchor orientation and structural considerations. In non-prestressed anchor system, free stressing length is not required and grouting in rock and structure may be applied at the same time.

6. Testing Requirement and Procedures. Field tests shall be performed before and during the installation to verify the adequacy of the anchor system and installation procedures. Tests before installation shall be used to check the performance of selected drilling method, conformability of hole size and drift tolerances, adequacy of anchor installation and grouting method, and accuracy of assumed bond strengths between grout and rock, grout and concrete, and grout and bar. Tests during the installation should be adequate to ensure that anchors are installed to the requirements of the plans and specifications and can develop the designed force. The number of tests required depends on the site specific information including drilling conditions, type and/or size of bars, and complexity of foundation formation and material.

7. Protection Criteria. Since the entire length of the bar is grouted in cement or resin and the system is considered temporary, no additional protection is required. However, if the bar is embedded in a highly corrosive environment, additional protection such as epoxy coating or plastic sheathing should be provided.