Guidance for Flood Risk Analysis and Mapping

Coastal Structures

November 2021

FEMA

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Requirements for the Federal Emergency Management Agency (FEMA) Risk Mapping, Assessment, and Planning (Risk MAP) Program are specified separately by statute, regulation, or FEMA policy (primarily the Standards for Flood Risk Analysis and Mapping). This document provides guidance to support the requirements and recommends approaches for effective and efficient implementation. Alternate approaches that comply with all requirements are acceptable.

For more information, please visit the FEMA Guidelines and Standards for Flood Risk Analysis and Mapping webpage (https://www.fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping). Copies of the Standards for Flood Risk Analysis and Mapping policy, related guidance, technical references, and other information about the guidelines and standards development process are all available here. You can also search directly by document title at https://www.fema.gov/resource-document-library.

Table of Revisions

Affected Section or Subsection	Date	Description
Section 2.1	November 2021	Revised to expand Operations & Maintenance language for clarity and to include conversion factor for 2% to max runup.
Throughout document	November 2021	Revised to correct broken URLs/links, and to update terminology.

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1. Topic Overview

This guidance document supports the standards related to approving coastal protection structures to be shown as providing protection on Flood Insurance Rate Maps (FIRMs) and outlines methods for analyzing the stability and effects of coastal structures during the 1-percent-annual-chance flood conditions.

Because coastal structures can significantly affect local topography and flood hazards, Mapping Partners must evaluate coastal structures as part of any flood hazard study. The evaluation should, where possible, determine whether a coastal structure will survive the 1-percent-annual-chance flood and what impacts it will have on upland flooding.

Criteria for evaluating the stability and performance of coastal armoring structures for Flood Risk Project purposes are well-developed and are discussed in detail. Criteria for evaluating beach stabilization structures have not been developed yet, and only basic guidance is provided. Criteria for evaluating miscellaneous structures are not standardized, and only basic guidance is provided. The Mapping Partner should coordinate with FEMA when only basic guidance is provided. Treatment of each structure must be clearly documented in the Technical Study Data Notebook (TSDN).

2. Evaluation Criteria

Mapping Partners are not required to perform detailed engineering evaluations of all coastal structures within the study area. During a flood risk study, engineering judgment is typically used in determining whether a structure should remain intact, failed, or removed from the analysis. A prudent analysis will analyze several scenarios and adopt the most conservative results. However, when such a detailed structure evaluation is performed, there are specific evaluation criteria that must be applied.

2.1. Detailed Engineering Evaluation of Coastal Armoring Structures

Where a Mapping Partner chooses to perform a detailed engineering evaluation of an existing coastal armoring structure during a Flood Risk Project, FEMA requires the evaluation to be based upon the criteria outlined below, and upon as-built documentation. When as-built documents are not available, the evaluation should be based upon best available data, standard design and engineering assumptions, and conservative estimates of material properties. The evaluation should be confirmed and documented by past performance during severe storm events. The underlying requirement is that the evaluation must yield an accurate assessment of coastal structure performance during the 1-percent-annual-chance flood, based upon available evidence.

It should be noted, however, that the art of coastal structure evaluation is constantly evolving. However, permission should be obtained from the FEMA Project Officer prior to utilizing alternative evaluation procedures and criteria.

General

For purposes of the National Flood Insurance Program (NFIP), FEMA will only recognize in its flood hazard and risk mapping effort those coastal flood protection structures that meet, and continue to meet, minimum design and maintenance standards that are consistent with the level of protection sought through the comprehensive floodplain management criteria cited in the Code of Federal Regulations (CFR) at Title 44, Chapter 1, Section 60.3 (44 CFR § 60.3). Accordingly, the procedure describes the types of information FEMA needs to recognize, on NFIP maps, that a coastal flood protection structure will survive and impact upland flooding during the base flood. This information must be supplied to FEMA by the community or other party seeking recognition of such a coastal flood protection structure at the time a flood risk study or restudy is conducted, when a map revision under the provision of 44 CFR Part 65 is sought based on a coastal flood protection structure, and upon request by the FEMA Administrator during the review of previously recognized structures. The FEMA review will be for the sole purpose of establishing appropriate risk zone determinations for NFIP maps and shall not constitute a determination by FEMA as to how a structure will perform in a flood event.

Design Criteria

For coastal flood protection structures to be recognized by FEMA, sufficient evidence must be provided that adequate design, construction, and maintenance have been undertaken to provide reasonable assurance of durable protection from the base flood. The following requirements must be met:

1. Design Parameters. A coastal flood protection structure must be designed using physical parameters that fully represent the base flooding event, including the following:

   i. Design water levels evaluated should range from the mean low water at the site, to the 1-percent-annual-chance stillwater elevation (SWEL). The full range of elevations must be examined to determine the critical water level because the most severe conditions may not occur at either extreme.

   ii. Wave heights and periods must be calculated for each water level analyzed. At a minimum, significant wave heights and periods should be used for "flexible" structures such as revetments, and larger wave heights, up to the 1-percent-annual-chance wave height (1.67 times the significant wave height), used for more rigid structures such as seawalls and bulkheads. The U.S. Army Corps of Engineers (USACE) Coastal Engineering Manual, provides guidance and procedures for determining appropriate wave heights and periods.

   iii. Breaking wave forces under structure-perpendicular loading must be considered in the design unless it can be demonstrated that the structure will not be subject to breaking waves. The very high, short duration "shock" pressures must be used for low mass structures such as bulkheads, while only the secondary "non-shock" pressures need to be used for massive structures such as gravity seawalls. Analyses of the breaking wave forces using methods such as those identified in the USACE report "Criteria for Evaluating Coastal Flood Protection Structures," (WES TR CERC-89-15) must be submitted.

2. Minimum Freeboard. The minimum freeboard for coastal flood protection structures to be recognized on FEMA flood maps for protection against the storm surge component of the base flood shall be 2 feet above the 1-percent-annual-chance SWEL [and 1 foot above the height of the 1-percent-annual-chance wave or the maximum wave runup (whichever is greater)]. Maximum wave runup can be determined applying the appropriate conversion factor based on the resulting runup wave height:
    a. $R_{max} = R_{mean} * 2.87$
    b. $R_{max} = R_{2\%} * 2.87/2.23 = R_{2\%} * 1.29$
3. Toe Protection. The loss of material and profile lowering seaward of the structures must be included in the design either through the incorporation of adequate toe protection or an evaluation of structural stability with potential scour equal to the maximum wave height on the structure. Engineering analyses such as those recommended in the USACE's Geotechnical Engineering in the Coastal Zone (WES IR CERC-87-1) or Design of Coastal Revetments, Seawalls, and Bulkheads (COE EM 1110-2-1614) must be submitted for toe protection, or an analysis of scour potential such as found in Criteria for Evaluating Coastal Flood Protection Structures (WES TR CERC-89-15) must be submitted.
4. Backfill Protection. Engineering analyses of wave runup, overtopping, and transmission must be performed using methods provided in the USACE report "Criteria for Evaluating Coastal Flood Protection Structures," (WES TR CERC-89-15). Where the structure height is not sufficient to prevent overtopping and/or wave transmission, protection of the backfill must be included in the design. This should address prevention of loss of backfill by rundown over the structures, by drainage landward, under, and laterally around the ends of the structure as well as through joints, seams, or drainage openings in the structures.

5. Structural Stability, Minimum Water Level. Analyses of the ability of the structures to resist the maximum loads associated with the minimum seaward water level, no wave action, saturated soil conditions behind the structures, and maximum toe scour must be submitted. For coastal dikes and revetments, geotechnical analyses of potential failure in a landward direction by rotational gravity slip must be submitted.
    i. For coastal dikes and revetments, geotechnical analyses of potential failure in a landward direction by rotational gravity slip must be submitted.
    ii. For gravity and pile-support seawalls, engineering analyses of seaward sliding, seaward overturning, and foundation adequacy using the maximum pressures developed in the sliding and overturning calculations must be submitted.
    iii. For anchored bulkheads, engineering analyses of shear failure, moment failure, and the adequacy of the tiebacks and deadmen to resist the loadings must be submitted.
6. Structural Stability, Critical Water Level. Analyses of the ability of the structure to resist the maximum loads associated with the critical water level, which may be any water level from the mean low water level to the 1-percent-annual-chance SWEL, including hydrostatic and hydrodynamic (wave) loads, saturated soil conditions behind the structure, and maximum toe scour must be submitted.

i. For coastal dikes and revetments, geotechnical analyses of potential failure in a seaward direction by rotational gravity slip and of foundation failure due to inadequate bearing strength must be submitted.

ii. For revetments, engineering analyses of the rock, riprap, or armor block stability under wave action; uplift forces on the rock, riprap, or armor blocks; toe stability; and adequacy of the graded rock and geotechnical filters must be submitted.

iii. For gravity and pile-supported seawalls, engineering analyses of landward sliding, landward overturning, and foundation adequacy using the maximum pressures developed in the sliding and overturning calculations must be submitted.

iv. For anchored bulkheads, engineering analyses of shear failure and moment failure using "shock" pressures must be submitted.

7. Material Adequacy. Documentation and/or analyses must be submitted that demonstrate that the materials used for the construction of the structure are adequate and suitable, including life expectancy considerations, for the conditions that exist at the site.

8. Ice and Impact Alignment. Where appropriate, analyses of ice and impact forces must be submitted.

9. Structure Plan Alignment. A shore protection project should present a continuous structure with redundant return walls at frequent intervals to isolate locations of failure. Isolated structures, or structures with a staggered alignment, must submit analyses of the additional forces from concentrated, diffracted, and/or reflected wave energy on the different sections and ends.

10. Other Design Criteria. FEMA will require that flood protection structures described above, regardless of type, be evaluated on the basis of how they may react structurally to applied forces. Therefore, analyses normally required of one structure type may also be required by another type that would react in a similar manner to applied forces. In unique situations, FEMA may require that other design criteria and analyses be submitted to show that the structure provides adequate protection. In such situations, sound engineering practice will be the standard on which FEMA will base its determinations. FEMA will provide the rationale for requiring any additional information.

Adverse Impact Evaluation

All requests for flood map revisions based upon new or enlarged coastal flood control structures shall include an analysis of potential adverse impacts of the structure on flooding and erosion within, and adjacent to, the protected area.

Community and/or State Review

For coastal flood protection structures to be recognized, evidence must be submitted to show that the design, maintenance, and impacts of the structures have been reviewed and approved by the affected communities and by any federal, state, tribe, territory or local agencies that have jurisdiction over flood control and coastal construction activities.

Operation and Maintenance Plans

For a coastal flood protection structure to be recognized, the structure must be maintained in accordance with an official adopted operations and maintenance plan. A copy of this plan must be provided to FEMA by the owner of the structure when recognition is being sought or when the plan for a previously recognized structure is revised in any manner. All operation and maintenance activities must be under the jurisdiction of a federal or state agency, an agency created by federal or state law, or any agency of a community participating in the NFIP that must assume ultimate responsibility for maintenance. This plan must document the formal procedure that ensures that the stability, height, and overall integrity of the structure and its associated structures and systems are maintained. At a minimum, maintenance plans may specify the maintenance activities to be performed, the frequency of their performance, and the person by name or title responsible for their performance. All operation of closure devices mechanical systems must occur in accordance with the plan, regardless of whether the systems are manual or automatic.

The Mapping Partner may ascertain (through discussions with the community and property owners) whether operation and maintenance plans exist for coastal structures that are expected to remain intact during 1-percent-annual-chance flood conditions. Mapping Partners may not have sufficient resources and time to conduct detailed evaluations of the operation and maintenance of each coastal structure within the study area. In such cases, the Mapping Partner may make an engineering judgment about the adequacy of structure operation and maintenance. The Mapping Partner must document data, materials, and assumptions associated with the flood hazard determinations related to structure operation and maintenance. Communities and property owners should be made aware that these evaluations are for mapping purposes only.

Certification Requirements

Data and analyses submitted to support that a given coastal flood protection structure complies with the structural design requirements set forth in paragraphs 1 through 10 above must be certified by a registered professional engineer. Also, certified as-built plans of the structure must be submitted. Certifications are subject to the definition given at 44 CFR § 65.2. In lieu of these certification requirements, a Federal agency with responsibility for design of coastal flood protection structures may certify that the structure has been adequately designed and constructed to provide base flood protection.

2.2. Coastal Armoring Structure Evaluation Based on Limited Data and Engineering Judgment

For the purposes of flood risk study, the Mapping Partner may not have sufficient resources and time to conduct a detailed evaluation of each coastal armoring structure within the study area. In such cases, the Mapping Partner can apply engineering judgment (albeit, guided by the guidance in Section 2.1 and USACE CERC Technical Report 89-15 Criteria for Evaluating Coastal Flood Protections Structures) to determine the likely stability of each structure during the 1-percent-annual-chance flood. These conclusions may be based largely on available archive information and local observations, including historic evidence of storm damage and maintenance. Note that any data and

procedures used in the evaluations shall be documented, and communities and property owners shall be made aware that these evaluations are for mapping purposes only.

If the available information does not clearly point to survival or failure of a coastal structure, the Mapping Partner may either:

1. Conduct a detailed evaluation based on the FEMA criteria (see the previous subsection).
2. Perform the erosion and wave analyses for both the intact and failed structure cases and map the flood hazards associated with the more hazardous case.

If option 2 is selected, the Mapping Partner shall clearly document the results of all cases investigated and specify which case is used for mapping purposes. It should be noted that a failed coastal structure may or may not yield the greatest flood hazards. Therefore, coastal flood analyses for the intact and failed conditions should be performed, with the greatest resulting flood hazard being mapped. Maintaining results of all analyses may be useful in the event map revisions are requested by property owners based upon certified structures[1].

2.3. Evaluation of Beach Stabilization Structures

Guidance on how to predict the survival or failure of groins, which usually fail by loss of profile (through settlement, displacement, or deterioration) and/or by becoming detached at their landward ends, is not readily available. Likewise, guidance on how to predict the failure of breakwaters, sills, and reefs (usually through loss of profile) is not readily available. Some information on failure modes may be available in technical or historical literature, and should be consulted by the Mapping Partner.

If a Mapping Partner chooses to evaluate beach stabilization structures during flood risk study, the proposed evaluation methods and procedures should be discussed with the FEMA Project Officer, in advance, and approval by FEMA must be obtained before the evaluations can be carried out.

3. Flood Risk Project Treatment of Coastal Structures

Technical Report 89-15 identifies four primary functional types of coastal flood protection structures: gravity seawalls, pile-supported seawalls, anchored bulkheads, and dikes or levees. A fifth type, revetment, is added here (see Figures 1 & 2).

Technical Report 89-15 recommends as a general policy that “FEMA not consider anchored bulkheads as providing flood protection during large storms.” Thus, the default assessment for open

[1] Often, property owners request revisions to the FIRM based upon existing, new, or proposed coastal structures. Map revisions based upon coastal structures require a detailed evaluation and certification by a professional engineer registered in the subject State. FEMA has distributed the *Coastal Structure Form* (MT-2, Form 5, available at https://www.fema.gov/sites/default/files/documents/fema_form-5_coastal-structures-form_ff-206-fy-21-104.pdf) to evaluate coastal structures as the basis for map revisions.

coast anchored bulkheads should be that they are assumed to fail during the 1-percent-annual-chance flood. Mapping Partners may choose to treat some anchored bulkheads as surviving the flood and/or providing some degree of flood protection, but those instances should be limited (e.g., to sheltered waters, where the bulkhead may be stable during 1-percent-annual-chance flood conditions).

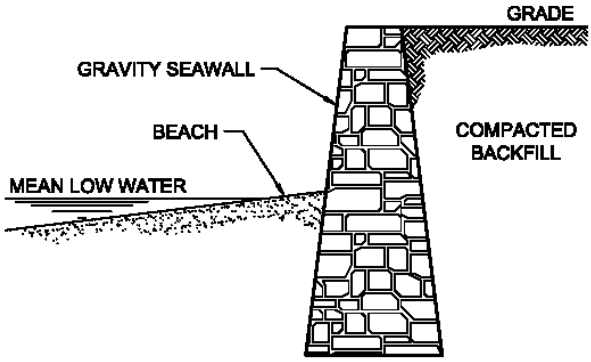
Many seawalls, revetments, and (some) bulkheads may be recognized on flood hazard maps if analysis based on the evaluation criteria in Section 2.1 shows they will remain intact during the 1-percent-annual-chance storm (in some cases, even if overtopped). These structures may provide total or limited protection against flooding, erosion, and waves, depending upon their location, strength, and dimensions.

3.1. Failure and Removal of Coastal Armoring Structures

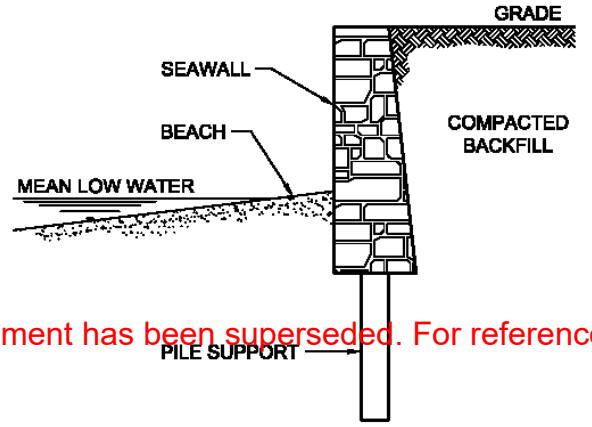
In the event that a coastal structure is determined to fail, the Mapping Partner shall remove the structure entirely from the analysis transect or estimate the partial collapse of the structures where appropriate (see Subsection 3.2). In general, structures may be completely removed if they are small and/or localized features such as non-engineered revetments; however, structures that are not expected to be completely destroyed and removed during a 1-percent-annual-chance event, such as large-scale, engineered rick revetments, should not. If the failed structure is removed entirely, the remaining soil profile should be altered to achieve its likely slope immediately after structure failure. Information on slopes behind failed structures is limited. These slopes may vary from 1 on 100 (v:h) for unconsolidated sands, to 1:1 or steeper for consolidated material landward of the failed structure.

For the purposes of a coastal Flood Risk Project, the post-failure slope for this analysis should be in the range of 1:1 to 1:1.5 (v:h). Note that the post-failure slope may not necessarily match the long-term stable slope, but will serve as the basis for subsequent site-specific, event-based erosion, wave height, wave runup, and wave overtopping analyses.

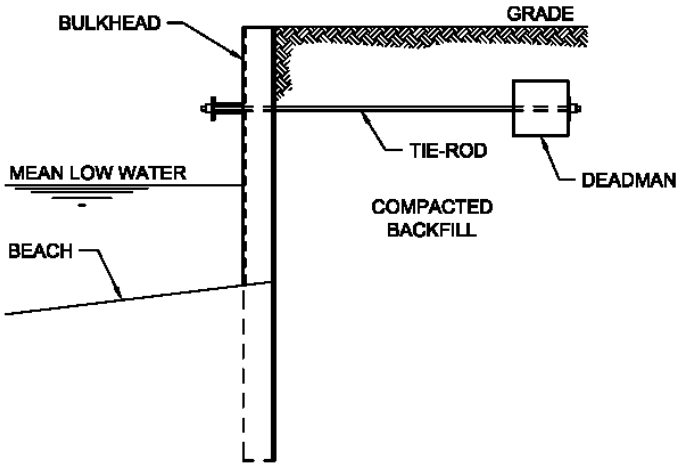
Figure 1: General Classification of Coastal Armoring Structures



GRAVITY SEAWALL



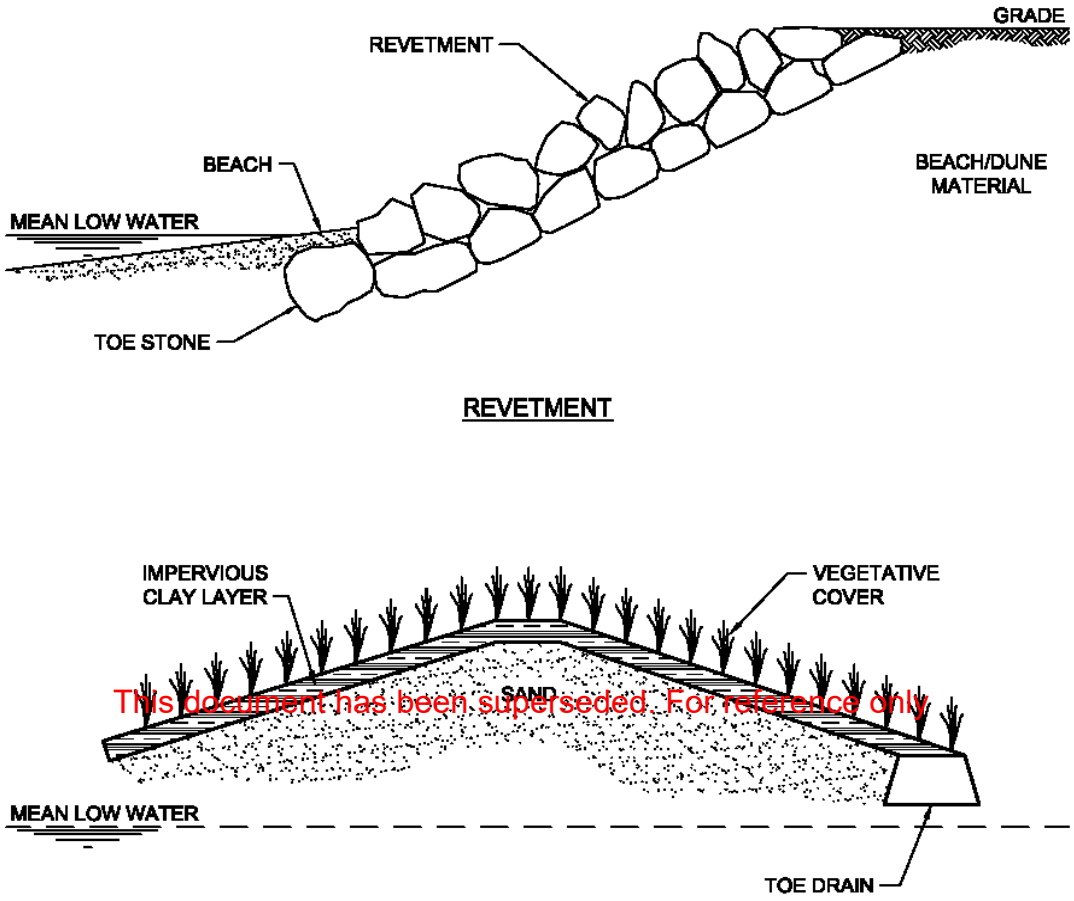
PILE SUPPORTED SEAWALL



ANCHORED BULKHEAD

PRIMARY FUNCTIONAL TYPE OF COASTAL ARMORING STRUCTURES

Figure 2: General Classification of Coastal Armoring Structures



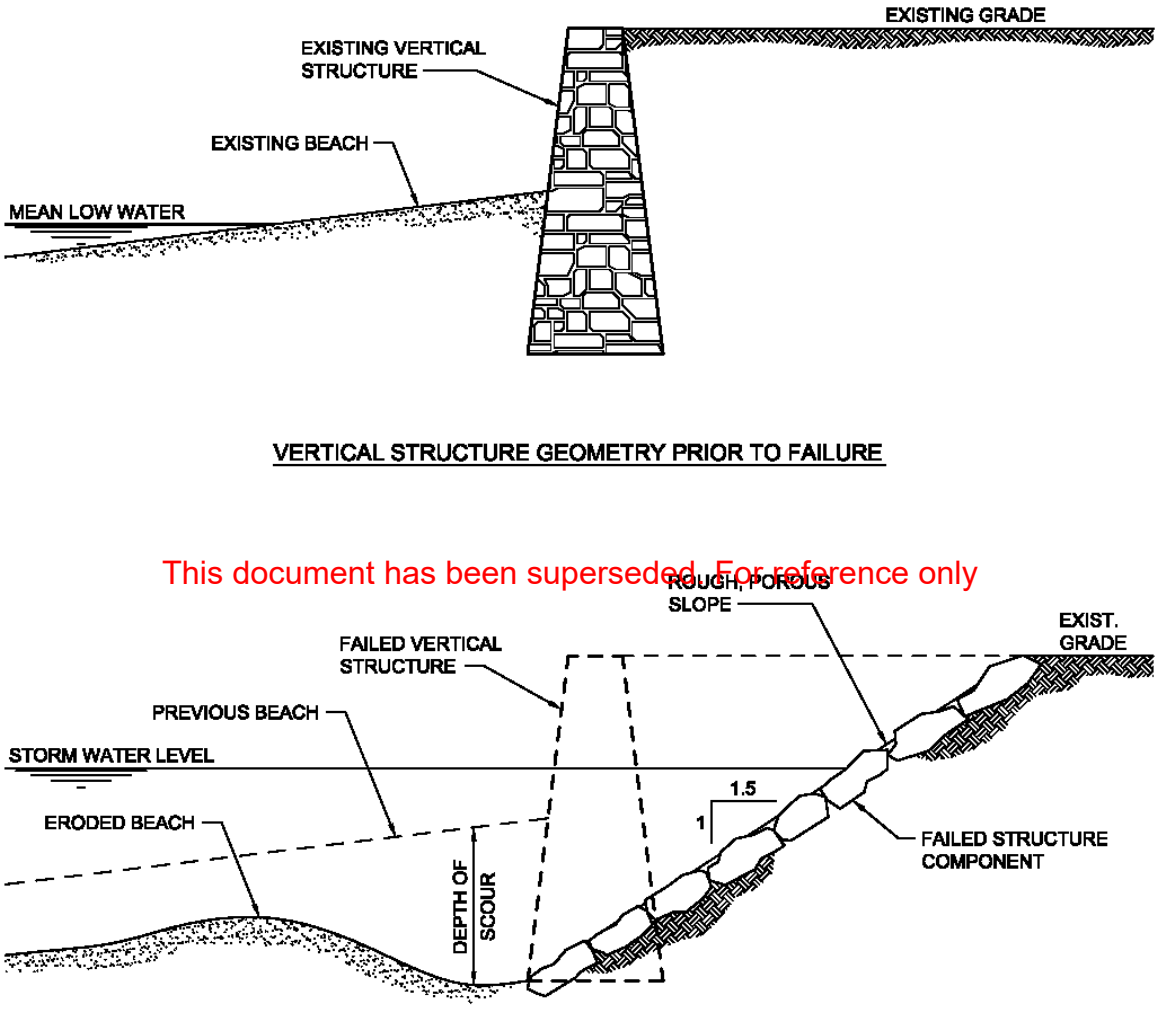
3.2. Partial Failure of Coastal Armoring Structures

It may be appropriate to assume partial failure of such structures and to model accordingly. A recommended simple geometric approach for approximating partial failure of a vertical or near-vertical coastal armoring structure is as follows (see Figure 3):

3. Estimate toe scour at the subject structure based upon the methods described in the Coastal Engineering Manual (USACE, 2003) www.publications.usace.army.mil/usace-publications/engineer-manuals/?udt_43544_param_page=1.

4. Assume the structure fails and falls into a rough, porous slope at 1:1.5 (v:h).
5. Extend the 1:1.5 failure slope from the depth of scour at the structure toe landward to the point where it intersects the existing grade.

Figure 3: Partial Failure of Vertical Coastal Structure



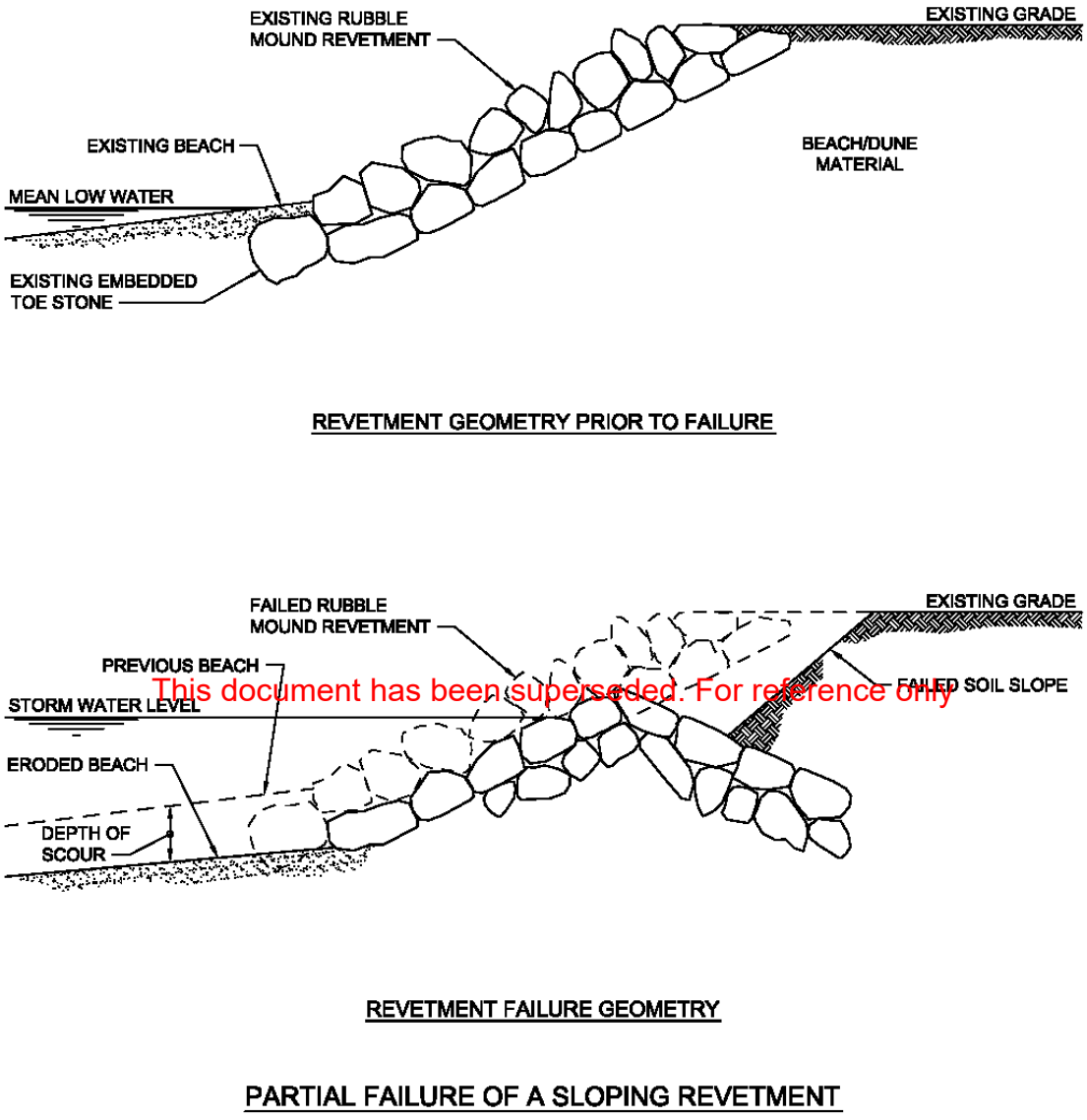
PARTIAL FAILURE OF VERTICAL COASTAL STRUCTURE

A recommended approach for approximating partial failure of a sloping revetment (due to undermining at the toe, or to collapse at the top due to erosion behind the structure) is as follows (see Figure 4):

6. Assume scour at the base of the structure is equal to the depth of the armor layer.
7. Assume the structure will collapse in place into a triangular section throughout the structure footprint, with side slopes equal to the original structure slope.
8. Assume the landward side of the failed configuration will be half exposed and half buried. Approximate the soil slope landward from the failed structure at a slope in the range of 1:1 to 1:1.5 (v:h).

After determining an appropriate failure configuration, the Mapping Partner shall conduct overland wave height propagation and wave runup analyses upon the failed structure. The Mapping Partner shall select an appropriate roughness factor when conducting runup and overtopping analyses on the failed structure.

Figure 4: Partial Failure of a Sloping Revetment



3.3. Buried Coastal Structures

Some buried structures are of a size and construction to possibly affect coastal flood hazards, and should—like exposed structures—be considered during the Flood Risk Project.

Once the Mapping Partner has determined that a coastal structure is likely buried at a site, the next steps are to collect information about the structure and follow the study process outlined in Figure 5. The erosion analysis will result in one of the following two scenarios: 1) the buried structure will

remain buried during the 1-percent-annual-chance flood (see Figure 6), or 2) the buried structure will be exposed by the 1-percent-annual chance flood (see Figure 7).

Note that the buried structure study process need not be followed unless the presence of buried structures is known or is highly likely. Field investigations are not required to identify buried coastal structures. There may be some instances where limited field work (such as soil probes to locate the structure) might be useful, but this should be limited to cases where large buried structures are known to exist.

Figure 5: Methodology for Evaluating Buried Coastal Structures

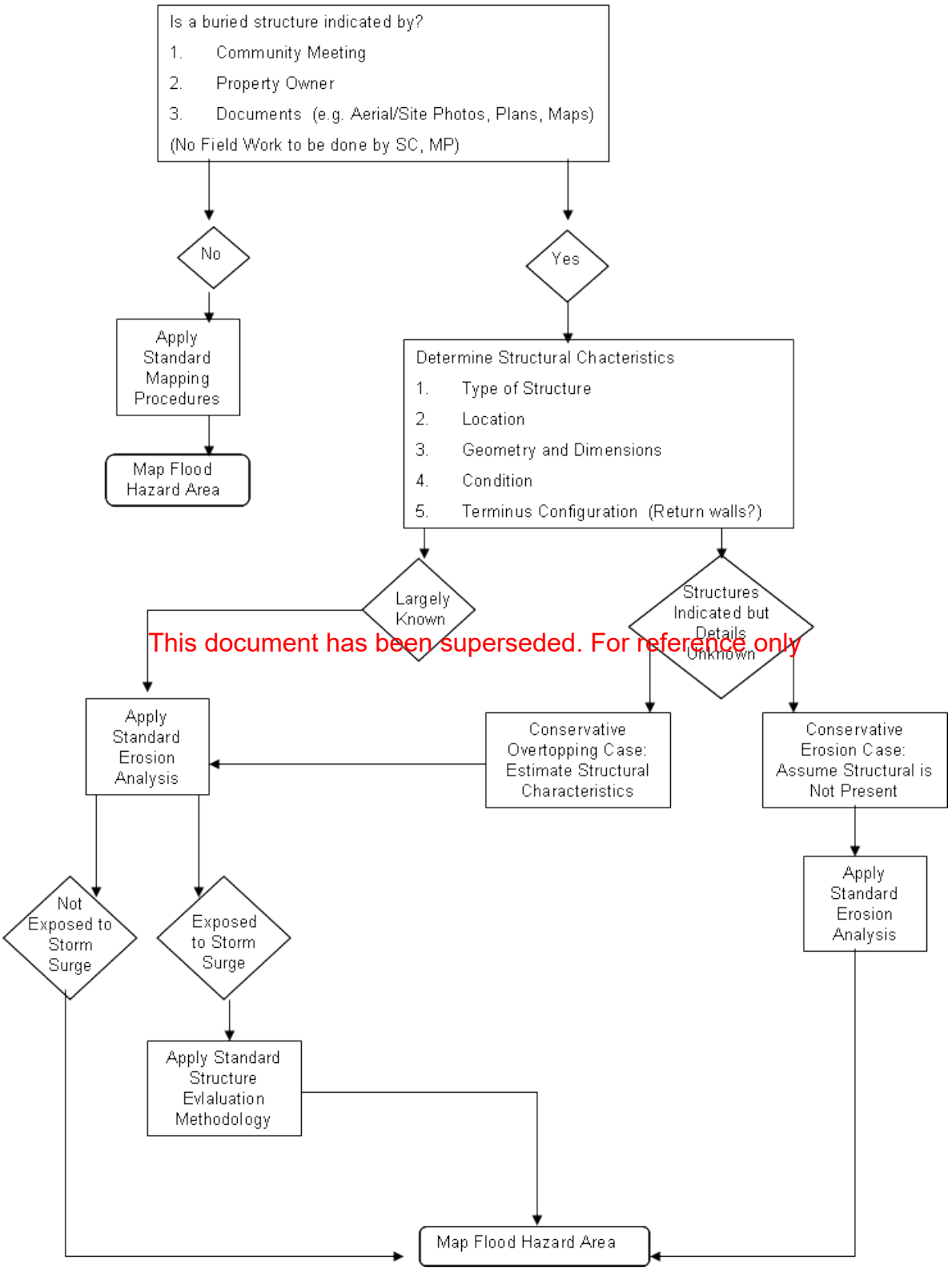
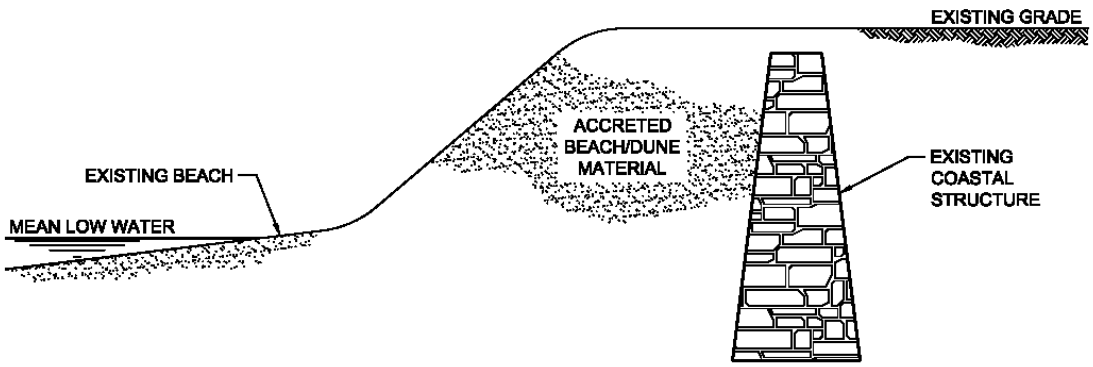
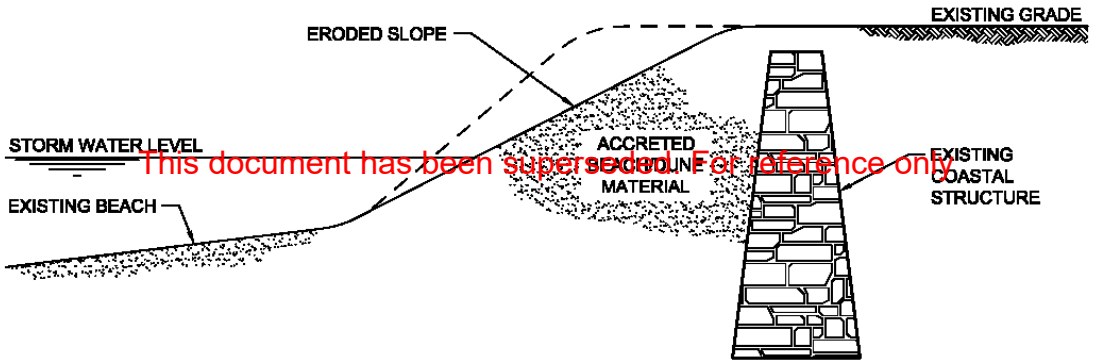


Figure 6: Buried Structure Remains Buried During 1-Percent-Annual-Chance Flood



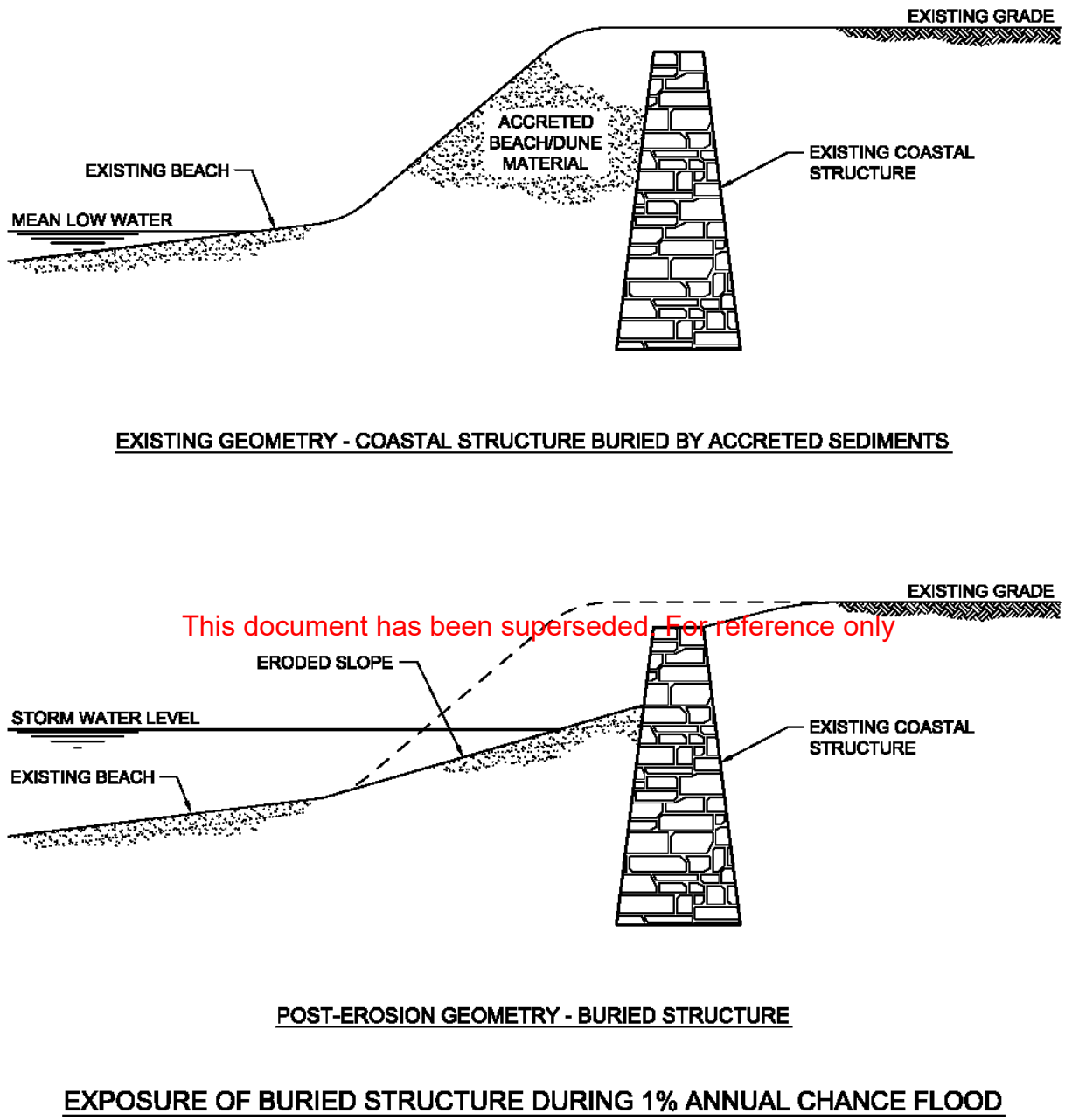
EXISTING GEOMETRY - COASTAL STRUCTURE BURIED BY ACCRETED SEDIMENTS



POST-EROSION GEOMETRY - BURIED STRUCTURE

NON-EXPOSURE OF BURIED STRUCTURE DURING 1% ANNUAL CHANCE FLOOD

Figure 7: Buried Structure Exposed During 1-Percent-Annual-Chance Flood



3.4. Coastal Levees

All levees are subject to Guidance Document No. 95, Guidance for Flood Risk Analysis and Mapping: Levees Guidance. Guidance Document No. 95 is accessible through the FEMA Guidelines and Standards for Flood Risk Analysis and Mapping webpage.

4. Flood Risk Project Treatment of Coastal Structures in Sheltered Waters

In sheltered waters, the Mapping Partner should use the recommended guidance below:

- Coastal Armoring Structures, Navigation Structures, and Beach Stabilization Structures (e.g. revetments, seawalls, jetties, quay walls, groins, breakwaters): These structures should generally be left intact in the storm surge model setup, unless the Mapping Partner has reason to believe that the failure or removal of such structures will best represent hydromorphologic conditions during storms; in such cases, the Mapping Partner should consult with the FEMA Project Officer prior to making final decisions regarding failure or removal of these structures. These structures should be evaluated for stability per existing guidance (for coastal armoring structures, miscellaneous or beach stabilization structures), as appropriate, during the analysis of overland wave propagation, wave runup, wave overtopping, etc. In instances where Total Water Levels (TWLs) are to be computed for several storm simulations, an initial evaluation should be made to determine which structural configuration (intact or failed structure), on average, best represents the most hazardous condition; this configuration should be used in computing the TWLs.

- Causeways, Roads, and Railroads: These obstacles should not be evaluated according to FEMA guidance on levees or coastal armoring structures even though they may act as such in certain instances. During storm surge modeling and the analysis of wave-related effects, these obstacles should generally be left in place as captured in the topographic data and no additional effort should be made to either remove or represent these structures in the modeling setup. If the Mapping Partner has reason to believe that the removal or the explicit representation of such obstacles might best represent hydro-morphologic conditions during storms, the Mapping Partner should consult with the FEMA Project Officer regarding possible removal or representation of these structures.

- Industrial Facilities, Tank Farms, Containment Berms, Perimeter Roads, and Related Structures: These structures should remain in place if captured in the topographic data and no additional effort should be made to represent these structures in the modeling setup unless the Mapping Partner has reason to believe that their explicit representation will best reproduce the hydraulic conditions during storms. If these structures are captured in the topographic data, engineering judgment should be used to ascertain whether their presence unreasonably results in the under-estimation or over-estimation of flood effects, and if the Mapping Partner believes this to be the case, should consult with the FEMA Project Officer regarding possible failure or removal of these structures.

5. Flood Risk Project Treatment of Beach Stabilization Structures

If a Mapping Partner chooses to evaluate beach stabilization structures (e.g., groins, jetties, sills, or similar structures) during Flood Risk Project, the following approach is recommended:

1. Identify any beach stabilization structures during the Flood Risk Project reconnaissance phase.
2. Use historical evidence and engineering judgment to determine whether the structures (or similar structures nearby) have been damaged or detached (during prior storms or gradually over time).
3. Document prior damage to the stabilization structures and any resulting shoreline recession attributable to the structural damage.
4. Notify the FEMA Project Officer if the Mapping Partner intends to remove beach stabilization structures or reduce their effects during the Flood Risk Project analyses. Obtain FEMA concurrence before proceeding with the following steps.
5. Use historical evidence and engineering judgment to predict the likely shoreline configuration (in plain view and elevation) if the structures fail during 1-percent-annual-chance flood conditions.
6. Subject the modified shoreline and profile to typical Flood Risk Project analyses (e.g., event-based erosion analysis, wave runup and overtopping analysis, and wave height analysis).
7. Note that in the case of some stabilization structures, it is unlikely that their failure will require "removal" from analysis transects; the effects of the structure failure on the shoreline configuration, however, should be considered by the analyses.

6. Flood Risk Project Treatment of Miscellaneous Structures

Current FEMA guidance does not address the effects of miscellaneous structures (e.g., piers, port and navigation structures, bridges, culverts, tide gates, etc.) on coastal flood hazard analysis and mapping. This subsection provides general guidance for identifying and analyzing the effects of miscellaneous structures on flooding areas as follows:

- The Mapping Partner may identify structures – in addition to the coastal armoring and beach stabilization structures addressed above – that could exert a significant influence on nearshore waves and currents, coastal sediment transport, or ponding in backshore areas, during 1-percent-annual-chance flood conditions, particularly in sheltered waters. This should be done during the Flood Risk Project reconnaissance phase.

- Once identified, the Mapping Partner may use historical evidence, other readily available data, and engineering judgment to determine whether the miscellaneous structures are likely to

survive the 1-percent-annual-chance flood conditions. If the structures are likely to fail, then they (and their effects on the shoreline and flooding) may be removed from subsequent analyses.

- The Mapping Partner shall notify the FEMA Project Officer as to how he/she intends to address miscellaneous structures and their effects during the Flood Risk Project analyses, and obtain FEMA concurrence before proceeding.

6.1. Piers and Wharves

Piers and wharves are structures extending from the shoreline into the water used for commercial and industrial operations, residential developments, and recreational activities; for the purposes of this guidance document, a pier shall be defined as a structure extending perpendicular to or at an angle to the shoreline and a wharf shall be defined as a structure oriented approximately parallel to the shoreline. The Mapping Partner should review relevant information including navigation charts and aerial photographs to identify piers and wharves within the study area. The Mapping Partner should verify basic structure and facility information with local agencies and communities to determine location and characteristics including its type of support structure: open structures supported on pilings or closed structures supported on fill. Field surveys should be utilized to augment this information, as needed, to confirm collected data and assess the structure's current condition.

Evaluation of coastal hazards at open construction piers and wharves should follow guidance in Section 6.1.2. Closed construction piers and wharves should be captured in delineation of the transect baseline and evaluation of coastal hazards should follow guidance in Section 6.1.3.

6.1.1. STABILITY IN A 1-PERCENT-ANNUAL-CHANCE EVENT

A pier or wharf must be of suitable material and design to be considered in the analysis of coastal flood hazards. Similar to the analysis of coastal armoring structures, engineering judgement may be sufficient to determine 1-percent-annual-chance survivability. However, if a detailed analysis is warranted, structural design should consider the applicable criteria detailed in Section 2.1 to evaluate the stability of the pier's structural support components. In addition, forces acting on the deck should be evaluated, including:

- Hydrostatic load
- Vertical uplift forcing
- Wave slam

Structures identified as insufficient to withstand a 1-percent-annual-chance event should be removed from subsequent coastal analyses unless a suitable partial failure geometry can be established based on research of failed piers and wharves of similar design.

6.1.2. OPEN PIERS AND WHARVES

At open piers and wharves, the dissipative effect of the pilings, substructure, and deck may be accounted for using empirical analysis or a numerical wave model. An empirical analysis should consider wave transmission through the pile openings based on depth, dimension of structures and piles, and water depths. The analysis should be performed at a resolution sufficient to capture major changes in bathymetry and spatial configuration of piles. Numerical modeling approaches should represent the physics of the wave-structure interaction with sufficient resolution to represent the characteristics of the structure.

Special considerations are recommended based on the deck elevation relative to the elevation of the wave envelope.

- For open, pile supported structures where the lowest horizontal structural member is above the crest of the design wave event, dissipation of wave energy propagating beneath the deck may be evaluated for wave-pile interaction. The analysis should evaluate any runup hazards where the SWEL intersects the underlying topography or support structure.

- For open, pile supported structures where the lowest horizontal structural member and/or deck interacts with the wave envelope, wave energy dissipation from piles, deck, and buildings atop the deck may be evaluated as the wave propagates toward the shoreline. At the seaward end and along transverse edges of the structure, wave runup/splash and overtopping should be considered on the deck itself.

- For open, pile supported structures where the SWEL is higher than the deck elevation, wave propagation analysis over the deck should be performed. The analysis should include attenuation from any building atop the pier expected to survive a 1-percent-annual-chance event.

A single pier or wharf in a response-based study may need to consider several of the configurations described above and the associated analyses based on the water level and wave combinations evaluated. For the first two configurations listed above, fixed pier or wharf structures (open piles, substructure, and deck) may interact with shoreward propagating waves to influence wave conditions at the shoreline. The interactive effect of the structure may be accounted for in determination of overland hazard zones.

In the vicinity of a pier or wharf, the area landward of the shoreline should be evaluated for coastal flood hazards using the wave parameters (height and period) propagated under or across the pier or wharf and its support structure. In the event that surge is below the elevation of the top of the deck, the overland analysis should consider any obstruction to wave hazards imposed by the deck itself.

6.1.3. CLOSED CONSTRUCTION PIERS AND WHARVES

Piers or wharves which have a closed substructure should generally be treated as extensions of the shoreline and be included in the coastal analyses. This includes representation of piers and wharves in storm surge and offshore wave modeling, as allowed by model resolution. Determination of

coastal Base Flood Elevations (BFEs) should follow standard overland wave analysis methods for assessing structural stability, wave propagation, wave runup, and overtopping:

- For closed structures where the deck is above the SWEL, wave runup and overtopping should be evaluated.
- For closed structures where the deck is below the SWEL, overland wave propagation should be evaluated, accounting for any obstructions upon the deck expected to survive a 1-percent-annual-chance event.

The Mapping Partner should position transect(s) to best represent the most hazardous conditions across the pier or wharf. The effects of closed piers and wharves on coastal hazards at adjacent shorelines should also be reflected in the surrounding modeling and mapping.

6.1.4. MAPPING PIERS AND WHARVES

Open construction piers or wharves not evaluated for stability or determined to fail during a 1-percent-annual-chance event should be mapped according to the highest hazard determined along the edge of the pier or wharf. An open pier or wharf can alternately be mapped in Zone D if it is judged stable during a 1-percent-annual-chance event. This alternative should be discussed with the community, as Zone D represents an undetermined flood hazard where purchase of flood insurance is not required.

Closed piers and wharves should be treated as an extension of the shoreline and mapped in accordance with Guidance Document No. 39, Guidance for Flood Risk Analysis and Mapping: Coastal Floodplain Mapping, regarding mapping of overland wave hazards including wave propagation, runup, and overtopping. Guidance Document No. 39 is accessible through the FEMA Guidelines and Standards for Flood Risk Analysis and Mapping webpage.

7. Data Requirements

The Mapping Partner shall obtain documentation for each coastal structure that could provide protection during 1-percent-annual-chance flood conditions, or significantly affect flood hazards in the study area. The documentation shall provide all information necessary to evaluate the structure according to the criteria set forth in Section 2.1. Documentation should include, but is not limited to, the following:

- As-built design parameters: structure type, location, layout, dimensions, crest elevation of structure, etc.
- Dominant site particulars (e.g., local water depth, tide, surge and wave conditions, erosion rate, sediment characteristics and geotechnical conditions, debris hazards, and ice climate)
- Construction materials and present integrity

- Historical record for structure including: construction date, plans, and specifications; recent inspection reports and photographs; maintenance plan and responsible party; and dates and descriptions of damage, repairs, and modifications

- Clear indications of effectiveness or ineffectiveness

The Mapping Partner may develop much of this information through office activity, including a careful review of aerial and site photographs, reports and information provided by the community and property owners, and other readily available information. In the case of some major coastal structures, site inspection would be advisable to confirm preliminary judgments.

Note that the level and detail of the structure and site data collected should be consistent with the level of analysis undertaken by the Mapping Partner. An analysis based on engineering judgment, or multiple analyses assuming different structure responses during 1-percent-annual-chance flood conditions (e.g., structure survives intact, partial failure, complete failure) will require less detailed and precise information than a structural engineering and geotechnical evaluation of a coastal structure.

8. Study Documentation

If coastal structures are present in the study area, the Mapping Partner shall document the data, methods, and procedures used to evaluate the likelihood that the structures will survive 1-percent-annual-chance flood conditions. This documentation shall include any assumptions or approximations used in the analyses. The same documentation shall be required in the event that coastal structures are indicated by information collected during the Flood Risk Project, but are apparently buried and not visible during the study.

The Mapping Partner shall document the results of all analyses of coastal structures conducted for the Flood Risk Project. In cases where the Mapping Partner cannot determine whether a given structure would survive the 1-percent-annual-chance flood intact, and where multiple analyses were conducted for the structure (i.e., intact condition, failed condition, and removed from the analysis transect), the Mapping Partner shall document each analysis and record the structure condition that was used to map flood insurance risk zones and BFEs.