



Structural Design Criteria For Structures Other Than Buildings

Course# ST-706

EZ-pdh.com
Ezekiel Enterprises, LLC
301 Mission Dr. Unit 571
New Smyrna Beach, FL 32128
386-882-EZCE(3923)
helpdesk@ezpdh.com

TECHNICAL MANUAL

**STRUCTURAL DESIGN CRITERIA
FOR STRUCTURES OTHER THAN
BUILDINGS**

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

TECHNICAL MANUAL
No. 5-809-6
AIR FORCE MANUAL
No. 88-3, Chapter 6

HEADQUARTERS
DEPARTMENTS OF THE ARMY
AND THE AIR FORCE
Washington, DC 6 December 1991

This publication contains copyrighted material

STRUCTURAL DESIGN CRITERIA FOR STRUCTURES OTHER THAN BUILDINGS

	Paragraph	Page
CHAPTER 1. GENERAL		
Purpose	1-1	1-1
Scope	1-2	1-1
References	1-3	1-1
Special designs	1-4	1-1
Overseas construction	1-5	1-1
Stability	1-6	1-1
Basic design reference	1-7	1-1
CHAPTER 2. MATERIALS AND CRITERIA		
Materials	2-1	2-1
Criteria	2-2	2-2
CHAPTER 3. TRANSPORTATION STRUCTURES		
Bridges	3-1	3-1
Tunnels	3-2	3-1
Docks and harbors	3-3	3-1
Pipelines and supports	3-4	3-1
CHAPTER 4. SITE STRUCTURES		
Drainage structures	4-1	4-1
Earth related structures	4-2	4-1
Other site structures	4-3	4-2
CHAPTER 5. STRUCTURES FOR BULK MATERIALS		
General	5-1	5-1
For granular materials	5-2	5-1
For liquid materials	5-3	5-1
CHAPTER 6. WATER RELATED STRUCTURES EXCEPT STORAGE TANKS		
General	6-1	6-1
Intake and discharge structures	6-2	6-1
Water transmission lines	6-3	6-1
Water and wastewater treatment structures	6-4	6-1
Underground structures	6-5	6-1
CHAPTER 7. MECHANICAL SYSTEM STRUCTURES		
General	7-1	7-1
Equipment supports and enclosures	7-2	7-1
Utility tunnels	7-3	7-1
Pipe supports	7-4	7-1
Gas and air conveyances	7-5	7-1
CHAPTER 8. ELECTRICAL AND COMMUNICATION STRUCTURES		
General	8-1	8-1
Transmission towers and poles	8-2	8-1
Substation structures and equipment	8-3	8-1
Antenna towers	8-4	8-1
Underground structures	8-5	8-1
CHAPTER 9. SPECIALTY STRUCTURES		
General	9-1	9-1
Blast-resistant construction	9-2	9-1
Corrosion-resistant structures	9-3	9-1

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

* This manual supersedes TM 5-809-6, dated 16 January 1984 and AFM 88-3, Chapter 6, dated 14 May 1982

TM 5-809-6/AFM 88-3, Chap. 6

	Paragraph	Page
Other structures	9-4	9-1
Load-tested designs	9-5	9-1
Miscellaneous structures	9-6	9-1
APPENDIX A. REFERENCES		A-1

LIST OF TABLES

Table 2-1.	Concrete strengths	2-1
7-1.	Steel stack allowable stresses	7-2

CHAPTER 1

GENERAL

1-1. Purpose

This manual establishes structural design criteria for structures other than buildings, furnishes design guidance for various types of structures, and identifies special considerations with regard to certain materials in specific applications.

1-2. Scope

Structures other than buildings which are covered by this manual include the following: bridges; dock and harbor facilities; drainage structures; bulk material structures; water and wastewater structures; and mechanical, electrical, and communication structures. Types of structures not covered include dams and pavements for which guidance can be found in other manuals. These criteria apply to all groups and agencies responsible for the design of military facilities.

1-3. References

Appendix A contains a list of references used in this document.

1-4. Special designs

Prior approval for special designs will be obtained from the appropriate headquarters (HQUSACE (CEMP-ET) WASH, DC 20314-1000 for Army projects; and HO, USAF/CECE, Boiling AFB, WASH, DC 20332-5000 for Air Force projects). The request for approval will contain a complete statement of the reasons for using such a system, including competitive costs, proposed special criteria and controls as applicable, performance history or tests (if available), the use of a recognized structural consultant for the design of the

unusual structures, and other pertinent data. The approval will apply to the specific project for which the special design use was requested and will not apply to other projects involving a similar application.

1-5. Overseas construction

Where local material of grades other than those referenced herein are to be used, working stresses, yield strengths, and details of construction will be modified as necessary to reliably represent the performance of the local material. Local material will be of equivalent or better grade than comparable materials referenced herein.

1-6. Stability

Unless noted otherwise, stability relates to sliding, overturning, buoyancy, and other sources of gross displacement and not to stability as related to buckling. Except for foundation elements, a structure or any of its elements will be designed to provide a minimum safety factor of 2.0 against failure by sliding, overturning, or uplift. This required degree of stability will be provided solely by the dead load plus any permanent anchorage. When load combinations are specified in the design standards to maximize potential uplift, the specified load factor on dead load is less than 1.0 (usually + 0.9), and this load factor will be used for stability calculations.

1-7. Basic design reference

TM 5-809-2/AFM 88-3, Chapter 2 will be the basic reference for design of structures other than buildings.

CHAPTER 2

MATERIAL AND CRITERIA

2-1. Materials

a. General. Although this chapter covers only certain materials and special considerations for those materials when used in particular applications, the category of structures “other than buildings” includes possible applications for virtually any material type. In general, requirements for materials used in structures other than buildings will be in accordance with paragraph 2-2a unless prior approval is obtained from the appropriate headquarters. In addition, consideration will be given to fire protection requirements regarding material selection as set forth in MIL-HDBK-1008A.

b. Concrete. Concrete properties will be selected to suit the expected conditions. Type H (modified) or Type V (sulfate resisting cement) will be used for concrete exposed to salt water or similar environments. For further discussion of considerations in selecting appropriate composition and properties for concrete, see Portland Cement Association (PCA) EB00IT. Concrete strengths for structures other than buildings will be in accordance with table 2-1. Concrete cover for protection of reinforcing will be increased when the structure is exposed to salt water or other corrosive conditions unless other means are employed to protect reinforcing from corrosion.

Table 2-1. Concrete Strengths

<u>Usage</u>	<u>Minimum Strength</u>
Mass concrete not exposed to atmospheric conditions or other deteriorating agents where mass rather than strength is the principal considerations.	2000 psi
Drainage and utility structures.	3000 psi
Structures to contain noncorrosive fluids (tanks and reservoirs).	3000 to 4000 psi
Waterfront structures on fresh water.	4000 psi
Reinforced concrete structures over seawater which are sufficiently elevated so that they are not ordinarily wetted by salt water.	4000 psi
Mass concrete exposed to seawater from 3 feet below low water to 3 feet above high water or above normal wave action.	4000 psi
Reinforced concrete decks of waterfront structures where the underside is frequently wetted by salt water.	4000 to 5000 psi

c. Fiber-reinforced concrete. Concrete and cementitious mortar can be reinforced with alkali-resistant, chopped-glass fibers, short steel fibers, or various organic plastic fibers to obtain enhanced strength, ductility, and toughness when compared to plain concrete and mortar. Fiber-reinforced concrete will be used only if approved by the appropriate headquarters. Design guidance and typical material properties can be found in American Concrete Institute (ACI) 544.1R, 544.2R, 544.3R, 544.4R, SP-81, and SP-105 and in Precast/Prestressed Concrete Institute (PCI) MNL-128.

d. Steel materials. Structural steel materials for typical applications will conform to American Society for Testing and Materials (ASTM) A 36, A 53, A 500, and A 572.

(1) Corrosion-resistant steel. Use of corrosion-resistant steel will be in accordance with the following. Steel conforming to ASTM A 690 will be used as set forth in MIL-HDBK-1025/6. Use of corrosion-resistant steel conforming to ASTM A 242 or A 588 is restricted. This type of steel will not be used in areas where the atmosphere contains salt spray and will not be used in a seawater environment. It offers no benefit, and ASTM A 36 material is a better choice. This type of steel will not be used in buried structures unless coated nor will it be used in locations where rust staining of the supporting elements is objectionable.

(2) Stainless steel. Use of stainless steel conforming to ASTM A 666, Types 306 or 316 is restricted. This material will not be used in salt spray zones, in buried applications,

TM 5-809-6/AFM 88-3, Chap. 6

or in an aqueous environment where contact with oxygen is precluded. (In such situations, e.g., under washers, accelerated corrosion will occur.)

(3) *Climatic and temperature considerations.* Special requirements will be considered for applications in severe cold (minimum toughness) or elevated temperatures (reduced yield and tensile strength) as set forth in paragraph 2-2a.

(4) *Abrasive wear.* Additional thickness will be provided in locations subject to abrasive wear, and use of replaceable wear plates for severe conditions will be considered.

e. Timber materials. Design requirements for timber materials will be in accordance with paragraph 2-2a.

f. Aluminum materials. Design requirements for aluminum materials will be in accordance with paragraph 2-2a.

g. Composite construction. Composite construction includes construction such as cast-in-place concrete bonded or connected to precast members, cast-in-place concrete bonded or connected to structural timber, sandwich panels having relatively stiff and strong facings bonded to lightweight cores of lesser strength, such as concrete over rigid insulation, etc. Composite construction has applicability to certain types of structures as covered in MIL-HDBK-1002/6. Composite construction also includes cast-in-place concrete used in conjunction with structural steel or metal decking. Design guidance for these types of composite construction is given in MIL-HDBK-1002/3. Applicable references for composite construction are ACI 318, Chapter 17; PCI MNL-120 and PCI MNL-126; American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges; National Forest Products Association National Design Specification for Wood Construction (timber portion) and ACI 318 (concrete portion); and American Institute of Timber Construction (AITC) Timber Design Handbook (2nd Edition, 1974, covers past practice — not covered in current edition). The combined action of flexible and rigid shear connectors will not be considered as providing simultaneous shear transfer. Rigid connectors include roughened and adhered surfaces and structural shapes. Flexible connectors include items such as bolts, stirrups, dowel bars, and ties.

h. Composites and structural plastics. Composites and structural plastics have limited applicability to military construction and then only to selected specialty structures. Composites and structural plastics will be used only when approved by the appropriate headquarters. Among the concerns associated with structural plastics are fire resistance characteristics and properties which generally do not conform to military fire protection criteria. Precautions will be observed when using composites and structural plastics in recognition of their unfavorable fire resistance properties.

2-2. Criteria

a. General. For a general discussion of considerations such as material selection, service life, etc., which are applicable to all structures, refer to TM 5-809-2/AFM 88-3, Chapter 2.

b. Design loads. Design loads will be determined and established in accordance with TM 5-809-1/AFM 88-3, Chapter 1, or MIL-HDBK-1002/2 except where provided otherwise by this manual or other established standard applicable to the type of structure under consideration. Seismic loading will be in accordance with TM 5-809-10/NAVFAC P-355/AFM 88-3, Chapter 13. Loadings not covered by the criteria in this manual will be obtained from available technical literature, manufacturer's brochures, or will be carefully formulated. In case of any conflict between criteria and available data, the most current acceptable data or practice will be used. Particular attention will be given to wind, seismic, dynamic, and fatigue loads on cable-supported structures and other similar force-oscillating structures.

c. Design stresses. Allowable stresses or load factors applicable to the various materials which may be used will conform to TM 5-809-2/AFM 88-3, Chapter 2, unless indicated otherwise by paragraph 2-2d.

d. Design requirements. Designs will conform to the general concepts and practices of the proper design specification listed in this manual. Where the design of a particular structure or of a special case is not covered, the design approach and technical formulas will be based on available technical literature or will be carefully formulated. Wherever possible, standard, easy-to-get materials will be specified. New materials, units, and systems of a progressive nature or creative design concepts that are economically and structurally sound may be considered. In all cases, the design method, structural framing system, and materials will be the most economical, effective, and efficient from the standpoints of the structure's initial and maintenance costs and its design life. If there are conflicts among the criteria given in this manual for a specific type of structure, the most conservative design method will be used. This will not preclude, however, the use of new codes or specifications which, although less conservative, are considered acceptable for military construction.

e. Design details.

(1) *Drainage.* A proper drainage system will be provided for the following conditions or locations:

(a) All structural surfaces exposed to weather will be sloped to drain.

(b) Intersecting surfaces forming valleys or pockets that may retain water will be arranged to provide drainage.

(c) Structural steel and wood members will be designed so they will not retain moisture or, when in pairs or multiples, so water or moisture will not be held between members.

(d) Structural items like expansion plates, rocker joints, and surfaces intended to permit movement will be designed so they are protected against direct contact with water or condensation and will be detailed to readily drain water.

(e) Surfaces and members will be designed so water will drain from points where steel contacts or enters into masonry or concrete.

(2) *Exposed conditions.*

(a) Wherever possible, contact between masonry and wood or metal in exposed conditions will be prevented. Usually, the best way to drain masonry is to put weep holes where they will not adversely affect member strength.

(b) Where exposed and uncoated steel structures are used, an increased thickness of at least 1/16 inch for corrosion allowance will be used over the computed thickness required. No corrosion allowance for corrosion-resistant or weathering steel is required.

(c) Exposed concrete structures will have enough protective concrete cover to protect the reinforcement. The concrete mixture will be of maximum density and minimum shrinkage, especially with regard to long-term shrinkage and expansion which may be caused by alternate wetting and drying. For bridges or structures exposed to corrosive chemicals or deicing salt, epoxy coated reinforcing bar, a

densely mixed overlay, or both will be provided to prevent corrosion of reinforcing steel. Specific guidance should be obtained from local or state highway department officials. Bridge decks subject to repeated applications of deicing salt will require more than additional concrete cover for reinforcing. Epoxy coated reinforcing bars and densely mixed concrete overlays are considered the most effective methods and are approved by the Federal Highway Administration.

(d) Vertical expansion and contraction joints for reinforced concrete retaining walls and similar structures will be spaced sufficiently close to reduce or eliminate wall cracking due to shrinkage and expansion.

(e) In coastal areas, continuous concrete or masonry foundation walls or grade beams will be extended 24 inches above grade for wood or steel exterior walls so the junction will be above the splash zone.

(3) *Buried or semi-buried structures.* Structures of this type will be designed to resist buoyant forces caused by the presence of water. The safety factor will be at least 1.5 at maximum water table using the dead weight of the structure without contents plus the weight of earth cover directly over the tank. A safety factor of 1.1 may be used when the maximum water table or the maximum flood level is at or above the top of the structure. Designers will consider the possible hydrostatic uplift at various stages of construction.

CHAPTER 3

TRANSPORTATION STRUCTURES

3-1. Bridges

a. Highway. Design of highway bridges will be in accordance with the AASHTO Standard Specifications for Highway Bridges and American Institute of Steel Construction (AISC) Highway Structures Design Handbook. Loading for military vehicles will be in accordance with TM 5-312 and FM 5-36.

b. Railroad. Design of railroad bridges will be in accordance with the American Railway Engineering Association (AREA) Manual for Railway Engineering.

c. Pedestrian. Design of pedestrian bridges will consider a minimum live load of 85 psf and possible loads by maintenance vehicles as set forth in the AASHTO standard specifications. Such loads will be considered in conjunction with wind, snow, and other loads to which the structure may be subjected.

d. Other. Bridges for other specialized applications, such as pipeline supports, transit systems, etc., will meet requirements unique to such applications for the service involved and the materials used. For example, bridges constructed of aluminum will be designed in accordance with the Aluminum Association Specifications for Aluminum Structures using allowable stresses for bridges and similar type structures. For additional guidelines for concrete bridge structures, see ACI 343R.

3-2. Tunnels

Analysis and design for tunneling and tunnel structures will be based on the information and references provided in NAVFAC DM-7.3 and American Society of Civil Engineers (ASCE) 402. Structural strength and stability will be considered, as well as the need for ventilation and other services.

3-3. Docks and harbors

a. Design. Design of docks and harbors will, in general, be in accordance with the MIL-HDBK-1025 series which addresses waterfront operational facilities. Additional guidance may also be found in the NAVFAC DM-26 series and the Coastal Engineering Research Center (CERC) Shore Protection Manual, Volumes I through m. Specific requirements applicable to particular types of dock and harbor structures will be established from references specially suited to those types of structures such as MIL-HDBK-1025/3 and MIL-HDBK-1025/5. Particular consideration will be given to corrosion-resistant design in seawater environments. For guidance in this regard, refer to MIL-HDBK-1025/6. Wave forces on vertical walls, piles, and other exposed structures will be determined in

accordance with the CERC Shore Protection Manual. Site wave studies will be performed to determine the effect of wave action on structures.

b. Piers and wharves.

(1) Main structure. Design of main pier or wharf structures will consider conditions of exposure and loadings applicable to the location and service for which the structure is intended. A discussion of appropriate design loads can be found in MIL-HDBK-1025/1. Design loads will include considerations of vertical live load, berthing forces, mooring loads, wave loadings, ice forces, as well as seismic and other forces as appropriate.

(2) Dolphins. Dolphins will be designed as described in the MIL-HDBK-1025 series and will be provided where required to resist ship berthing, mooring, and/or turning forces. Guidance regarding the determination of berthing, mooring, and turning forces is also provided in the MIL-HDBK-1025 series.

(3) Fendering. Fender systems will be designed to protect the pier or wharf structure, as well as the berthing vessel itself, from forces which can result from the impact of the vessel against the structure. Design of fender systems will be in accordance with MIL-HDBK-1025/1 for vessel sizes appropriate for the structure and for the recommended approach velocity and angle.

c. Offshore platforms. Offshore platforms will be designed considering requirements and loadings set forth in the MIL-HDBK-1025 series and the CERC Shore Protection Manual and will be designed in conformance with applicable portions of the American Petroleum Institute (API) RP 2A. For additional design guidance, see ACI 357R, 357.1R, and 357.2R.

d. Offshore POL unloading facilities. Design of offshore POL unloading systems will be in accordance with NAVFAC DM-22. Wave studies will be made for the design of the mooring system and platforms. Submarine pipelines will be properly designed and anchored against undersea current and underwater tow.

3-4. Pipelines and supports

Design requirements for pipelines and their supports will depend on the nature of the material being transported and the materials used for construction. Among the standards which should be consulted when undertaking design of pipeline systems are the following:

a. American Society of Mechanical Engineers (ASME) B31.8.

b. American Petroleum Institute (API) Standard 1104 and Recommended Practices 1102 and 1110.

TM 5-809-6/AFM 88-3, Chap. 6

c. American Society of Civil Engineers (ASCE) Publications 368, 418, and 428.

d. American Water Works Association (AWWA) Publications M9 and M11.

e. American Concrete Institute (ACI) 346 and 346R. When necessary, reference may be made to appropriate publications of specialty associations such as the American Concrete Pipe Association (ACPA) and the American Concrete Pressure Pipe Association (ACPPA).

CHAPTER 4

SITE STRUCTURES

4-1. Drainage structures

a. Box culverts. Concrete box culverts will be designed for loadings defined in the AASHTO Standard Specifications for Highway Bridges in accordance with design requirements presented therein. Consideration will also be given to requirements set forth in ASTM C 789 and C 850 as applicable. Box culverts, if constructed of other materials, will be designed in accordance with the generally recognized codes and standards applicable to such materials.

b. Manholes and inlets. Manholes and inlets will be designed to resist earth, water, temperature, and other loads to which they will be subjected. Structural design of concrete structures will be in accordance with ACI 318. Design of other types of manhole construction will be in accordance with applicable codes covering that type of construction. Additional guidance for watertight construction and load distribution coefficients for these types of structures may be found in PCA IS003.02D and IS072.01D. Special consideration will be given to the effect of roof and wall openings, and proper allowance will be made for differential movement due to settlement, thermal expansion, etc., between manholes and interconnecting elements. To the extent practical, precast components for manhole construction will be used. Precast components will be furnished in accordance with ASTM C 478.

c. Miscellaneous drainage structures. Corrugated culvert pipes will be designed in accordance with American Iron and Steel Institute (AISI) SG-861. Concrete culvert pipe will be reinforced and furnished in accordance with ASTM C 76. Required three edge bearing strength will be determined in consideration of class of bedding and applicable load factor as set forth in Foundation Engineering by Leonards. Corrugated aluminum culvert pipe will be furnished in accordance with ASTM B 745. Other materials will be considered subject to acceptance by the appropriate headquarters provided any special requirements such as bedding, etc., are met.

d. Sewers. Criteria for structural design of the various components of sewer systems will be established from information presented in Water Pollution Control Federation (WPCF) MOP9CTG, TM 5-814-1/AFM 88-11, Volume 1, and TM 5-814-2/AFM 88-11, Volume 2.

4-2. Earth related structures

a. General. NAVFAC DM-7.1, DM-7.2, and DM-73 will be the basic references for design of earth related structures. Additional references including MIL-HDBK-1025/4, the Structural Engineering Handbook by Gaylord & Gaylord, Foundation Analysis and Design by Bowles, Principles of Foundation Engineering by Das, as well as

publications by the manufacturers of proprietary products and systems will be consulted as necessary.

b. Retaining structures. Retaining structures can be classified with respect to the manner in which forces are transmitted to the surrounding soil as either gravity, cantilever, or anchored types. Though numerous variations exist within each general type, only a few are identified in the following discussions.

(1) Gravity structures. Gravity structures are those which rely solely on their own weight to maintain stability. Among the types of construction which act as gravity structures are concrete gravity blocks, bin or cellular cofferdams, crib walls, bin walls, gabions, and reinforced earth type structures.

(2) Cantilever structures. Cantilever structures are those which interact with the surrounding earth through flexural bending in such a way that a portion of the earth mass is brought into play in resisting the forces imposed on the structure. Among the types of construction which act as cantilever structures are reinforced concrete "tee" walls, counterfort or buttress walls, cantilevered concrete or steel sheet piles, overlapping drilled piers, and reinforced concrete slurry walls.

(3) Anchored bulkheads. Anchored bulkhead type structures are structures which typically employ a flexural "wall" type element to retain the earth and an anchor system connected near the top of the wall to reduce the magnitude of the reactions at the base of the wall. Typical anchored bulkhead type structures are anchored bulkhead waterfront structures, soldier beam and lagging systems, braced walls, and slurry walls when anchored near their top. Depending on the characteristics of the earth materials, the stiffness of the wall, etc., the base of the wall of such structures may be considered to be rotationally fixed to some degree which results in a reduction in the required flexural strength for the wall. There are also a number of options available regarding the type of anchor structure which can be used including anchor wall, batter pile system, earth or rock anchors, etc.

c. Shore protection structures. Shore protection structures will be designed as described in the CERC Shore Protection Manual, Volumes I through III. Additional information available from manufacturers of specialized shore protection products, e.g., revetment mattresses, interlocking articulated blocks, etc., will be considered where the use of such systems is warranted. Care will be taken in selection of material for such systems and regard given to the possibility of reduced service life when artificial materials are used.

TM 5-809-6/AFM 88-3, Chap. 6

4-3. Other site structures

a. Canopies and shelters.

(1) *Open canopies.* Open canopies include unenclosed roofed areas and one-, two-, and three-sided enclosures. Design of such structures will be based on the specialized loading considerations set forth in TM 5-809-1/AFM 88-3, Chapter 1 or MIL-HDBK-1002/2 and American National Standards Institute (ANSI) A58.1.

(2) *Mobile.* Mobile canopies and shelters will be designed for the loads which would otherwise apply to stationary structures of that type with additional provisions

regarding impact factors appropriate for the speed at which the structures are to be moved. Additional consideration will be given to possible load increases which can result from irregularities in alignment of the support system over which the structures will be moved, e.g., enforced displacements or variable support conditions.

b. Light poles, flag poles, and sign supports. Design of light poles, flag poles, and sign supports will be in accordance with the special provisions for such structures set forth in ANSI A58.1.

CHAPTER 5

STRUCTURES FOR BULK MATERIALS

5-1. General

Design of structures for bulk materials will include consideration of the special characteristics of the material being handled or stored. Design values for material density, maximum conveyor slopes, etc., will be carefully determined, and consideration will be given to the need for special structural construction or supports to assure the smooth flow of materials into or out of the tanks or bins used for bulk storage.

5-2. For granular materials

a. Silos, bins, and bunkers. Design of these types of structures, if constructed from steel or other metal, will be in accordance with procedures presented in Design of Welded Structures by Blodgett and the Structural Engineering Handbook by Gaylord & Gaylord. If constructed of concrete, design of these types of structures will be in accordance with ACI 313, Handbook of Concrete Engineering by Fintel, and Silos: Theory & Practice by Reimbert & Reimbert.

b. Conveyor system supports. Design of conveyor system supports will be in accordance with relevant publications of the Conveyor Equipment Manufacturers Association (CEMA) such as Belt Conveyors for Bulk Materials and cited references. Design loads will be determined from ANSI A58.1 where applicable and as furnished by the conveyor system manufacturer. The design agency will verify that appropriate impact factors have been included in loads provided by the conveyor system manufacturer.

5-3. For liquid materials

a. General. Structures associated with the storage and handling of bulk liquid materials will be designed in accordance with the codes and standards applicable to the type of material being handled. Earthquake loads will be in accordance with TM 5-809-10/NAVFAC P-355/AFM 88-3, Chapter 13. Among the codes and standards applicable to the design of structures for bulk liquid materials are AWWA D100, AWWA D103, AWWA D110, AWWA D120, API 650, and the Structural Engineering Handbook by Gaylord & Gaylord.

b. Materials. Selection of materials of construction for tanks in which liquids are to be stored will consider the environmental conditions to which the tank will be exposed as well as the properties of the liquid being stored. In general, inherently corrosion-resistant materials should be selected for buried tanks although steel tanks will be acceptable if properly protected against corrosion. See Steel Tank Institute (STI) sti-P3 Specification and Manual for

External Corrosion Protection of Underground Steel Storage Tanks for guidance in protecting this type of tank.

c. Tanks. Design of structural systems for tanks will include the necessary interfaces between the supporting structure or base and the tank itself. For that reason, it is important that the agency designing the support structure be familiar with the specifications applicable to the tank.

(1) References. The following are among the references applicable to structural design for tanks in addition to those indicated above:

(a) Department of the Navy NAVFAC DM-22.

(b) American Petroleum Institute (API) Publications 1615 and 1632 and Standard 2000.

(c) American Iron and Steel Institute (AISI) Steel Tanks for Liquid Storage.

(d) Steel Tank Institute (STI) Dual Wall Underground Steel Storage Tanks, Recommended Practice for Optional Interior Corrosion Control System for Steel Tanks, and Guideline for Underground Piping for Fuel Storage Tanks.

(e) Portland Cement Association (PCA) IS003.02D and 15072.1D.

(f) American Concrete Institute (ACI) 344R, 344R-T, 344R-W, and 350 R.

(g) Precast/Prestressed Concrete Institute (PCI) JR-334.

(2) Additional considerations. Additional considerations apply to tank design depending on the type of tank and other factors as discussed in the following.

(a) Elevated tanks. Design of elevated tanks will include consideration of lateral loads due to earthquake as set forth in TM 5-809-10/NAVFAC P-355/AFM 88-3, Chapter 13. For individual leg foundations, the weight of the foundation alone (not considering weight of the earth cover) will provide a minimum safety factor of 1.2 against uplift, overturning, and sliding.

(b) Ground-level tanks. The provisions of NAVFAC DM-7.2 will apply to the design of foundations for ground level tanks. Although ring beams are required only for tank foundations in seismic zones 3 or 4, this type of construction or comparable provisions necessary to prevent frost heave will be made in all areas. Consideration will be given to the need for and alternate means of accomplishing corrosion protection of the underside of the tank floor plates.

(3) Below-grade. Design of below-grade or buried tanks will consider the potential buoyancy of the tank, and a suitable ballast slab or other anchoring system will be provided to assure that the tank will not float when the dead weight of the empty tank and soil cover directly over the tank are insufficient to prevent flotation. Dual walled tanks will be used consistent with requirements of the Environmental

TM 5-809-6/AFM 88-3, Chap. 6

Protection Agency and local agencies who would have jurisdiction for privately developed projects.

(a) *Earth cover.* Earth cover will be provided over the top of tanks in accordance with frost penetration requirements (considering concrete distribution slab thickness) but will be not less than 2 feet 6 inches.

(b) *Backfill material.* Backfill for underground tanks will include a 6-inch course of inert sand or fine gravel placed against exposed exterior surfaces.

(4) *Concrete tanks and reservoirs.* Tanks and reservoirs designed to contain fresh water and other non-deteriorating substances will have a clear cover over the reinforcement of not less than 1-1/2 inches for slabs and 2 inches for beams and girders or shall be constructed using conventional depth of cover but with surface sealants or coated reinforcing or both. A minimum temperature differential of 40 degrees F will be assumed to exist between inside and outside faces of tank walls.

(a) *Reinforced concrete tanks.* Design of reinforced concrete tanks will be in accordance with PCA 15003.02D

and 15072.01D. Other acceptable standard design methods or concepts may also be used.

(b) *Prestressed concrete tanks.* Design of prestressed concrete tanks will be in accordance with ACT 344R. Other current acceptable methods may also be used.

(5) *Petroleum, oil and lubricant (POL) tanks and facilities.* Design of POL tanks will be in accordance with API 650.

(6) *Water storage tanks.* Design of water storage tanks will be in accordance with applicable American Water Works Association publications but subject to specific design restrictions as set forth above.

(7) *Tanks for other than oil or water.* The basis for design of steel tanks will be API 650, but special considerations related to the product stored in the tank must be accounted for. Steel tanks to store liquefied gases at or near atmospheric pressures will be designed in accordance with API 620. Storage of corrosive solutions and the effects of temperature in conjunction with corrosive solutions will be considerations in selecting tank materials.

CHAPTER 6

WATER RELATED STRUCTURES EXCEPT STORAGE TANKS

6-1. General

Design of water related structures will comply with the need to maintain watertight and durable construction. In this interest, design of concrete structures will be in accordance with the recommendations of ACI 350R. Where appropriate, water related concrete structures will be designed as hydraulic structures. Additional design guidance will be obtained from applicable design agency reference documents and the Handbook of Concrete Engineering by Fintel.

6-2. Intake and discharge structures

Intake and discharge structures, such as for power plants and pumping stations, will be designed to sustain wave forces, hydrostatic pressures, earth pressures, surcharges, and other superimposed loads. Trash racks and screens will be provided. The amount of trash, debris, or seaweed expected to accumulate in intake structures will be the primary consideration in deciding whether or not a continuously cleaning mechanical traveling screen will be used. Design will consider the maximum permissible differential head across the trash rack or screening device.

6-3. Water transmission lines

Design of water transmission lines will include consideration of items such as maintaining watertightness, avoiding erosive velocities, and providing gradual transitions in cross-section and alignment. Structures will be designed to carry the weight of the aqueduct or pipeline with fluid and to resist loads due to wind, snow, and seismic activity. Reaction blocking will be designed and provided where necessary to resist forces due to pressure, thrust, impact, water hammer, etc. The structural design will be coordinated with the

selection of pipeline materials and layout to assure that proper allowance has been made for these forces as well as expansion movements, etc.

6-4. Water and wastewater treatment facilities

a. General. Design of water supply facilities will be in accordance with TM 5-813-1/AFM 88-10, Volume 1; TM 5-813-4/AFM 88-10, Volume 4; and ASCE Water Treatment Plant Design. Design of wastewater treatment facilities will be in accordance with TM 5-814-3/AFM 88-11, Volume 3 and WPCF MOP8CTG.

b. Basins and similar construction. Structures such as primary settling basins, clear wells, sedimentation tanks, Imhoff tanks, filters, sludge digesters, and similar structures will be designed in accordance with concepts set forth in earlier paragraphs under the discussion of structures for bulk liquid materials and TM 5-814-3/AFM 88-11, Volume 3. Pipeline support structures, sluice gates, equipment foundations, and other miscellaneous structures will be designed in accordance with criteria given elsewhere in this manual and current standard practices. Manufacturer's recommended designs may also be considered.

6-5. Underground structures

Design of underground structures associated with water related facilities, e.g., manholes, pits, etc., will comply with criteria for manholes and inlets in paragraph 4-1. Paved inverts and similar details will be provided as required for the particular system being incorporated. Applicable portions of ASTM C 32, C 857, and C 858 will also be considered.

CHAPTER 7

MECHANICAL SYSTEM STRUCTURES

7-1. General

Design of support features for mechanical systems such as heating, ventilating, and air-conditioning (HVAC) systems (including items such as foundations, support frames, braces, and other items) will be in accordance with current practice, sound engineering principles, and manufacturer's recommendations as appropriate. The minimum safety factor for stability against overturning and for resistance against sliding will be as set forth in paragraph 1-6. For design of structures associated with power plants, see applicable portions of TM 5-811-6. Design of mechanical support systems for seismic restraint is covered in TM 5-809-10/NAVFAC P-355/AFM 88-3, Chapter 13.

7-2. Equipment supports and enclosures

a. Static. Design of supports and enclosures for static equipment will consider the maximum weight and eccentricity of the equipment as well as the required clearance for access to and maintenance of the equipment. Lateral supports and bracing will be provided as necessary to maintain the stability of the equipment under lateral loading, particularly seismic.

b. Rotating or vibrating. Design of supports and enclosures for vibrating or rotating machinery will consider the need for isolation pads, isolation joints, and damping devices either alone or in combination. Care will be taken to assure that the natural frequency of supports is sufficiently offset from the operating frequency of the equipment so that there is no danger of objectionable or damaging resonant vibration. Whenever practical, supports for rotating or vibrating equipment will be physically isolated from the adjacent structure to prevent the transmission of vibration into occupied areas. NAVFAC DM-7.3 and Design of Structures and Foundations for Vibrating Machines by Arya, O'Neill, and Pincus are among the references which will be consulted for further guidance on structural design for vibrating equipment.

7-3. Utility tunnels

Utility tunnels will be provided for mechanical systems where a number of systems follow the same general alignment. Design of utility tunnels and similar underground structures will be in accordance with ASTM C 857 and ASTM C 858 unless more stringent requirements are imposed by the agency having jurisdiction.

7-4. Pipe supports

Pipe supports will be designed to resist the various forces to which the piping system will be subjected. As a minimum, all pipe supports will be designed to carry the weight of the piping system plus water to account for hydrostatic testing. Other forces including those due to wind, snow, seismic activity, thermal expansion and contraction, thrust, impact, etc., will be considered as appropriate for the details of the system and materials being used. For systems conveying materials at temperatures other than ambient, consideration will be given to the effect of thermal expansion and contraction on the support system. Where possible, the flexibility of the support structure will be considered to avoid the need for slide bearings or similar construction. In any case, appropriate allowance will be made for movement and restraint to conform with the assumptions made in the pipe system flexibility analysis. In regions of potential seismic activity, particular attention will be given to assure that sufficient lateral support is provided.

7-5. Gas and air conveyances

Gas and air conveyances, particularly for hot gases, will be designed to meet fire protection requirements including National Fire Protection Association (NFPA) 211. Design of supports for HVAC systems will comply with TM 5-8 10-1.

a. Large-scale ductwork. Large-scale ductwork refers to ductwork typically associated with major supply air and hot gas conveyances, e.g., between the various components of large industrial or power generation boiler plants. Large-scale ductwork may be of either circular or rectangular cross section and is usually constructed of steel. Structural design of large-scale ductwork will be in accordance with the following Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) publications: Accepted Industry Practice for Industrial Duct Construction, Rectangular Industrial Duct Construction Standards, and Round Industrial Duct Construction Standards. Design considerations will include forces exerted on the duct system such as those due to gas pressure, dead and live loads, wind loads, snow loads, seismic loads, and loads due to thermal expansion and contraction. In addition, the design will consider the effects of elevated temperature which can reduce the yield point and other mechanical properties of steel. The layout of duct systems will include a sufficient, but minimum number of expansion joints, adequate provisions for movement, and appropriate restraint at supports. For duct with large, circular cross sections, structural design may be based on methods described in the Structural Engineering

TM 5-809-6/AFM 88-3, Chap. 6

Handbook by Gaylord & Gaylord for circular steel stacks. Components will be proportioned so that resonance due to vortex shedding at low wind velocities is avoided. For duct of rectangular cross section, structural design will be in accordance with the AISI Design of Plate Structures, Design of Welded Structures by Blodgett, and applicable portions of the American Institute of Steel Construction (AISC) Specification for Structural Steel Buildings Allowable Stress Design and Plastic Design that relates to plate girders. Design will include a determination of plate thickness required to resist flexural loading, the size and spacing of stiffeners, the size and location of internal bracing, and additional plate thickness and features which may be required if the duct is designed as a spanning box girder.

b. Stacks. In addition to maximum loadings, stacks will be designed to resist the effects of vortex shedding or fluttering caused by steady wind. Stack designs will consider pressure differential stresses caused by virtue of the stack's

conveying a gas of different specific gravity than atmospheric conditions and to temperature differential stresses caused by an uneven temperature distribution within the stack. See also ASCE Design and Construction of Steel Chimney Liners.

(1) *Reinforced concrete stacks.* Reinforced concrete stacks will be designed in accordance with ACI 307.

(2) *Aluminum stacks.* If constructed of aluminum, design of stacks will follow similar design guidance and general references given for design of steel stacks.

(3) *Steel stacks.*

(a) Design of steel stacks will be in accordance with the AISC Specification for Structural Steel Buildings Allowable Stress Design and Plastic Design; Structural Engineering Handbook by Gaylord & Gaylord; SMACNA Guide for Steel Stack Design and Construction; and ASME STS-1. Allowable stresses will be in accordance with table 7-1. The allowable stress is for a design condition of dead load combined with either seismic or wind loads.

Table 7-1. Steel stack allowable stresses*

The basic formula for allowable longitudinal compressive stress is: $F = XY$

where:

$$X = \begin{cases} 0.0625E/tR & \text{for } 0 \leq t/R \leq 8F_p/E \\ 0.5[F_y - k_s(F_y - F_p)] & \text{for } 8F_p/E \leq t/R \leq 20F_y/E \\ 0.5F_y & \text{for } t/R \geq 20F_y/E \end{cases}$$

$$k_s = [(F_y - 0.05E/tR)/(F_y - 0.4F_p)]^2$$

$$Y = \begin{cases} 1 & \text{for } L/r \leq 60 \text{ and } F_y \leq 50 \text{ ksi} \\ 21,600/[18,000 + (L/r)^2] & \text{for } L/r > 60 \text{ and } F_y \leq 50 \text{ ksi} \end{cases}$$

and:

F_y = yield strength at mean shell temperature, ksi.

F_p = proportional limit at mean shell temperature, ksi; may be taken as $0.7F_y$.

E = modulus of elasticity at mean shell temperature, ksi.

t = shell plate thickness, in., at the section under consideration.

R = radius of shell, in.

L = length of stack between points of lateral support.

For a self-supporting stack, L should be taken as the effective length, i.e., $L = 2 \times$ stack height, in.

r = radius of gyration = $0.707R$ for circular stack, in.

* Obtained from Structural Engineering Handbook, Second Edition, Gaylord & Gaylord, McGraw Hill Book Company, 1979. Reproduced with permission of McGraw-Hill, Inc.

(b) Shell thickness will be at least 1/4 inch for lined stacks and 5/16 inch for unlined stacks. The computed shell thickness will be increased by 1/16th inch to allow for possible corrosion. The net section area (gross area minus

bolt hole areas) will be used to determine actual stresses. Allowable stresses for parts other than the shell plate will be in accordance with AISC Specification for Structural Steel Buildings Allowable Stress Design and Plastic Design.

CHAPTER 8

ELECTRICAL AND COMMUNICATION STRUCTURES

8-1. General

Electrical and communication system structures will be designed in accordance with TM 5-811-1/AFM 88-9, Chapter 1 and the following. In all cases, the Institute of Electrical and Electronics Engineers (IEEE) National Electric Safety Code (NESC) will be considered as establishing minimum requirements for design of structures associated with electric power systems. For aluminum towers and antennas, the one-third increase in allowable stresses under wind or seismic loads permitted in the Aluminum Association Specifications for Aluminum Structures will not be used. Design of electrical support systems for seismic restraint is covered in TM 5-809-10/NAVFAC P-355/AFM 88-3, Chapter 13.

8-2. Transmission towers and poles

Power transmission towers and pole structures will be designed in accordance with the NESC (IEEE (22)), and the following ASCE publications: Manual 52, applicable technical papers in its Structural Division Journal (including Design of Steel Transmission Pole Structures), and Guide for the Design and Use of Concrete Poles. In case of conflicting criteria, the most conservative method will be used.

8-3. Substation structures and equipment

Substation, switching station, and similar structures for supporting electrical equipment will be constructed, where possible, of manufacturer's standard unit components. All

structures, however, must be strong enough to resist the climatic design load requirements for the site. Where special structure design is needed, design criteria will conform to the National Electrical Manufacturers Association (NEMA) SG-6. General layouts and configurations for electrical support structures are given in TM 5-811-1/AFM 88-9, Chapter 1. Equipment foundations will be designed in accordance with current practices; the safety factor for stability against overturning and for resistance against sliding will be as set forth in paragraph 1-6.

8-4. Antenna towers

Antenna towers will be designed using applicable criteria from the Electronic Industries Association (EIA) 222-D. Design methods and stresses will be as appropriate for the material used for the supporting structure.

8-5. Underground structures

Underground structures associated with electrical and communication systems, e.g., manholes, handholes, pull boxes, etc., will be designed according to the criteria for manholes and inlets in paragraph 4-1. The need for water resistance and provisions for drainage and sumps will be examined, as well as cable bending radii and details of required support systems, when establishing the layout and dimensions of such structures. Design will also comply with ASTM C 857 and C 858.

CHAPTER 9

SPECIALTY STRUCTURES

9-1. General

This chapter deals primarily with those types of specialty structures which have potential application in military construction. Basic guidance regarding design of other types of specialty structures which may have only limited applicability to military projects is also provided.

9-2. Blast-resistant construction

Design of structures to resist the effects of accidental explosions will be in accordance with TM 5-1300/NAVFAC P-397/AFM 88-22. The reference is mandatory for explosive safety design. Design of structures to resist the effects of conventional weapons will be in accordance with TM 5-855-1, and design of facilities to resist the effects of nuclear weapons will be in accordance with TM 5-858-1, TM 5-858-2, TM 5-858-3, TM 5-858-4, TM 5-858-5 and TM 5-858-8. The design of blast-resistant structures must consider the transient loadings and dynamic response of the structure that results from the specified design event. Blast-resistant design is often required in conjunction with the construction of weapons system facilities, both developmental and operational, as well as for structures designed to resist the effects of intentional attack.

9-3. Corrosion-resistant structures

Specialty structures are often required for use in extremely corrosive areas such as in chemical processing plants, plating rooms, demineralizing and water polishing areas, and severe salt water environments. To attain the necessary corrosion resistance, structures in such areas are frequently fabricated from nonmetallic materials including fiberglass reinforced plastic, etc. When used, manufacturer's literature regarding the selected nonmetallic material will be carefully reviewed and closely followed during design of the structure. For additional discussions regarding corrosion-resistant

structures and construction refer to TM 5-809-2/AFM 88-3, Chapter 2; MIL-HDBK-1025/6; and NAVFAC DM-11.1.

9-4. Other structures

Other types of specialty structures include plate and shell structures, major arenas and stadiums, orbital space structures, test stands, launch structures, carbon fiber composite structures, etc. Design of structures of these types is highly specialized and is beyond the scope of this manual. If confronted with the need for structures such as these, the agency providing the design will obtain relevant references and identify the appropriate specialty consultants to assist in the design.

9-5. Load-tested designs

In lieu of the design approach discussed above and when consistent with budget and schedule, load-tested designs may be considered. This approach can be applicable to certain composite type structures or components such as those involving adhesive bonded elements, cellular foam, and newly developed materials. Toward that end, approved research laboratories will perform load tests and submit a full report including all test data for review. Minimum safety factors will be 2.5 with respect to ultimate strength or 1.65 with respect to yield strength of the material or system. Information describing any new load-tested materials or systems determined necessary, advantageous, and economical will be submitted for approval to appropriate headquarters.

9-6. Miscellaneous structures

Miscellaneous structures are those not listed elsewhere in this manual or not covered by a specific code or specification. Designs for these structures will be in accordance with related design codes, sound engineering practice and judgement, and relevant criteria based on the materials involved and the predicted loading.

APPENDIX A REFERENCES

Government Publications

Department of Defense

MIL-HDBK-1002/2 Loads.	
MIL-HDBK-1002/3	Structural Engineering Steel Structures.
MIL-HDBK-100216	Aluminum Structures, Composite Structures, Structural Plastics, and Fiber-Reinforced Composites.
MIL-HDBK-1008A	Fire Protection for Facilities, Engineering, Design, and Construction.
MIL-HDBK-1025/1	Piers and Wharves.
MIL-HDBK-1025/2	Dockside Utilities for Ship Service.
MIL-HDBK-1025/3	Cargo Handling Facilities.
MIL-HDBK-1025/4	Seawalls, Bulkheads, and Quaywalls.
MIL-HDBK-1025/5	Ferry Terminals and Small Craft.
MIL-HDBK-1025/6	General Criteria for Waterfront Construction.

Departments of the Army, the Navy and the Air Force

TM 5-809-10/NAVFAC	Seismic Design for Buildings.
P-355/AFM 88-3, Ch. 13	
TM 5-1300/NAVFAC	Structures to Resist the Effects
P-397/AFM 88-22	of Accidental Explosions.

Departments of the Army and the Air Force

TM 5-809-1/AFM 88-3, Ch. 1	Structural Design Criteria-Loads.
TM 5-809-2/AFM 88-3, Ch. 2	Structural Design for Buildings-Materials.
TM 5-811-1/AFM 88-9, Ch. 1	Electric Power Supply and Distribution.
TM 5-813-1/AFM 88-10, Vol. 1	Water Supply: Sources and General Considerations.
TM 5-813-4/AFM 88-10, Vol. 4	Water Supply: Water Storage.
TM 5-814-1/AFM 88-11, Vol. 1	Sanitary and Industrial Waste-water Collection - Gravity Sewers and Appurtenances.
TM 5-814-2/AFM 88-11, Vol. 2	Sanitary and Industrial Waste-water Collection - Pumping Stations and Force Mains.
TM 5-814-3/AFM 88-11, Vol. 3	Domestic Wastewater Treatment.

Department of the Navy

NAVFAC DM-7.1	Soil Mechanics.
NAVFAC DM-7.2	Foundations and Earth Structures.
NAVFAC DM-73	Soil Dynamics, Deep Stabilization, and Special Geotechnical Construction.
NAVFAC DM-22	Petroleum Fuel Facilities, Underground Concrete Storage Tanks.
NAVFAC DM-26.1	Harbors.
NAVFAC DM-26.2	Coastal Protection.
NAVFAC DM-26.3	Coastal Sedimentation and Dredging.
NAVFAC DM-26.4	Fixed Moorings.
NAVFAC DM-26.5	Fleet Moorings.
NAVFAC DM-26.6	Mooring Design Physical and Empirical Data.

TM 5-809-6/AFM 88-3, Chap. 6

Department of the Army

TM 5-312	Military Fixed Bridges.
TM 5-810-1	Mechanical Design: Heating, Ventilating and Air Conditioning.
TM 5-855-1	Fundamentals of Protective Design for Conventional Weapons
TM 5-858-1	Designing Facilities to Resist Nuclear Weapon Effects - Facilities System Engineering.
TM 5-858-2	Designing Facilities to Resist Nuclear Weapon Effects - Weapon Effects.
TM 5-858-3	Designing Facilities to Resist Nuclear Weapon Effects - Structures TM 5-858-4 Designing Facilities to Resist Nuclear Weapon Effects - Shock Isolation Systems.
TM 5-858-5	Designing Facilities to Resist Nuclear Weapon Effects - Air Entrainment, Fasteners, Penetration Protection, Hydraulic-Surge Protective Device, EMP Protective Devices.
TM 5-858-8	Designing Facilities to Resist Nuclear Weapon Effects - Illustrative Examples.
TM 5-811-6	Electric Power Plant Design.
FM 5-36	Route Reconnaissance and Classification.

Corps of Engineers, Coastal Engineering Research Center, (CERC), Kingman Building, Fort Belvoir, VA 22060
Shore Protection Manual, Volumes I, II, and m.

Nongovernment Publications

Aluminum Association, 900 19th Street, NW, Suite 300, Washington, DC 20006

SAS 30-86 Specifications for Aluminum Structures

American Association of State Highway and Transportation Officials (AASHTO), 444 North Capitol Street, NW, Suite 225, Washington, DC 20001

HB-13-83 Standard Specifications for Highway Bridges,

American Concrete Institute (ACI), P.O. Box 19150, Redford Station, Detroit, MI 48219-0150

307-88	Concrete - Design and Construction of Cast-in-Place Reinforced Concrete Chimneys.
313-77 (Revised 1983)	Recommended Practice for Design and Construction of Concrete Bins, Silos, and Bunkers for Storing Granular Materials.
318-89	Building Code Requirements for Reinforced Concrete.
343R-88	Analysis and Design of Reinforced Concrete Bridge Structures.
344R-70 (Reapproved 1981)	Design and Construction of Circular Prestressed Concrete Structures.
344R-T	Design and Construction of Circular Prestressed Concrete Structures with Circumferential Tendons.
344R-W	Design and Construction of Circular Wire and Strand Wrapped Prestressed Concrete Structures.
346-81	Standard Specification for Cast-in-Place Nonreinforced Concrete Pipe.
346R-81	Recommendations for Cast-in-Place Nonreinforced Concrete Pipe.
350R-89	Environmental Engineering Concrete Structures.
357R-84	Guide for the Design and Construction of Fixed Offshore Concrete Structures.
357.1R-85	State-of-the-Art Report on Offshore Concrete Structures for the Arctic.
357.2R-88	State-of-the-Art Report on Bargelike Concrete Structures.
544.1R-82 (Revised 1986)	State-of-the-Art Report on Fiber Reinforced Concrete.

544.2R-78 (Revised 1983)	Measurement of Properties of Fiber Reinforced Concrete.
544.3R-84	Guide for Specifying, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete.
544.4R-88	Design Considerations for Steel Fiber Reinforced Concrete.
SP-81	Fiber Reinforced Concrete- International Symposium.
SP-105	Fiber Reinforced Concrete Properties and Applications.

American Institute of Steel Construction (AISC), 400 North Michigan Avenue, Chicago, IL 60611-4185

Highway Structures Design Handbook, Volumes I and II, (1986).
Specification for Structural Steel Buildings Allowable Stress Design and Plastic Design including Commentary (1989).

American Institute of Timber Construction (AITC), 11818 SE Mill Plain Boulevard, Suite 415,
Vancouver, WA 98684

Timber Design Handbook (1974 and Errata).

American Iron and Steel Institute (AISI), 1000 16th Street, NW, Washington, DC 20036

SG-861-83	Handbook of Steel Drainage & Highway Construction Products,
PS 268-685-5M-SL	Design of Plate Structures,
PS 291-582-10M-NB	Steel Tanks for Liquid Storage,.

American National Standards Institute (ANSI), 1430 Broadway, New York, NY 10018

A58.1-1982 Minimum Design Loads for Buildings and Other Structures.

American Petroleum Institute (API), 1220 L Street, NW, Washington, DC 20005

RP 2A-87	Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms.
620-82	Design and Construction of Large, Welded, Low-Pressure Storage Tanks.
650-88	Welded Steel Tanks for Oil Storage.
RP 1102-81	Liquid Petroleum Pipelines Crossing Railroads and Highways.
1104-88	Welding of Pipelines and Related Facilities.
RP 1110-81	Pressure Testing of Liquid Petroleum Pipelines.
1615-79	Installation of Underground Petroleum Storage Systems.
1632-83	Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems.
2000-82	Venting Atmospheric and Low-Pressure Storage Tanks (Nonrefrigerated and Refrigerated).

American Railway Engineering Association (AREA), 50 F Street, NW, Suite 7702, Washington, DC 20001

Manual for Railway Engineering (Fixed Properties), Volumes I and II, (1988-89).

American Society of Civil Engineers (ASCE), 345 East 47th Street, New York, NY 10017

Design and Construction of Steel Chimney Liners.	
Design of Steel Transmission Pole Structures, (ST12 - Dec 1974).	
Guide for the Design and Use of Concrete Poles.	
Water Treatment Plant Design.	
52-71	Design of Steel Transmission Towers.
368-83	Seismic Response of Buried Pipes and Structural Components.
402-84	Tunnel Lining Design.

TM 5-809-6/AFM 88-3, Chap. 6

418-84 Pipeline Materials and Design.
428-84 Seismic Design of Oil and Gas Pipeline Systems.

American Society of Mechanical Engineers (ASME), 345 East 47th Street, New York, NY 10017
B31.8-86 Gas Transmission and Distribution Piping Systems.
STS-1-1986 Steel Stacks.

American Society for Testing and Materials (ASTM), 1916 Race Street, Philadelphia, PA 19103

A 36/A 36M-88c Structural Steel.
A 53-89 Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless.
A 242/A 242M-88 High-Strength Low-Alloy Structural Steel.
A 500-89 Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes.
A 572/A 572M-8& High-Strength Low-Alloy Columbium-Vanadium Steels of Structural Quality.
A 588/A 588M-88a High-Strength Low-Alloy Structural Steel with 50 ksi [345 MPa] Minimum Yield Point to 4 in. [100 mm] Thick.
A 666-88 Austenitic Stainless Steel, Sheet, Strip, Plate, and Flat Bar for Structural Applications.
A 690/A 690M-88 High-Strength Low-Alloy Steel H-Piles and Sheet Piling for Use in Marine Environments.
B 745/B 745M-89 Corrugated Aluminum Pipe for Sewers and Drains.
C 76-89 Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe.
C 478-90 Precast Reinforced Concrete Manhole Sections.
C 789-88 Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers.
C 850-88 Precast Reinforced Concrete Box Sections for Culverts, Storm Drains, and Sewers with Less Than 2 ft. of Cover Subjected to Highway Loadings.
C 857-87 Minimum Structural Design Loading for Underground Precast Concrete Utility Structures.
C 858-83 Underground Concrete Utility Structures.

American Water Works Association (AWWA), 6666 West Quincy Avenue, Denver, CO 80235

D100-84 Welded Steel Tanks for Water Storage.
D103-87 Factory Coated Bolted Steel Tanks for Water Storage.
D110-86 Wire-Wound Circular Prestressed-Concrete Water Tanks.
D120-84 Thermosetting Fiberglass-Reinforced Plastic Tanks.
M9-79 Concrete Pressure Pipe.
M11-85 Steel Pipe—a Guide for Design and Installation.

Conveyor Equipment Manufacturers Association (CEMA), 932 Hungerford Drive, Suite 36, Rockville, MD 20850

Belt Conveyors for Bulk Materials.

Electronic Industries Association (EIA), 2001 Eye Street, NW, Washington, DC 20006

222-D-86 Structural Standards for Steel Antenna Towers and Antenna Supporting Structures.

Institute of Electrical and Electronics Engineers (IEEE), 345 East 47th Street, New York, NY, 10017

C2-87 National Electrical Safety Code and Interpretations.

National Electrical Manufacturers Association (NEMA), 2101 L Street, NW, Washington, DC 20037

SG-6-79 Power Switching Equipment.

National Fire Protection Association (NFPA), Publications Department, Batterymarch Park, Quincy, MA 02269

211-88 Standard for Chimneys, Fireplaces, Vents and Solid Fuel Burning Appliances.

National Forest Products Association, 1250 Connecticut Avenue, NW, Suite 200, Washington, DC 20036

National Design Specification for Wood Construction (1986 and Supplement).

Portland Cement Association (PCA), 5420 Old Orchard Road, Skokie, IL 60077-1083

EB001T Design and Control of Concrete Mixtures.
IS003.02D Rectangular Concrete Tanks.
IS072.01D Circular Concrete Tanks without Prestressing.

Precast/Prestressed Concrete Institute (PCI), 175 West Jackson Boulevard, Chicago, IL 60604

JR-3M Recommended Practice for Precast Prestressed Concrete Circular Storage Tanks.
MNL-120-85 Design Handbook-Precast and Prestressed Concrete.
MNL-126-85 Manual for the Design of Hollow Core Slabs.
MNL-128-87 Recommended Practice for Glass Fiber Reinforced Concrete Panels.

Sheet Metal and Air Conditioning Contractors' National Association (SMACNA), P.O. Box 70, Merrifield VA 22116

Accepted Industry Practice for Industrial Duct Construction.
Guide for Steel Stack Design and Construction.
Rectangular Industrial Duct Construction Standards.
Round Industrial Duct Construction Standards.

Steel Tank Institute (STI), 728 Anthony Trail, P.O.Box 4020, Northbrook, IL 60065

Dual Wall Underground Steel Storage Tanks.
sti-P3 Specification and Manual for External Corrosion Protection of Underground Steel Storage Tanks.
Recommended Practice for Optional Interior Corrosion Control System for Steel Tanks.
Guideline for Underground Piping for Fuel Storage Tanks.

Water Pollution Control Federation (WPCF), 2626 Pennsylvania Avenue, NW, Washington, DC 20035

MOP8CTG-77 Wastewater Treatment Plant Design.
MOP9CTG-69 Design and Construction of Sanitary and Storm Sewers (Joint publication with ASCE).

Textbooks and Handbooks

Suresh C. Arya, Michael W. O'Neill, and George Pincus, *Design of Structures and Foundations for Vibrating Machines*, Gulf Publishing Company, Houston, TX, 1979.

Omer W. Blodgett, *Design of Welded Structures*, The James F. Lincoln Arc Welding Foundation, Cleveland, OH, 1966.

TM 5-809-6/AFM 88-3, Chap. 6

Joseph E. Bowles, *Foundation Analysis and Design*, Second Edition, *McGraw-Hill Book Company*, New York, NY, 1977.

Braja M. Das, *Principles of Foundation Engineering*, *Wadsworth, Inc.*, Belmont, CA, 1984.

Mark Fintel, *Handbook of Concrete Engineering*, Second Edition, *Van Nostrand Reinhold Company*, New York, NY, 1985.

Edwin H. Gaylord & Charles N. Gaylord, *Structural Engineering Handbook*, Second Edition, *McGraw-Hill Book Company*, New York, 1979.

G. A. Leonards, *Foundation Engineering*, *McGraw-Hill Book Company*, 1962.

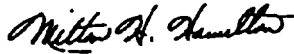
M. Reimbert & A. Reimbert, *Silos: Theory & Practice*, (Bulk Materials Handling Ser: Vol. 1, No. 3), *Trans Tech*, Germany, 1976.

The proponent agency of this publication is the Office of the Chief of Engineers, United States Army. Uses are invited to send comments and suggested improvements on DA Form 2028 (Recommended Changes to Publications and Blank Forms) to HQUSACE, (CEMP-ET), WASH DC 20314-1000.

By Order of the Secretaries of the Army and the Air Force:

Official:

GORDON R. SULLIVAN
General, United States Army
Chief of Staff



MILTON H. HAMILTON
Administrative Assistant to the
Secretary of the Army

Official:

MERRILL A. McPEAK, General, USAF
Chief of Staff

EDWARD A. PARDINI, Colonel, USAF
Director of Information Management

Distribution:

Army: To be distributed in accordance with DA Form 12-34-E, requirements for nonequipment technical manuals.

Air Force: F

