WATER AGENCIES' STANDARDS

Design Guidelines for Water, and Sewer Facilities

SECTION 9.2
STRUCTURAL GUIDELINES

9.2.1 PURPOSE

The purpose of this section is to provide general guidelines for structural design. These design criteria should be considered in the appropriate stage of the design submittals for a pipeline project.

9.2.2 STANDARD TERMS AND DEFINITIONS

Wherever technical terms occur in these guidelines or in related documents, the intent and meaning shall be interpreted as described in Standard Terms and Definitions.

9.2.3 GENERAL

It is the responsibility of the user of these documents to make reference to and/or utilize industry standards not otherwise directly referenced within this document. The Engineer of Work may not deviate from the criteria presented in this section without prior written approval of the Agency's Engineer.

9.2.4 GUIDELINES

This section defines the codes, standards, reports, and design aids to be used in the design of water facility structures.

9.2.5 REFERENCE STANDARDS AND CODES

The current version of the following standards, codes, reports and design aids govern and must be used for the structural design of pumping stations or other water facility structures:

- Building Code Requirements for Minimum Design Loads in Building and Other Structures, ASCE 7 by American Society of Civil Engineers and ANSI A58.1 by American National Standard Institute, Inc.
- Title 24, Part 2, California Building Code.
- Uniform Building Code (UBC) of the International Conference of Building Officials as adopted by the City of San Diego Municipal Code.
- Building Code Requirements for Reinforced Concrete, ACI 318, and commentary ACI 318R, as contained in UBC and as adopted by the City of San Diego Municipal Code.
- Environmental Engineering Concrete Structures (ACI 350 R).
- Concrete Manual by the U. S. Bureau of Reclamation.
- Concrete Reinforcing Steel Institute (CRSI) Handbook.

- Rectangular Concrete Tanks, by Portland Cement Association (PCA).
- Water resources technical publication, Engineering Monograph No. 27, Moments and Reactions for rectangular Plates by the U. S. Department of Interior Bureau of Reclamation.
- American Institute of Steel Construction, Specification of the Design, Fabrication, and Erection of Structural Steel for Buildings, AISC Publication No. S-326.
- American Institute of Steel Construction (AISC) manual of Steel Construction, Allowable Stress Design (ASD).
- The standard specifications for open web, Longspan, and Deep Longspan Steel Joists and Joist Griders.
- Structural Welding Code Steel, ANSI/AWS-D1.1.
- Specification for the Design of Cold Formed Steel Structural Members, by American Iron and Steel Institute (AISI).
- Specification for Aluminum Structures.
- Engineering Data for Aluminum Structures.
- Specifications for the Masonry Structures, ACI 530/ASCE6.
- Reinforced Masonry, Engineering Handbook by Amrhein.
- Timber Construction manual, by the American Institute of Timber Construction (AITC).
- National Design Specifications for Stress-grade Lumber and its Fastenings, by National Forest Product Information.
- Recommended Lateral Force Requirements and commentary by the Seismology Committee of the Structural Engineers Association of California, commonly known as Blue Book, (SEAOC Blue Book).
- Formulas for Stress and Strain, by Roark and Yong.
- Standard of the Occupational Safety and Health Administration (OSHA).
- State of California Construction Safety Orders (Cal-OSHA).

9.2.6 DESIGN LOADS

The following criteria define the minimum design loads to be used in the design of pumping station structures or other water facility structures. Without limiting the generality of the other requirements of these criteria, all design loads must conform to or exceed the requirements of the UBC and all applicable requirements of other documents referenced in paragraph 9.1.15 A of this chapter.

Dead loads, live loads, wind loads, hydrostatic and hydrodynamic loads, lateral loads, seismic loads, impact and vibration loads and miscellaneous loads are described below.

A. Dead Loads:

Dead loads, which are defined as the weight of all permanent construction, including equipment and piping, permanently connected to the water facility structure are determined using the following unit weights:

Material	**Dead Load**
Concrete	150 pcf
Steel	490 pcf
Aluminum	169 pcf
Fiberglass	100 to 115 pcf
Wood	40 pcf
Masonry, concrete block, solid grouted 8 inches wide	75 psf (lightweight) 84 psf (normal weight)
12 inches wide	118 psf (lightweight) 133 psf (normal weight)

In addition to the load of the basic structural elements, the following items are considered dead load:

- All equipment (including all internal and refractory lining) and piping permanently attached to and considered part of the structure, including future equipment and piping.
- Fireproofing used on structural steel, equipment, etc.
- Structural steel platform framing and floor plates (use an estimate of 20 psf). Heavy beams or girders, such as those required to carry other than platform live loads, are considered separately.
- Piping 12 inches in diameter and smaller are treated as uniformly distributed loads. A typical minimum value of 20 psf is used.
- Piping larger than 12 inches in diameter is treated as concentrated loads.

B. Live Loads:

Live loads in addition to concentrated loads are determined as follows:

- Roof Loads: in accordance with the ASCE 7/ANSI A58.1, UBC, or local code, whichever is more stringent.
- Stairs, Platforms, and Walkways: 100 psf or local code, whichever is more stringent.
- Minimum concentrated load on ladders and stairs is in accordance with the requirements of ANSI-A58.1, OSHA, Cal-OSHA or local code, whichever is more stringent.
- Electrical equipment areas are designed for a minimum of 100 psf live load. Additional consideration is given for the type, size, and weight of specific equipment and the maintenance of equipment in determining the actual design live load and concentrated loads. Minimum loads for some specific areas are:

- Pump Room or Generator Floor 150 psf
- Auxiliary Equipment and Control Rooms 250 psf
- Equipment Rooms 200 psf

- Mechanical areas are designed for a minimum 100 psf of live load. Additional consideration should be given for the type, size, and weight of specific equipment and the maintenance of equipment in determining the actual design live load and concentrated loads. Minimum loads for some specific areas are:

  - Equipment Floors 300 psf
  - Shaft, Duct or Vent Floors 100 psf
  - Lifting eyebolts capable of lifting concentrated equipment loads is incorporated into design as live loads.

C. Wind Loads:

Wind loads must be in accordance with the ASCE 7/ANSI A58.1, UBC, on the basis of a minimum basic wind speed of 100 mph and appropriate exposure or the requirements of the local code, whichever is more stringent. Maximum wind or maximum seismic loads govern the design whichever is greater.

D. Hydrostatic and Hydrodynamic Loads:

Pumping station structures are considered environmental engineering structures and are designed for hydrostatic forces imposed by the fluid contained in these structures. All environmental engineering structures are designed for hydrodynamic forces using the ground acceleration and the response spectra provided by the geotechnical report and in accordance with the seismic loads described in this chapter.

E. Lateral Loads:

All pumping station structures, and any other water facility that apply, are designed for the applicable pressures, as follows:

- For all yielding structural components, lateral soil loads are determined by using active soil pressure conditions as recommended in the geotechnical report.

- For all non-yielding structural components, lateral soil loads are determined by using at-rest soil pressure conditions as recommended in the geotechnical report.

- A minimum surcharge pressure equal to an additional 2 feet of soil is used for all structures adjacent to the traffic loading conditions.

- Hydrostatic pressure imposed by the fluid contained is considered in the design. The unit weight of water is 62.4 pcf.

- Hydrostatic pressure imposed by groundwater conditions in addition to lateral soil pressure are considered in the design. The unit weight of water is 62.4 pcf. Lateral pressure distribution is as recommended in the geotechnical report.

- Seismic soil pressure is determined in accordance with current seismic codes

F. Seismic Loads:

Seismic loads must conform to or exceed the current seismic code requirements. Basic guidelines for determining the design ground acceleration and seismic forces include:

- Seismic lateral loads due to soil and water are determined in accordance with the recommendations in the geotechnical report.

All seismic forces must be determined using the preceding guidelines and load factors given in ACI 318 and ACI 350R.

- When selecting ground motions for seismic design of pumping station structures, consider the requirements for uninterrupted operation after a major earthquake.

G. Impact and Vibration Loads:

If applicable, impact and vibration loads are considered in the design as follows:

- Craneways are designed to resist a horizontal transverse force equal to 20% of lifted load plus the weight of the trolley, applied at the top of the rails and distributed with due regard for lateral stiffness of the structure supporting the rails. Craneways must also resist a horizontal longitudinal force equal to 10% of the maximum wheel loads of the crane applied at the top of each rail.

- For structures carrying live loads, which include impact, the assumed live loads must be increased in accordance with the current edition of American Institute of Steel Construction, Specification of the Design, Fabrication, and Erection of Structural Steel for Buildings, AISC Publication No. S-326.

- All forces produced by the equipment or machinery having a tendency to vibrate is considered in the design of supporting structures. The magnitude of force is obtained from the equipment supplier for use in the design.

- Impact forces due to process operation such as surging fluid.

H. Miscellaneous Loads:

If applicable, miscellaneous loads are considered in the design as follows:

- Miscellaneous loads of a special nature, such as thrust from expansion joints and special appurtenances.

- Surcharge loads, such as due to adjacent structures and vehicular loads.

- Thermal loads.

- Operating pressure forces, forces due to surging fluids and test forces and loads.

- Construction loads and conditions.

9.2.7 LOADING COMBINATIONS

Structures are designed for various loading conditions. As a minimum the following load combinations are determined:

- Static soil pressure (active or at rest) plus hydrostatic loading plus hydrodynamic loading plus seismic forces due to dead loads.

- Static soil pressure (active or at rest) plus seismic soil pressure plus seismic forces due to dead loads plus permanent surcharge.

- Suspended Slabs Walls and Roofs: Dead loads plus seismic dead loads or wind load, whichever is greater, plus percent of live load as required by the UBC.

9.2.8 ALLOWABLE STRESSES

All allowable stresses listed in the following paragraphs may be increased by 33% for seismic loading for evaluations performed using working stress methods.

A. Reinforced Concrete Structures:

Allowable stresses for concrete structures must be in accordance with ACI 318/ACI 350R.

B. Steel and Aluminum Structures:

Unless modified for various major facilities, the allowable stress steel members and connectors must be in accordance with the requirements of the allowable stress design method of the AISC specification.

Allowable stress for aluminum members must be in accordance with the requirements of the specifications of the Aluminum Association.

C. Masonry Structures:

Allowable stresses for masonry structures must be in accordance with the requirements of the ACI 530 and UBC.

D. Timber Structures:

Allowable stresses for timber structures must be in accordance with the requirements of the National Design Specifications for Stress-Grade Lumber and its Fasteners, Timber Construction Manual by AITC and UBC.

9.2.9 STRUCTURAL DESIGN REQUIREMENTS

A. Reinforced Concrete Structures:

Reinforced concrete structures are designed using the strength design method or the working stress method pursuant to the following requirements:

- The structural design of reinforced concrete environmental engineering structures and support facility structures must be in accordance with the general requirements of ACI 318 and ACI 350R.

- Reinforced concrete environmental engineering structures are designed for strength and serviceability. The strength design method and the working stress design method (an alternative design method) are acceptable methods of reinforced concrete design.

- The structural engineer must establish the design criteria for each structure within the limitations of the ACI and the UBC.

- **Strength Design Method.** Use the following guidelines in applying the strength design method:

    - All concrete support facility structures such as administration, operation, and process building which are not considered environmental engineering structures (hydraulic structures) must be designed by the strength design method in accordance with ACI 318.

    - All environmental engineering structures (hydraulic structures) are **not recommended** for design by the **strength design method** in accordance with ACI 318. However, if structural engineers choose to use the **strength design method,** the load factors of ACI 318 are modified in accordance with the ACI 350R. The load factor modifications must be in accordance with Section 2.6.5 of ACI 350R.

    - Serviceability requirements for both support facility structures and environmental engineering structures must be in accordance with the provisions of the ACI 318 and Section 2.6.6 of the ACI 350R.

- **Working Stress Design (Alternative Design Method).** Use the following guidelines in applying the working stress design:

    - The alternative design method must be in accordance with the ACI 318, Appendix A, and the exceptions given in Section 2.6.7 of the ACI 350R.

- **Minimum Material Strength.** Minimum strengths for concrete and reinforcing steel are:

    - Concrete: 28 day compressive stress of 4,000 psi.

    - Reinforcing Steel: Yield strength of 60,000 psi per ASTM A615.

- **Joints.** Expansion, contraction and construction joints must be provided in accordance with ACI 350R to allow flexibility and to adequately tolerate differential movements, as well as temperature and shrinkage stress. All types of joints in environmental engineering structures are provided with waterstops and sealant where water tightness is required. All joint detailing, type and location criteria must be in accordance with Section 2.8 of ACI 350R. The locations of all joints are shown on the drawings.

- **Expansion Joints.** In general, expansion joints are provided at abrupt changes in the structural configuration.

- **Contraction Joints.** Contraction joints are a type of movement joint used to dissipate shrinkage stresses. If used, contraction joint spacing is at intervals not to exceed 24 feet, unless additional reinforcement is provided in accordance with Figure 2.5 of the ACI 350R. For environmental engineering structures in high seismic zones, partial contraction joints where 50% of the reinforcement passes through the joint are used.

- **Construction Joints.** Construction joints are located so as to least impair the strength of the structure, to provide logical separation between segments of the structure, and to facilitate construction. All reinforcement is continued across or through the joint unless designed as a contraction or expansion joint.

- **Lifting Devices.** Lifting devices are provided as required. Lifting devices have galvanized coating to reduce corrosion and are mechanically connected to rebar where reinforced concrete construction is used.

- Current seismic codes criteria.

B. Steel Structures:

Steel structures must be designed in accordance with the requirements of AISC specifications and following additional requirements:

- **Seismic Design.** Seismic design must be in accordance with paragraph 9.1.12 A.6 of this chapter and current seismic codes criteria.

- **Minimum Material Strength.** Minimum strength is as follows:

  - All structural steel shapes, plates, and bars must be ASTM A36.

  - Structural steel pipe must be ASTM A501 or ASTM A53, Type E or S, Grade B.

  - Structural tubing must be ASTM A500, Grade B.

  - Composite beam with formed steel deck (FSD) may be used for floor support. Economics determine the usage. Composite design must be in accordance with the requirements of the AISC, Manual of Steel Construction.

  - Formed steel deck must be in accordance with the requirements of AISI specifications.

  - Open web, longspan and deep longspan steel joists can be used for roof support; camber and other requirements must comply with the specifications of SJI.

  - Crane supports are designed for a maximum deflection of 1/450 times the span or as required by the equipment manufacturer, whichever is more restrictive.

  - All aluminum shapes, plates, bars and pipes must meet minimum requirements of ASTM 6061-T6 alloy.

  - All stainless steel shapes, plates, bars, pipes, anchor bolts and fasteners must meet the requirements of ASTM A167 and ASTM 276, Type 316.

- **Joints.** Structural joints or connections are bolted or welded and must be designed in accordance with the requirements of AISC Specifications and the following additional requirements:

- Connection bolts must be ASTM A307, A325 or A490. When high strength bolts are used, Type N connections are used for regular framing design. When structural members are subjected to vibration, cyclic or fatigue loading SC connections are used.

- Connections are designed for all tributary forces and the minimum force is 6 kips.

- All welding must be in accordance with the requirements of ANSI/AWS D1.1 code. All butt and bevel welds are complete penetration. E70XX electrocodes are used.

- Shop connections are either welded or bolted. Use field bolt connections when possible.

- All aluminum and stainless steel connections must be made with type 316 stainless steel fasteners meeting the requirements of ASTM A167 and ASTM A276.

C. Masonry Structures:

Masonry structures must be designed in accordance with the requirements of Specifications for the Masonry Structures, ACI 530/ASCE 6, UBC, and the following additional requirements:

- **Seismic Design.** Seismic design must be in accordance with the paragraph 9.1.15 B.6 of this chapter and current seismic codes criteria.

- **Minimum Material Strength.** Minimum strength is as follows:

  - Concrete Blocks: 28 days compressive strength of 1,500 psi meeting the minimum requirements of ASTM C 90, grade N, Type I.

  - Mortar for Unit Masonry: Meeting the minimum requirements of ASTM C270, type M or S, or the requirements of UBC.

  - Reinforcing Steel: Yield strength of 60,000 psi per ASTM A615.

  - Cold-Drawn Steel Wire: ASTM A82.

  - Mortar and Grout for Reinforced Masonry: Meeting the minimum requirements of ASTM C476 or the requirements of UBC.

- **Joints.** Expansion and control joints must be provided in accordance with the requirements of ACI 530/ASCE 6, UBC, and the Engineering Handbook Reinforced Masonry by Amrhien.

D. Timber Structures:

Timber structures must be designed in accordance with the requirements of the National Design Specification for Stress-Grade Lumber and its Fastenings, UBC, and the following additional requirements:

- **Seismic Design.** Seismic design must be in accordance with paragraph 9.1.12 B.6 of this chapter and current seismic codes criteria.

- **Minimum Material Strength.** Minimum strength is as follows:

  - Beams and Stringers: Douglas Fir-Larch (surface dry or green used at 19% maximum moisture content).

- Plywood: Douglas Fir Plywood, Structural Type I.

- Allowable Stresses: Refer to paragraph 6.12.4.D of this chapter.

- **Joints.** Structural joints or connections are bolted type and must be designed in accordance with the requirements of the National Design Specifications for Stress-Grade Lumber and its fasteners and the UBC.

9.2.10 DETAILING

Detailing is performed in accordance with the seismic provisions of the following codes and references:

A. The latest edition of UBC.

B. The provisions in Chapter 21 of the latest edition of ACI 318.

C. The provisions in the latest edition of ACI 350R.

D. Detailing of different structural elements to ensure that ductility and other requirements are in accordance with the requirements of the UBC and SEAC Blue Book.

E. Current seismic codes criteria.

9.2.11 MAJOR ELEMENT DESIGN REQUIREMENTS

These procedures define general guidelines for the DESIGN CONSULTANT when designing major elements of pumping station structures or other water facility structures.

A. Concrete Slab:

The following structural concepts must be considered when designing reinforced concrete slab:

- A one-way or two-way slab system with beams.

- When the slab system is rigidly connected to the walls, a frame analysis is performed in which the relative rigidity and stiffness of the different elements are considered.

- Control, construction and contraction joints must be provided in the slab structure system in accordance with the ACI 350R. Roof joints are aligned with wall joints.

- On large exposed slabs used in pumping station structures requiring expansion joints, ductile moment resisting frames are provided to resist seismic forces. The maximum recommended spacing for expansion joints is 120 feet.

B. Concrete Walls:

The following structural concepts are considered in designing concrete walls:

- Cantilever walls, which are considered yielding walls, and active soil pressure.

- Walls restrained at the top, which are considered non-yielding walls, and at rest soil pressures.

- For long structures, where walls are designed as cantilever, consider restraint at the end or cross walls.

- Contraction, construction and expansion joints must be provided in walls in accordance with ACI 350R. All wall joints should line up with slab joints. The maximum recommended spacing of expansion joints is 120 feet. All joints are provided with water stops.

- Reinforced concrete walls over 10 feet high in contact with water shall have a minimum thickness of 12 inches. The minimum wall thickness of any reinforced concrete structure is 8 inches.

C. Concrete Foundation:

Unless groundwater or other geotechnical requirements dictate a mat foundation, the foundation consists of a spread-footing cast monolithically with the floor slabs. Floor slabs are designed as a membrane reinforced concrete slab with a minimum 6-inch thickness. The floor slab is provided with contraction, construction and expansion joints detailed and spaced to allow movement at these joints and to adequately tolerate differential settlement, temperature and shrinkage stresses.

Where a mat foundation is required, it is designed as a slab on an elastic foundation or by other accepted rational method.

All foundations and floor slabs must be provided with contraction, construction, contraction and expansion joints in accordance with the recommendation of the ACI 350R. All joints are provided with water stops.

D. Equipment Footing:

Equipment support is designed for the maximum load under operating or testing conditions. Only 50% of floor live load is combined with the test loading in the design. Test and seismic loading need not be combined.

The most unfavorable effects from wind and seismic loads are considered in the design. Wind and seismic loads are assumed not to be acting on the equipment simultaneously. The factor of safety against wind and seismic overturning and sliding is not less than 1.5. Piping connected to the equipment may not be used as a means to resist the wind or seismic loading.

Movement and shear acting on equipment support caused by removing any components from the equipment is considered in support design.

E. Support for Rotating and Reciprocating Equipment:

The effect of impact, vibration, and torque from the equipment must be considered in accordance with the requirements of Section 2.9, ACI 350R. In the absence of equipment data required for the support structure vibration design, preliminary support is sized by $W_1/W_2 = 3$ (minimum).

Where: W_2 = weight of equipment

W_1 = weight of supporting structure, or

= in horizontal direction, weight of entire diaphragm, or

= in vertical direction, weight of an area equal to the shadow area + 2t (where t = thickness of supporting slab), or

= weight of pedestal

Final support design must be in accordance with the requirements of Section 2.9, ACI 350R.

Support is isolated from the surrounding slab to minimize the effect of vibration on adjacent structure whenever possible.

Equipment is anchored to the support using anchor bolts. Bolts are designed for vibration, impact, torque, seismic and wind loading. Only type 316 stainless steel bolts are used to anchor equipment. Minimum bolt size is 3/4-inch. Expansion anchors may not be used to anchor equipment. Current seismic codes criteria shall also apply.

9.2.12 REFERENCE

A. Should the reader have any suggestions or questions concerning the material in this section, contact one of the member agencies listed.

B. The publications listed below form a part of this section to the extent referenced and are referred to in the text by the basic designation only. Reference shall be made to the latest edition of said publications unless otherwise called for. The following list of publications, as directly referenced within the body of this document, has been provided for the users convenience. It is the responsibility of the user of these documents to make reference to and/or utilize industry standards not otherwise directly referenced within this document.

1. Water Agencies' Standards (WAS):

a. Design Guidelines:

1. Section 9.1, Water Pump Station Design

END OF SECTION