Engineering Standard

SAES-M-001 19 December 2010

Structural Design Criteria for Non-Building Structures

Document Responsibility: Onshore Structures Standards Committee

Saudi Aramco DeskTop Standards

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1 Scope

This standard covers the mandatory minimum requirements governing the structural design of all onshore facilities except buildings, pre-engineered buildings, blast resistant buildings, communication towers and offshore structures.

Commentary Notes:

A building is defined as an enclosed structure, such as a house, office building, maintenance shop, warehouse, etc. Buildings are covered by SAES-M-100, "Saudi Aramco Building Code."

Communication towers are covered by SAES-T-744, "Design Criteria and Installation of Communication Towers". The criteria for design of communication towers vary significantly from AISC and therefore, SAES-T-744 must be applied to these structures.

Offshore structures are covered by SAES-M-005, "Design and Construction of Fixed Offshore Platforms", which is based on API RP2A. API RP2A varies significantly from AISC and therefore must be used for the design of offshore structures.

Pre-Engineered Buildings are covered by 12-SAMSS-014.

Blast-Resistant Buildings are covered by SAES-M-009.

2 Conflicts and Deviations

2.1 Any conflicts between this standard and other applicable Saudi Aramco Engineering Standards (SAESs), Materials System Specifications (SAMSSs), Standard Drawings (SASDs), or industry standards, codes and forms shall be resolved in writing by the Company or Buyer Representative through the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

2.2 Direct all requests to deviate from this specification in writing to the Company or Buyer Representative, who shall follow internal company procedure SAEP-302 and forward such requests to the Manager, Consulting Services Department of Saudi Aramco, Dhahran.

3 References

The selection of material and equipment, and the design construction, maintenance, and repair of equipment and facilities covered by this standard shall comply with the latest edition of the following applicable codes, standards, specifications, and references in effect on the date of contract award shall be used, except as otherwise specified.

3.1 Saudi Aramco References

Saudi Aramco Engineering Procedures

SAEP-302 *Instructions for Obtaining a Waiver of a*

Mandatory Saudi Aramco Engineering Requirement

SAEP-1142	*Qualification of Non-Saudi Aramco NDT Personnel*

Saudi Aramco Engineering Standards

SAES-A-112	*Meteorological and Seismic Design Data*
SAES-A-204	*Preparation of Structural Calculations*
SAES-B-006	*Fireproofing for Plants*

Commentary Note:

> *SAES-B-006, "Fireproofing for Plants", is used to determine fireproofing requirements for steel structures. Standard Drawing AD-036711 details the minimum normal weight concrete cover that will provide the protection required by SAES-B-006. The use of normal weight concrete fireproofing may result in a significant increase in the structural member size because of additional dead load and wind exposure area but normally is the least expensive fireproofing material. In some instances, the use of lightweight concrete or other fireproofing materials may be more cost-effective and should be evaluated in cooperation with the Chief Fire Prevention Engineer, Loss Prevention Department.*

SAES-B-054	*Access, Egress, and Material Handling for Plant Facilities*
SAES-B-055	*Plant Layout*
SAES-L-310	*Design of Plant Piping*
SAES-L-410	*Design of Pipelines*
SAES-L-440	*Anchors for Buried Pipelines*
SAES-M-100	*Saudi Aramco Building Code*
SAES-Q-001	*Criteria for Design and Construction of Concrete Structures*
SAES-Q-005	*Concrete Foundations*
SAES-Q-006	*Asphalt Concrete Paving*
SAES-Q-007	*Foundations and Supporting Structures for Heavy Machinery*
SAES-Q-009	*Concrete Retaining Walls*
SAES-Q-010	*Cement Based, Non-Shrink Grout for Structural and Equipment Grouting*

SAES-Q-011	*Epoxy Grout for Machinery Support*
SAES-Q-012	*Criteria for Design and Construction of Precast and Prestressed Concrete Structures*

Saudi Aramco Materials System Specifications

09-SAMSS-097	*Ready-Mixed Portland Cement Concrete*
12-SAMSS-007	*Fabrication of Structural and Miscellaneous Steel*
12-SAMSS-008	*Erection of Structural and Miscellaneous Steel*

Saudi Aramco Standard Drawings

AA-036322 Sht. 001 (Rev. 08 or later)	*Anchor Bolt Details - Inch and Metric Sizes*
AD-036711 Sht. 001	*Concrete Fireproofing for Structural Members*

Saudi Aramco Best Practice

SABP-M-006	*Wind Loads on Pipe Racks and Open Frame Structures*

3.2 Industry Codes and Standards

American Association of State Highway & Transportation Officials (AASHTO)

AASHTO HB	*Specifications for Highway Bridges*

American Concrete Institute (ACI)

ACI 318/318R	*Building Code Requirements for Structural Concrete and Commentary*
ACI 350	*Code Requirements for Environmental Engineering Concrete Structures*
ACI 530/ASCE 5/TMS402	*Building Code Requirements for Masonry Structures*

American Institute of Steel Construction (AISC)

AISC	*Steel Construction Manual – Thirteenth Edition*
AISC	*Specification for Structural Joints Using ASTM A325 or ASTM A490 Bolts*
ANSI/AISC 341	*Seismic Provisions for Structural Steel Buildings*

American Iron and Steel Institute (AISI)

AISI – SG 673, Part I	*Specification for the Design for Cold-Formed*

Steel Structural Members

AISI – SG 673, Part II	*Commentary on the Specification for the Design for Cold-Formed Steel Structural Members*
AISI – SG 913, Part I	*Load and Resistance Factor Design Specification for Cold-Formed Steel Structural Members*
AISI – SG 913, Part II	*Commentary on the Load and Resistance Factor Design Specification for Cold-Formed Steel Structural Members*

American National Standards Institute (ANSI)

ANSI A1264.1	*Safety Requirements for Workplace Walking/Working Surfaces and Their Access - Workplace Floor, Wall and Roof Openings - Stairs and Guardrails Systems*

American Petroleum Institute (API)

API STD 650	*Welded Steel Tanks for Oil Storage*

American Society of Civil Engineers (ASCE)

ASCE/SEI 7-05	*Minimum Design Loads for Buildings and Other Structures*
SEI/ASCE 37-02	*Design Loads on Structures During Construction*
ASCE - Report	*Guidelines for Seismic Evaluation and Design of Petrochemical Facilities*
ASCE - Report	*Wind Loads and Anchor Bolt Design for Petrochemical Facilities*

American Society of Mechanical Engineers (ASME)

ASME A17.1	*Safety Code for Elevators and Escalators*

American Society for Testing and Materials (ASTM)

ASTM A36/A36M	*Standard Specification for Carbon Structural Steel*
ASTM A193/A193M	*Standard Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications*
ASTM A307	*Standard Specification for Carbon Steel Bolts and Studs, 60,000 psi Tensile Strength*

ASTM A325	*Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength*
ASTM A325M	*Standard Specification for Structural Bolts, Steel, Heat Treated 830 MPa Minimum Tensile Strength [Metric]*
ASTM A354	*Standard Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners*
ASTM A490	*Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength*
ASTM A490M	*Standard Specification for High-Strength Steel Bolts, Classes 10.9 and 10.9.3, for Structural Steel Joints (Metric)*
ASTM A572/A572M	*Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel*
ASTM A992/A992M	*Standard Specification for Structural Steel Shapes*

The American Welding Society (AWS)

AWS D1.1/ D1.1M	*Structural Welding Code - Steel*

Crane Manufacturers Association of America (CMAA)

Spec #70	*Specifications for Top Running Bridge and Gantry Type Multiple Girder Electric Overhead Traveling Cranes*
Spec #74	*Specifications for Top Running and Under Running Single Girder Electrical Overhead Cranes Utilizing Under Running Trolley Hoist*

Precast / Prestressed Concrete Institute (PCI)

PCI - MNL 120	*Design Handbook, Precast and Prestressed Concrete*
PCI - MNL 122	*Architectural Precast Concrete*

Steel Deck Institute (SDI)

Design Manual for Composite Decks, Form Decks and Roof Decks - No. 31

Steel Joist Institute (SJI)

Standard Specifications and Load Tables for Steel Joists and Joist Girders

3.3 Government Regulations

Federal Standards and Instructions of the Occupational Safety and Health Administration (OSHA 1910), including any requirements by Saudi Aramco Standards O-Series, Safety & Security Standards.

US Department of Labor, Occupational Safety and health Administration (OSHA)

OSHA 29 CFR 1910 *Occupational Safety and Health Standards*

OSHA 29 CFR 1926 *Safety and Health Regulations for Construction*

4 Design References

a) SAES-A-112 shall be used for determining the temperature variance, wind loads and the earthquake seismic acceleration values to be used for design.

b) SAES-B-006 shall be used to determine fireproofing requirements for steel structures in hydrocarbon processing plants or outside plant plot limits where flammable materials are present. The dead load due to structural fireproofing shall be included in the design, where applicable.

c) SAES-B-054 shall be used to provide for safe means of access and maintenance in the layout and design of structures.

d) SAES-B-055 shall be used to provide for minimum horizontal and vertical spacing or clearance requirements of structures.

e) SAES-L-440 shall be used for the design of reinforced concrete or structural steel anchors used on buried pipelines.

f) SAES-Q-007 shall be used for designing supports for heavy machinery.

g) SAES-Q-010 shall be the basis for the selection of cement based, non-shrink grout for use in equipment grouting and various structural applications.

h) SAES-Q-011 shall be the basis used for the design and installation of epoxy grout.

i) Specifications 12-SAMSS-007 and 12-SAMSS-008 cover the requirements fabrication and erection of structural steel.

j) Standard Drawing AD-036711 shall be used for detailing and inclusion in procurement and installation documentation as the minimum fireproofing requirements for structural steel structures or portions of structures identified in accordance with SAES-B-006.

k) The AISC shall be the basis for the design, fabrication, and erection of steel structures. Commonly accepted structural steel shapes other than those specified in the manual may be used in accordance with Appendix 1 of 12-SAMSS-007.

Commentary Note:

> *Universal Beams and Universal Columns (UB & UC) and split tees rolled to BS EN 10025-2 S355JR/JO may be used as substitutes for W & WT shapes. Commonly accepted shapes include shapes specified to Japanese Standards (JS), British Standards (BS), European Standards (EuroNorm) and German Standards (DIN).*

l) The American Iron and Steel Institute (AISI SG-673) document shall be the basic standard for the design of cold-formed steel members.

Commentary Note:

> *AISI SG-673 & SG-913, Specifications for Cold-Formed Steel Structural Members, is specified for the design of all structural members that are cold-formed, have curved corner sections, and high forming-induced stress concentrations.*

m) CMAA Spec #70 and CMAA Spec #74 shall be the basis for the design of the supports for traveling cranes.

n) AASHTO Specification for Highway Bridges shall be used for minimum design requirements for structural steel and reinforced concrete bridges, culverts and pipeline crossing.

Commentary Note:

> *Structural steel bridges must conform to special criteria, including cambered longitudinal members, restrictive fabrication tolerances, special fatigue allowances and stiffness criteria. AASHTO Specifications for Highway Bridges is specified for the design of all bridges. Bridge design shall also consider any truck loadings, military vehicle loadings, and Saudi Aramco equipment loadings unique to Saudi Arabia or Saudi Aramco operational areas which may significantly exceed AASHTO standard truck loads of HS20 (Refer to SAES-Q-006 for traffic loads).*

o) ANSI A1264.1 shall be used for design requirements for platforms, runways, stair railings, guard rails and toeboards.

p) ASCE/SEI 7-05 shall be used for minimum design load requirements.

q) AWS D1.1/D1.1M shall be used for all structural welding.

5 Design Loads

5.1 General

5.1.1 New facilities, and other structures, including floor slabs and foundations, shall be designed to resist the minimum loads defined in ASCE/SEI 7-05, and this section. The design shall be adequate for the structure's intended use in accordance with commonly accepted engineering practice and the requirements of this section.

5.1.2 In addition to the loads in this section, other loads shall be considered as appropriate. These loads shall include, but are not limited to, snow, ice, rain, hydrostatic, dynamic, upset conditions, earth pressure, vehicles, buoyancy, and erection.

5.1.3 Future loads shall be considered when specified in the project specifications or by Saudi Aramco.

5.1.4 For existing facilities, actual loads may be used in lieu of the minimum specified loads.

5.1.5 Eccentric loads (piping, platforms, etc.) shall be considered. This particularly applies to horizontal and vertical vessels and exchangers.

5.2 Dead Loads (D)

5.2.1 Dead loads are the actual weight of materials forming the structure, foundation, and all permanently attached appurtenances.

5.2.2 Weights of fixed process equipment and machinery, piping, valves, electrical cable trays, and the contents of these items shall be considered as dead loads.

5.2.3 For this Practice, dead loads are designated by the following nomenclature:

D_s, D_f, D_e, D_o, and D_t, where:

D_s = Structure dead load is the weight of materials forming the structure, foundation, soil above the foundation resisting uplift, and all permanently attached appurtenances (e.g., lighting, instrumentation, HVAC, sprinkler and deluge systems, fireproofing, and insulation, etc.). D_s does not include the empty weight of process equipment, vessels, piping, or cable trays which are covered below.

D_f = The erection weight of process equipment or vessels (as further defined in Section 5.2.4.1).

D_e = Empty dead load is the empty weight of process equipment of process equipment, vessels, tanks, piping, and cable tray (as further defined in Sections 5.2.4 through 5.2.6).

D_o = Operating dead load is the empty weight of process equipment, vessels, tanks, piping, and cable trays plus the maximum weight of contents (fluid load) during normal operation (as further defined in Sections 5.2.4 through 5.2.6).

D_t = Test dead load is the empty weight of process equipment or vessels, and/or piping plus the weight of the test medium contained in the system (as further defined in Section 5.2.4.4).

5.2.4 Process Equipment Loads

5.2.4.1 Erection dead load (**D_f**) for process equipment is normally the fabricated weight and is generally taken from the certified vessel drawing.

5.2.4.2 Empty dead load (**D_e**) for process equipment and vessels is the empty weight of the equipment or vessels, including all attachments, trays, internals, insulation, fireproofing, agitators, piping, ladders, platforms, etc. Empty dead load also includes weight of machinery (e.g., pumps, compressors, turbines, and packaged units).

5.2.4.3 Operating dead load (**D_o**) for process equipment and vessels is the empty dead load plus the maximum weight of contents (including packing/catalyst) during normal operation.

5.2.4.4 Test dead load (**D_t**) for process equipment and vessels is the empty dead load plus the weight of test medium contained in the system. Test medium shall be as specified in the contract documents or by Saudi Aramco. Unless otherwise specified, a minimum specific gravity of 1.0 shall be used for the test medium. Equipment and pipes that may be simultaneously tested shall be included. Cleaning load shall be used for test dead load if higher than hydrotest load (e.g., the cleaning fluid is heavier than water).

5.2.4.5 Large vapor lines may require hydrotesting. If so, it may be possible to test them one at a time while the other lines on the support are empty and thus avoid the heavy pipe support loading. When such procedures are used, special notes should be placed on the structural and piping drawings to specify test procedures. Small vapor lines are normally considered filled with water.

5.2.4.6 For major equipment, the manufacturer's certified equipment loads shall be used in the design.

5.2.5 Pipe Rack Piping Loads

5.2.5.1 Piping loads on pipe racks shall be considered dead loads and shall be estimated as follows, unless actual load information is available and warrant otherwise:

a. Operating dead load (Do): A uniformly distributed load of 40 psf (1.9 kPa) for piping, product, and insulation.

Comment:

This is equivalent to 8-inch (203-mm) diameter, Schedule 40 pipes, full of water, at 15-inch (381-mm) spacing.

b. Empty dead load (De): For checking uplift and components controlled by minimum loading, 60% of the estimated piping operating loads shall be used if combined with wind or earthquake unless the actual conditions require a different percentage.

c. Test dead load (D_t) is the empty weight of the pipe plus the weight of test medium contained in a set of simultaneously tested piping systems. The test medium shall be as specified in the contract documents or as specified by the owner. Unless otherwise specified, a minimum specific gravity of 1.0 shall be used for the test medium.

5.2.5.2 For any pipe larger than 12-inch (304-mm) nominal diameter, a concentrated load, including the weight of piping, product, valves, fittings, and insulation shall be used in lieu of the 40 psf (1.9 kPa). This load shall be uniformly distributed over the pipe's associated area.

5.2.5.3 Pipe racks and their foundations shall be designed to support loads associated with full utilization of the available rack space and any specified future expansion.

5.2.6 Pipe Rack Cable Tray Loads

Dead loads for cable trays on pipe racks shall be estimated as follows, unless actual load information is available and requires otherwise:

a. Operating dead load ($\mathbf{D_o}$): A uniformly distributed dead load of 20 psf (1.0 kPa) for a single level of cable trays and 40 psf (1.9 kPa) for a double level of cable trays.

Comment:

These values estimate the full (maximum) level of cables in the trays.

b. Empty dead load ($\mathbf{D_e}$): For checking uplift and components controlled by minimum loading, a reduced level of cable tray load (i.e., the actual configuration) should be considered as the empty dead load. Engineering judgment shall be exercised in defining the dead load for uplift conditions.

5.2.7 Ground Supported Storage Tank Loads

Dead loads for ground supported storage tanks are shown using the same nomenclature as other dead loads in this document for consistency.
As discussed below, the individual load components making up the dead loads may have to be separated for actual use in design.

a. Operating dead load (Do): Operating dead load for a ground supported storage tank is made up of the metal load from the tank shell and roof, vertically applied through the wall of the tank in addition to the fluid load from the stored product. The fluid load acts through the bottom of the tank and does not act vertically through the wall of the tank. Therefore, the metal dead load and the fluid load must be used separately in design.

b. Empty dead load (De): For checking uplift and components controlled by minimum loading, the corroded metal weight (when a corrosion allowance is specified) should be considered as the empty dead load.

c. Test dead load (D_t): Test dead load for a ground-supported storage tank is made up of the metal load from the tank shell and roof, vertically applied through the wall of the tank, in addition to the fluid load from the test medium. The fluid load acts through the bottom of the tank and does not act vertically through the wall of the tank. Therefore, the metal dead load and the fluid load must be used separately in design. The test medium shall be as specified in the contract documents or as specified by the owner. Unless otherwise specified, a minimum specific gravity of 1.0 shall be used for the test medium.

5.3 Live Loads (L)

5.3.1 Live loads are those gravity loads produced by the use and occupancy of the structure. These include the weight of all movable loads, such as personnel, tools, miscellaneous equipment, movable partitions, wheel loads, parts of dismantled equipment, stored material, etc.

5.3.2 Areas for maintenance use (i.e., heat exchanger tube bundle servicing) shall be designed to support these loads.

5.3.2.1 Areas of floors that support mechanical equipment shall be designed to include loads that may be produced during maintenance by workers, equipment, and material.

5.3.2.2 Maintenance loads are temporary forces caused by dismantling, repair or painting of equipment. They shall be considered in load combinations as live loads.

5.3.3 Minimum live loads shall be in accordance with ASCE/SEI 7-05, applicable codes, standards, and, unless otherwise specified, in Table 1.

Table 1 – Minimum Live Loads

	Uniform**	**Concentrated****
Stairs and Exitways	100 psf (4.8 kN/m^2)	1,000 lb (4.5 kN)
Operating, Access Platforms, and Walkways	75 psf (3.6 kN/m^2)	1,000 lb (4.5 kN)
Control, I/O, HVAC Room Floors	100 psf (4.8 kN/m^2)	1,000 lb (4.5 kN)
Manufacturing Floors and Storage Areas: Light	125 psf (6.0 kN/m^2)	2,000 lb (9.0 kN)
Heavy	250 psf (12.0 kN/m^2)*	3,000 lb (13.5 kN)
Ground Supported Storage Tank Roof	25 psf (1.2 kN/m^2)	NA

*This 250 psf (12.0 kN/m^2) live load includes small equipment.
**The loads provided in this table are to be used unless noted otherwise in the contract documents.

5.3.4 Uniform and concentrated live loads listed in Table 1 need not be applied simultaneously.

5.3.5 According to ASCE/SEI 7-05, concentrated loads equal to or greater than 1,000 pounds (4.5 kN) may be assumed to be uniformly distributed over an area of 2.5 feet (762 mm) by 2.5 feet (762 mm), and shall be located so as to produce the maximum load effects in the structural members.

5.3.6 Stair treads shall be designed according to OSHA regulations or building code as applicable.

5.3.7 Live loads reductions shall be as permitted in ASCE/SEI 7-05. For manufacturing floor areas not used for storage, the live load reduction permitted by SEI/ASCE 7-05 for lower live loads may be used.

5.3.8 Pipeline and pipe support structure loads shall be calculated in accordance with SAES-L-310, SAES-L-410 and SAES-L-440.

5.3.9 Fluid surge loads: Forces due to surging action of liquids or fluidized solids in process equipment or piping shall be considered in the design of structures. They shall be considered in load combinations as ***live loads.***

5.3.10 Fixed ladder and runway loads shall be as specified in ANSI A1264.1.

5.3.11 The loadings on handrail and guardrail for process equipment structures shall be per OSHA 1910.

5.3.12 For uses not designated, the live load shall be determined in a manner satisfactory to the Supervisor, Civil Engineering Unit, Rotating Equipment & Civil Engineering Division, Consulting Services Department, Dhahran, and specified in the design documentation.

5.4 Wind Loads (W, Wp)

5.4.1 Wind loads shall be computed and applied in accordance with ASCE/SEI 7 - *05*, and the recommended guidelines for open frame structures, pressure vessels, and pipe racks in ASCE's *Wind Loads and Anchor Bolt Design for Petrochemical Facilities.*

5.4.2 Wind load calculations shall be based on basic wind speed V of 3-second gust speed at 33 ft (10 m) above the ground and associated with an annual probability 0.02 of being equaled or exceeded (50-year mean recurrence interval). The basic wind speed V for each site is defined in SAES-A-112, *Meteorological and Seismic Design Data*.

5.4.3 The Importance Factor I used to compute wind pressures shall be based on Table 6-1 of ASCE 7-05 and on the appropriate Occupancy Category from Table 1-1 of ASCE 7-05 as amended below:

- Car sunshades shall use Occupancy Category I (I = 0.87)
- All structures within facilities that manufacture, process, handle, store, process, use, or dispose of toxic or explosive substances shall use Occupancy Category IV (I = 1.15)

5.4.4 Exposure Category C shall be used, except for structures close to the shoreline, as defined in ASCE/SEI 7-05, where Exposure Category D shall be used. The Exposure category for each site is defined in SAES-A-112, *Meteorological and Seismic Design Data*.

Commentary Note:

> *For detailed wind load calculations on pipe racks, refer to the guidelines specified in Saudi Aramco Best Practice SABP-M-006 "Wind Loads on Pipe Racks and Open Frame Structures".*

5.4.5 The full design wind load shall be used when calculating wind drift (see Section 7.7).

5.4.6 A solid width of 1.5 ft (460 mm) shall be assumed when calculating the wind load on ladder cages.

5.4.7 Partial Wind Load (Wp) shall be based on the requirements of *SEI/ASCE 37-02*, Section 6.2.1, for the specified test or erection duration. The design wind speed shall be 0.75 multiplied by the Basic Wind Velocity according to *SEI/ASCE 37-02* for test or erection periods of less than 6 weeks. For test or erection periods longer the six weeks refer to SEI/ASCE 37-02.

5.5 Earthquake Loads (E)

5.5.1 Except for API STD 650 ground-supported storage tanks, earthquake loads shall be computed and applied in accordance with ASCE/SEI 7-05, unless otherwise specified.

Commentary Note:

> *The earthquake loads in ASCE/SEI 7-05 are limit state earthquake loads, and this should be taken into account if using allowable stress design methods or applying load factors from other codes. Earthquake loads for API STD 650 storage tanks are allowable stress design loads. ASCE "Guidelines for Seismic Evaluation and Design of Petrochemical Facilities" may also be used as a general reference for seismic design.*

5.5.2 Seismic accelerations and site soil coefficient shall be determined in accordance with SAES-A-112, *Meteorological and Seismic Design Data*. All plant area structures shall be considered essential facilities.

5.5.3 Earthquake loading shall be determined using ASCE/SEI 7-05, Chapter 15 for non-building structures (as defined in ASCE/SEI 7-05, Section 15.1.1, Table 15.4.1 and Table 15.4.2). Nonbuilding structures include but are not limited to elevated tanks or vessels, stacks, pipe racks, and cooling towers.

5.5.4 The Importance Factor I used to compute seismic design forces shall be based on Table 11.5-1 of ASCE 7-05 and on the appropriate Occupancy Category from Table 1-1 of ASCE 7-05 as amended below:

- All structures within facilities that manufacture, process, handle, store, process, use, or dispose of toxic or explosive substances shall use Occupancy Category IV (I = 1.50)

5.5.5 For the load combinations in Section 4.2 the following designations are used:

Eo = Earthquake load considering the operating load case

Ee = Earthquake load considering the empty load case

5.6 Impact Loads

5.6.1 An impact load shall be defined as an equivalent static load that conservatively approximates the dynamic effect of reciprocating machinery, rotating machinery, or a moving load. Impact and hoist loads shall be considered to be ***live loads***. Impact loads shall be per ASCE/SEI 7-05, and as amended in paragraphs 5.6.2 through 5.6.5.

Commentary Note:

Impact factors shall be in accordance with ASCE/SEI 7-05, Section 4.7 or vendor provided criteria.

5.6.2 Crane beams, support brackets and connections shall be designed for impact load. Impact factors shall be as listed below or in vendor provided criteria, whichever is greater:

a) To account for impact, the maximum vertical wheel load shall be increased as follows:

Gantry and bridge crane supports	25%
Monorail supports and underhung cranes	25%

Davits, jib cranes	25%

b) Transverse impact shall be as follows:

Craneway	20% of the rated load capacity of the crane and the weight of the hoist and trolley. The lateral force shall be assumed to act horizontally at the traction surface of the runway beam, in either direction perpendicular to the beam, and shall be distributed with due regard to the lateral stiffness of the runway beam and supporting structure.
Davits	20% of the lifted loads

c) Longitudinal impact load shall be as follows:

Craneways	10% of the maximum wheel load applied at the top of the runway
Monorails	10% of the lifted load, hoist and trolley
Davits	10% of the lifted load

5.6.3 Lifting lugs or pad eyes and internal members (included both end connections) framing into the joint where the lifting lug or pad eye is located shall be designed for 100% impact.

5.6.4 All other structural members transmitting lifting forces shall be designed for 15% impact.

5.6.5 Allowable stresses shall not be increased when combining impact with dead load.

5.7 Thermal Loads (T)

5.7.1 For this Standard, thermal loads are designated by the following nomenclature:

T_p, T, A_f, and F_f, where

Tp = Forces on a vertical vessels, horizontal vessels, or heat exchangers caused by the thermal expansion of the pipe attached to the vessel. These forces shall be included in the operating load combinations. Dead load factors shall be applied to the resultants of thermal loadings.

T = Self-straining thermal forces caused by the restrained expansion of horizontal vessels, heat exchangers, structural members in pipe racks or in structures.

A_f = Pipe anchor and guide forces which shall be obtained from the checked pipe stress analysis.

F_f = Pipe rack friction forces caused by the sliding of pipes or friction forces caused by the sliding of horizontal vessels or heat exchangers on their supports, in response to thermal expansion.

5.7.2 Thermal loads shall be defined as forces caused by changes in temperature and may result from either operating or environmental conditions. Such forces should include those caused by vessel, piping, and structure expansion and contraction. The temperature variation for various locations shall be as specified in SAES-A-112, *Meteorological and Seismic Design Data.*

5.7.3 All support structures and elements thereof shall be designed to accommodate the loads or effects produced by thermal expansion and contraction of equipment and piping.

5.7.4 Thermal loads shall be included with operating loads in the appropriate load combinations. Thermal load shall have the same load factor as dead load. Thermal forces caused by the expansion or contraction of structural members shall be considered in the design.

5.7.5 Thermal loads (T) and displacements shall be calculated on the basis of the difference between ambient or equipment design temperature and installed temperature. Where the maximum ambient temperature is higher than the installed temperature, add 35°F (20°C), to the ambient temperature to account for the significant increase in temperatures of steel exposed to sunlight.

Commentary Note:

Unless specified otherwise in the contract documents, the installed temperature can be assumed to be 85°F (30°C).

5.7.6 Friction loads (F_f) caused by thermal expansion shall be determined using the appropriate static coefficient of friction. Some commonly used coefficients shall be in accordance with Table 2.

Table 2 – Coefficients of Friction

a.	Steel to steel	0.4
b.	Steel to concrete	0.6
c.	Proprietary Sliding Surfaces or Coatings (e.g., "Teflon")	According to Manufacturer's Instructions

5.7.7 For pipe racks supporting multiple pipes, 10% of the total piping weight shall be taken as an estimated horizontal friction load ($\boldsymbol{F_f}$) applied only to local supporting beams. However, an estimated friction load equal to 5% of the total piping weight shall be accumulated and carried into pipe rack struts, columns, braced anchor frames, and foundations.

Commentary Note:

> *Under normal loading conditions with multiple pipes, torsional effects on the local beam need not be considered since the pipes supported by the beam limit the rotation of the beam to the extent that the torsional stresses are minimal. Under certain circumstances, engineering judgment shall be applied to determine whether a higher friction load and/or torsional effects should be considered.*

5.7.8 Pipe anchor (A_f) and guide loads shall be considered as dead loads. Pipe rack beams, struts, columns, braced anchor frames, and foundations shall be designed to resist actual pipe anchor and guide loads. For local beam design consider only the top flange as acting in horizontal bending unless the pipe anchor engages both flanges of the beam. Anchor and guide forces shall be obtained from the checked pipe stress analysis and piping isometric drawings.

5.7.9 Internal pressure and surge shall be considered for pipe anchor and guide loads

5.7.10 Friction loads shall be considered temporary and shall not be combined with wind or earthquake loads. However, anchor and guide loads (excluding their friction component) shall be combined with wind or seismic loads.

5.8 Bundle Pull Load (B_p) – (Heat Exchangers)

5.8.1 Structures and foundations supporting heat exchangers subject to bundle pulling shall be designed for a horizontal load equal to 1.0 times the weight of the removable tube bundle but not less than 2,000 lb (9.0kN). If the total weight of the exchanger is less than

2,000 lb (9.0kN), the bundle pull design load need not exceed the total weight of the exchanger.

5.8.2 The portion of the bundle pull load at the sliding end support shall equal the friction force or half of the total bundle pull load, whichever is less. The remainder of the bundle pull load shall be resisted at the anchor end support.

5.8.3 Bundle pull load shall be applied at the center of the bundle. If it can be assured that the bundles will be removed strictly by the use of a bundle extractor attaching directly to the exchanger (such that the bundle pull force is not transferred to the structure or foundation), the structure or foundation need not be designed for the bundle pull force. Such assurance would typically require the addition of a sign posted on the exchanger to indicate bundle removal by an extractor only.

5.9 Traffic Loads

Concrete slab on grade, trenches and underground installations accessible to truck loading shall be designed to withstand HS20 load as defined by AASHTO *Standard Specifications for Highway Bridges* and the maximum legal Saudi Arabian truck loads defined in SAES-Q-006, unless specified otherwise in project specifications. Maintenance or construction crane loads shall be considered also, where applicable. Truck or crane loads shall have the same load factor as live load.

5.10 Vibration Loads (V)

Where vibration is induced by equipment such as pumps, blowers, fans and compressors, supporting members shall be designed in accordance with SAES-Q-007 to prevent fatigue failure and to avoid misalignment or malfunction of machinery and equipment.

The primary source of vibration in superstructures is harmonic unbalanced forces generated by rotating or reciprocating equipment. The final design shall be such that vibrations are neither intolerable nor troublesome to personnel, nor cause damage to the machine or structure as per the requirements of SAES-Q-007.

Commentary Notes:

> *As a general rule, none of the natural frequencies of the structure shall be within a band of the operating frequency of the supported machinery.*
> *The recommended band is 1.3 times above the operating frequency and 0.7 times below the operating frequency. To find structural natural frequencies, a computer analysis will generally be required.*

In lieu of performing a computer analysis, the engineer may use approximate hand solutions for natural frequencies and adjust the design so that the structure is sufficiently high or low tuned. The manufacturer's recommendations shall be considered in designing structures containing vibratory equipment.

5.11 Pressure Loads (Ground Supported Tanks Only)

For this Practice, pressure loads for ground supported tanks are designated by the following nomenclature:

P_i, P_e, and P_t, where

P_i = Design Internal Pressure

P_e = External Pressure

P_t = Test Internal Pressure

5.12 Construction Loads

The minimum design loads for buildings and other structures shall be in accordance with SEI/ASCE 37-02.

Commentary Note:

In certain cases, structural steel members and vertical bracing are temporarily removed to allow for the installation of equipment. In this case, the actual structural steel configuration needs to be checked for the construction condition.

6 Load Combinations

6.1 General

Structures, equipment, and foundations shall be designed for the appropriate load combinations from ASCE/SEI 7-05, this standard, and any other probable and realistic combination of loads. This document shall be used for load combinations for either strength design or allowable stress design. Load combinations for vertical vessels, horizontal vessels, heat exchangers, pipe racks, pipe bridges and ground supported tanks shall be as listed below.

The load combinations shown below are the most common load combinations but may not cover all possible conditions. Any credible load combination that could produce the maximum stress or govern for stability should be considered in the calculations.

6.1.1 Allowable Stress Design

1. The use of a one-third stress increase for load combinations including wind or earthquake loads shall not be allowed for

design using the Allowable Stress Design (ASD) method.

2. The non-comprehensive list of typical load combinations for each type of structure provided below shall be considered and used as applicable.

3. Engineering judgment shall be used in establishing all appropriate load combinations.

4. Steel structures in Seismic Design Category D or higher shall use factored load combinations as specified in ANSI/AISC 341 - 02 *Seismic Provisions for Structural Steel Buildings*, Part III (Allowable Stress Design Alternative).

Commentary Notes:

1. The dead load factor used for the seismic uplift ASD load combinations is generally taken as 0.9. This factor is greater than the 0.6 dead load factor used in the ASD load combinations of ASCE/SEI 7-05 Section 2 because the dead loads of nonbuilding structures are known to a higher degree of accuracy than the corresponding dead loads of buildings. A dead load factor of 0.9 instead of 1.0 is used to account for the effect of vertical seismic forces. The use of this reduction is necessary since foundations sized using ASD loads, with the exception of foundations for ground supported storage tanks, are generally not required to consider the effect of vertical seismic uplift forces if a dead load factor of 0.6 is used. A dead load factor of 1.0 is used for the wind uplift ASD load combinations because of the higher accuracy of dead loads of nonbuilding structures.

2. Hydrotest Combinations: Full live and wind loads do not need to be combined with hydrotest loads unless unusually long hydrotest duration is planned (i.e., when there is a significant probability that the "partial wind velocity" will be exceeded). Engineering judgment shall be used in establishing hydrotest load combinations that include earthquake loads. For allowable stress design, a 20% allowable stress increase is permitted for any hydrotest load combination. However, for ultimate strength/limit states design, no load factor reduction is permitted for any hydrotest load combination.

6.1.2 Strength Design

1. The non-comprehensive list of typical factored load combinations for each type of structure provided below shall be considered and used as applicable.

2. Engineering judgment shall be used in establishing all appropriate load combinations.

3. The following load combinations are appropriate for use with the strength design provisions of either *AISC LRFD* or *ACI 318* (2002 edition or later).

6.2 Load Combinations and Load Factors

6.2.1 General Plant Structures

Load combinations for general plant structures and process structures shall be in accordance with ASCE/SEI 7–05, Chapter 2.

6.2.2 Vertical Vessel Support Design

Table 3 – Load Combination - Allowable Stress Design (Service Loads)

Load Comb. No.	Load Combination	Allowable Stress Multiplier	Description
1	$D_s + D_o + L$	1.00	Operating Weight + Live Load
2	$D_s + D_o + (W \text{ or } 0.7\ E_o{}^{a})$	1.00	Operating Weight + Wind or Earthquake
3	$D_s + D_e + W$	1.00	Empty Weight + Wind (Wind uplift case)
4a	$0.9\ (D_s + D_o) + 0.7\ E_o{}^{a}$	1.00	Operating Weight + Earthquake (Earthquake operating uplift case)
4b	$0.9\ (D_s + D_e) + 0.7\ E_e{}^{a}$	1.00	Empty Weight + Earthquake (Earthquake uplift case)
5	$D_s + D_t + W_p$	1.20	Test Weight + Partial Wind
6	$D_s + D_f + W_p$	1.00	Erection Weight + Partial Wind[b] (Wind uplift case)

a. For skirt-supported vertical vessels and skirt-supported elevated tanks classified as Occupancy Category IV in accordance with ASCE/SEI 7-05, Section 1.5 and Table 1-1, the critical earthquake provisions and implied load combination of ASCE/SEI 7-05, Section 15.7.10.5, shall be followed.

b. Erection weight + partial wind is required only if the erection weight of the vessel is significantly less than the empty weight of the vessel.

c. Thrust forces caused by thermal expansion of piping should be included in the calculations for operating load combinations, if deemed advisable. The pipe stress engineer should be consulted for any thermal loads that are to be considered.

Table 4 – Load Combinations and Load Factors – Strength Design

Load Comb. No.	Load Combination	Description
1	$1.4\ (D_s + D_o)$	Operating Weight
2	$1.2\ (D_s + D_o) + 1.6\ L$	Operating Weight + Live Load
3	$1.2\ (D_s + D_o) + (1.6\ W \text{ or } 1.0\ E_o{}^{a})$	Operating Weight + Wind or Earthquake
4	$0.9\ (D_s + D_e) + 1.6\ W$	Empty Weight + Wind (Wind uplift case)
5a	$0.9\ (D_s + D_o) + 1.0\ E_o{}^{a}$	Operating Weight + Earthquake (Earthquake operating uplift case)
5b	$0.9\ (D_s + D_e) + 1.0\ E_e{}^{a}$	Empty Weight + Earthquake (Earthquake uplift case)

Load Comb. No.	Load Combination	Description
6	$0.9\ (D_s + D_f) + 1.6\ W_p$	Erection Weight + Partial Wind[b] (Wind uplift case)
7	$1.4\ (D_s + D_t)$	Test Weight
8	$1.2\ (D_s + D_t) + 1.6\ W_p$	Test Weight + Partial Wind

a. For skirt-supported vertical vessels and skirt-supported elevated tanks classified as Occupancy Category IV in accordance with ASCE/SEI 7-05, Section 1.5 and Table 1-1, the critical earthquake provisions and implied load combination of ASCE/SEI 7-05, Section 15.7.10.5, shall be followed.

b. Erection weight + partial wind is required only if the erection weight of the vessel is significantly less than the empty weight of the vessel.

c. Thrust forces caused by thermal expansion of piping should be included in the calculations for operating load combinations, if deemed advisable. The pipe stress engineer should be consulted for any thermal loads that are to be considered.

6.2.3 Horizontal Vessel & Heat Exchanger Support Design

Table 5 – Load Combinations - Allowable Stress Design (Service Loads)

Load Comb. No.	Load Combination	Allowable Stress Multiplier	Description
1	$D_s + D_o + (T \text{ or } F_f)^b$	1.00	Operating Weight + Thermal Expansion or Friction Force
2	$D_s + D_o + L + (T \text{ or } F_f)^b$	1.00	Operating Weight + Live Load + Thermal Expansion or Friction Force
3	$D_s + D_o + (W \text{ or } 0.7\ E_o)$	1.00	Operating Weight + Wind or Earthquake
4	$D_s + D_e + W$	1.00	Empty Weight + Wind (Wind uplift case)
5a	$0.9\ (D_s + D_o) + 0.7\ E_o$	1.00	Operating Weight + Earthquake (Earthquake uplift case)
5b	$0.9\ (D_s + D_e) + 0.7\ E_e$	1.00	Empty Weight + Earthquake (Earthquake uplift case)
6	$D_s + D_f + W_p$	1.00	Erection Weight + Partial Windc (Wind uplift case)
7	$D_s + D_t + W_p$	1.20	Test Weight + Partial Wind (for Horiz. Vessels Only)
8	$D_s + D_e^d + B_p$	1.00	Empty Weight + Bundle Pull (For Heat Exchangers Only)

Notes:

a. Wind and earthquake forces shall be applied in the both transverse and longitudinal directions, but need not be applied simultaneously.

b. The design thermal force for horizontal vessels and heat exchangers shall be the lesser of T or Ff.

c. Erection weight + partial wind is required only if the erection weight of the vessel is significantly less than the empty weight of the vessel.

d. Heat exchanger empty dead load will be reduced during bundle pull due to the removal of the exchange head.

e. Sustained thermal loads not relieved by sliding caused by vessel or heat exchanger expansion shall be considered in operating load combinations with wind or earthquake.

f. Thrust forces caused by thermal expansion of piping shall be included in the calculations for operating load combinations, if deemed advisable. The pipe stress engineer should be consulted for any thermal loads that are to be considered.

Table 6 – Load Combinations and Load Factors - Strength Design

Load Comb. No.	Load Combination	Description
1	$1.4(D_s + D_o) + 1.4\ (T \text{ or } F_f)^b$	Operating Weight + Thermal Expansion or Friction Force
2	$1.2(D_s + D_o) + 1.6\ L + 1.2\ (T \text{ or } F_f)^b$	Operating Weight + Live Load + Thermal Expansion or Friction Force
3	$1.2(D_s + D_o) + (1.6\ W \text{ or } 1.0\ E_o)$	Operating Weight + Wind or Earthquake
4	$0.9(D_s + D_e) + 1.6\ W$	Empty Weight + Wind (Wind uplift case)
5a	$0.9(D_s + D_o) + 1.0\ E_o$	Operating Weight + Earthquake (Earthquake uplift case)
5b	$0.9(D_s + D_e) + 1.0\ E_e$	Empty Weight + Earthquake (Earthquake uplift case)
6	$0.9(D_s + D_f) + 1.6\ W_p$	Erection Weight + Partial Wind (Wind uplift case)
7	$1.4\ (D_s + D_t)$	Test Weight (For Horizontal Vessels Only)
8	$1.2\ (D_s + D_t) + 1.6\ W_p$	Test Weight + Partial Wind (For Horizontal Vessels Only)
9	$1.2\ (D_s + D_e^d) + 1.6\ Bp$	Empty Weight + Bundle Pull (For Heat Exchangers Only)
10	$0.9\ (D_s + D_e^d) + 1.6\ Bp$	Empty Weight + Bundle Pull (For Heat Exchangers Only) (Bundle pull uplift case)

Notes:

a. Wind and earthquake forces shall be applied in the both transverse and longitudinal directions, but need not be applied simultaneously.

b. The design thermal force for horizontal vessels and heat exchangers shall be the lesser of T or Ff.

c. Erection weight + partial wind is required only if the erection weight of the vessel is significantly less than the empty weight of the vessel.

d. Heat exchanger empty dead load will be reduced during bundle pull due to the removal of the exchange head.

e. Sustained thermal loads not relieved by sliding caused by vessel or heat exchanger expansion shall be considered in operating load combinations with wind or earthquake.

f. Thrust forces caused by thermal expansion of piping shall be included in the calculations for operating load combinations, if deemed advisable. The pipe stress engineer should be consulted for any thermal loads that are to be considered.

6.2.4 Pipe Rack and Pipe Bridge Design

Table 7 – Load Combinations - Allowable Stress Design (Service Loads)

Load Comb. No.	Load Combination	Allowable Stress Multiplier	Description
1	$D_S + D_O + F_f + T + A_f$	1.00	Operating Weight + Friction Force + Thermal Expansion + Anchor Force
2	$D_S + D_O + A_f$ + (W or 0.7 E_O)	1.00	Operating Weight + Anchor + Wind or Earthquake
3	$D_S + D_e^c + W$	1.00	Empty Weight + Wind (Wind uplift case)
4a	$0.9\ D_S + 0.6\ D_O + A_f + 0.7\ E_O^d$	1.00	Operating Weight + Earthquake (Earthquake uplift case)
4b	$0.9\ (D_S + D_e^c) + 0.7\ E_e$	1.00	Empty Weight + Earthquake (Earthquake uplift case)
5	$D_S + D_t + W_p$	1.20	Test Load + Partial Wind[e]

Notes:

a. Wind forces normally need not be considered in the longitudinal direction because friction and anchor loads will normally govern.

b. Earthquake forces shall be applied in both transverse and longitudinal directions, but need not be applied simultaneously.

c. $0.6D_O$ is used as a good approximation of the empty pipe condition D_e.

d. Full $D_S + D_O$ value shall be used for the calculation of E_O in Load Comb. 4a.

e. Test Weight + Partial Wind normally is required only for local member design because hydrotest is not normally performed on all pipes simultaneously.

Table 8 –Load Combinations and Load Factors - Strength Design

Load Comb. No.	Load Combination	Description
1	$1.4\ (D_S + D_O + F_f + T + A_f)$	Operating Weight + Friction Force + Thermal Expansion + Anchor
2	$1.2\ (D_S + D_O + A_f)$ + (1.6W or 1.0 E_O)	Operating Weight + Anchor + Wind or Earthquake
3	$0.9\ (D_S + D_e^c) + 1.6\ W$	Empty Weight + Wind (Wind uplift case)
4a	$0.9(D_S + D_O) + 1.2\ A_f + 1.0\ E_O^d$	Operating Weight + Earthquake (Earthquake uplift case)
4b	$0.9\ (D_S + D_e^c) + 1.0\ E_e$	Empty Weight + Earthquake (Earthquake uplift case)
5	$1.4\ (D_S + D_t)$	Test Weight
6	$1.2\ (D_S + D_t) + 1.6\ W_p$	Test Load + Partial Wind[d]

Notes:

a. Wind forces normally need not be considered in the longitudinal direction because friction and anchor loads will normally govern.

b. Earthquake forces shall be applied in both transverse and longitudinal directions, but need not be applied simultaneously.

c. $0.6D_o$ is used as a good approximation of the empty pipe condition D_e.

d. Test Weight + Partial Wind normally is required only for local member design because hydrotest is not normally done on all pipes simultaneously.

6.2.5 Hydrotest Combinations

6.2.5.1 Engineering judgment shall be used in establishing the appropriate application of test load combinations to adequately address actual test conditions in accordance with project and code requirements while avoiding overly conservative design.

6.2.5.2 Consideration shall be given to the sequence and combination of testing for various equipment, vessels, tanks, and/or piping systems supported on common structures, pipe racks, or foundations.

6.2.5.3 Full live wind and earthquake loads are typically not combined with hydrotest loads unless an unusually long hydrotest duration is planned (i.e., if a significant probability exists that the "partial wind velocity" will be exceeded or an earthquake event may occur).

6.2.5.4 Additional loading shall be included with hydrotest if specified in the contract documents.

6.2.5.5 For allowable stress design, a 20% allowable stress increase shall be permitted for any hydrotest load combination.

6.2.5.6 For ultimate strength/limit states design, no load factor reduction shall be permitted for any hydrotest load combination.

6.2.6 Ground Supported Storage Tank Load Combinations

Load combinations for ground-supported storage tanks shall be taken from API STD 650. Load combinations from API STD 650 and modified for use with ASCE/SEI 7-05 loads and are shown in Table 9 below.

Table 9 –Load Combinations – Allowable Stress Design (Service Loads)

Load Comb. No.	Load Combination	Description
1.	$D_s + D_o + P_i$	Operating Weight + Internal Pressure[a]
2.	$D_s + D_t + P_t$	Test Weight + Test Pressure
3.	D_s + (D_e or D_o) + W + $0.4P_i$[b]	Empty or Operating Weight + Wind + Internal Pressure[a]
4a.	D_s + (D_e or D_o) + W + $0.4P_e$[b]	Empty or Operating Weight + Wind + External Pressure
5.	$D_s + D_o + L + 0.4P_e$[b]	Operating Weight + Live + External Pressure
6.	D_s + (D_e or D_o) + 0.4 L + P_e	Empty or Operating Weight + Live + External Pressure
7.	$D_s + D_o + E_o$[c] + 0.4 P_i[b]	Operating Weight + Earthquake + Internal Pressure [a] (Earthquake uplift case)
8.	$D_s + D_o + E_o$[c]	Operating Weight + Earthquake

Notes:

a. For internal pressures sufficient to lift the tank shell according to the rules of API STD 650, tank, anchor bolts, and foundation shall be designed to the additional requirements of API STD 650 Appendix F.7.

b. If the ratio of operating pressure to design pressure exceeds 0.4, the owner should consider specifying a higher factor on design pressure in load combinations 3, 4, 5, and 7 of Table 9.

c. Earthquake loads for API STD 650 tanks taken from ASCE/SEI 7-05 "bridging equations" or from *API STD 650* already include the 0.7 ASD seismic load factor.

6.2.7 Load combinations for static machinery, skid and modular equipment, filters, and other equipment.

Load combinations for static machinery, skid and modular equipment, filters, etc., shall be similar to the load combinations for vertical vessels.

7 Structural Design

7.1 Steel

7.1.1 Steel design shall be in accordance with AISC ASD or AISC LRFD specifications.

7.1.2 For cold-formed shapes, design shall be in accordance with AISI specifications.

7.1.3 Steel joists shall be designed in accordance with SJI standards.

Comment:

Supplement number 1 to the AISC ASD specification deleted the one-third stress increase for use with load combinations including wind or *earthquake loads. Because of the deletion of the one-third stress increase, designs made to the AISC LRFD specifications should be considered for economy.*

7.1.4 Structural steel wide-flange shapes, including WT shapes, shall be in accordance with ASTM A572/A572M or ASTM A992/A992M.

7.1.5 All other structural shapes, plates, and bars shall be in accordance with ASTM A36/A36M.

7.1.6 Base plate hole sizes for structural steel columns shall be as follows:

Anchor bolts ½ to 7/8 inch (12-22 mm) – 5/16 inch (8 mm) oversize

Anchor bolts 1 to 1-3/4 inch (25-44 mm) – ½ inch (12 mm) oversize

Anchor bolts over 2 to 2-1/4 inch (50 - 57 mm) – 3/4 inch (19 mm) oversize

Anchor bolts 2-1/2 inch and over (64 mm) – 1 inch (25 mm) oversize

7.1.7 Compression flanges of floor beams, not supporting equipment, may be considered braced by decking (concrete or floor plate) if positively connected thereto.

7.1.8 Grating shall not be considered as lateral bracing for support beams.

7.1.9 Steel design, including steel joists and metal decking, shall be designed in accordance with OSHA 29 CFR 1926, Subpart R, to provide structural stability during erection and to protect employees from the hazards associated with steel erection activities. A brief summary of some the more common requirements that effect steel design is provided as follows. (This is not an all inclusive list):

a) All column base plates must be designed with a minimum of four anchor bolts. Posts (which weigh less than 300 pounds [136 kg]) are distinguished from columns and are excluded from the four – anchor bolt requirement.

b) Columns, column base plates, and their foundation must be designed to resist a minimum eccentricity gravity load of 300 pounds (136 kg) located 18 inches (450 mm) from the extreme outer face of the column in each direction at the top of the column shaft. Column splices must be designed to meet the same load-resisting characteristics as those of the columns.

c) Double connections through column webs or at beams that frame over the tops of columns must be designed so that at least one installed bolt remains in place to support the first beam while the second beam is being erected. The fabricator must also supply a seat or equivalent device with a means of positive attachment to support the first beam while the second beam is being erected.

d) Perimeter columns must extend 48 inches (1200 mm) above the finished floor (unless constructability does not allow) to allow the installation of perimeter safety cables. Provision shall be made for the attachment of safety cables.

e) Structural members of framed metal deck openings must be turned down to allow continuous decking, except where not allowed by design constraints or constructability. The openings in the metal deck shall not be cut until the hole is needed.

f) Shear stud connectors that will project vertically from or horizontally across the top flange of the member are not to be attached to the top flanges of beams, joists, or beam attachments until after the metal decking or other walking/working surface has been installed.

7.1.10 Pipe Rack Construction

All pipe racks shall be constructed using structural steel. Concrete pipe racks are not permitted.

7.1.11 Structural Steel Expansion

For pipe rack design, provisions shall be made for thermal expansion of steel, with the structural steel checked for temperature change. Slotted connections (sliding connection) shall be provided in each segment of the pipe rack to allow for structural steel thermal expansion. The maximum segment for the pipe rack shall be limited to 42.5 meters (140 feet) in length unless calculations show otherwise. Details and requirements for the slotted connection and special bolting procedures to ensure the connection can slip fully shall be detailed on the engineering drawings.

7.1.12 Connections

7.1.12.1 All field connections shall be bolted where possible. All shop connections may be either bolted or welded. Connections may be field welded when conditions are such that a bolted connection is not suitable. All field welded connections shall be detailed with erection bolts to facilitate the welding and erection.

7.1.12.2 Field connections for primary structural members, as shown on drawings, shall be bolted with high-strength bolts conforming to ASTM A325-N, bearing-type connections with threads included in the shear plane. However, slip-critical-type connections shall be used in connections subject to vibration or repeated stress reversal. Slip-critical (friction-type) connections shall also be used for crane girders and crane girder supports connections. All high-strength bolts shall be furnished with nuts and washers.

Commentary Notes:

Structural joints using ASTM A490 alloy steel bolts are not permitted because of possible exposure to corrosive atmosphere.

Primary structural members shall be defined as the main frames and any members that are part of the lateral load carrying system.

7.1.12.3 Bolted joints shall conform to the requirements of the latest edition of AISC *Specification for Structural Joints using ASTM A325 or A490 Bolts*.

7.1.12.4 The minimum size of high-strength bolts shall be 3/4 inch (20 mm) diameter. A minimum of two bolts is required per connection.

7.1.12.5 Field connections for secondary structural members (purlins, girts, stair framing, stair treads, stair bracing, toe plate, handrail, ladders, small miscellaneous platforms, stiles, etc.) may be bolted with machine bolts conforming to ASTM A307. When ASTM A307 bolts are used, the sizes used should not be the same diameter as any A325 bolts for the same Purchase Order. ASTM A307 bolts are to be limited to sizes 16 mm (5/8 inch) diameter and smaller.

Commentary Note:

The requirements of this paragraph are aimed at preventing the inadvertent substitution of ASTM A307 bolts for ASTM A325 bolts. There is an opportunity to confuse the bolts when bolts of different strengths and the same size are present on the same job site. The use of ASTM A307 bolt in the place of an ASTM A325 bolt could result in a failure of the connection under the design loads.

7.1.12.6 All gusset and stiffener plates shall be 3/8 inch (10 mm) minimum thickness. For minor structures such as small access platforms and miscellaneous structures, ¼ inch (6 mm) thick gusset and stiffener plates may be used. The minimum thickness for connection plates in electrical transmission towers or communication towers shall be ¼ inch (6 mm).

7.1.12.7 All shear connections, except special connections, shall be designed and detailed by the fabricator. The minimum design capacity of all bolted, or mixed bolted and welded, framed-beam connections shall be the member end reaction shown on the design drawings. If the member end reaction is not shown on the design drawings, the minimum available strength shall be one-half of the maximum total uniform load capacity as shown in the Allowable Uniform Load Tables in the AISC *Steel Construction Manual* for the given beam size, span and grade of steel.

7.1.12.8 The minimum number of rows of bolts for framed beam connections shall be in accordance with Table 10-1 of the AISC *Steel Construction Manual*.

7.1.12.9 One-sided framed-beam connections shall not be permitted without approval of Saudi Aramco. Support reactions for plate girders and other built-up or composite members shall also be shown on the drawings.

7.1.12.10 Moment connections shall be designed for calculated forces and moments shown and detailed on engineering drawings by the design contractor.

7.1.12.11 Loadings for special connections shall be noted, and the connections shall be fully detailed, on the design drawings.

7.1.12.12 The forces in truss members and all main bracing shall be shown on the engineering drawings, with plus signs indicating tension forces and minus signs indicating compression forces. Alternately, truss member connections may be designed and detailed on the engineering drawings by the design contractor.

7.1.12.13 Vertical bracing connections shall be designed for forces given on design drawings. A minimum of two bolts per connection is required.

7.1.12.14 Braces for structures subject to vibration from equipment shall be designed as compression braces.

7.1.12.15 Additional connection requirements are covered in Saudi Aramco Materials System Specification 12-SAMSS-007.

7.1.13 Welding

7.1.13.1 All welded structural connections shall use weld filler material conforming to AWS D1.1 Section 3.3 (including Table 3.1) with an electrode strength of 58 ksi (400 MPa) minimum yield strength and 70 ksi (480 MPa) tensile strength, unless otherwise required.

7.1.13.2 All structural strength welding shall be continuous.

7.1.13.3 The edges of all tightly contacting surfaces shall be completely seal welded.

Commentary Notes:

The preferred method of protection against corrosion is to minimize and, where possible, eliminate pocket areas where moisture may accumulate. If seal-welding is required, it need not exceed a 3 mm fillet weld regardless of the base metal thickness.

A seal weld is not a strength weld. However, a continuous strength weld may eliminate the need for a seal weld.

7.2 Metal Decking

7.2.1 Metal deck shall be designed in accordance with Steel Deck Institute (SDI) *Design Manual for Composite Decks, Form Decks and Roof Decks – No. 31*.

7.2.2 When roof or floor metal decking is used as a diaphragm to carry lateral forces, both the metal deck and the deck attachments to the structural frame shall be designed to transfer the lateral forces in accordance with the requirements of SDI.

7.2.3 In areas where steel deck is used as form for concrete slab, and in order for the steel decking to provide lateral bracing to the top flange of beams in a corrosive environments, shear connectors shall be installed on the top flange at positions providing the desired unbraced length (say at spacing = lc or lu). The connectors function is to engage the slab providing a positive lateral brace point at the beam flange.

Connector strength shall provide shear strength equal to or greater than 2% of the compression strength of the compression element being braced (the beam).

Commentary Note:

In a corrosive environment, the decking can corrode away negating the assumption of bracing of the compression flange by the decking. In areas where corrosion of the deck is not a concern, deck can be puddle welded to the beams.

7.3 Concrete

7.3.1 Concrete design shall be in accordance with SAES-Q-001, ACI 318/318R, and ACI 350 for liquid containing structures.

7.3.2 Reinforcing shall be in accordance with SAES-Q-001.

7.3.3 Precast and prestressed concrete shall be in accordance with SAES-Q-012 and PCI Design Handbooks (MNL 120 & MNL 122).

7.4 Masonry

Masonry design shall be in accordance with ACI 530/ASCE 5/TMS 402.

7.5 Elevator Supports

Elevator support design shall be per ASME A17.1.

7.6 Crane Supports

7.6.1 Vertical deflection of support runway girders shall not exceed the following limits if loaded with the maximum wheel load(s), without impact (where L = the span length):

Table 10 – Maximum Allowable Girder Deflections

Top running CMAA Class A, B and C cranes	L/600
Top running CMAA Class D cranes	L/800
Top running CMAA Class E and F cranes	L/1000
Under running CMAA Class A, B and C cranes	L/450
Monorails	L/450

7.6.2 Vertical deflection of jib cranes shall not exceed L/225 (where L = the maximum distance from the support column to load location along the length of the jib beam) if loaded with the maximum lifted plus hoist load(s), without impact.

7.6.3 Lateral deflection of support runway girders for cranes with lateral moving trolleys shall not exceed L/400 (where L = the span length) if loaded with a total crane lateral force not less than 20% of the sum of the weights of the lifted load (without impact) and the crane trolley. The lateral force shall be distributed to each runway girder with due regard for the lateral stiffness of the runway girders and structure supporting the runway girders.

7.6.4 Crane stops shall be designed per manufacturer's requirements, or if not specified, the following load:

$$F = WV^2 / (2gTn) \qquad (1)$$

where,

- F = Design force on crane stop, kips (kN)
- W = 50% of bridge weight + 90% of trolley weight, excluding the lifted load, kips (kN)
- V = Rated crane speed, ft/sec (m/s)
- g = Acceleration of gravity, 32.2 ft/sec² (9.8 m/sec²)
- T = Length of travel (feet), of spring or plunger required to stop crane, from crane manufacturer (usually 0.15 ft (0.05 m))
- n = Bumper efficiency factor (0.5 for helical springs, see mfg for hydraulic plunger)

7.7 Allowable Drift Limits

a) Allowable drift limits for pipe racks due to wind loads shall not exceed H/100 (where H = pipe rack height).

b) Allowable wind drift limits for process structures and personnel access platforms shall not exceed H/200 (where H = structure height at elevation of drift consideration).

c) Allowable seismic drift limits shall be in accordance with ASCE/SEI 7-05.

7.8 Deflections

For all structures designed in accordance with this standard, the maximum deflection for flexural elements shall be documented in the design. Deflection criteria shall consider the AISC *Steel Construction Manual*, *Commentary on the Specifications for Structural Steel Buildings*, Chapter L, Section L3 and as listed in paragraph below.

Commentary Notes:

The governing criteria in a structure supporting vibrating machinery will generally be based on machinery shaft alignment requirements rather than human comfort considerations. Perceptible vibrations are expected and accepted in plant areas. Vibration should be limited to avoid damage to structures, machinery, and appurtenances.

Unless a flexible structure is required to control vibration, the calculated drift should be limited to the values listed in paragraph 7.7. Maximum deflection may be further limited to accommodate equipment or appurtenance requirements.

Beam Deflection: The maximum allowable total load deflection (dmax) for beams supporting floor systems and equipment shall be as follows:

dmax = L/240 (where, L = the span length)

7.9 Foundations

7.9.1 Foundation design shall be in accordance with SAES-Q-005.

7.9.2 Concrete Retaining Walls design shall be in accordance with SAES-Q-009.

7.10 Vibrating Machinery Supports

Machinery foundations shall be designed per SAES-Q-007. Amplitudes of vibration shall be limited to manufacturer's recommendations.

7.11 Anchor Bolts

Anchor bolts materials shall be in compliance with 12-SAMSS-007 and the design and installation shall be per SAES-Q-005 and Standard Drawing AA-036322, Sht. 001, (Rev. No. 08 or later).

7.12 Other Requirements

For structural elements exposed to severe corrosion, wear conditions, or other extraordinary environmental conditions, special materials, protection, or material thickness allowance shall be used instead of decreasing allowable stresses.

Commentary Notes:

Where the structure may be continuously exposed to an environmental temperature exceeding 260°C, such as flare support structures or adjacent to fired equipment, the structural steel mechanical properties must be thoroughly reviewed. The AISC "Steel Construction Manual" provides a discussion of the *effect of elevated temperatures on yield strength, tensile strength, coefficient of expansion and modulus of elasticity of structural steels.*

Heavy pedestrian or equipment traffic and wind-blown or water-borne sand scour are wear conditions which cause erosion of the steel and may require additional material thickness allowance in design.

7.13 Design Calculations and Drawings

7.13.1 Design calculations shall be prepared in accordance with SAES-A-204.

7.13.2 All drawings shall be made using the SI metric system of units, unless instructed otherwise in writing by Saudi Aramco.

7.13.3 Design calculations shall be assembled in an orderly manner and checked. They shall include a summary of all loads and load combinations considered in the design and a clear statement of design assumptions. All computer models shall be accompanied by sketches that show joint and member numbers, support conditions and loadings. All design information shall be based on checked calculations.

8 Structural Design Criteria for Existing Structures

If a structure is altered or subject to additional load, then the structure shall be checked for its adequacy based on the design code in effect at the time of the original design and the following:

8.1 If additions or alterations of an existing structure do not increase the force in any structural element or connection by more than 5%, then no further analysis is required.

8.2 If the increased forces on the element or connection are greater than 5%, then the element or connection shall be analyzed to show that it is in compliance with the applicable code for new construction. The existing foundations shall also be checked to ensure that it is adequate to support the additional loads.

8.3 The strength of any structural element or connection shall not be decreased to less than that required by the applicable design code or standard for new construction, for the structure in question.

8.4 Where structural elements are found to be unsound or structurally deficient, such elements shall be made to conform to the applicable design code for new structures.

9 Fabrication and Installation

Fabrication and erection of structural steel shall conform to Saudi Aramco Materials System Specifications 12-SAMSS-007 and 12-SAMSS-008.

10 Inspection and Testing

10.1 Inspection and testing of structural steel shall conform to 12-SAMSS-007.

10.2 Testing of ready-mix Portland Cement concrete shall be in accordance with 09-SAMSS-097.

10.3 All NDT personnel shall be qualified at least to the minimum requirements of SAEP-1142.

Revision Summary

19 December 2010 Revised the "Next Planned Update." Reaffirmed the content of the document, and reissued with minor revision.