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Structural Design Guidelines



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Structural Design Guidelines

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Structural Design Guidelines

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1.0 STRUCTURAL

The principles, guidelines, and requirements for design and construction of structures and structural systems are provided in this document. These are generic guidelines which are applicable to common and typical structural system. The Entity shall modify the requirements specific to project. The design shall confirm to Saudi Building Code (SBC), refer to Volume 6, Chapter 5 - Codes, Standards and References (EPM-KE0-GL-000014).

- The instructions and use of 'guidelines', and the applicability of codes and standards are defined and explained in Volume 6, Chapter 7, Section 1 of the document EPM-KE0-GL-000016, General Design Guidelines.
- The section has six subsections organized based on the following classification:
 - 2.0 Building Structures.
 - 3.0 High Rise Building Structures.
 - 4.0 Non-Building Structures.
 - 5.0 Transportation Structures.
 - 6.0 Foundation and Earth Retaining Structures.
 - 7.0 Corrosion Protection.
- Each of the six subsections (2.0 to 7.0) has an "Applicability" section defining the type of structures and structural systems for which the provisions of the subsection apply. Requirements for structural calculations and drawings are included in the Appendices to this section.

Important Note:

In this structural design guidelines, references and design parameters related to SBC and ASCE/SEI 7 were provided based on SBC (2007) and ASCE/SEI 7 (2005). Users shall verify the data/information against applicable latest edition of SBC and ASCE.

1.1.1 Definitions

Definitions	Description
Abutment	Substructure unit supporting the ends of a bridge and, usually, retaining the approach embankment.
Allowable Stress Design	A method of proportioning structural members, such that elastically computed stresses produced in the members by nominal loads do not exceed specified allowable stresses (also called "working stress design").
Backwall	The portion of the abutment above the level of the bridge seat that primarily acts as a retaining wall. It may also act as a support for the bridge deck and/or the approach slab.
Bearing	A support element used to transfer loads from superstructure to substructure while permitting some rotation and horizontal movement of the superstructure.
Bridge Seat	Horizontal surface of the abutment stem upon which rest the pedestals and/or the bearings.
Brush Curb	A curb used with steel railing to channel water off of a bridge and preventing it from falling onto the feature crossed.
Cofferdam	A watertight enclosure which permits dewatering of an excavation and for construction in a waterway.
Cross Section	A view taken transverse to the longitudinal axis of an element.
Culvert	A structure that provides passage of water or utilities through an embankment. Usually constructed of precast concrete boxes, round concrete pipe, or elliptical concrete pipe (Usually with a clear opening of less than 6.2 m).
Dead Loads	The weight of materials of construction incorporated into the building and other structures, including but not limited to walls, floors, roofs, ceilings, stairways, built-in partitions, finishes, cladding and other similarly incorporated architectural and structural items, and the weight of fixed service equipment, such as cranes, plumbing stacks and risers, electrical feeders, heating, ventilating and air-conditioning systems and automatic sprinkler systems.



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Definitions	Description
Deck	That portion of a bridge that provides a riding surface for vehicular and/or pedestrian traffic.
Diaphragm	A horizontal or sloped system acting to transmit lateral forces to the vertical-resisting elements. When the term "diaphragm" is used, for steel structures, it shall include horizontal bracing systems.
Diaphragm Chord	A diaphragm boundary element perpendicular to the applied load that is assumed to take axial stresses due to the diaphragm moment.
Duration of Load	The period of continuous application of a given load, or the aggregate of periods of intermittent applications of the same load.
Entity	Includes Government Ministry, EPMO, Engineering Management Company or any other agency authorized by the Government Ministry to work on its behalf.
Essential Facilities	Buildings and other structures that are intended to remain operational in the event of extreme environmental loading from flood, wind, snow or earthquakes.
Factored Load	The product of a nominal load and a load factor.
Fascia	The outside vertical edge of a concrete deck.
Fascia Girder	The outermost girder on each side of a bridge.
Feature Carried	The roadway, railway, or pathway that is carried by the bridge.
Feature Crossed	The roadway, railway, ravine, stream, or other physical feature that is crossed over by the bridge.
Fixed Support	In terms of bridge bearings, a support that allows rotation only. In analysis, this type of connection is commonly defined as 'pinned'.
Flexible Diaphragm	A diaphragm is flexible for the purpose of distribution of story shear and torsional moment.
Impact Load	The load resulting from moving machinery, elevators, crane ways, vehicles and other similar forces and kinetic loads, pressure and possible surcharge from fixed or moving loads.
Limit State	A condition beyond which a structure or member becomes unfit for service and is judged to be no longer useful for its intended function (serviceability limit state) or to be unsafe (strength limit state).
Live Loads	Those loads produced by the use and occupancy of the building or other structure and do not include construction or environmental loads such as wind load, snow load, rain load, earthquake load, flood load or dead load.
Live Loads (Roof)	Those loads produced (1) during maintenance by workers, equipment and materials; and (2) during the life of the structure by movable objects such as planters and by people.
Load and Resistance Factor Design (LRFD)	A method of proportioning structural members and their connections using load and resistance factors such that no applicable limit state is reached when the structure is subjected to appropriate load combinations. The term "LRFD" is used in the design of steel, concrete and wood structures.
Load Effects	Forces and deformations produced in structural members by the applied loads.
Load Factor	A factor that accounts for deviations of the actual load from the nominal load, for uncertainties in the analysis that transforms the load into a load effect, and for the probability that more than one extreme load will occur simultaneously.
Loads	Forces or other actions that result from the weight of building materials, occupants and their possessions, environmental effects, differential movement and restrained dimensional changes. Permanent loads are those loads in which variations over time are rare or of small magnitude, such as dead loads. All other loads are variable loads.
Nominal Loads	The magnitudes of the loads specified in this section (dead, live, soil, wind, snow, rain, flood, and earthquake).
Occupancy Category	A category used to determine structural requirements based on occupancy.
Other Structures	Structures, other than buildings, for which loads are specified in this section.
Resistance Factor	A factor that accounts for deviations of the actual strength from the nominal strength and the manner and consequences of failure (also called "strength reduction factor").
Rigid Diaphragm	A diaphragm is rigid for the purpose of distribution of story shear and torsional moment when the lateral deformation of the diaphragm is less than or equal to two times the average story drift.



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Definitions	Description
Strength Design	A method of proportioning structural members such that the computed forces produced in the members by factored loads do not exceed the member design strength [also called "load and resistance factor design" (LRFD)]. The term "strength design" is used in the design of concrete and masonry structural elements.
Strength Required	Strength of a member, cross section or connection required to resist factored loads or related internal moments and forces in such load combinations as stipulated by Model Building Code (MBC) and other provisions as applicable.
Strength, Nominal	The capacity of a structure or member to resist the effects of the loads, as determined by computations using specified material strengths and dimensions and equations derived from accepted principles of structural mechanics or by field tests or laboratory tests of scaled models, allowing for modeling effects and differences between laboratory and field conditions.
Substructure	Any supporting member below the superstructure (such as abutments, piers, and wingwalls).
Superelevation	The cross slopes of a roadway at a horizontal curve.
Superstructure	That part of the structure above and supported by, the bearings.
Surcharge	Load that acts on a retaining wall in addition to normal soil forces, such as a vehicular load or a building load.
Underdrain Filter	A method of conveying groundwater away from behind a wall or abutment through the use of porous medium and weep hole.
U-Wingwall	A wingwall that is parallel to the feature carried.
Vertical Clearance	The minimum vertical distance between the bottom of the structure and the surface of the feature crossed.
Wingwall	A retaining wall placed adjacent to an abutment stem to retain the fill behind an abutment (See in-line wingwall, flared wingwall, and U-wingwall).

1.1.2 Abbreviations

Abbreviations	Description
AAC	Autoclaved Aerated Concrete Masonry Units.
AREMA	American Railway Engineering and Maintenance-of-Way Association
MBMA	Metal Building Manufacturers Association.
MEP	Mechanical, Electrical and Plumbing
PEMB	Pre-Engineered Metal Buildings.
PECS	Pre-Engineered Canopy Structures.

1.1.3 Related Chapters

- Refer to Volume 6, Chapter 2 for Definitions and References- EPM-KE0-GL-000011
- Refer to Volume 6, Chapter 7, Section11 for Geotechnical Guideline- EPM-KE0-GL-000002
- Refer to Volume 6, Chapter 7, Section 1 for General Design Guidelines - EPM-KE0-GL-000016.

1.1.4 Approvals

- The Entity reviews and approves all reports, drawings and specifications related to design of building structures within the Entity jurisdiction. This is shared with the building owner, if other than the Entity.

1.1.5 Commissioning

- Commissioning shall verify that the new/rehabilitated building structure achieves project requirements as intended by the Entity /building owner and as designed by the AE and/or Contractor.



2.0 BUILDINGS STRUCTURES

2.1 General

2.1.1 Introduction

- Building structures are defined as those structures enclosed by walls and roofs, and constructed to provide support or shelter for an intended occupancy. The subsection provides the minimum technical requirements to be adopted by the AE and/or Contractors to enable safety, quality, and cost effectiveness in the design and construction of building structures and building systems that meet the needs and expectations of the Entity.

2.1.2 Scope

- The scope of this subsection is to provide guidance on design and construction of building structures and building systems constructed of concrete, masonry, steel and wood. The design requirements provided herein, or cited by reference, are based on a Model Building Code (MBC), industry standards, and best practices embraced by the Entity.

2.1.3 Applicability

- The principles, guidelines, and requirements included in this subsection should govern all building structures and building systems, as defined in the introduction herein.

2.1.4 General Requirements

- Building designer should understand how the building responds to vertical and lateral loads, and follow all loads through the structure to ensure that all structural elements and connections along the load path have sufficient strength and stiffness to maintain structural integrity. Direct and continuous load paths from the roof to foundation must be provided. Building configuration, continuous and redundant load paths, connection detailing, system ductility, quality of materials, and construction are very important to overall building performance, and should properly addressed in the design.
- In accordance with the MBC, building structures are designed to sustain local damage under extreme loading conditions with the structural system as a whole remaining stable.
- This objective of structural integrity can be achieved by an arrangement of structural elements which ensures loads can be transferred from any locally damaged region to adjacent regions capable of resisting the acting loads. This can be accomplished by providing sufficient continuity, redundancy, and energy dissipating capability (ductility) in the design.
- Lateral loads must be transferred from their point of application to the foundation. All structural elements and connections along the load path must have sufficient strength, sufficient ductility to transfer the lateral loads in a manner that does not impair structural performance. The A/E shall provide detailed design and drawings which reflect lateral load paths, such as:
 - Transfer shear from floor and roof diaphragms to the lateral load resisting system.
 - Transfer shear from the lateral load resisting system to the foundations.
 - Transfer shear between individual wall panels (for precast wall panel systems).
 - Transfer tension caused by overturning forces.
 - Transfer shear, bending, and axial loads between beams and columns and between beams and walls.
- The A/E shall also provide detailed design and drawings for connections between structural elements, including:
 - Column to foundation
 - Column to column
 - Beam to column
 - Slab to beam



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- Beam to girder
 - Beam to beam
 - Slab to slab
 - Wall to foundation
 - Slab to wall
 - Beam to wall
 - Wall to wall.
- Stability
 - Stability shall be provided for the structure as a whole and for each of its elements. Any method that considers the influence of second-order effects, flexural, shear and axial deformations, geometric imperfections, and stiffness reduction due to residual stresses on the stability of the structures and its elements is permitted.
 - The building foundation must be capable of safely transferring all vertical and horizontal forces, due to specified design load combinations, to the supporting soil or rock. The mechanism used for the transmission of horizontal forces may be friction between the bottom of the footing and ground, friction between the floor slab and ground, and/or lateral resistance of soil against vertical surfaces of grade beams, basement walls, footings, piles, or pile caps. The net upward forces on footings and piles, which must be resisted to prevent overturning and/or flotation, are discussed in the foundation design. Structures shall be designed to resist overturning effects caused by seismic forces. Building structures should have, in general, a minimum safety factor of 1.5 against sliding, overturning, and flotation.
- The following requirements shall be reflected in the design and construction of the building structures covered under this subsection:
 - Structures shall have adequate structural configurations acceptable to the Entity and shall meet architectural and functional requirements of the project.
 - Structures shall demonstrate the high standards for safety, durability, and cost effectiveness required by the Entity.

2.1.5 Codes and Standards

- Design and construction of all building structures shall be based upon the requirements of this subsection and existing buildings standards; these shall be from the MBC, **the Saudi Building Code 2018 (SBC 2018)**. The AE responsibility is to demonstrate compatibility between SBC and IBC requirements.
- The material building codes and standards for all structures shall be those versions referenced by the MBC. Where a code or standard is not referenced by the MBC, but is referenced by a material building code, the adopted version of the code shall be that is referenced by the material building code. If a later version of a code or standard has provisions which improve safety or quality of construction, such improvements may be implemented with Entity's approval.
- Adopted codes for building-type structures include:

2.1.5.1 Saudi Building Code (SBC) - Model Building Code (MBC)

Codes	Description
SBC 301	Loads and Force Requirements
SBC 302	Testing and Inspection Requirements
SBC 304	Concrete Structures Requirements
SBC 305	Masonry Structures Requirements
SBC 306	Steel Structures Requirements



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2.1.5.2 ACI: American Concrete Institute

Codes/Standards	Description
ACI 117M	Specification for Tolerances for Concrete Construction and Materials and Commentary (Metric)
ACI 207.1R	Guide to Mass Concrete
ACI 207.2R	Report on Thermal and Volume Change Effects on Cracking of Mass Concrete
ACI 207.4	Cooling and Insulating Systems for Mass Concrete
ACI 313	Standard Practice for Design and Construction of Concrete Silos and Stacking Tubes for Storing Granular Materials
ACI 315	Details and Detailing of Concrete Reinforcement
ACI 318M	Building Code Requirements for Structural Concrete and Commentary
ACI 350M	Metric Code Requirements for Environmental Engineering Concrete Structures and Commentary
ACI 350.2R	Concrete Structures for Containment of Hazardous Materials
ACI 351.1R	Grouting between Foundations and Bases for Support of Equipment and Machinery
ACI 351.2R	Foundations for Static Equipment
ACI 351.3R	Foundations for Dynamic Equipment
ACI 360R	Guide to Design of Slabs-on-Ground
ACI 371R	Guide for the Analysis, Design, and Construction of Elevated Concrete and Composite Steel-Concrete Water Storage Tanks
ACI 530/530.1	Building Code Requirements and Specification for Masonry Structures and Companion Commentaries
ACI 544.1R	State-of-the-Art Report on Fiber Reinforced Concrete
ACI 544.2R	Measurement of Properties of Fiber Reinforced Concrete
ACI 544.3R	Guide for Specifying, Proportioning, Mixing, Placing and Finishing Steel Fiber Reinforced Concrete
ACI 544.4R	Design Considerations for Steel Fiber Reinforced Concrete
ACI SP 226	Autoclaved Aerated Concrete-Properties and Structural Design.

2.1.5.3 AISC: American Institute of Steel Construction

- Manual of Steel Construction
- AISC 303 Code of Standard Practice for Steel Buildings and Bridges
- AISC 360 Specification for Structural Steel Buildings
- Specification for Structural Joints Using High Strength Bolts
- AISC Design Guide Series Numbers 1- 29.

2.1.5.4 AISI: American Iron and Steel Institute

- AISI S100 North American Specification for the Design of Cold-Formed
- Steel Structural Members and Commentary
- AISI D100 Cold-Formed Steel Design Manual
- AISI S200 North American Standard for Cold-Formed Steel Framing

2.1.5.5 ANSI: American National Standards Institute

- ANSI/ASCE3 Standard for the Structural Design of Composite Slabs

2.1.5.6 ASCE: American Society of Civil Engineers

- ASCE 10 Design of Latticed Steel Transmission Structures
- ASCE 20 Standard Guide for the Design and Inst. of Pile Foundations

2.1.5.7 ASCE/SEI: American Society of Civil Engineers - Structural Engineering Institute

- ASCE 5/ACI 530 Building Code Requirements for Masonry Structures



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- ASCE/SEI 7 Minimum Design Loads for Buildings and Other Structures
- ASCE/SEI 8 Specification for the Design of Cold Formed Stainless Steel Structural Members
- ASCE/SEI 11 Guideline for Structural Condition Assessment of Existing Buildings
- ASCE/AF&PA 16 Standard for Load and Resistance Factor Design (LRFD) for Engineered Wood Construction
- ASCE/SEI 19 Structural Applications of Steel Cables for Buildings
- ASCE/SEI 23 Specifications for Structural Steel Beams with Web Openings
- ASCE/SEI 24 Flood Resistant Design and Construction
- ASCE/SEI 37 Design Loads on Structures During Construction
- ASCE/SEI 48 Design of Steel Transmission Pole Structures
- ASCE/SEI 49 Wind Tunnel Testing for Buildings and Other Structures
- ASCE/SEI 52 Design of Fiberglass-Reinforced Plastic (FRP) Stacks
- ASCE/SEI 55 Tensile Membrane Structures
- ASCE/SEI 59 Blast Protection of Buildings
- ASCE/SEI/SFPE 29 Standard Calculation Methods for Structural Fire

2.1.5.8 AWS: American Welding Society

- AWS D1.1M Structural Welding Code
- AWS D1.4M Structural Welding Code Reinforcing Steel

2.1.5.9 CRSI: Concrete Reinforcing Steel Institute

- Manual of Standard Practice
- CRSI Design Handbook
- Reinforcing Bars: Anchorages and Splices

2.1.5.10 ICC: International Code Council

- ICC IBC International Building Code
- ICC IEBC International Existing Building Code
- ICC IECC International Energy Conservation Code
- ICC ICCPC Performance Code for Buildings and Facilities
- ICC IRC International Residential Code for One-and Two-Family Dwellings
- ICC ISPCS International Swimming Pool and Spa Code

2.1.5.11 MBMA: Metal Building Manufacturers Association

- MBMA Manual Metal Building Systems Manual

2.1.5.12 MSMA: Metal Stud Manufacturers Association

2.1.5.13 AWC: American Wood Council

- National Design Specification for Wood Construction - ASD/LRFD

2.1.5.14 PCA: Portland Cement Association

2.1.5.15 OSHA: Occupational Safety and Health Administration

- OSHA 1910 Regulations for General Industry
- OSHA 1926 Regulations for Construction



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2.1.5.16 PCI: Precast/Pre-Stressed Concrete Institute

- PCI TR-7 PCI Standard Design Practice
- PCI MNL-116 Manual for Quality Control for Plants and Production of Structural Precast Concrete Products

2.1.5.17 PCI: Precast Concrete Products

- PCI MNL-117 Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products
- PCI MNL-119 PCI Drafting Handbook - Precast and Pre-Stressed Concrete
- PCI MNL-120 PCI Design Handbook
- PCI MNL-123 Design and Typical Details of Connections for Precast and Pre-Stressed Concrete

2.1.5.18 PCI: Pre-Stressed Concrete

- PCI MNL-124 Design for Fire Resistance of Precast/Pre-Stressed Concrete
- PCI MNL-129 Precast Pre-Stressed Concrete Parking Structures: Recommended Practices for Design and Construction
- PCI MNL-138 PCI Connections Manual for Precast & Pre-Stressed Concrete Construction

2.2 General Design Requirements

2.2.1 General

- The MBC, i.e., the **SBC 2018**, provides minimum design requirements for buildings structures. However, the A/E may resort to the codes and standards listed in Subsection 2.1.5 for design requirements not adequately addressed by the MBC.
- The A/E shall develop cost-effective designs that provide the Entity with the most efficient buildings structures. Therefore, the A/E shall incorporate repetitive/modular structural members and components in designs.
- The A/E shall design all structures in the scope of work, and shall not relegate this task, directly or indirectly, to a Fabricator or Contractor. Use of the word "Similar" in description of details is discouraged. The A/E shall provide sufficient details on the drawings so that structural work can be accurately priced and constructed.
- The A/E shall coordinate structural work with all other disciplines, and be "proactive" in this by reviewing all other disciplines' related drawings, and be aware of revisions in the other disciplines designs at the various design stages (10%, 30%, 60%, 90% and 100%). This would ensure incorporation of all coordination-related revisions in the final structural design.
- The A/E shall be aware of all loads and requirements of other disciplines, including those for housekeeping, inertia bases, operating weights and equipment, window washing equipment etc.
- The A/E shall verify that there are no conflicts of "space" in the design and that structural framing is not clashing with any other components of the building introduced by other disciplines' designs.
- The A/E shall show all structural penetrations, due to above conflicts, on the drawings and show sections through the building in critical areas indicating the location on the structure and its relation in space to the conflicting components.
- The A/E shall review and design all "secondary" structures detailed on other disciplines' drawings, such as stairs shown on architectural drawings, retaining walls shown on landscape drawings, mechanical platforms shown on mechanical drawings.
- The A/E shall coordinate, design, and detail all connections of nonstructural elements to supporting structural elements.
- Building structures shall be configured to comply with the Fire and Smoke Protection Features chapter of the MBC, other regulations, codes & standards, as applicable, and as directed by Entity.



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- Other structures shall be configured for fire and smoke protection in accordance with industry standards, and/or as directed by the Entity.
- Design Details:

Proper drainage shall be provided for the following conditions or locations:

- All surfaces of the structure exposed to weather shall be sloped to drain.
- Intersecting surfaces forming valleys or pockets that may retain water shall be arranged to provide proper drainage of the surfaces.
- Structural steel and wood members shall be designed so that they would not retain moisture or, when arranged in pairs or multiples, water or moisture is not trapped between the members.
- Structural items such as expansion plates, rocker joints, and surfaces intended to permit movement shall be designed so that they are protected against direct contact with water or condensation and shall be detailed to readily drain water.
- Surfaces and members shall be designed so that water may be drained from points where steel contacts or enters into masonry or concrete.

2.2.2 Strength

- Buildings and other structures, and all parts thereof, shall be designed and constructed to support safely the factored loads in the load combinations defined in this subsection without exceeding the specified strength limit states for the materials of construction. Alternatively, buildings and other structures, and all parts thereof, shall be designed and constructed to support safely the nominal loads in the load combinations defined in this subsection, without exceeding specified allowable stresses for the materials of construction.

2.2.3 Serviceability

- Serviceability is a state in which the function of a building, its appearance, maintainability, durability and comfort of its occupants are preserved under normal usage. Limiting values of structural behavior for serviceability (such as maximum deflections and accelerations) shall be chosen with due regard to the intended function of the structure. Serviceability shall be evaluated using appropriate load combinations for the specified serviceability limit states.
- Serviceability limit states, service loads, and appropriate load combinations for serviceability requirements can be found in ASCE/SEI 7-05, Appendix C and Commentary to Appendix C. Service loads, as stipulated herein, are those that act on the structure at an arbitrary point in time and are not usually taken as the nominal loads.

2.2.3.1 Camber

Where camber is used to achieve proper position and location of the structure, the magnitude, direction and location of camber shall be specified in the structural drawings.

- For Reinforced Concrete Members:
 - Beam and Slab Form Cambers:
 - Where beams and/or slabs have centerline to centerline support spans greater than or equal to 9 m, the forms shall be cambered up 3 mm for each 3 m of span.
 - Where cantilevered beams and/or slabs have centerline of support to end of member spans greater than or equal to 3 m, the forms shall be cambered up 25 mm for each 3 m of cantilever span.
- For Pre-Cast/Pre-Stressed Concrete Members:
 - Camber for all pre-cast/pre-stressed members shall be designed in accordance with the PCI design handbook.
- For Structural Steel Members:
 - Camber for all structural steel members shall be designed in accordance with the **SBC 2018-306**, Chapter 12, Section 12.1 and AISC DG-3, Chapter 5.



2.2.3.2 Deflections

- Deflections in structural members and structural systems under appropriate service load combinations shall not impair serviceability of the structure. Generally, deflection of structural members shall not exceed the more restrictive of the limitations specified in:
 - SBC 2018-301 Table 1.4-1.
 - SBC 2018-304 For Concrete Structural Members.
 - SBC 2018-305 For Masonry Structural Members.
 - SBC 2018-306 For Steel Structural Members.
- Conditions to be considered include levelness of floors, alignment of structural members, integrity of building finishes, and other factors that affect normal usage and function of the structure. For composite members, additional deflections due to shrinkage and creep of concrete shall be considered in the design.

2.2.3.3 Drift

Drift of a structure shall be evaluated under service loads to provide required serviceability performance of the structure, including integrity of interior partitions and exterior cladding. Drift under strength load combinations shall not cause collision with adjacent structures or exceed the limiting drift values specified by the MBC.

- Drift of a structure shall not exceed the limitations outlined in the SBC 2018-301 Chapter 10, Section 10.12 for seismic loading concerning stability under ultimate loading condition.
- Drift due to wind shall be checked under service level loads and shall not exceed $h/500$, where "h" is story height of the structure with the following exceptions:
 - For brittle cladding, story drift shall not exceed $h/600$, or criteria set by manufacturer, whichever governs.
 - For glazed cladding, maximum story drift shall be limited to 10 mm, or criteria set by manufacturer, whichever governs.

2.2.3.4 Vibration

- Floor systems susceptible to vibration shall be designed so that vibrations would have no significant adverse effects on the intended occupancy of the building.
- Where the fundamental vibration frequency of a structural system supporting an assembly occupancy used for rhythmic activities such as jumping exercises, gymnastics, pedestrian loading, vibrating machinery, etc. is less than 6Hz, the effects of resonance shall be investigated by means of dynamic analysis.
 - For Concrete Structural Members:
 - Pre-Cast/Pre-Stressed Concrete Structural Members shall be designed for vibration in accordance with PCI Design Hand Book guideline.
 - For Steel Structural Members:
 - Steel Structural Members shall be designed for vibration in accordance with AISC DG-3, Chapter 6 and DG-11.

2.2.3.5 Expansion and Contraction

- The effects of thermal expansion and contraction of a building shall be considered in the design. Damage to building cladding can cause water penetration and may lead to corrosion-related problems.

2.2.3.6 Connection Slip

- The effects of connection slip shall be included in the design where slip at bolted connections may cause deformations that impair serviceability of the structure. Where appropriate, the connection shall be designed to preclude slip in accordance with the SBC 2018-306, Chapter 10, Section 10.3.

2.2.4 Analysis



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- Load effects on individual structural members shall be determined by methods of structural analysis that take into account equilibrium, general stability, geometric compatibility, and both short- and long-term material properties.
- The A/E shall develop an accurate 3D model of the structure which captures actual rigidities of the lateral force resisting systems and accurate load application. The total lateral force is generally distributed to the various elements of the lateral-force-resisting system in proportion to their rigidities, including rigidities of horizontal bracing systems and diaphragms.

2.2.5 Risk Category

- Each building and structure shall be classified in accordance with the SBC 2007-301 Chapter 1, Section 1.6 for the purposes of applying "Importance Factor" in flood, wind and earthquake provisions. Where a referenced standard specifies an occupancy category or the risk category, it shall not be taken as lower than the occupancy category specified therein.

2.2.6 Counteracting Structural Actions

- All structural members and systems, and all components and cladding in a building-type or other structure, shall be designed to resist forces due to earthquake, wind, soil and hydrostatic pressure and flood loads, with consideration of overturning, sliding, and uplift, and continuous load paths shall be provided for transmitting these forces to the foundation. Where sliding is used to isolate the elements, the effects of friction between sliding elements shall be included as a force. Where all or a portion of the resistance to these forces is provided by dead load, the dead load shall be taken as the minimum dead load likely to be in place during the event causing the considered forces. The effects of vertical and horizontal deflections resulting from such forces shall be considered in the design.

2.2.7 Self-Straining Forces

- In addition to the self-straining effects from restrained dimensional changes due to temperature, moisture, shrinkage, creep, and similar effects described in the previous sections, the A/E shall also consider the self-straining effects on structural members due to:

2.2.7.1 Angular Distortion Due to Differential Settlement

- Building or other structures shall be designed such that angular distortion of the structure is within the limits specified in the SBC 2007-303, Chapter 5, Table 5.2. In case these limits cannot be met, the A/E shall consider the effect of angular distortion to structural elements in the design.

2.2.7.2 Sensitivity Analysis

- The value for Modulus of Subgrade Reaction (k_s) shall be verified from in situ tests for sensitive and important structures. Where k_s cannot be verified, the A/E shall perform sensitivity analysis with a minimum of two different values of the Modulus of Subgrade Reaction values. Selected k_s values for sensitivity analysis shall be minimum $\frac{1}{2} k_s$, and maximum $2k_s$, where k_s is the best estimated subgrade modulus as recommended in the Geotechnical Design Report (GDR).

2.3 **Design Loads**

2.3.1 General

- Design loads, load combinations, and design methods shall be as provided in the MBC and in the respective standards and material building codes referenced by the MBC. Any conflicts in definition, notation, terminology, or methodology between the MBC and the other codes and standards referenced in the MBC shall be evaluated and reconciled.
- Design loads not provided in the MBC shall be determined and established in accordance with the references and standards listed in this subsection. Loadings not covered by the references and standards in this manual shall be obtained from available technical literature, manufacturer's data, or be carefully formulated. Such formulation shall be described in the design basis report and detailed in



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the calculations. Where there is conflict between standard and other available data, the most current acceptable data or practice shall be used, subject to Entity's approval.

- Design loads and their sources shall be clearly indicated on construction documents in accordance with the provisions of the MBC. Dead weights of prefabricated components, unit and concentrated live loads, dead and operating weights of fixed equipment, and any loadings that are in excess of the code prescribed weights and loads shall be indicated in the General Notes section of the drawings and referenced in the floor plans drawings.

2.3.2 Special Considerations

- Factors that may result in differences between actual and calculated loads, which shall be considered in the design include:
 - Actual weights of members and construction materials may exceed the values used in design due to such conditions as increased member thickness resulting from deflections of formwork and supports.
 - Allowance shall be made for the weight of future wearing, protective, or finish surfaces where there is high probability that such surfacing may be applied.
 - Special consideration shall be given to the likely types and positions of partitions. Insufficient provision for partitioning may reduce future utilization of the building.
- Future Change of Occupancy
 - Where use and/or occupancy of all or part of a building structure could be changed in the future, design loads shall be increased as required to those of the anticipated future use and occupancy.
 - The above increase in design loads shall only be made when such changes are reflected in the architectural design. Increased design loads and architectural changes implemented for this purpose shall be described in the design basis report and detailed in the calculations.

2.3.3 Applicable Loads

- Dead load (D).
- Live load, except roof live load, including any permitted live load reduction (L).
- Roof Live load including any permitted live load reduction (L_r).
- Combined effect of horizontal and vertical earthquake induced forces (E).
- Load due to fluids with well-defined pressures and maximum heights (F).
- Flood load (F_a).
- Load due to lateral earth pressures, ground water pressure or pressure of bulk materials (H).
- Rain load (R).
- Self-straining force (arising from contraction or expansion resulting from temperature change, shrinkage, moisture change, creep in component material, displacements due to differential settlement, or combinations thereof) (T).
- Load due to wind pressure (W).
 - Members of the structure shall be designed for the combination of loads and forces that can occur simultaneously to produce the most critical design conditions as specified in the MBC code.

2.3.4 Dead Loads (D)

- For purposes of design, the actual weights of materials of construction and fixed service equipment shall be used. In the absence of definite information, values used shall be subject to the approval of the Entity.
- Where tanks, vessels, bins, or other containers of significant weight are located in a building/structure, the dead weight of the item shall be applied to the structure at the points of support. The dead weight



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reactions of connected pipelines and supported conveyance systems shall also be included the design.

- Minimum allowance of 0.2 kN/m^2 shall be added to self-weight of floor or roof system to account for weight of mechanical ducts, electrical cabling and plumbing runs, etc.
- Minimum allowance of 0.5 kN/m^2 may be added to self-weight of floor or roof system to account for additional weight due to design development of the slab thickness.
- The structural design shall consider "sloped screed" weight for roof as dead load. The A/E shall clearly indicate minimum and maximum "screed" thicknesses on construction drawings.
- Where a roof garden is located in a building/structure, self-weight of soil (wet) shall be applied to the structure.
- In areas of a building/structure where partitions other than permanent partitions are shown on the drawings, or where partitions might be added in the future, the following allowances shall be made for the weight of partitions:
 - For Light Gauge Steel Framed Partitions: 1.0 kN/m^2
 - For Masonry Partitions: 2.0 kN/m^2
 - Partition allowance used in design shall be shown on the drawings, including type of partition anticipated.
 - In cases where dead load of partitions is counteractive, the load allowances shall not be included as counteracting dead load in design calculations.

2.3.5 Live Loads (L)

- Live loads used in the design of buildings and other structures for uses and occupancies which are not specified in the MBC shall be based on the maximum loads expected for the intended use or occupancy, but shall in no case be less than a uniformly distributed unit load of 1 kN/m^2 or a line load of 1 kN/m .
- Handrails, guards, grab bars, accessible seats, accessible benches, and vehicle barrier systems shall be designed and constructed to the more stringent of the structural requirements of the SBC 2007, IBC 2009.
- Where tanks, vessels, bins, or other containers of significant weight are located in a structure, those items and their content shall be treated as live loads, calculated based on operating weight of the item and the fluid/infill material in the filled item. The minimum live load calculated as such shall not be less than 1 kN/m^2 .
- Where moveable (on wheels) tanks, vessels, bins, or other containers of significant weight are located in a structure, those items and their contents shall also be treated as live loads, calculated based on operating weight of the item and the fluid/infill material in the filled item. The live load calculated as such for an item shall be divided by the number of wheels and applied as concentrated loads placed on the structure in a manner that maximizes load effects. The minimum live load on each wheel in kN shall not be less than the area of the item divided by the number of wheels. Floor systems shall be evaluated for punching, as warranted by the magnitude of the applied load.
- For listing of minimum uniformly distributed and concentrated live loads, refer to the SBC 2007-301 Chapter 4, Table 4-1 / 4-2 / 4-3.
- For occupancies or uses not designated herein, the specified live loads due to use and occupancy of the area shall be determined from analysis of the loads resulting from the weight of :
 - The probable assembly of persons.
 - The probable accumulation of equipment and furnishing.
 - The probable storage of materials.
 - Analysis methods and results shall be subjected to Entity's approval.

2.3.6 Roof Live Loads (Lr)

- Minimum uniformly distributed Roof Live Load to be used for Structures:
 - Flat Roof = 1.0 kN/m^2



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- Sloped Roof = 1.0 kN/m² for slope 5 20°
= 0.6 kN/m² for slope > 20°
- Minimum Roof Live Load for accessible roofs, Lr = 2.0 kN/m²
- For Roofs used for promenade purposes, Lr = 3.0 kN/m²
- For Roofs used for Roof Garden and Assembly purposes, Lr = 5.0 kN/m²
- Minimum specified concentrated live loads on an area of roof shall be:
 - 1.3 kN over an area of 750 mm x 750 mm.

2.3.7 Rain Loads (R)

- Reference SBC 301 Chapter 8.
- Coordinate with Entity for expected rainfall in specific project area and the minimum rain load to be used in design.

2.3.8 Flood Loads (Fa)

- Reference SBC 301 Chapter 5, Section 5.3.
- Use of ASCE 7-05, Chapter 5 is permitted with local data provided by the MBC.
- Army Corps of Engineers Publication, EM-1110-2-2502, Engineering and Design of Retaining and Flood Walls

2.3.9 Wind Loads (W)

Buildings and other structures, including the main wind force-resisting system and all components and cladding thereof, shall be designed and constructed to resist wind loads as specified herein with reference to the SBC 2007-301, Chapter 6.

- The Basic Wind Velocities varies with locations in Saudi Arabia. The Entity shall be provided Basic Wind speed specific to project location or existing project information can be used with approval of Entity.
- The wind exposure condition for all building sites shall be Exposure D unless noted otherwise. For modifications to existing structures, the wind exposure may be that of the original design, unless directed otherwise by the Entity.
- Story Drift due to Wind Loads.
 - Story drift limitations shall be in accordance with Subsection 2.2.3.
 - For structures supporting steel pipelines, story drift limitations shall be in accordance with the provisions of the Process Industry Practices Guidelines.
- The design wind pressure for components and cladding shall be calculated in accordance with the SBC-301, Chapter 7, but shall not be less than 0.5 kN/m² acting in either direction normal to the surface.
- In the design of interior walls and partitions, consideration shall be given to differences in air pressure on opposite sides of the wall or partition which may result from:
 - Pressure differences between the windward and leeward sides of a structure.
 - Stack effects due to a difference in air temperature between exterior and interior of the structure.
 - Air pressurization by the mechanical services of the structure.

2.3.10 Seismic Loads (E)

- Design Seismic Acceleration Parameters:
The Entity shall be provided Seismic Acceleration Parameters specific to project location or existing project information can be used with approval of Entity.



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- Every building structure, and portion thereof, shall be designed and constructed to resist the effects of earthquake motions.
- Seismic design shall be taken to completion in the calculations regardless of whether the wind base shear exceeds the seismic base shear. (The specified earthquake loads are based on post-elastic energy dissipation in the structure, and because of this fact, the provisions for design, detailing, and construction shall be satisfied even for structures and members for which load combinations that do not contain the earthquake effect indicate larger demands than combinations including earthquake).
- Additions to existing structures shall be designed and constructed to resist the effects of earthquake motions in accordance with the provisions of the MBC. Existing structures and alterations to existing structures need only comply with these provisions when required by the MBC.
- Story drift due to seismic loads limitations shall be in accordance with the provisions of the SBC 2007-301, Chapter 10, Section 10.9.7 or 10.10.6 depending on analysis procedure.

2.3.11 Self-Straining Loads (T)

- Self-Straining Thermal Forces
 - Saudi Arabia has a dry climate with very high temperatures in most of the country. Temperatures in Saudi Arabia however are different in each part of the country. The south has moderate temperatures, which can go as low as 10 degrees Celsius (50° Fahrenheit) during the summer. In winter the temperatures are moderate in general, but turning cold at night sometimes descending below freezing.
 - Provision shall be made for stresses or movements resulting from variations in temperature. The rise and fall in temperature shall be fixed for the locality in which the structure is to be constructed and shall be computed from an assumed temperature at the time of erection. Due consideration shall be given to the lag between air temperature and the interior temperature of massive concrete members or structures.
- Thermal Reactions from Piping, Ductwork, or Other Systems.
 - Thermal loads from any source other than ambient atmospheric temperature changes shall be treated as dead loads.
 - The thermal load effects of a mechanical system on a structure shall be based on the actual design temperatures of the system and the type of support utilized. The following cases shall be considered in the load combinations:
 - Maximum expansion of the system with the maximum expansion of the structure.
 - Maximum expansion of the system with the maximum contraction of the structure.
 - Maximum contraction of the system with the maximum expansion of the structure.
 - Maximum contraction of the system with the maximum contraction of the structure.Where it is not possible for the conditions to occur simultaneously, the case may be omitted. Justification for omission of any load case shall be provided to Entity for approval.
- The load induced by each condition shall be considered in the load combinations, as well as the condition of no thermal reactions.
- Where sliding connections are used, the friction force shall be considered in the design of the supporting structural elements.
- Where slotted connections are used, the slots shall be of sufficient length to accommodate maximum displacements of the system. Bolts used in slotted connections shall be finger tight (very slightly loose) and restricted from loosening - either by the use of double nuts (interlocked) or nylon insert lock-nuts, by thread deformation, or by tack-welding.

2.3.12 Loads Due to Lateral Earth Pressure, Ground Water (H)

Load effect on basement walls and/or underground structures due to lateral earth pressure and ground water shall be calculated in accordance with the SBC 2007-301, Chapter 5.



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2.3.13 Hoisting Devices Loads

Structures that support hoisting devices (cranes, monorails, jibs, etc.) shall be designed for the forces induced by the operation or movement of the components of the hoisting device.

- Hoisting device loads shall be considered live loads.
- Impact, braking, and other relevant dynamic forces shall be considered in the design.
- For exterior devices, the effect of wind shall be considered in the design.
- For devices that can move freely when exposed to wind, safety restraint mechanisms shall be provided.
- For hoisting devices that are exposed to the local environment such that dust, sand, and windborne corrosive chemicals can accumulate on the device, the most robust protective coating system available from the manufacturer shall be used, subject to Entity's approval. Sealed protective covers shall be used to prevent dust and sand intrusion into
- the electrical motors and mechanical gears of the device. The effect of continuous exposure to elevated temperatures and of the contained heat from enclosure of the motors shall be considered in the selection of the device.
- Hoisting device loads shall be combined with other design loads in accordance with ASCE 7. Any load combinations that could produce the maximum stress or govern for stability shall be considered in the calculations.
- Anchorage of jib cranes to a structure shall be based on the forces generated by the dead weight of the jib mechanism plus the rated load plus 25% impact. The anchorage shall be capable of supporting the jib crane with the jib located at all of the possible angular positions and with the hoist (if movable) located at the position that causes the most unfavorable effect.
- Cranes: Engineering and configuration of the supporting crane rail runway girders and the loads imparted to the building structure shall be established in accordance with the more conservative of the provisions of the AISE Technical Report N° 13_2003 Guide for the Design and Construction of Mill Buildings and the provisions in the Crane Loads section of the report.
- Vibration Loads: Where vibration is induced by equipment such as pumps, blowers, fans and compressors, supporting members shall be designed to prevent fatigue failure and to avoid misalignment or malfunction of machinery and equipment. Refer to AISE Technical Report No. 13 for guidelines on vibratory loadings.

2.3.14 Crane Loads

1. All vertical, lateral, and longitudinal crane forces (reactions) shall be transferred through a clearly defined and continuous load path to the ground. All lateral forces shall be transferred through frame action to the transverse bracing system of the building. All longitudinal forces shall be transferred as axial loads through girders and brace members. Brace systems shall preferably be tension-only X-braces. Brace connections shall be designed as slip-critical and configured with minimal eccentricity, and shall transfer forces into rigid elements of the main structural members.
 2. The crane live load shall be the rated capacity of the crane. Design loads for the runway beams, including connections and support brackets, of moving bridge cranes and monorail cranes shall include the maximum wheel loads of the crane and the vertical impact, lateral, and longitudinal forces induced by the moving crane.
- Maximum Wheel Load. The maximum wheel loads shall be the wheel loads produced by the weight of the bridge, as applicable, plus the sum of the rated capacity and the weight of the trolley with the trolley positioned on its runway at the location where the resulting load effect is maximum.
 - Vertical Impact Force. The maximum wheel loads of the crane shall be increased by the following percentages to determine the induced vertical impact or vibration force:

○ Monorail cranes (powered)	25%
○ Cab-operated or remotely operated Bridge cranes (powered)	25%
○ Pendant-operated bridge cranes (powered)	10%



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- Bridge cranes or monorail cranes with hand-gear bridge, trolley, and hoist 0%
- Lateral Force. The lateral force on crane runway beams with electrically powered trolleys shall be calculated as 20 percent of the sum of the rated 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 a runway beam, and shall be distributed with due regard to the lateral stiffness of the runway beam and supporting structure.
- Longitudinal Force. The longitudinal force on crane runway beams, except for bridge cranes with hand-gear bridges, shall be calculated as 10 percent of the maximum wheel loads of the crane, and assumed to act horizontally at the top of the runway beam.
- Crane Loading Condition:

For a bridge crane, the location and lateral movement of the trolley produces 4 crane conditions which shall be considered in the design of crane buildings:

 - The maximum wheel loads at the left end truck and the minimum wheel load at the right end truck, acting simultaneously with the lateral force acting to the left.
 - The maximum wheel loads at the left end truck and the minimum wheel load at the right end truck, acting simultaneously with the lateral force acting to the right.
 - The maximum wheel loads at the right end truck and the minimum wheel load at the left end truck, acting simultaneously with the lateral force acting to the left.
 - The maximum wheel loads at the right end truck and the minimum wheel load at the left end truck, acting simultaneously with the lateral force acting to the right.
- Design Loads for Runway Beams and Suspension Systems:
 - Cranes shall be located longitudinally in the aisle in the positions that produce the most unfavorable effect on the runway beam, runway beam connections, and support brackets or suspension systems. Consideration shall be given to eccentric loads which may be induced by a single crane.
 - The following recommendations are applicable to the design of runway beams and their connections and support brackets or suspension systems for single or multiple cranes:
 - Single Crane
 - The runway beam, including its connections and support bracket or suspension system, shall be designed for the maximum wheel loads plus 100% of the vertical impact, acting simultaneously with 100% of the lateral force assumed to act horizontally in either direction.
 - Multiple Cranes
 - If the runway beams are simple span and the cranes are separated by spacer struts or electronic spacer controls so the minimum distance between the nearest end truck wheels of any two adjacent cranes equals or exceeds the span of runway beam, only the crane loads for the crane producing the most severe effect need be considered for the design of the runway beam.
 - If the runway beam is continuous or the cranes are not separated as described above, the runway beam, including its connections and support brackets or suspension system, shall be designed for the worst case crane loads of: a single crane producing the most unfavorable effect, or for any two adjacent cranes producing the most unfavorable effect. For the two crane condition, the maximum wheel loads without vertical impact for the two cranes shall be used simultaneously with 50% of the lateral force for each of the two cranes or 100% of the lateral force of either of
 - the cranes, whichever produces the most unfavorable effect. For continuous runway beams, the lateral force of adjacent cranes shall be considered to act in the same direction or opposing directions.
- Design Loads for Building Frames and Support Columns:
 - The crane or cranes shall be located longitudinally in the aisles in the positions that produce the most unfavorable effect on the building frame or support columns. Consideration shall be given to eccentric loads which may be induced by a single crane operating in a crane aisle, or by a crane or cranes operating in one crane aisle of a building with multiple crane aisles.
 - The following requirements are applicable to the design of building frames and support columns for crane buildings with single or multiple cranes acting in one or more aisles:



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- **Single Crane Aisle with One Crane**
The frame and support columns shall be designed for the 4 crane loading conditions. The wheel loads without vertical impact shall be used with 100% of the lateral force.
- **Single Crane Aisle with Multiple Cranes**
 - If the runway beams are simple span and the cranes are separated by spacer struts or electronic spacer controls so the minimum distance between the nearest end truck wheels of any two adjacent cranes equals or exceeds the largest bay of the building, only the crane loads for the crane producing the most severe effect need be considered for the design of the building frame and support columns.
 - If the runway beams are continuous or the cranes are not separated as described above, then the frame and support columns shall be designed for the worst case crane loads of: a single crane producing the most unfavorable effect, or of any two adjacent cranes producing the most unfavorable effect. For the two crane condition, the wheel loads without impact shall be used simultaneously with 50% of the lateral force from both of the two cranes, or with 100% of the lateral force from either of the two cranes, whichever produces the most unfavorable effect.
 - The crane loading conditions shall be used for each crane. When the lateral forces for two cranes are used, only those conditions in which lateral forces act in the same direction need be considered.
- **Multiple Crane Aisles with Single Cranes**
 - Frame and support columns shall be designed for the single crane producing the most unfavorable effect or for any one crane acting in each of any two aisles. For the two cranes, the wheel loads without impact shall be used with 50% of the lateral force from both of the two cranes or 100% of the lateral force from either of the two cranes.
 - The crane loading conditions shall be used for each crane. When the lateral forces for two cranes are used, only those conditions in which the lateral forces act in the same direction need be considered.
- **Multiple Crane Aisles with Multiple Cranes**
 - If the runway beams are simple span and the cranes in all aisles are separated by spacer struts or electronic spacer controls so the minimum distance between the nearest end truck wheels of any two adjacent cranes equals or exceeds the largest bay of the building, only the crane loads for the crane producing the most unfavorable effect in each aisle need be considered for the design of the building frame and support columns.
 - If the runway beams are continuous or the cranes are not separated as described above, then the frame and support columns shall be designed for the most unfavorable effects of crane loads of:
 - A single crane,
 - Any two adjacent cranes in any one aisle,
 - Any two adjacent cranes in one aisle acting simultaneously with one crane in any other non-adjacent aisle, or
 - Any one crane acting in each of any two adjacent aisles.
 - The crane arrangement producing the most unfavorable effect on the frame and support columns shall be used. For these conditions, the wheel loads without impact for each crane shall be used with 50% of the lateral force from each of the cranes acting simultaneously, or with 100% of the lateral force from any one of the cranes.
- The crane loading conditions shall be used for each crane. When the lateral forces for two or more cranes are used, only those conditions in which lateral forces act in the same direction may be considered.
- **Crane Supports**
 - Vertical deflection of support runway girders shall not exceed the following limits due to maximum wheel load(s), without impact (where L = the span length):
 - Top running CMAA Class A, B, and C cranes L/600



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- Top running CMAA Class D cranes L/600
- Top running CMAA Class E and F cranes L/1000
- Under running CMAA Class A, B, and C cranes L/1000
- Monorails L/1000
- 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) due to the maximum lifted load plus hoist load(s), without impact.
- Lateral deflection of support runway girders for cranes with lateral moving trolleys shall not exceed L/400 (where L = the span length) based on 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.
- Bumper Force. Crane stops shall be designed in accordance with the manufacturer's requirements, or, if not specified, the following load:

$$F = \frac{W \cdot V^2}{2 \cdot g \cdot T \cdot \eta}$$

where:

- F = Design force on crane stop, kN
- W = 50% of bridge weight+90% of trolley weight, excluding the lifted load, kN
- V = Rated crane speed, m/s
- g = Acceleration of gravity, 9.81 m/s²
- T = Length of travel (m), of spring or plunger required to stop crane, from crane manufacturer (usually 50 mm)
- η = Bumper efficiency factor (0.5 for helical spring, see mfg. for hydraulic plunger)

2.3.15 Vibration Loads

Refer to vibration requirements in applicable subsections 2.4.3.5.

2.3.16 Railway Loads

- Design of buildings and other structures interfacing with railway traffic shall be based on AREMA 2017 Manual for Railway Engineering.
- Building structures supporting railway traffic on curved tracks shall be designed to resist centrifugal forces due to railway traffic by shear walls or braces, with a clearly defined and continuous load path to the foundation.
- Building structures supporting railway traffic shall be founded on deep foundations, unless recommended otherwise in the GDR.
- Surcharge load due to railway traffic on supporting and adjacent building structures shall be considered in the design of these structures.

2.3.17 Areas Accessible to Vehicular Loads

- Areas in building structures accessible to vehicular traffic shall be designed with consideration for permitted vehicular loads.
- Floors in garages or portions of building used for storage of motor vehicles shall be designed for the uniformly distributed live loads shown in SBC 2007-301, Chapter 4, Table 4-1 or the following concentrated load:
 - For garages restricted to passenger vehicles accommodating not more than nine passengers, 13.0 kN acting on an area of 100 mm by 100 mm, footprint of a jack.



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- For mechanical parking systems without slab or deck which are used for storing passenger cars only, 10 kN per wheel.
- Areas accessible to pedestrian traffic, but not to vehicular traffic, shall be designed for their intended use, but not for less than the greater of:
 - The live load of 12.0 kN/m².
 - Other loads as prescribed in Subsection 2.3.
- Transportation structures shall be designed in accordance with Subsection 5.

2.4 Load Combinations

Buildings and other structures shall be designed using the allowable or ultimate strength provisions of Section 2.3 or 2.4 of the SBC 2007, with the exceptions listed in this sections. Either Section 2.3 or 2.4 of the SBC 2007 shall be used exclusively for proportioning elements of a particular construction material in the structure.

2.5 Geotechnical Information

2.5.1 General

The information in this section is intended to provide the A/E with the basic understanding of the geotechnical investigation process and the Geotechnical Design Report (GDR).

2.5.2 Geotechnical Investigation

- Geotechnical investigation is required for all projects. If the Entity has pre-existing Geotechnical investigation for the same location; this shall be reevaluated by the Entities A/E Geotechnical Engineering firm to ensure accuracy. After review and approval from both the Entities A/E and the A/E Geotechnical Engineering firm it may be used.
- Specific requirements for geotechnical investigation are included in Volume 6, Chapter 7. Section 11 (EPM-KES-GL-000002 - Geotechnical Guideline)

2.5.3 Geotechnical Design Report (GDR)

For all projects, a GDR shall be prepared by A/E based on geotechnical investigation at the project site and submitted to the Entity for review and approval. The report generally includes:

- A plot showing the location of all test borings and/or excavations.
- Elevation of the water table, if encountered.
- Recommendations for foundation type and design criteria, including net allowable bearing pressure and the allowable peak bearing pressure of the stratum of soil where shallow footings would normally be founded, and provisions to mitigate the effects of expansive and highly plastic soils.
- Recommend type of cement for foundation and protection degree for concrete surfaces in contact with soil, such as:
 - Retaining, basement, pit, and other walls.
 - Soil densities for dry, moist, and saturated conditions.
 - Active and passive pressure coefficients for the soil.
 - Recommended procedure for combining hydrostatic pressure with lateral soil pressure.
- For walls resisting lateral forces transmitted through soil resulting from the presence of distributed or concentrated surcharge loads, the report provides recommended procedures for determining resulting vertical and horizontal pressures on vertical and horizontal surfaces.
- Where soil stratigraphy or presence of fills is indicated, and the potential for differential settlement is high, the GDR provides instructions on how to achieve uniform foundation settlement.
- Where existing structures are adjacent to new construction, the GDR provides instruction on how to mitigate the effects of new construction on the existing structures.
- When expansive and highly plastic soils are present, special provisions are usually made in the foundation design and construction to safeguard against damage due to these soils. In such cases, the GDR provides design and construction criteria to mitigate the prevailing conditions.



2.6 Concrete Design

2.6.1 General

- Engineering and configuration of concrete structures shall be as provided in the SBC 2007-304 & 304C and in the respective material building codes referenced by the MBC.
- The design, construction, maintenance and selection of materials covered herein shall comply with the SBC 2007-304, Chapter 3, Section 3.8.

2.6.2 Materials

- For reinforced concrete structures, Portland Pozzolan Cement concrete (Type I Cement) shall be used in accordance with guideline specifications for structural concrete for the following types of structures:
 - All concrete structures in contact with the ground or the ground water — up to 1 m above finished grade.
 - All waterfront structures in contact with seawater or in a location subject to seawater spray.
 - All mass-concrete construction (mass concrete is defined here as monolithically poured structural elements with least dimension over 1m in thickness). Construction of mass concrete elements shall comply with ACI provisions for casting and curing of mass concrete. Where mass concrete is required in a project, the drawings shall include locations, notes, and construction instructions. Due to the increased cost, effort, and time associated with the casting and curing of mass concrete, A/E and/or EPC Contractor shall make an effort to avoid proportioning structural members as mass concrete.
- For reinforced concrete not in contact with the ground, Type I Cement shall be used in accordance with the guideline specification for structural concrete.
- For plain concrete blinding, Type V Cement shall be used in accordance with the guideline specification for structural concrete.
- Refer to Subsection 7 for additional requirements on corrosion protection.

2.6.3 Concrete Durability

- Concrete Durability shall meet the requirements of the SBC 2007-304, Chapter 4.
- Engineering of concrete structures shall be performed with due consideration of the corrosive nature of the local environment and occupancy conditions. Unless conditions warrant durability to be engineered, details for the protection of concrete should meet the requirements of the Entity's, guideline specifications, and typical construction details drawings.

2.6.4 Cast-In-Place Concrete

- Reinforced Concrete
 - Reinforcing steel details shall be in accordance with the provisions of the SBC 2007304, Chapter 7. Use of ACI 315 is allowed where the specific design requirements are not addressed by the MBC.
 - Tolerances for fabrication and placement of reinforcing steel bars shall be in accordance with ACI 117M, "Specification for Tolerances for Concrete Construction Materials and Commentary [Metric]". The effect of these tolerances shall be considered in the design.
 - The minimum yield strength of reinforcing steel shall be as follows:
 - Reinforcing Steel Bars: 414 MPa (60 ksi)
 - Welded Wire Fabric: 240 MPa (36 ksi)
 - Epoxy coated reinforcing steel shall be used for those portions of structures situated below grade and up to 1m above grade, provided that the reinforcement is not cathodically protected.
 - The maximum diameter size of reinforcing steel bars to be used shall be 32 mm and the minimum shall be 10 mm. Larger reinforcing steel sizes shall be used only when technically feasible, design cannot be achieved, and only upon approval of the Entity.
 - Configuration of structural members such that they have the maximum code permitted ratio of reinforcing steel area to concrete area shall be avoided. For members that intersect with



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other members, the preferred maximum ratio shall be 75% of the maximum code permitted ratio. Exceptions are permissible for isolated cases.

- Particular care shall be exercised in the configuration of joints that have members framing from multiple directions.
 - Bar spacing limitations shall apply to all splices and laps in the joint.
 - Curvature of bends of bars larger than 12mm shall be considered.
 - Positions of offset bends of column bar splices shall be considered.
 - When multiple beams frame horizontally into a joint, beams other than the primary beam shall be configured with the top longitudinal reinforcing steel positioned successively below the longitudinal steel of the primary beam.
 - Longitudinal beam reinforcing steel cannot be in the same position in space as the longitudinal column steel. Size and spacing of members shall be selected such that reinforcing steel does not have to be reoriented or repositioned at the joint. Bunching of bars at the joint shall not be permitted.
 - Bottom reinforcing steel that terminates at a joint shall be hooked only if required by structural analysis or by structural integrity provisions.

- Concrete Specified Compressive Strength to be Used in Building Structures

The following shall govern the use of concrete for the design of reinforced concrete Building Structures:

- Structural Concrete
The minimum design compressive strength (ASTM C39M) of structural concrete, including those with minimum reinforcement for shrinkage and temperature control, shall be 25 MPa.
- Pre-cast/Pre-stressed Concrete
The minimum design compressive strength (ASTM C39M) of Pre-cast/Pre-stressed Concrete, shall be 35 MPa.
- Non-Structural Concrete
The minimum design compressive strength (ASTM C39M) of unreinforced concrete of no significant structural value such as concrete blinding or lean concrete, and concrete for duct banks shall be 20 MPa.

- b. Plain Concrete

- Engineering of plain concrete structures shall be in accordance with the Structural Plain Concrete chapter of the MBC and/or codes and standards referenced in the MBC.
 - Structural plain concrete basement walls shall be exempt from the requirements for special exposure conditions.
 - Design and construction of soil-supported slabs, such as sidewalks and slabs-on-ground, shall not be governed by ACI 318 unless they transmit vertical loads or lateral forces from other parts of the structure to the soil.
- For special structures, such as arches, underground utility structures, gravity walls, and shielding walls, provisions of this subsection shall govern where applicable.
- Minimum Concrete compressive strength for plain concrete shall be no less than 20 MPa.

- Architectural Concrete

- A cast-in-place architectural concrete structure shall be any structure indicated on the Architectural drawings that does not participate in the resistance of loads as an element or a component of the building structure, and that is not an off-the-shelf architectural element. They exist independently and resist no loads other than those applied directly to them. Examples are concrete steps, benches, signs, fences, screens, artwork, etc. that are of such nature that only minimal and repetitive grid reinforcement is required. They shall not be shown on the structural drawings unless it is deemed that there is complexity or potential risk to human life to warrant more careful detailing.
- Engineering of architectural concrete shall be done by the A/E.
- The finished surfaces of a cast-in-place architectural concrete structure shall be as specified on the architectural design drawings.

- Concrete Finishing



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- Concrete finishes exposed to view in the finished structure shall be as specified in the Architectural construction documents. Refer to document no. EPM-KEA-GL-000001 (Architectural design guidelines) for fair-face concrete color finish requirements.
 - For all concrete surfaces not exposed to view in the finished structure, a rough-formed finish, defined as having an as-cast concrete texture imparted by the form facing material, tie holes filled, defects repaired, and fins and other projections removed, shall be acceptable. Unformed surfaces shall be struck off smooth, unless additional concrete is to be cast against the surface, whereupon the surface shall be struck off and intentionally roughened. Surface roughness shall be as provided in ACI 318-08.
 - The finished surface for cast-in-place concrete that will have an architectural finish adhered shall be coordinated with the supplier of the finish product.

2.6.5 Precast / Pre-Stressed Concrete

- Precast/pre-stressed concrete structures shall be fabricated at an off-site, certified manufacturing facility.
- Engineering of Precast/pre-stressed concrete structures should be performed by the manufacturer, unless noted otherwise.
- Engineering of Precast/pre-stressed concrete structures shall be as provided in the SBC 2007-304, Chapter 16 & 18 and in the respective material building codes referenced by the MBC, and in accordance with the provisions and recommendations of the PCI Design Handbook, MNL 120.
- Fabrication, rebar placement, embedment placement, and erection tolerances shall be in accordance with PCI MNL 116.

2.6.6 Precast Architectural Concrete

Engineering of precast Architectural concrete shall be in accordance with the provisions and recommendations of the PCI Architectural Precast Concrete Manual, MNL-122.

2.6.7 Pre-Engineered/Pre-Fabricated Precast Buildings

Modular building design for utilization of precast concrete elements, the following directive for designing of reinforced concrete buildings shall be adopted as a favored construction method.

- Whenever feasible and economically viable, precast elements shall be utilized in the design. Whenever feasible, precast elements already manufactured in the Kingdom shall be utilized, taking into consideration Saudi material availability and manufacturing capability. Design of structural details such as connections shall be complete.
- A complete single set of structural design calculations and contract drawings shall be developed by the A/E such that the construction contractor can submit an alternative proposal for structural systems and components, which are shown on the Contract bid package with minimum alterations and additional calculations. The alternative proposal may consist of either a modified cast-in-place or precast concrete structural system. To comply with this requirement, the general layout, structural details and dimensions of structural components shall reflect the modular concept (i.e., variation of dimensions and details shall be minimized, and conversely, repetition of dimensions and utilization of identical building components shall be maximized).

2.6.8 Post-Tensioned Concrete

Engineering of post-tensioned concrete structures shall be as provided in the SBC 2007-304, Chapter 18 and in the respective material building codes referenced by the MBC, and in accordance with the provisions and recommendations of the PTI Post-Tensioning Manual, TAB.1.

2.6.9 Composite Construction

- Engineering and configuration of composite steel and concrete structures shall be in accordance with the SBC 2007-306, Chapter 9.
- Specific products used in the implementation of a composite system that are not in direct compliance with the building codes shall be certified by the International Code Council (ICC) Evaluation Service.



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Engineering shall be based on the values and limitations provided in the ICC Evaluation Service Report (ESR). Applications outside of the range of testing shall not be permitted. Test reports and design values produced by other independent product testing and certification organizations may be used, subject to Entity's approval.

2.6.10 Slab on Grade

- Design Requirements
 - In general, slabs on grade structures are designed for bending stresses due to uniform loads and concentrated loads and for in-plane stresses due to drying shrinkage and subgrade drag resistance. When appropriate for the type of facility being designed, slabs are designed for the effects of warehouse loadings involving aisles, posts and racks, etc. In such instances, particular attention shall be given to the design for negative moment in aisles.
 - Proper construction methods, workmanship, and concrete mix proportioning generally follow the guidelines of ACI 302.1R, "Guide to Concrete Floor and Slab Construction". Slabs are required to have a minimum thickness of 100 mm. TABLE 2.1 provides criteria for selection of slab thickness based on design live load, for slabs on grade having a reaction modulus (k_s) of at least 2.75 kg/cm³.

TABLE 2.1 SLAB ON GRADE LIVE LOAD

Thickness of Slab	Maximum Uniform Design Live Load
100 mm	7 kN/m ²
150 mm	12 kN/m ²
200 mm	20 kN/m ²

Unless otherwise specified above, the correct slab thickness shall be determined in accordance with the Portland Cement Association (PCA) Publication, "Slab Thickness Design for Industrial Concrete Floors on Grade." In the PCA design process compressive strength is converted to modulus of rupture, which is then reduced by a factor of safety to obtain the maximum allowable flexural tensile stress. The maximum allowable flexural tensile stress is then used to determine the required slab thickness.

- When partition walls are situated over slab on grade, the slab on grade shall be thickened under partition wall.
- Mechanical equipment pads shall be isolated from slab on grade.

2.6.11 Joints

- Slab on Grade Joints
 - Expansion Joints (EJ)
 - Expansion joints shall be provided to accommodate the effects of displacements caused by shrinkage, temperature, creep, and settlement.
 - Expansion joints shall be located such that they divide the slab on grade into a number of approximately equal individual sections.
 - Expansion joints shall be provided at approximately 50 m centers both longitudinally and transversely. For exposed slabs, expansion joints shall be provided at approximately 25 m spacing.
 - Expansion joints shall be at least 25 mm wide.
 - Contraction/Control Joints (CCJ)
 - Contraction joints shall be provided to accommodate the effects of shrinkage, temperature, and settlement. Contraction joints attempt to control the location of cracks that occur due to contraction of the slab.



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- Contraction joints shall be located such that they divide the slab on grade into a number of approximately equal individual sections between edges and expansion joints.
- Contraction joints shall preferably be straight, located on or near building grid lines, and at approximately equal intervals between grid lines.
- The location of contraction joints shall be clearly indicated on the plans.
- Construction Joints (CJ)
 - Construction joints shall be provided to facilitate separate casting of different sections of a slab. A construction joint may be used as a contraction joint provided that the contraction joint features are implemented.
 - Construction joints shall preferably be straight.
 - The location of construction joints shall be clearly indicated on the plans.
- All Joints
 - Where the use of the slab involves the movement of traffic or heavy equipment across the joint, provisions shall be made to transfer shear across the joint. The shear transfer mechanism shall permit free movement (opening and closing) of the joint, and, where required, lateral translation.
 - Joints shall preferably be straight and located on or near building grid lines.
- Structure Movement Joints
 - Movement joints shall be provided in structures to accommodate the effects of displacements caused by wind, seismic, other lateral loads, shrinkage, temperature, creep, and settlement. Joint width shall be determined based on the calculated service displacements of the structures on both sides of the joint. The minimum clearance between deflected structures shall be 12 mm, unless noted otherwise. Expected maximum and minimum deflected joint widths shall be indicated on the structural drawings.
 - For reinforced concrete structures, movement joints allowing for at least 25 mm shall be provided at approximately 50 m centers both longitudinally and transversely.
 - Movement joints shall be located such that they divide the structure into a number of individual sections.
 - The joints shall pass through the height of the structure above ground level in one plane — preferably straight. Joints must be designed to accommodate all expected movements at the joint.
 - The structure shall be framed on both sides of a movement joint.
 - Details for accommodating finished floor, internal and external wall, and other sliding joints per architectural requirements shall be provided.
 - Movement joints shall be provided where there is significant change in the type of foundation.
 - Movement joints shall be considered where there is significant change in the height of the structure.
 - Joint spacing in exposed parapets shall be approximately 12 m.
 - The A/E shall coordinate with all disciplines to ensure that all systems crossing the joints are configured correctly to accommodate the expected range of movement. This includes mechanical services pipes, ducts, and wires; electrical services; architectural finish, glazing, and cladding systems; and any other elements or systems that cross or are near a movement joint.

2.7 Masonry Design

2.7.1 General

- Engineering and configuration of masonry structures shall be as provided in the SBC 2007-305 and in the respective material building codes referenced by the MBC. Any conflicts in definition, notation, terminology, or methodology between the MBC and the codes and standards referenced by the MBC shall be evaluated and reconciled.
- This section provides engineering, planning and design guidelines for masonry structures including:



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- Reinforced Concrete Masonry
- Non-Reinforced Masonry
- Load Bearing Masonry
- Non-Load Bearing Masonry
- Composite Construction.
- Engineering of masonry structures shall be performed with due consideration of the corrosive nature of the local environment. Unless conditions warrant a more aggressive treatment, details for the protection of exposed masonry should be in accordance with the requirements of the Entity's, guideline specifications, and typical construction details drawings.
- specifications and details.

2.7.2 Composite Masonry Construction

- Composite masonry wall systems are comprised of multiple masonry wall units set side by side and tied together utilizing metal ties.
- Metal ties transfer shear stress between wythes allowing interaction between masonry wall units or brick and masonry units.
- Composite masonry is usually constructed with reinforced cores which may be partially or fully grouted depending on the required wall geometry and loading.
- Refer to the National Concrete Masonry (NCMA) TEK Notes and SBC 2007-305 for general design guidance.

2.7.3 Autoclaved Aerated Concrete (AAC) Masonry Units

- AAC masonry units are ultra-light concrete blocks with a unique cellular structure which provide increased energy efficiency, fire resistance and acoustical properties.
- Structural Properties
- AAC masonry units may be used in low-rise load-bearing buildings as shear walls, partition walls, and infill walls. See TABLE 2.2 for AAC Physical Properties.

TABLE 2.2 - AUTOCLAVED AERATED CONCRETE MASONRY UNITS

ASTM C1693 — PHYSICAL REQUIREMENTS				
Strength Class	Compressive Strength (MPa)	Nominal Dry Bulk Density	Density Limits	Average Drying Shrinkage %
	minimum	kg/m ³	kg/m ³	50.02
AAC-2	2.0	400	350-450	50.02
		500	450-550	50.02
AAC-4	4.0	500	450-550	50.02
		600	550-650	50.02
		700	650-750	50.02
		800	750-850	50.02
AAC-6	6.0	600	550-650	50.02
		700	650-750	50.02
		800	750-850	50.02

- Mortar
 - The first course of AAC units may be placed on a thin mortar set consistent with ASTM C270.



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- The remaining courses are set on thin bed mortar fabricated from Portland cement based adhesives consistent with ASTM C1660.
 - Moisture
- AAC Unit moisture content is in the range of 25% to 30% at fabrication and reduces to 4% to 6% within four years. The linear shrinkage is 0.02%.
- It is recommended that a breathable coating be applied to the AAC Units to facilitate moisture dissipation.

2.7.4 Approval of Special Systems of Design or Construction

Comply with the SBC 2007-305 Section 1.3.5.

- Design Load
 - Design loads shall be determined and established in accordance with Subsection 2.3.
- Basic Design References
 - SBC 2007-305 and/or The Building Code Requirements for Masonry Structures (ACI 530/ASCE 5/TMS 402), Specification for Masonry Structures (ACI 530.1/ASCE 6/TMS 602) shall be the basic references for design of masonry structures.

2.7.5 Design Basis

- General
 - Masonry walls used as a part of the structural system shall be reinforced.
 - Un-reinforced masonry walls shall be used for non-structural applications, but such walls shall be designed to sustain lateral loads.
 - Structures of masonry construction shall be designed such that the masonry is not in contact with the soil.
- Control Joints
 - Cracking of walls constructed of concrete masonry units is caused by the development of tensile stresses within the wall assembly which exceed the tensile strength of the materials comprising the assembly. Generally, it is due to tensile stresses which develop when wall movements accompanying temperature and moisture change as restrained by other elements, or when concrete masonry places restraint on the movements of adjoining elements. Moisture loss depends on the shrinkage potential of the masonry units and the drying conditions at the building site, expressed in terms of relative humidity. Major methods employed to control cracking in masonry structures are:
 - Materials specifications to limit the drying-shrinkage potential,
 - Reinforcement to increase crack resistance, and
 - Control joints to accommodate movement.
 - Any crack control measure taken shall be compatible with the structural design for lateral forces. Control joints provide a complete separation of the masonry. Hence, location of control joints fixes the length of wall panels and, in turn, the rigidity of the walls, the distribution of lateral forces and the resulting stresses. Therefore, adding, eliminating or relocating control joints shall not be permitted once the structural design is completed.
 - Control joints shall never be assumed to transfer bending moments or diagonal tension across the joint. Joint reinforcement and bars in nonstructural bond beams shall be terminated at control joints; deformed bars in structural bond beams shall be made continuous for length of the diaphragm. Using quality controlled concrete-masonry-units and the prescribed minimum reinforcement for lateral forces, cracking is not normally a problem when maximum horizontal spacing of control joints is limited to 4 times the diaphragm-to-diaphragm height or 30 m on center, whichever is less.
- Connection to other Elements
 - Connections between vertical resisting elements (shear wall-panels) and horizontal resisting elements (floor and roof diaphragms) shall be designed to make the walls integral parts of the



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structural system. Positive means shall be provided for transferring shear from the plane of the diaphragm into the shear wall-panels.

- In designing connections or ties, it is necessary to carry out the forces and their stress paths, and to make connections along each path consistent with the basic assumptions of behavior and distribution of forces according to relative rigidities. Connections contribute to integrity of the structure, and therefore they shall be properly designed, fabricated and installed. Design and detailing of connections shall be based on the actual nature of forces transmitted through the connection (static/dynamic, tensile/compressive, etc..).
- Connections Design
 - Forces to be considered in the design of joints and connections are gravity loads; temporary erection loads; horizontal loads normal to wall; horizontal forces parallel to wall; and creep, shrinkage, and thermal forces — separately or combined, as applicable.
 - Bond beams acting as flange (chord) for horizontal diaphragms shall be reinforced at dummy control joints to resist chord stresses induced by diaphragm-beam action.
 - Maximum spacing of anchor dowels or bolts used in connections shall not exceed 1.2 m, and connections shall be designed based on rational analysis in accordance with well-established principles of mechanics. Anchor dowels or bolts shall not be used in structural applications where they are subjected to tensile forces.
 - Strength of connections, as a general rule, shall be sufficient to develop useful strength of connected structural elements. Joints and connections for elements resisting lateral forces shall be designed for at least 2 times the calculated shear when using the prescribed lateral loads, except that the connection need not be required to develop forces greater than the ultimate capacity of the connected elements.
- Cautionary Notes for Designers and Detailers

Avoid connection and joint details which could result in stress concentrations that might cause spalling or splitting at contact surfaces. Liberal chamfers, adequate reinforcement, and cushioning materials are a few means by which adverse effects of stress concentrations may be reduced. Avoid direct bearing of heavy concentrated loads on concrete masonry units. Avoid welding to any embedded metal items which might cause damage to the adjacent masonry by spalling, in particular where the expansion of the heated metal is restrained by masonry. All bolts and dowels which are embedded in masonry shall be grouted solidly in place with not less than 25 mm of grout between bolt or dowel and the masonry. At tops of piers and columns, vertical bolts shall be set inside the horizontal ties.
- Reinforcements around Openings
- Since the area around wall openings is vulnerable to failure, at least two (2) 12 mm diameter reinforcing bars shall be provided around the perimeter of openings.
- The lintel bars above the opening may serve as the top horizontal reinforcing bars.

2.8 Steel Design

2.8.1 General

- Engineering of steel structures shall be as provided in the SBC 2007-306 and in the respective material building codes referenced by the model building code. Any conflicts in definition, notation, terminology, or methodology between the MBC and the codes and standards referenced in the MBC shall be evaluated and reconciled with the model building code.
- Either the Allowable Stress Design (ASD) or the Load and Resistance Factor Design (LRFD) method may be used for design of steel structures, unless noted otherwise. The entire structural system shall be designed based on the selected method.
- Engineering of steel structures shall be performed with due consideration of the corrosive nature of the local environment. Unless conditions warrant a more aggressive treatment, details for the protection of steel shall be in accordance with the specifications, or as noted in Subsection 7, Corrosion Protection. Any deviations from the specified corrosion protection methods shall require Entity's approval.



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- Guidance related to engineering, planning, and design of structural steel frames and elements, including structural steel, steel joists, steel decks, composite construction, cold formed steel, and pre-engineered buildings is provided in the next sections.

2.8.2 Structural Steel

- Engineering and configuration of steel structures shall be as provided in the SBC 2007-306 and in the respective material building codes referenced by the MBC. Shape designations shall be based on the metric system.
- All structural steel exposed to the weather shall be galvanized or coated per the corrosion protection subsection of this manual (5.2.6). Exposed anchor rods/bolts shall be provided with an allowance for corrosion of 2 mm (i.e., required $d + 4$ mm, where "d" is diameter of the anchor rod/bolt). Refer to Section 7 for additional requirements on corrosion.
- Steel structures shall be designed such that the steel is not in contact with soil.
- Hot-rolled structural steel shape elements (such as webs, flanges, legs) shall have a minimum thickness of 4 mm for use in bolted connections.

2.8.3 Steel Joists

- Engineering and configuration of steel joists shall be as provided in the SBC 2007-306 and in the respective material building codes referenced by the MBC.
- Joists used in floor systems shall be sized to minimize perceptible vibration.
 - K-Series joists are lower capacity joists ideally suited for roof systems.
 - LH and DLH are joists with higher capacity suitable for longer spans or for shorter spans and heavier loads.
- Joist Girders are designed to carry reaction loads from joists or other members. Open web system of construction is considered cost effective solution.
- Refer to Standard Specifications from the Steel Joist Institute for design guidance such as:
 - Standard Specifications for Open Web Steel Joists, K-Series.
 - Standard Specifications for Open Web Steel Joists, LH-Series.
 - Standard Specifications for Joist Girders.

2.8.4 Cold Formed Steel

- Cold formed steel shall be engineered in accordance with AISI S-100 and D-100. It shall not be engineered in accordance with AISC.
- Cold formed steel sections are economical for the purpose of constructing lightly loaded structures. The cold form steel wall and roof systems are non-combustible and require lighter equipment to install. Cold formed steel systems include the following:
 - Light-loadbearing Wall Framing: System is capable of carrying horizontal and vertical load systems when properly braced.
 - Exterior Non-Loadbearing Wall Framing: Able to carry wind and seismic horizontal forces when utilized as exterior cladding system with brick, masonry or other cementations material.
- Cold formed steel members may be used to construct steel roof trusses for various spans.
- Cold formed steel stud members shall meet the requirements of the "Steel Stud Manufacturers Association (SSMA)."

2.8.5 Pre-Engineered / Pre-Fabricated Metal Buildings (PEMB)

- Engineering and configuration of pre-engineered metal buildings shall be as provided in the Structural Steel sections of the SBC 2007-306 for hot-rolled steel members and AISI S-100 for Cold Formed Steel members, and in the respective material building codes and standards referenced by the MBC.



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- Additional design information and recommendations available from the Metal Building Manufacturers Association (MBMA) may be used.
- Engineering of the PEMB system - steel frame structure, girts, purlins, metal deck (roof and side); all appurtenances, appendages, and accessories attached to the steel frame; the connections of all system components; and the provision for connections to attach all A/E coordinated building system components (MEP Services) - is the responsibility of the manufacturer of the PEMB system. The loading effect of the functioning of all building components and systems attached to the PEMB shall be considered for all operating conditions (doors opened or closed, monorail at critical locations, motor start-up torque, etc.).
- The A/E shall coordinate with all relevant internal disciplines and the PEMB Manufacturer to ensure that the PEMB is engineered and configured to function with all interfacing building systems. The PEMB Manufacturer and his engineer of record, shall indicate on the drawings the locations and magnitudes of all concentrated loads agreed upon in coordination with the A/E and as provided in construction documents.
- The PEMB Manufacturer shall provide to the Entity and A/E all PEMB reactions as service loads such that all load combinations required by the building codes may be calculated. Factored loads may additionally be provided, if available.
- The PEMB Manufacturer shall provide to the Entity and A/E the required layout of the anchor rods for the PEMB, including the required type, sizes, projections, and other anchorage details for the PEMB member base attachments.
- The PEMB Manufacturer shall provide erection and shop drawings to Entity and A/E for approval before commencing any physical work.
- Engineering of substructure elements of a PEMB system is the responsibility of the A/E's structural engineer. Provision shall be made to resist all reactions from the PEMB structural system and to transfer these reactions to the ground. Where tension ties are used in the slab- on-ground or structural slab, A/E shall consider the presence of trenches or building MEP services in the design. Engineering and configuration of the anchor rods below the base plate of the PEMB members shall be the responsibility of the A/E. Engineering and configuration of the attachment of the base member of the side deck to the supporting base shall be the responsibility of the A/E and shall be consistent with the PEMB system details.
- Features of a PEMB System:
 - The PEMB superstructure steel is approximately 30% lighter than conventional construction due to the tapered fabrication of structural steel, cold form steel for purlins and girts, and the use of light gage members in roof and wall construction.
 - Delivery and installation time is reduced significantly for PEMB construction versus conventional construction.
 - PEMB structures are approximately 20% less expensive to construct than conventional construction for the following reasons:
 - Installers are preapproved to construct PEMB facilities, and they are usually well experienced in this type of construction.
 - Installation details are typical and standardized.
 - Products used in the construction of PEMB such as doors, windows, roofing and siding are the least expensive products available for the proposed facility use.
 - PEMB Manufacturer is generally concerned with the design of the superstructure, as design of the substructure is the responsibility of the A/E. However, success of any PEMB project requires close coordination between the two parties during both design and construction stages.
 - PEMB facilities may be a good fit for simple structures such as warehouses, industrial centers, and trucking stations.
 - PEMB structures may not be applicable to more complex facilities where architectural features drive the facility superstructure layout such as schools, courthouses, office buildings, or hospitals.
 - The use of other, more architecturally appealing facade systems and other building amenities, may be utilized in PEMB facilities, however cost savings usually associated with PEMB facilities may not always be realized.



2.9 Wood Design

2.9.1 General

- Engineering of wood structures shall be in accordance with the Wood Chapter of the IBC 2009.
- All connection hardware shall be galvanized or stainless steel.
- All lumber exposed to the weather and not within the closed airspace of a building structure, shall be treated with preservatives consistent with AASHTO-M133 for preservatives and pressure treatment processes.

3.0 HIGH RISE BUILDING STRUCTURES

3.1 General

3.1.1 Introduction

This section includes the basic principles and guidelines for design and construction of high rise building structures, and provides the minimum technical requirements to be adopted by the A/E and/or EPC Contractors to enable safety, quality, and cost effectiveness in the design and construction of high rise building structures and high rise building systems that meet the needs and expectations of the ENTITIES. High-rise buildings are defined as structures with an occupied floor located more than 23 m above the lowest level of fire department vehicle access (this specific criterion shall be verified by A/E and appropriate Entity).

3.1.2 Scope

The scope of this subsection is to provide guidance on design and construction of high rise building structures constructed of concrete and steel materials. The design requirements provided herein, or cited by reference, are based on a MBC and industry standards.

3.1.3 Applicability

The principles, guidelines, and requirements included in this subsection shall govern all high rise building structures, as defined in the introduction herein.

3.1.4 General Requirements

- Engineering of high rise buildings shall be as provided in the structural design chapter of the MBC and in the respective material building codes and standards referenced by the MBC.
- Complete description of the lateral force resisting systems and of any special mechanisms used for the dampening or control of lateral response in high rise building structure shall be provided in the design basis report. The systems shall be analyzed and detailed in the calculations, and their important structural design parameters and limitations included in the general notes section of the drawings.

3.1.5 Codes/Standards

High-rise buildings shall be designed based on the ASCE 7-05. Design and construction of all high-rise building structures shall be based upon the requirements of this subsection and industry buildings standards. These shall follow the provisions of the ASCE 7-05 and the special requirements specified in the MBC.

3.2 Structural Design and Design Considerations

3.2.1 Structural Design

- Engineering of high-rise buildings shall be as provided in the Structural Design chapter of the MBC and in the respective material building codes and standards referenced by the MBC.
- Complete description of the lateral force resisting systems and of any special mechanisms used for the dampening or control of lateral response shall be provided in the design basis report, in the calculations, and in the structural general notes on the construction drawings.



3.2.2 Design Considerations

- High-rise buildings shall be designed as performance based structures as outlined in various chapters of ASCE 7-05.
- Linear seismic response spectra analysis shall be conducted using three dimensional structural modeling.
- Nonlinear dynamic behavior of structure is required when the response spectra analysis exceeds demand to capacity ratio outlined in the ASCE 7-05, AISC 341, and AISC 360.
- Site specific response spectrum to be used in structural design shall be as recommended in the GDR.
- Spectrum used in seismic design shall conform to the requirements of the ASCE 7-05.
- Non-Linear dynamic shaking motion is required, using the Maximum Considered Earthquake shaking motion with a 5% damped acceleration.
- Determine required wind speeds and associated pressures per the base wind speeds specified in this section.
- Consider wind tunnel studies that accurately model dynamic behavior.
- Slab-Wall Connections
 - Concrete core walls provide substantial building support making connections an important consideration.
 - Tower sway induces lateral deformation creating shear and rotation forces in these connections.
- Story Drift shall not exceed 0.5% of story height of any story for service level shaking.

3.2.3 High Rise Building Limits

- Concrete Structures
 - Construction
 - Concrete rigid frame buildings are the preferred system for up to 20 stories.
 - Concrete shear wall structures are the preferred system from 21 to 35 stories.
 - Combination frame-shear wall structures are the preferred system from 36 to 50 stories.
 - Perimeter Concrete formed tube or bundled tube construction is the preferred system from 50 stories to 75 stories.
- Steel Structures
 - Construction
 - Steel Staggered truss is the preferred system for up to 20 stories.
 - Steel Rigid frame is the preferred system from 21 to 30 stories.
 - Steel Rigid frame combined with concrete shear wall is the preferred system from 31 to 40 stories.
 - Steel belt truss is the preferred system from 41 to 60 stories.
 - Steel framed tube and bundled tube arrangements are the preferred system from 61 stories to 140 stories.

3.3 Damping System

3.3.1 General

1. Dampers assist in the dissipation of energy generated by seismic shaking and wind gust frequency.
 2. Types of dampers are as follows:
- Passive Dampers are uncontrolled and require no power to work.
 - Examples of passive dampers are as follows:



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- Viscous dampers
 - Friction dampers.
- Active Dampers generate forces on a structure to counter wind or seismic imposed disturbance.
 - Examples of active dampers are as follows:
 - Tuned mass damper
 - Tuned liquid damper.

4.0 NON-BUILDING STRUCTURES

1. This subsection provides structural design criteria for structures other than buildings, furnishes design guidance for various types of non-building structures, and identifies special considerations with regard to certain materials in specific applications.
2. The non-building structures and systems covered under this subsection include:

- Drainage Structures.
- Catch Basins and Manholes.
- Pre-engineered Canopy Structures.
- Shade Structures.
- Water and Wastewater Structures.
- Liquid Retaining Structures.
- Flow Chambers.
- Valve Chambers.
- Thrust Blocks.
- Mechanical and Process Structures.
- Pipeline Corridor Structures.
- Electrical and Communication Structures.
- Generator Support Structures.
- Concrete Duct Banks.
- Security Crash Barriers.
- Supports for Signs, Luminaires, Traffic Signals.

4.1 General

4.1.1 Introduction

- This subsection mandates the principles, guidelines, and requirements for design and construction of the non-building structures, and provides the minimum technical requirements to be adopted by the AE and/or AE EPC Contractors to enable safety, quality, and cost effectiveness in the design and construction of non-building structures that meet the needs and expectations of the Entity. This subsection provides structural design criteria for structures other than buildings, and furnishes design guidance on materials and applications for these structures.
- Non-building structures include all self-supporting structures that are not included under the purview of the MBC, that resist gravity loads and environmental and/or other lateral loads.
- Engineering and configuration of non-building structures shall be in accordance with the applicable provisions of the MBC and the standards of the various organizations referenced in this subsection, and as amended herein.
- Industrial buildings may be classified as non-building structures in certain situations for the purposes of determining seismic design coefficients and factors, system limitations, height limits, and associated detailing requirements. Therefore, when the occupancy is limited primarily to maintenance and monitoring operations, these structures may be designed in accordance with the provisions of the SBC 2007-301, Chapter 13 for non-building structures (non-buildings similar to buildings).



4.1.2 Scope

The scope of this subsection is to provide guidance on design and construction of non-building structures, constructed of various materials. This scope is limited to non-building type structures and systems defined in the introduction to this subsection. The design requirements provided herein, or cited by reference, are based on applicable provisions of the MBC, industry standards, and best practices embraced by the Entity.

4.1.3 Applicability

The principles, guidelines, and requirements included in this subsection shall govern design and construction of all non-building type structures and systems listed in the introduction to this section and discussed herein.

4.1.4 General Requirements

- For non-building structures not listed in this subsection, design requirements, specifications, and construction details for such structures shall be developed by the A/E, for review and approval by the Entity.
- Although this section covers certain materials and special considerations for those materials when used in particular applications, the category of structures classified as "non-buildings" shall not be limited in materials to those discussed in this subsection.

4.1.5 Codes and Standards

1. Design and construction of all non-building structures and systems shall be based upon the requirements of this section and industry standards; these shall be from the applicable requirements of the MBC and the codes and references included herein.
- Subsection 2.1.4: General Reference.
 - ACI: American Concrete Institute
 - ACI 554 Specification for Glass Fiber Reinforced Concrete Materials and Commentary (Metric).
 - ACI 350M Metric Code Requirements for Environmental Engineering Concrete Structures and Commentary.
 - ACI 350.2R Concrete Structures for Containment of Hazardous Materials.
 - ACI 351.1R Grouting between Foundations and Bases for Support of Equipment and Machinery.
 - ACI 351.2R Foundations for Static Equipment
 - ACI 351.3R Foundations for Dynamic Equipment
 - ACI 371R Guide for the Analysis, Design, and Construction of Elevated Concrete and Composite Steel-Concrete Water Storage Tanks
 - ACI 544.1R Report on Fiber Reinforced Concrete
 - ACI 544.2R Measurement of Properties of Fiber Reinforced Concrete
 - American Concrete Pipe Association
 - Concrete Pipe Design Manual
 - American Railway Engineering and Maintenance-of-Way Association
 - AREMA: American Railway Engineering and Maintenance-of-Way Association Manual for Railway Engineering.
 - ASCE: American Society of Civil Engineers
 - ASCE 10 Design of Latticed Steel Transmission Structures
 - ASCE/SEI 48 Design of Steel Transmission Pole Structures
 - ASCE/SEI 74 Guidelines for Electrical Transmission Line Structural Loading
 - ASCE Publication Structural Reliability Based Design of Utility Pole Structures



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- ASCE Design of Circular Concrete Tanks
 - ASCE Considerations for Rectangular Concrete Tanks
 - ASCE Engineering Practice Report 113
 - ASCE/SEI 49 Wind Tunnel Testing for Buildings and Other Structures
 - ASCE/SEI 52 Design of Fiberglass-Reinforced Plastic (FRP) Stacks
- American Water and Waste Water Association
 - AWWA M42 Steel Water Storage Tanks
- NACE RP0193 External Cathodic Protection of on Grade Carbon Steel tank bottom
- ASTM International
 - ASTM A775M Standard Specification for Epoxy-Coated Steel Reinforcing Bars
 - ASTM A934M Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars
 - ASTM C478M Standard Specification for Precast Reinforced Concrete Manhole Sections
- API: American Petroleum Institute
 - API 650 Welded Steel Tanks for Oil Storage
 - API 651 Cathodic Protection Systems
 - API RP 615 Installation of Underground Petroleum Storage Tanks and Piping Systems
 - API RP 1632 Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems
 - API STD Venting Atmospheric and Low Pressure Storage Tanks
- AWWA: American Water Works Association
 - M11 Steel Pipe: A Guide for Design and Installation
 - M42 Steel Water Storage Tanks
- PCA: Portland Cement Association
 - PCA Design of Rectangular Concrete Tanks
 - PCA Design of Circular Concrete Tanks
- AASHTO: American Association of State Highway and Transportation Officials
 - AASHTO Standard Specifications for Structural Supports of Highway Signs, Luminaries and Traffic Signals
 - AASHTO Standard Specifications for Highway Bridges, American Association of State Highway and Transportation Officials (AASHTO)
 - AASHTO LRFD Bridge Design Specification, American Association of State Highway and Transportation Officials (AASHTO)
 - AASHTO Standard Specifications for Highway Drainage Structures
- PCI: Precast/Pre-Stressed Concrete Institute
 - PCI MNL-120 PCI Design Handbook
- PIP: Process Industry Practices
- PTI: Post-Tensioning Institute
 - PTI TAB 1.0 Post-Tensioning Manual
- STI: Steel Tank Institute
- US Government Agencies
 - US Department of Defense, UFC-4-022
 - US Department of State, SD-STD-02.01
 - FEMA 430, Perimeter Security Design
- ANSI/TIA: Telecommunications Industry Association
 - ANSI/TIA-222G Structural Standards for Antenna Supporting Structures

4.2 Principles and Guidelines

4.2.1 Concrete



Structural Design Guidelines

- General

- Concrete properties shall be selected to suit the expected conditions. For discussion of considerations in selecting appropriate composition and properties of concrete, refer to the specifications.
- Portland-Pozzolan cement shall also be used for non-building structures. For un-reinforced concrete in contact with the earth, Type V cement shall be used.
- TABLE 4.1.A and Subsection 2.6 shall be used for selection of minimum concrete classes.
- Refer to Subsection 7 for additional guidance and requirements on corrosion protection.

TABLE 4.1.A - MINIMUM RECOMMENDED CONCRETE CLASSES

Mass concrete not exposed to deteriorating agents where mass rather than strength is the principal consideration	C20
Drainage and Utility Structures	C25
Structures to contain non-corrosive fluids (tanks and reservoirs)	C30
Waterfront structures on fresh water	C30
Reinforced concrete structures over seawater which are sufficiently elevated so that they are ordinarily wetted by salt water	C30
Reinforced concrete decks of waterfront structures where the underside is frequently wetted by salt water	C35

- Concrete reinforcing steel shall be in accordance with the specifications. Epoxy coated reinforcement shall be used for the following structures, provided that reinforcement is not cathodically protected (Refer to Subsection 7):
 - Portions of structures situated below grade and up to 1 m above finished grade. Where splices with uncoated reinforcement occur, splicing shall begin above this location.
 - Drainage structures.
 - Bulk structures to contain liquid and corrosive materials.
 - Water related structures.
 - Waterfront structures.
- Concrete cover for protection of reinforcement shall be in accordance with the specifications.
- Fiber Reinforced Concrete:

Concrete and cementitious mortar may be reinforced with alkali-resistant, chopped-glass fibers, short steel fibers, or various organic plastic fibers to obtain enhanced strength, ductility, and toughness when compared to plain concrete and mortar. Fiber reinforced concrete shall be used only if it is approved by the Entity. Design guidance and typical material properties are found in the SBC 2007-304.

Requirements and limitations for use of Fiber Reinforced Concrete, are included in the ACI 554.

4.2.2 Structural Design

- Design Loads
 - Design loads shall be in accordance with the guidelines listed in Subsection 2.3, and as modified in this subsection.
 - Loadings not covered by the criteria in this section shall be obtained from available technical or manufacturer's literature, or formulated with Entity's approval.
 - Particular attention shall be given to wind, seismic, dynamic, and fatigue loads on cable-supported structures and other similar force-oscillating structures.
- Design Stresses
 - Conform to MBC and referenced codes and standards.
- Design Requirements
 - Design shall conform to the general concepts and practices of the proper design specification cited in this subsection. Where the design of a particular structure or of a special case is not



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covered, the design approach and technical formulae shall be based on available technical literature or shall be formulated, with Entity approval. If formulated, such formulation shall be included in the design basis report and related calculations.

- Wherever possible, standard, readily available materials, units, and systems of construction shall be specified. New materials, units, and systems of a sustainable or creative design concepts that are economically and structurally sound may be used, subject to Entity approval.
- Structural systems and materials shall be selected based on safety, quality, and cost effectiveness.
- Industrial buildings may be classified as non-building structures in certain situations for the purposes of determining seismic design coefficients and factors, system limitations, height limits, and associated detailing requirements. Therefore, when the occupancy is limited primarily to maintenance and monitoring operations, these structures may be designed in accordance with the provisions of the SBC 2007-301, Chapter 13 for non-building structures similar to buildings.
- **Stability** – the provided criteria shall be verified by A/E based on applicable codes and standards, and/or project specifics
 - **Factor of Safety Against Overturning, Sliding, and Uplift**
 - Unless noted otherwise, stability relates to sliding, overturning, and other sources of gross displacement and not to stability as related to buckling. Structure or any of its elements shall be designed to provide a minimum safety factor of 2.0 against failure to sliding, overturning, or uplift. This required degree of stability shall be provided solely by dead load plus any permanent anchorage.
 - Stability calculations shall be based on service loads.
 - Soil shall not be considered unless it is directly supported by the foundation and it is certain that the soil cannot be removed. Soil wedges shall not be considered.
 - For tanks, vessels, bins, etc. structures both cases (empty and with content) shall be considered for stability analysis. Structural design shall be based on the most stringent load effects under the two cases.
 - Overturning, sliding, and uplift stabilities shall be evaluated with and without the effects of buoyancy.
 - **Factor of Safety Against Buoyancy**
 - The safety factor against buoyancy shall be at least 1.2 against the highest anticipated hydrostatic uplift pressure. Where the weights calculated are well established, this factor may be reduced to 1.1. In determining the safety factors, allowance shall be made for future removal of weights, removal of soil, for example.

4.3 Design Standards and Requirements

4.3.1 Culverts and Drainage Structures

- Culverts convey surface water through a roadway or other structure into a channel. The culvert design should fulfill both structural and hydraulic guidelines. When designing a culvert, the following shall be considered:
 - The most common shapes used are:
 - Circular (most common shape)
 - Pipe Arch and Elliptical (used where there is limited cover)
 - Box (singular or multiple boxes)
 - Three-Sided Arch (used for spanning water with natural bed as the bottom)
 - Shape selection shall be based on:
 - Materials may be corrugated steel, precast concrete, or cast-in-place concrete.
 - Corrugated Steel structures may not be utilized without authorization by the Entity
 - Material selection
 - Upstream elevation
 - Embankment height
 - Hydraulic performance



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- The selection of material for the culvert is based on the following:
 - Structural strength (fill height, loading condition, foundation condition)
 - Durability (considering water and soil environment)
 - Availability of materials
 - Roadway or feature profile
 - Channel characteristics
 - Construction and Maintenance costs
 - Service Life

Structural design of culverts is generally preceded with hydraulic design, where the culvert material, shape, and other related design parameters are determined. Depending on the site and nature of the flow, the culvert hydraulic design may call for additional measures such as protection against scour due to high discharge velocity. Such protection may be in the form of rip rap, concrete mats, or stone fill.

- Loading

Drainage and culvert structures shall be designed for the loadings defined in the AASHTO Standard Specification for Highway Bridges and in accordance with the design requirements presented herein (See also Subsection 5.2.4).

- Methodology

- Design of circular and elliptical culverts are based on the Marson-Spangler Design procedure, as detailed by the American Concrete Pipe Association, Concrete Pipe Design Manual or the FHWA procedures.

This procedure is based on the following criteria:

- culvert backfill
- trench size
- culvert geometry
- culvert materials

- Design of Concrete Box Culverts

The principal criteria of design for culverts and drainage structures are as follows:

- Depth of backfill over structure: 0 to 2.5 m.
 - The greater the depth, the higher the lateral soil pressure on the walls and the more soil weight on the culvert top
 - Truck loading is superimposed on the culvert side walls via surcharge and is distributed through the backfill to the top of the culvert.
- Depth of backfill over structure: Greater than 2.5 m
 - Truck live load dissipates and does not need to be considered
 - Soil weight on culvert top and passive pressure on side walls governs the design
- Soil pressures shall be considered fully saturated unless a drainage system is installed with the culvert system.
- Interior culvert water pressure is required to be considered, but rarely governs the design of culverts and drainage structures.

- Design Considerations

Applicable loads and load combinations shall be analyzed per AASHTO Standard Specification for Highway Drainage Structures. Additional design considerations include:

- Drainage Structures are also referred to as manholes inlets vaults and valve boxes. Drainage structures shall be designed to resist earth, water, temperature, and other loads to which they will be subjected. Structural design of concrete structures shall be in accordance with the SBC 2007, ACI 350 or other applicable Codes and Standards.
- Special consideration shall be given to the effect of proper allowance for differential movement due to settlement, thermal expansion, etc., between manholes and interconnecting elements and vaults. To the extent practical, precast and prefabricated components for manhole construction shall be used. Precast components shall be furnished in accordance with ASTM C478M.
- Design of underground precast structures shall include ground floatation:



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- Downward gravity forces including the weight of walls, slabs, inverts, and soil
- Weight of earth fill and overburden on extended base
- Frictional resistance of the soil on an extended edge
- Buoyant forces
- The factor of calculated safety will determine if the structure complies with the factor of safety required in ACI 350M.
- The factor of safety against buoyancy may be addressed by increasing member thickness, deeper placement or by anchors.

4.3.2 Catch Basins and Manholes

- a. General:
 - Catch basins are vertical flow chambers for routing water to drainage structures. Manholes are vertical access chambers for maintenance personnel.
 - Structures may be reinforced precast concrete or reinforced cast-in-place concrete and can be designed as round or rectangular in shape.
- b. Design Requirements:
 - Catch Basins and Manholes are required to be watertight.
 - Resist buoyant forces.
 - Resist vertical Truck and/or Construction Loading and horizontal surcharge loads when placed in vehicle right-of-way.
 - Design for lifting lugs and associated forces if structure is precast construction.
 - Minimum interior spacing between pipe openings shall be 150 mm.
 - Required structural design data
 - Soil investigations are required to determine the following information:
 - Soil and groundwater profile
 - Strength parameters for natural soils and engineered fills
 - Soil density (dry, moist, and saturated)
 - Coefficients of lateral earth pressure
 - Design Loads:
 - Rectangular Structures
$$P = \text{Soil Weight} \times \text{Active pressure Coefficient} \times \text{Height} + \text{Water Weight} \times \text{Wall Height}$$
 - Round Structures
$$\text{Hoop Stress} = \text{Pressure} \times \text{Diameter} / (2 \times \text{Wall Thickness})$$
 - Add Truck Loading surcharges per Ministry of Transportation (MOT) guideline, when required

4.3.3 Pre-Engineered Canopy Structures (PECS) Including Shades

- General: PECS are those that are pre-manufactured for assembly on any site. While some purchase contracts provide for supply only, others provide for supply and installation, in the appropriate situation, off-the-shelf structures may provide a readily available, cost-effective method of shade provision.
- References and Standards:
 - Saudi Building Code SBC-301 — Loads and Force Requirements
 - Saudi Building Code SBC-304 — Concrete Structures Requirements
 - Saudi Building Code SBC-305 — Masonry Structures Requirements
 - Saudi Building Code SBC-306 — Steel Structures Requirements
 - American Society of Civil Engineers — ASCE 7 — Minimum Design Loads for Buildings and Other Structures
 - Guidelines for Shade Planning and Design Grounded



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- Purpose:
 - The purpose of Canopy Structures is to provide maximum protection of the public or equipment from UV rays and weather. PECS provide cost effective solution, which improves installation schedule, and provides effective weather protection.
- The following preliminary steps are recommended in developing a Pre-Engineered Canopy structure design.
 - Shade conceptual design
 - Total Installed Cost (TIC)
 - Geotechnical Design Report
 - Environmental design parameters and design life service
 - Approval of the Entity
 - Architectural/Landscape Architecture Layout of Canopy
- Materials: Canopy materials are to be determined and shown on architectural layout drawings.
- Components of Canopy Structures: All superstructure components of the canopy shall be designed, shipped, and installed by the Pre-Engineered Canopy supplier including:
 - All member sizes and materials
 - Connections
 - Decking and Waterproofing
 - Engineering
 - Certificates and Warranties
- Design and Construction:
 - The A/E is responsible for supplying the following information:
 - Design Loads per the SBC 301 including with initial tensile forces for tensile structures and ponding over canopies, if applicable
 - Size, location and materials of proposed canopy structure
 - Foundation design of proposed canopy structure
 - The A/E is responsible to review and approve shop drawings prior to construction, verify materials and certifications meet required parameters.

4.3.4 Shade Structures

Shade structures shall be designed based on the requirements of the proprietary shade structure manufacturer, the soil parameters recommended in the GDR, environmental design parameters and the wind speed.

4.3.5 Water and Wastewater Structures

- General:

Water and Wastewater structures are required to have the following characteristics:

 - Serviceability.
 - Durability.
 - Limited deflection
- References:
 - ACI 350M, Code Requirements for Environmental Engineering Concrete Structures & Commentary.
 - Rectangular Concrete Tanks, Portland Cement Association (1994).
 - Circular tanks without Pre-stressing, Portland Cement Association (1993).
 - Moments and Reactions for Rectangular Plates, US Bureau of Reclamation.
- Steel Reinforcement:
 - ASTM A775 Epoxy Coated reinforcing bars
 - Minimum Concrete Cover:
 - Concrete Base = 75 mm.
 - Concrete Wall = 50 mm.



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- Stilling Basin = 150 mm.
- Flotation Criteria (Flotation Stability Criteria for Concrete Hydraulic Structures, US Army COE).
 - Loading Conditions FS
 - Construction 1.3
 - Normal Operation 1.5
 - Extreme (max. pool) 1.1
- Crack Reduction:
 - Reinforcement Distribution - use smaller diameter reinforcement and reduce bar spacing not to exceed 300 mm.
 - For additional requirements related to crack reduction, refer to following standards:
 - ACI 207 / ACI 224 / ACI 350.4 / ACI 350M
- Temperature and Shrinkage Reinforcement:
 - Refer to ACI 350M for minimum of reinforcement requirement.
- Minimum Thickness:
 - As required by ACI 350M, wall with height greater than 3 m shall be a minimum of 300 mm in thickness and shall have reinforcement on both faces.
 - A minimum of 200 mm is required where 50 mm concrete cover is desired.

4.3.6 Liquid Retaining Structures

- General: Liquid retaining structures may comprise the following:
 - Concrete Tanks
 - Buried or below ground
 - Above ground
 - Structural Steel
 - Buried or below ground
 - Above ground
 - Concrete tanks shall conform to the following:
 - ASCE - Design of Circular Concrete Tanks
 - PCA - Circular Concrete Tanks
 - ASCE - Considerations for Rectangular Tank Design
 - PCA - Rectangular Concrete Tanks
 - ACI 350M
- In addition, the following parameters / considerations shall be incorporated into the design:
- Minimum steel for crack control
 - Concrete mix design
 - Minimize shrinkage effect by pouring the sections of the work between construction joints in a sequence such that there will be suitable time delays between adjacent pours
 - Curing methodology
- Joint Sealing:
 - Provide PVC water-stops for all cast-in-place joint interfaces. Hydrophilic, mastic type, water-stops shall not be used.
 - Interfaces between Precast and cast-in-place to be detailed on the design drawings.
 - Where joint sealing is to include a primary and secondary seal, water tightness test is to be completed and passed prior installation of secondary seal.
 - Concrete Repairs:
 - Repair all air voids, bolt holes, and honeycombs using a suitable epoxy mortar applied strictly in accordance with manufacturer's instructions.
 - Repairs by bagging using cement mortar, etc. shall not be permitted. A work method statement should be submitted to the Entity for approval 48 hours prior to undertaking repairs.



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- Other repair methodologies may be acceptable, subject to Entity approval, such as injection methods.
- Water tightness Test:
 - Refer to ACI 350.1
 - Determine evaporation during testing period by direct measurement of evaporation losses in a manner approved by the Entity.
- Steel tanks shall conform to the following:
 - API 650 - Welded Steel Tanks for Oil Storage
 - AWWA M42 - Steel Water Storage Tanks
 - Special corrosion resistant materials shall be used to protect steel tanks including:
 - Cathodic Protection Systems. Per API-651 or NACE RP0193 External Cathodic Protection of on-grade carbon steel tank bottoms.
 - A steel tank that is coated and cathodically protected;
 - A steel tank jacketed or clad with a non-corrodible material;
 - A steel tank that is cathodically protected and internally-lined.
- Tank Type Descriptions:
 - Protected Steel: Steel tank coated at the factory and built with sacrificial (galvanic) anodes, and usually equipped with dielectric nylon bushings in the bunnholes.
 - Fiberglass-Reinforced Plastic: While the term Fiberglass-Reinforced Plastic (FRP) is technically correct, these tanks are more commonly referred to as fiberglass tanks.
 - Polyethylene-Jacketed Steel Tank: This is a double-wall tank with a steel inner wall and a plastic outer wall.
 - Fiberglass-Jacketed Steel Tank: This is a double-wall tank with a steel inner wall and an outer wall made of fiberglass reinforced plastic material.
 - Clad Steel Tank: this is a steel tank that has a thick layer of non-corrodible material such as fiberglass or urethane that is mechanically bonded to the outer wall of the steel tank which protects the outer part of the steel wall from corroding.
 - Steel with Impressed Current: These tanks are either:
 - Bare steel tanks that have been retrofitted with an impressed current system, or
 - Protected steel tanks that had an anode failure that could not be remedied by addition of one or more galvanic anodes, and consequently were retrofitted with impressed current.
- In addition, the following parameters shall be incorporated into the wall and floor plate design:
 - A minimum corrosion allowance of 2 mm for all plates.
 - Design limiting stress for base bending up to 0.5 x Yield Stress is considered acceptable.
 - The maximum additional horizontal deflection due to filling shall be the lesser of height/250 and 20 mm.
 - Careful handling methodologies or procedures are to be developed and employed on-site to minimize plate buckling / deformation.
- Bolted Steel Tanks:
 - Bolted steel tanks shall not be accepted except for shorter design life applications up to 15 years.

4.3.7 Flow Chambers

- General:
 - Flow chambers route water or wastewater.
- Design Requirements:
 - Chambers are constructed from reinforced concrete — precast concrete or cast-in-place concrete.



Structural Design Guidelines

- For size and dimensions of chambers, structural designer shall coordinate with mechanical discipline and obtain required sizes.
- Chambers shall be designed in accordance with the requirements of ACI 350.
- Chambers are required to be watertight, to prevent leakage of water or wastewater.
- Access in and out of valve chambers shall be in accordance with the requirements of OSHA 1910.27 using FRP ladder and minimum 900 mm diameter manhole opening.
- Most Flow chambers have interior walls routing water to different sections of the chamber. Therefore, Interior Walls are required to be designed for unbalanced water levels.
- Exterior walls are to be designed for interior water /wastewater levels.
- Similar forces to catch basins and manholes apply to valve chambers.
 - Soil Surcharge (assume saturated)
 - Hydrostatic pressure (assume based on finished grade level)
 - Buoyancy
 - Truck Loading as per MOT

4.3.8 Valve Chambers

- General:
 - Valve Chambers house buried high pressure utility control gates and valves such as water mains or sanitary sewer control housing.
- Design Requirements:
 - Chambers are constructed from reinforced cast-in—place concrete or precast concrete.
 - For size and dimensions of chambers, structural designer shall coordinate with mechanical discipline and obtain required sizes.
 - Chambers shall be designed in accordance with requirements of ACI 350.
 - Chambers are required to be watertight.
 - Access in and out of the valve chambers to be in accordance with the requirements of OSHA 1910.27 using FRP ladder and minimum 900 mm diameter manhole opening.
 - Gate valves and bends in pressure pipe result in large reaction loads superimposed on the chamber walls, floor, or both. Pipe supports and associated attachments must be designed to resist these forces.
 - Concrete chamber walls, floors, and roof must be designed for pipe thrust reaction forces.
 - Recommend incoming pressure pipe to be supported on interior of chamber instead of on perimeter walls to prevent chamber water penetration and wall damage.
 - Where environment around chamber is unknown and surcharge loads cannot be established, a minimum surcharge of 15 kN/m² shall be considered in the design of chamber walls.
 - Similar forces to catch basins and manholes apply to valve chambers.
 - Soil Surcharge (assume saturated)
 - Hydrostatic pressure (assume based on finished grade)
 - Buoyancy
 - Truck Loading as per MOT
 - Interior water forces do not apply - Valve Chambers are required to remain watertight.

4.3.9 Thrust Blocks

- a. General:
 - When thrust blocks are required at tees, elbows, wyes, caps, valves, hydrants, reducers, and caps, etc. they should be designed and constructed per the requirements of this subsection.
 - Inertial thrust forces act during the following situations:
 - Change in fluid velocity
 - Change in pipe size

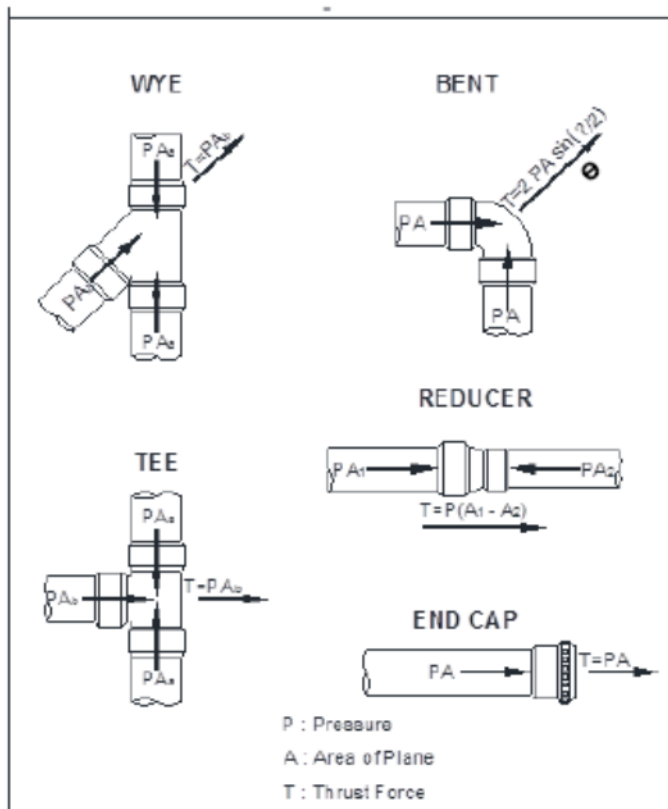


Structural Design Guidelines

- Change in pipeline direction
- Connection at different pipe types and connection diameters.

FIGURE 4.1.A depicts the net thrust force at various configurations. In each case the expression for T can be derived by the vector addition of the axial forces.

FIGURE 4.1.A THRUST BLOCK TYPES.



- Design Requirements:
 - For pipe diameter larger than 300mm shall be designed in accordance with requirements listed herein. For pipe diameter equal or less than 300mm thrust block size shall be in accordance to industry standards.
 - Internal design pressures and test pressure shall be specified by the designer of the pipeline.
 - Locate the thrust block such that its passive pressure zone of influence does not affect other utilities or structures. Thrust blocks should not be placed in close proximity to each other to prevent overlap of passive pressure soil zones.
 - Provide a minimum soil cover of 600 mm over all thrust blocks. For pipelines under roadway right-of-way, provide a minimum 90 mm soil over thrust block.
 - Elevation of groundwater table must be below the bottom of the block for upper vertical bends or the invert of the pipe for all other blocks. If the actual groundwater table is higher than the above, then evaluate the standard block size for submerged conditions and note that a special design block may be required.
 - There are two possibilities for design of the thrust block. The first design allows for small movement of the thrust block and the second does not allow for such movement. The designer of the pipeline system shall decide between the two possibilities based on the assumptions made at the thrust block location in the pipeline analysis. Thrust blocks which rely on lateral resistance of the soil will generally undergo small movement before passive soil resistance is developed. On the other hand, thrust blocks which rely on soil frictional force will generally develop frictional soil resistance practically without any slippage or movement. Thrust blocks shall be designed considering either lateral or frictional soil resistance, and never both of them together.
 - For thrust blocks designed to rely on lateral soil resistance, soil investigation is required to determine the following information:



Structural Design Guidelines

- Soil and groundwater profile
- Strength parameters for natural and engineered fills
- Soil Classification
- Soil density (dry, moist and saturated)
- Coefficients of lateral pressure

Depending on the lateral soil pressure assumed in the design (full passive or fraction of it), the A/E shall include the displacement associated with the assumed soil pressure in the analysis of the pipeline.

This design follows the NFPA 24 Code, and is commonly used for thrust blocks associated with small diameter pipes commonly used in residential and commercial areas.

- General considerations and earth pressure theories to be used when designing thrust blocks.
 - Horizontal bends, reducers, tees, TS&V, TA&V, plugs and caps.
 - Design horizontal bends, reducers, tees, TS&V, TA&V, plugs and caps using the appropriate earth pressure theories and state the specific references if used in the design calculations.
 - For blocks in cohesive soils, evaluate the soil resistance in terms of short and long term shear strengths and use the lowest resistance between the two for the design.
 - Calculated net soil resistance for the block is to be at least 1.5 times the design pressure thrust force and 1.2 for the test pressure force.
 - Upper vertical bends: Design the thrust blocks for upper vertical bends such that the sum of the effective weight of the concrete, bend and fluid is equal to or greater than the vertical component of the design thrust force.
 - Lower vertical bends: Design the thrust blocks for lower vertical bends such that the contact pressure at the bottom of the block is within the allowable soil bearing capacity.
- Earth bearing surface of thrust block shall be cast against either undisturbed soil or structural fill.
- Concrete strength of thrust block encasement shall be no less than 25 MPa.
- Thrust blocks shall generally be configured similar to those shown in the standard details. A rectangular shaped front face shall be used for the blocks for horizontal bends, reducers, tees, plugs and caps if possible. The reasonable range of depth to width ratio for the rectangular face shall be between 1 and 3.

4.3.10 Mechanical Equipment Support Structures

- General: This section includes design requirements for the following:
 - Static Equipment Support Structure including Foundation
 - Dynamic Equipment Support Structure including Foundation
 - Pipe Supports
- References:
 - ACI 351.1R - Grouting Between Foundations and Bases for Support of Equipment
 - ACI 351.2R - Foundations for Static Equipment
 - ACI 351.3R - Foundations for Dynamic Equipment
- Static Equipment Foundation:
 - Static Equipment Foundations shall be designed in accordance with the provisions of the SBC and the following Codes/Standards:
 - ACI 351.2R - Foundations for Static Equipment.
 - ASCE-7
- Dynamic Equipment Foundation
 - Dynamic Equipment Foundations shall be designed in accordance with the provisions of the SBC and the following Codes/Standards:
 - ACI 351.3R - Foundations for Dynamic Equipment



Structural Design Guidelines

- ASCE-7
- Foundations for vibrating machinery shall be isolated from adjacent foundations via expansion joints or other systems which allow independent system movement.
- Pipe Support Systems:
 - Pipe support systems shall be designed in accordance with the following:
 - SBC-301
 - ASCE-7
 - Structural Engineer shall collect information from pipe stress analysis performed by others for all pipe support systems including thermal forces, gravity forces, and pressure piping forces.
 - Pipe supports shall be provided based on the pipe stress analysis reactions.
 - Pipe Support Analysis shall include the following:
 - Guide Pipe Supports
 - Hanger Pipe Supports
 - Feed Pipe Supports

4.3.11 Pipeline Corridor Structures

- General
 - Introduction
 - This section establishes minimum safety requirements for existing and new pipeline support structures for the pipeline corridors under the jurisdiction of the Entity.
 - Review of submittals for design and installation of pipeline support structures in the pipeline corridors requires coordination with other disciplines' designs (mainly, Civil, Mechanical, and Electrical design).
- Applicability
 - This section is applicable to the following area of jurisdiction:
 - Pipeline assets operated by Industries in the pipeline corridors.
 - Pipeline systems that transport hazardous liquids, petrochemicals and gases.
 - This section does not apply to the following pipeline facilities:
 - In-plant piping systems as defined in the Pipeline Corridors (PLC) and Utility Corridors (UC) Regulations
 - Pipelines outside the limits of the Pipelines and Utility Corridors
 - Pipelines that have been exempted by the Entity
- Pipeline Support Structures
 - Structural Supports
 - A/E shall always remain responsible for ensuring that their designs and construction conform to their contractual obligations and all applicable regulations, Codes, and Standards. The design of pipe supports, pipe racks, pipe sleepers, cross access structures, expansion loops, intersection support structures, foundations, and other related supports carrying, anchoring, and guiding pipes shall be made to acceptable industry Standards.
 - Horizontal expansion loops may be used in the areas where such loops currently exist and where there is sufficient space in accordance with the applicable standards to allow their use without harming future expansion; otherwise, vertical expansion loop systems shall be adopted by all projects throughout Pipeline Corridors and Utility Corridors.
 - The piping manufacturer is responsible for providing its own anchors that are required based on their own analysis of load conditions on the pipeline. Anchors are not allowed to be added to any existing Entity structure.
 - All Pipe Supports shall be designed and constructed to resist stresses produced by load combinations in accordance with the SBC 2007 and the requirements of this section.



Structural Design Guidelines

- Any new structure or extension of an existing structure (except for a cantilevered member that can accommodate only one pipe) must be designed for full pipe load of 5 kN/m².
- Design Loads and Load Combinations
 - Symbols and Notations
 - D = Dead load, including load of empty piping and equipment
 - E = Seismic load effect, which shall include both E_h and E_v with
 - p = 1.0 for SDC = B-TBD
 - F = Load due to fluids in piping and equipment at hydro-test conditions
 - H = Load due to lateral earth and groundwater pressures
 - L = Live load due to occupancy; uniform, concentrated, impact and vibratory
 - T = Self-restraining force; thermal expansion and contraction; and friction
 - W = Wind load
 - Load Combinations for Factored Loads Using Strength Design
 - 1.4 (D + F)
 - 1.2 (D + F + T) + 1.6(L + H)
 - 1.2 (D + F) + 1.6W + 0.5L
 - (1.2 + 0.2 SDS) (D + F) + 1.0E + .05L
 - 0.9D + 1.6W + 1.6H
 - (0.9 - 0.2SDS) D + 1.0E + 1.6H
 - Load Combinations for Nominal Loads Using Allowable Stress Design
 - D + F
 - D+H+F+L+T
 - D+H+F+W
 - (1.0 + 0.14SDS) (D + F) + H + 0.7E
 - D + H + F + 0.75W + 0.75L
 - (1.0 + 0.105SDS) (D + F) + H + 0.75 (0.7) E + 0.75L
 - 0.6D + W + H
 - (0.6 - 0.14SDS) D + 0.7E + H
- Exceptions to Factored and Nominal Load Combinations
 - Where lateral earth pressure provides resistance to structural actions from other forces, it shall not be included in H but shall be included in the design resistance. H shall be set to zero if the structural action due to H counteracts that due to the other load cases.
 - Effects of one or more loads not acting in whole or in part shall be investigated. This includes patterning transient loads in continuous and cantilever framing.
 - Increases in allowable stress shall not be used with the load combinations given for Allowable Stress Design.
 - E and W are permitted to be applied independently in each of two orthogonal directions and orthogonal interaction effects are permitted to be neglected.
 - Minus E and minus W directions shall be investigated.
- Stability against Overturning, Uplift, Sliding, and Buoyancy
 - Stability analysis shall demonstrate the ability of the structures to resist overturning, uplift, sliding, and buoyancy, and that the allowable soil bearing values are not exceeded. Stability shall be provided solely by dead load plus permanent mechanical anchorages. In determining the safety factors, allowance shall be made for the potential removal of resisting dead loads (i.e., excavation, erosion, etc.).
 - Retaining wall sliding resistance shall be developed by friction (and passive soil pressure where necessary) utilizing particularly detailed shear keys to engage the friction-resistance plane below the plane of the waterproofing and protection.
- Deflections
 - The maximum allowable vertical deflection of Pipe Supports determined from ASD Load Combinations shall be L/400 (where L is the beam length), except L/600 shall be used for pipe supports for fixed service equipment and high temperature or pressure piping.
 - Acceptable deflection shall also consider the parameters used in the design of the piping and the pipe supports. Coordination between the structure design and piping design is critical.



Structural Design Guidelines

- Materials
 - All materials shall conform to the specifications and material designations as listed herein. All steel materials shall be new.
 - AE should follow Saudi Arabian Standards Organization (SASO), as applicable.
 - Design calculations shall conform to the Entity's requirements stipulated in this manual, without exceptions.
- Concrete Design
 - All concrete Pipe Support elements shall be designed in accordance with ACI 318 with load factors and combinations given in this guideline.
 - Concrete formwork, constituents, proportions, and maximum water-cement ratios shall be in accordance with the specifications.
 - Reinforcing steel shall be fusion bonded epoxy-coated (FBEC) in accordance with ASTM A775M and specifications.
 - The concrete cover for reinforcing bars shall be 75 mm.
 - The height of pipe support foundations above adjacent, finished grade shall be 300 mm minimum.
 - Pipe support drawings shall explicitly show and specify the foundation waterproofing and protection, blinding slab, sand-cement screed, chamfers, fillets, reglets, counterflashing, coal tar epoxy coating, concrete class, concrete mix design, cementitious material, and FBEC reinforcing requirements.
 - Material designations for steel material in the pipeline corridor shall be as shown in Table 4.1. B

TABLE 4.1. B MATERIAL DESIGNATIONS

Structural Steel Shapes, Plates, Bars, and Fittings	ASTM A36 or A992
Hollow structural shapes (HSS) square, rectangular, and round	ASTM A500 Grade B
Pipes	ASTM A53 Type E, Grade B
High-strength Bolts, Nuts, and Washers for Joints	ASTM A325, Type 1; Nuts - ASTM A563, Grade DH; Washers - ASTM F436, Type 1; all hot-dip galvanized
Anchor Rods (headed-type or threaded/nutted with double nuts and plate washers)	ASTM A36 or F1554 Grade 36; Double nuts -ASTM A563, Grade DH; Plate washers - ASTM A3 6; all hot-dip galvanized
Welding Processes and Electrodes	AWS D1.1, D1.4, and D1.6. Low hydrogen electrodes with a minimum tensile strength of 480 MPa, (e.g., "E7018" for SMAW)
Cementitious Materials	ASTM C150 Type I and V Cements; ASTM C618, C989, and C1240 Pozzolan replacements
Non-Shrink, Non-Metallic Grout	ASTM 1107 with minimum 7 day compressive strength at least twice the base concrete strength
Reinforcing Steel	ASTM A615, Grade 60 (414 MPa); ASTM A775M Fusion bonded epoxy-coated reinforcing (FBECR)
Chemical Anchors	Epoxy adhesives with hot-dip galvanized or stainless steel high-strength bolt assemblies as manufacturer by Hilti Corp. or approved equivalent

4.3.12 Electrical and Communication Structures

- Substation electrical and communication structures are used to support above-grade components and electrical equipment such as cable bus, rigid bus, and strain bus conductors; switches; surge arresters; insulators; and other equipment. Substation and switchyard structures may be fabricated from latticed



Structural Design Guidelines

angles that form chords and trusses, wide flanges, tubes (round, square, and rectangular), pipes and polygonal tubes (straight or tapered). Common materials used are concrete, steel, aluminum, and wood.

- References and Standards:
 - Saudi Building Code SBC-301 — Loads and Force Requirements
 - Saudi Building Code SBC-304 — Concrete Structures Requirements
 - Saudi Building Code SBC-306 — Steel Structures Requirements
 - American Society of Civil Engineers — ASCE-7 — Minimum Design Loads for Buildings and Other Structures
 - ASCE Engineering Practice Report 113
 - ASCE 48 - Design of Steel Transmission Pole Structures
 - ASCE Report No. 74 - Guidelines for Electrical Transmission Line Structural Loading
 - ASCE Publication - Guide to Improved Earthquake Performance of Electric Power Systems
 - ASCE Publication - Structural Reliability Based Design of Utility Pole Structures
 - ASCE 10- Design of Latticed Steel Transmission Structures
 - ASCE/SEI 48 - Design of Steel Transmission Pole Structures
- Materials of Electrical and Communication Structures:
 - 1) Steel Structures
 - ASCE 10 is recommended for design of lattice structures using steel angles.
 - AISC is recommended for design of structures using standard structural shapes.
 - ASCE/SEI 48 is recommended for design of structures using hollow tubular member shapes.
 - Concrete Structures:

Concrete Structures are designed to accommodate cracking behavior. In a corrosive environment, water may be absorbed into the open cracks and corrode the reinforcing steel. Typical substation concrete structures shall provide enough concrete cover to protect the reinforcing steel. For structural members subjected to sustain flexural loading, such as dead-end structures, it may be desirable to allow no tensile stress along the member cross section under everyday loading conditions. If zero- tension, no cracks under normal situations will preclude the reinforcing steel from corroding.

 - Reinforced Concrete Structures - Reinforced concrete structures shall be engineered and configured in accordance with ACI 318.
 - Pre-stressed Concrete Structures - Pre-stressed concrete structures shall be engineered and configured in accordance with PCI MNL-120. This handbook uses the ultimate strength method with factored design loads, linear material properties, and second-order elastic analysis. Member capacity reduction factors shall be used as specified in PCI MNL-120.
 - Pre-stressed Concrete Poles - The pre-stressed concrete pole type structures, either static cast or spun cast, should be engineered and configured in accordance with PCI. This guideline uses the ultimate strength design method and, in general, follows all ACI and PCI recommendations.
 - Aluminum Structures:

The United States Aluminum Association's design criteria for aluminum structures are recommended in this guideline.

Aluminum with Dissimilar Materials - Aluminum corrodes when in contact with dissimilar materials such as steel, wood, or concrete. These dissimilar materials have a different pH than that of aluminum. Aluminum functions best when in contact with material having a pH range of 5 to 9.

 - Steel - Aluminum surfaces to be placed in contact with steel should be given one coat of a zinc chromate primer or the equivalent, or one coat of a suitable non-hardening joint compound that may exclude moisture from the joint during prolonged service. Additional protection may be obtained by applying the joint compound in addition to the zinc chromate primer. The zinc chromate paint should be allowed to dry before the parts are assembled. Aluminum surfaces to be placed in contact with stainless, aluminized, hot-dip galvanized, or electro-galvanized steel need not be painted.



Structural Design Guidelines

- Wood - Aluminum surfaces to be placed in contact with wood should be given a heavy coat of an alkali-resistant bituminous paint before installation. The paint should be applied in the condition in which it is received from the manufacturer without the addition of any thinner.
- Concrete - Aluminum should not come into contact with wet concrete. Aluminum reacts with the alkaline constituents of the cement and generates hydrogen gas. The hydrogen gas will cause expansion of the mortar and reduce the concrete's compressive strength.
- Wood Structures:
 - Ultimate Strength Design - Wood structures and poles shall be engineered and configured in accordance with IEEE 751 and NESC. IEEE 751 describes a probabilistic and a deterministic method for designing wood structures. ANSI-05.1 and 05.1c may be used for wood pole stresses with the NESC 0.65 strength factor. Additional design information may be found in Navigation Data Standards (NDS).
- Design Loading:
 - All structures shall be designed in accordance with the requirements of applicable codes and standards.
 - The following loads described in ASCE Engineering Practice Report 113 shall be included:
 - Wire Tension Loads
 - Terminal Connection Loads
 - Concentrated Loads on Strain Bus Systems
 - Substation Dead-End Structure Forces

4.3.13 Generator Support Structures

- The generator shall be supported by foundation and housekeeping pad sufficient to support the weight of the equipment. This shall include the engine-generator, fuel storage, batteries, and engine exhaust silencer and piping.
- Vibration isolation shall be provided to avoid the transmission of vibration to the surrounding occupancies. The selection of the vibration isolation shall address any applicable seismic requirements and the sensitivities of the adjacent facilities.
- Rotating and vibrating loads shall be individually considered and, where feasible, shall be independently supported.
- Natural Frequency
 - Structural supports of rotating and vibrating equipment shall be designed to avoid resonant vibration with the equipment and limit amplitude to acceptable values.
 - Acceptable values shall be verified with suppliers of individual equipment such as motors, drives, etc.
 - Appropriate models considering mass, stiffness, and damping shall be used. The equipment operation shall be examined to understand the acting forces.
 - If the design considers only the supporting beams, they shall be designed with a ratio between the natural frequency (f_n) and the equipment frequency (f_e) equal to or larger than the values given below. f_e / f_n

Beam Span	Type of Support	Ratio f_e / f_n
< 5.0 m	Directly connected to columns	1.5
> 5.0 m	2.0	
< 5.0 m	Not directly connected to columns	2.0
> 5.0 m	2.5	

Otherwise a complete 3D model is required for the supporting structure and corresponding vibrations need to satisfy the vendor allowable criteria for vibrations. If this criterion is not available, the Richard Chart presented below needs to be satisfied.

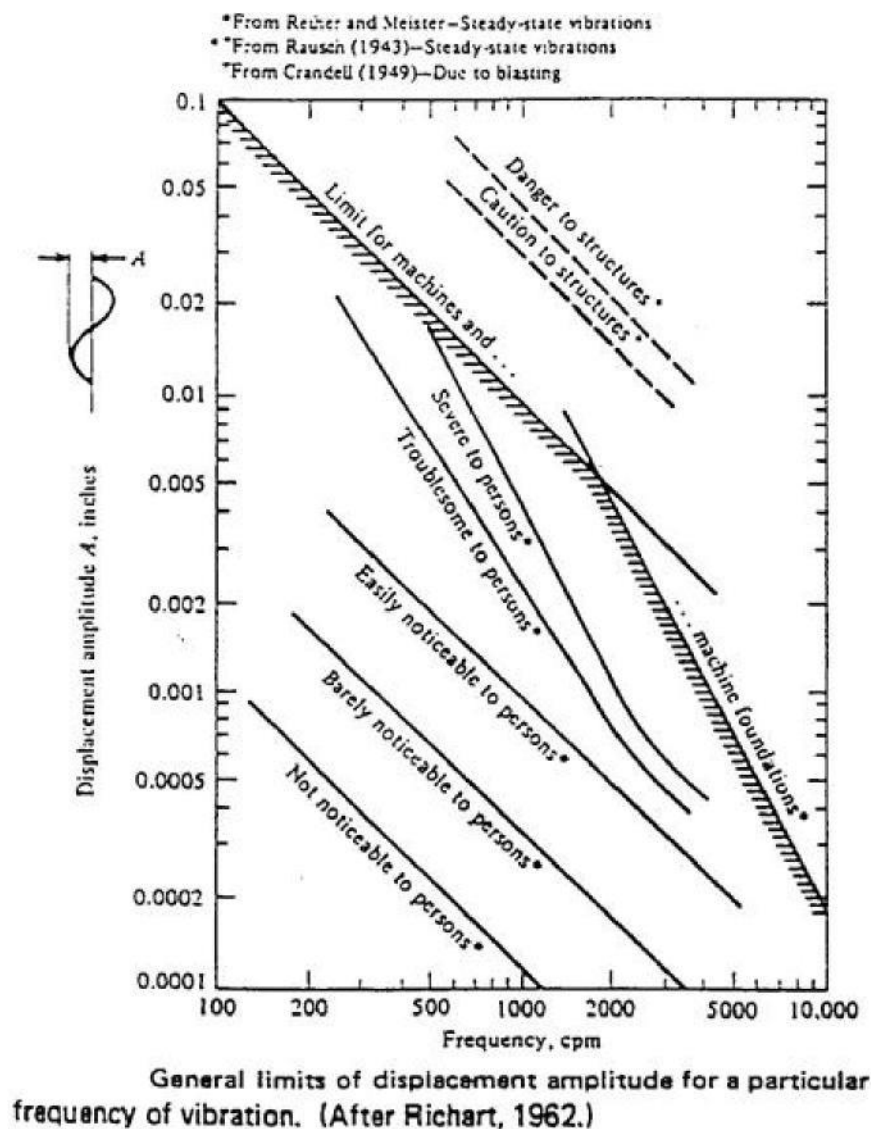
 - When detailed evaluation is warranted, the Designer shall ensure the separation of the fundamental mode structural frequency from the machine frequency. The recommended criterion is as follows:
 - Structure frequency < 1/2 of machine operating frequency



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- Structure frequency > 1.5 times machine operating frequency
- Structures that shall be verified are those that support equipment that may induce excessive vibration to the supporting structure, as for example: fans, pumps, blowers, compressors and other similar equipment.
- The global sway modes of the entire structure shall be calculated by means of a structural model with concentrated masses on node points. Masses and stiffness used for modeling shall be those needed for obtaining representative frequencies of the dynamic response. Unbalanced forces, generated as a result of operations, such as material build up on pulleys, belt misalignment, uneven wear, shall be considered in analysis and design.
- The soil/structure interaction shall be evaluated in the determination of structural natural frequency.
- Allowable Equipment Vibration
 - The below Richart Chart (FIGURE 4.2.B) sets general guidelines for vibration amplitude. However, equipment and its functional activity must be carefully considered in setting design amplitude to assure proper functioning and personnel comfort in its operation. Vibration limits set by equipment suppliers shall be verified and complied with.

FIGURE 4.2.B RICHART CHART





4.3.14 Concrete Duct Banks

- a. General:

Concrete encased duct banks are a group of conduit or pipes that are fully encased in concrete. The purpose of the encasement is to protect the utility lines from superimposed ground loading and from being pierced by future excavation equipment.

- b. Design Requirements:

- Concrete strength of duct bank encasement shall be no less than 20 MPa.
- All concrete duct banks shall be reinforced with minimum temperature reinforcement in accordance with ACI 350.
- All reinforcement shall be epoxy coated.
- Minimum ratio of horizontal reinforcement area to gross concrete area shall be based on the length between movement joints, and shall conform to ACI 350 Section 7.12. Maximum spacing of reinforcement bars shall be 450 mm; minimum of one bar in each corner of duct bank.
- Provide steel tie bars in the transverse direction enclosing the longitudinal bars minimum size of 10 mm bars. Contractor is to determine the minimum spacing of bars based on proper support of ducts during placement of concrete minimum clear concrete cover over reinforcement steel shall be 75 mm where concrete is cast directly against earth.
- Special consideration requires where duct bank enters rigid underground structures. Structural engineer shall provide details indicating method employed to prevent differential settlement from damaging duct bank.
- Top surface of duct bank shall be dyed red.
- Ducts shall be installed with duct separators with no less than 5 separators in 3 m.
 - Secure separators to earth to prevent uplift during concrete installation.
 - Tie assembly together using fabric straps - metal ties are not to be used to prevent conductive loops.
 - Minimum duct spacing in banks 30 mm.
 - Ducts should be placed no less than 500 mm below grade.

4.3.15 Security Crash Barriers

- General:

Security crash barriers are designed to protect employees, visitors, and building functions from unauthorized vehicle approach.

- Design Requirements:

- Security crash barriers are designed to meet crash test standards based on the following publications:
 - ASTM F 2656/2656M, Standard Test Method for Crash Testing of Vehicle Security Barriers
 - United States Department of State, SD-STD-02.01 Ballistic Standards
 - USA Department of Defense, UFC — 4-022 Security Engineering: Entry Control Facilities / Access Control Points
 - FEMA 430, Perimeter Security Design
- Security crash barriers are designed for the following load classification:
 - K12: 6803 kg Truck traveling 80 Kph
 - K8: 6803 kg Truck traveling 65 Kph
 - K4: 6803 Kg Truck traveling 48 Kph
- Project specifications dictate the required load level of design.
- Barrier Materials
 - Steel or cast iron is the most effective barrier material and the most easily installed, but requires regular maintenance.



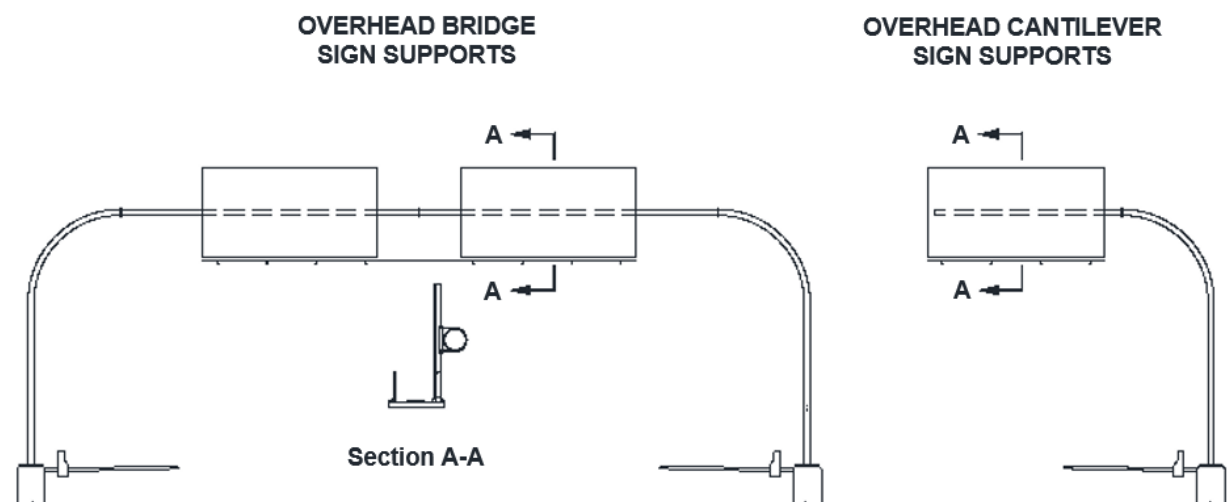
Structural Design Guidelines

- Reinforced Concrete barrier systems are more expensive and require more time to install but are maintenance free.
- 5) Types of Barriers
 - Passive Barriers
 - Fixed in Place Barriers preventing vehicle access.
 - Walls, Berms, Fixed bollards, Engineered Planters, Fences.
 - Active Barriers
 - Used at vehicle access and control points
 - Retractable bollards
 - Crash Gates
 - Rotating Wedge Systems

4.3.16 Supports for Signs, Luminaries, Traffic Signals

- General: This provision applicable to structural support for Highway Signs, Luminaries and traffic signals.
- Type of Supports:
 - Sign Supports:
 - Overhead Signs:
Refer to FIGURE 4.3.A or types of overhead sign support structures.
 - Roadside Signs:
Refer to FIGURE 4.3.B for types of roadside sign support structures.
 - Luminaire:
Luminaires are complete lighting units to illuminate highways, bridges, streets, parks, playgrounds, etc. Types of street lightings are shown on FIGURE 4.3.C.
 - Traffic Signals:
Refer to FIGURE 4.3.D for types of traffic signals support structures.

FIGURE 4.3.A OVERHEAD SIGNS STRUCTURES





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FIGURE 4.3.B ROADSIDE SIGNS

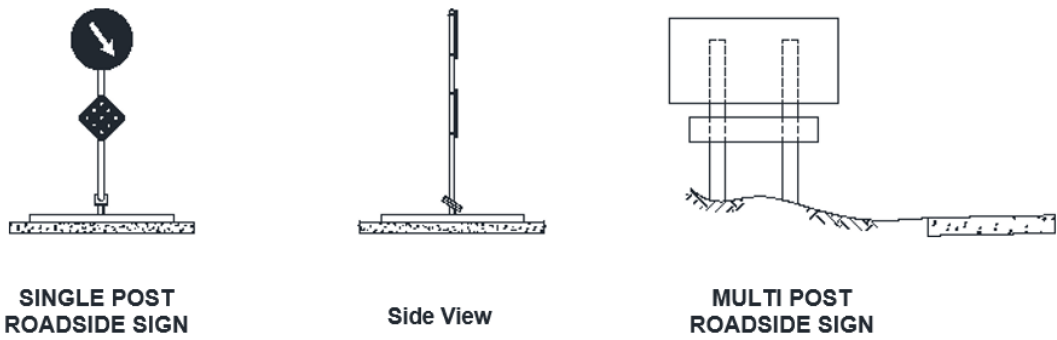
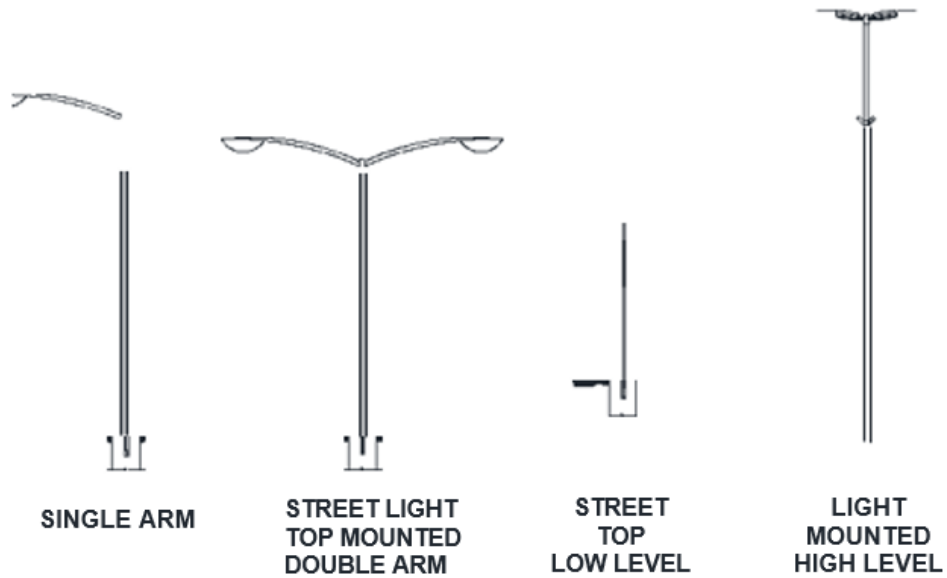


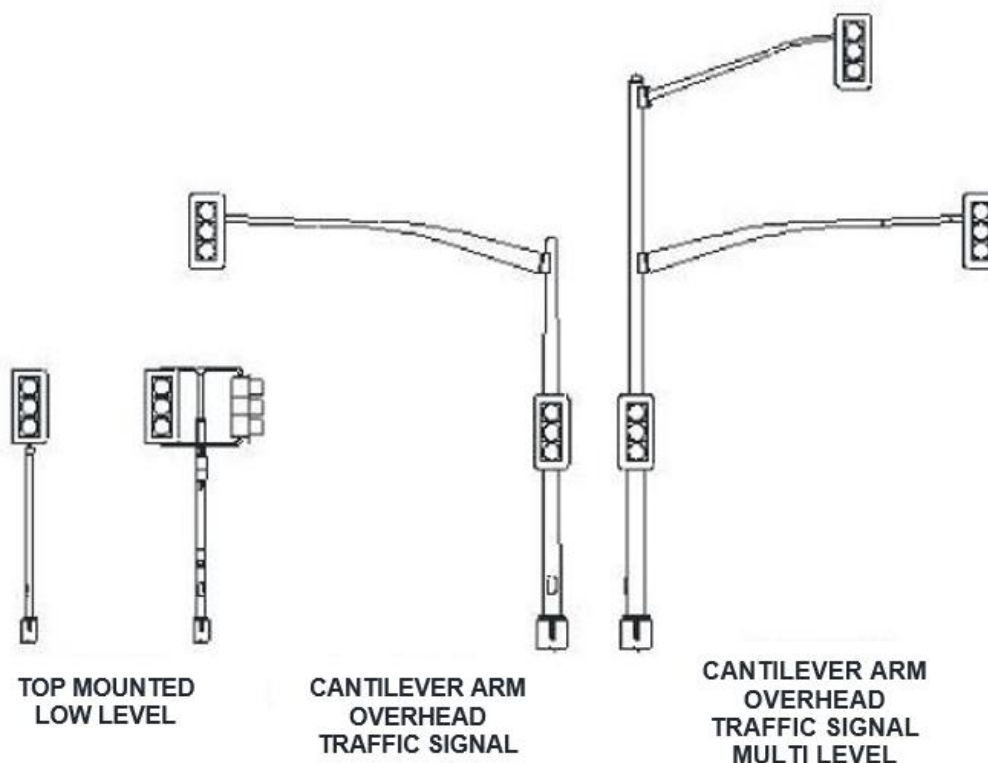
FIGURE 4.3.C LUMINARIES





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FIGURE 4.3.D TRAFFIC SIGNALS



- Design Requirements:
 - The Support Structures for signs, luminaires and traffic lights to be designed in accordance with the AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals (5th Edition).
 - Wind speed based on 3-second gust.
 - The Design Life/Recurrence Interval shall be 50-years.
 - For overhead sign structures, cat walk to be added for future maintenance and lighting fixture installation. Structural engineer shall design cat walk for min of 2 kN live load over 750 mm x 750 mm area.
 - Hot-dipped galvanized or protected steel and hardware shall be used for support structures. For corrosion protection for steel support structures, refer to Subsection 7.
 - Luminaire structures may be Standard Aluminum Light Poles, Standard High Mast Lighting, or custom design. In any case, structural engineer shall provide full analysis and design calculation for Entity's approval.
 - Fluted pole luminaires supports are only allowed on vertical posts that have a single luminaire load at the top. No fluted vertical poles are allowed on the Highways with luminaire arms that produce torsion in the vertical shaft.
 - A fluted shell cover that fits around the standard round pole can be used. The fluted shell has a different drag coefficient and calculations are required for the pole and foundation.
 - Structural engineer shall consider future addition, galloping, wind drag, truck induced gust and fatigue in the design.
 - Full geotechnical investigation and geotechnical report are required for foundation design of support structures.
 - Foundation design of support structures shall be designed in accordance with Subsection 6 and Section 13.6 of the 4th Edition 2001 AASHTO.
 - Any foundation to be designed for support structures height higher than 10 m shall be designed without contribution of passive soil pressure.
 - AASHTO Specifications require damping or energy absorbing devices on aluminum overhead sign support structures to prevent vibrations from causing fatigue failures.



5.0 TRANSPORTATION STRUCTURES

5.1 General

5.1.1 Introduction

This subsection mandates the principles, guidelines, and requirements for design and construction of the structures carrying highway and/or rail traffic loads, and provides:

- Guidance on preliminary planning, selection, design, and construction of these structures.
- Minimum technical requirements to be adopted by AE Contractors to enable safety, quality, and cost effectiveness in the design and construction of structures that meet the needs and expectations of the Entity.

5.1.2 Applicability

The principles and requirements included in this section shall govern structures on regular truck route sections of the highway network. This excludes structures on the Module Path sections of the network.

5.1.3 General Requirements

- Technical requirements for the transportation structures shall not preclude highway traffic interoperability within the Kingdom of Saudi Arabia.
- The following requirements shall be reflected in the design and construction of the transportation structures covered under this subsection:
 - Structures shall have adequate configurations acceptable to the Entity and shall meet aesthetic and functional requirements of the project. Minimum aesthetic design requirements are included in this section.
 - Structures configurations shall include features such as simplicity, regularity, integrity, redundancy, and ease of inspection, maintenance, and repair.
 - Structures shall demonstrate the high standards for safety, durability, and cost effectiveness as required by the Entity.

5.1.4 Codes

Design and construction of all transportation structures shall be based upon the requirements of this subsection and existing highway standards; these shall be from Saudi Ministry of Transportation (MOT) to ensure interoperability, American Association of State Highway and Transportation Officials (AASHTO), or those of the authority having jurisdiction over the structure such as ARAMCO and SAR, as most appropriate to the individual application. Where the requirements stipulated by these standards are in conflict, the most stringent shall govern unless otherwise noted herein and shall require the Entity approval. A listing of the adopted codes follows.

- Volume 3 - Structural Design Specifications, Highway Design Manual, Ministry of Transportation (MOT), the Kingdom of Saudi Arabia, 1992.
- AASHTO Standard Specifications for Highway Bridges, 17th Edition. American Association of State Highway and Transportation Officials (AASHTO), 2002.
- AASHTO LRFD Bridge Design Specification, American Association of State Highway and Transportation Officials (AASHTO), 7th edition, 2014, with 2015 and 2016 interim revisions.
- AASHTO Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges. American Association of State Highway, Federal Highway Association and Transportation Officials (AASHTO), with current interim revisions
- AASHTO Manual for Bridge Evaluation, 2nd Edition, with 2011, 2013, 2014, 2015, and 2016 Interim Revisions.
- AASHTO Steel Guide Specifications for Horizontally Curved Steel Girder Highway Bridges. American Association of State Highway and Transportation Officials (AASHTO).
- LRFD Guide Specifications for the Design of Pedestrian Bridges, 2nd Edition, 2015 Interim Revisions.
- FHWA publication - FHWA - NH1-10-034 Technical Manual for Design and Construction of Road Tunnels.



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- Manual for Railway Engineering, the American Railway Engineering and Maintenance-of-Way Association (AREMA), 2016 Edition.

5.1.5 Standards

- American Association of State Highway and Transportation Officials (AASHTO)/National Steel Bridge Alliance (NSBA) Steel Bridge Collaboration documents for steel bridges "AASHTO/NSBA".
- AASHTO Policy on Geometric Design of Highways and Structures.
- Federal Highway Association FHWA Office of Bridge Technology Report No. FHNA-1F-02-034.
- Manual of Standard Practice, Concrete Reinforcing Steel Institute (CRSI).
- PCI Bridge Design Manual, First Release, PCI, November 2011.
- Royal Commission for Saudi Arabia, Guidelines for Aesthetics Design of Transportation Structures, 1st edition, 2016.
- Standard Specifications for Construction of Roads and Bridges of Federal Highway Projects, FP-03, Publication No. Federal Highway Administration (FHWA) A-FLH-03-002.

5.2 Structures Groups

The principles, guidelines, and requirements specified under this subsection shall apply to the transportation structures groups defined in TABLE 5.1.A. The table provides concept designs for the types of structures that would be required to carry highways over existing roadways/railways and terrain. Additional structures also covered under this subsection include pedestrian bridges, earth retaining structures and cut and cover tunnel structures.

TABLE 5.1.A APPLICABLE STRUCTURES

Group	Structure Designation	Configuration	Structure type
1	Drainage/Utility Culvert	Roadway Over Culvert	Precast box/three-sided/arch/ reinforced concrete/unreinforced concrete culvert structures
2	Bridge Over Pipelines	Roadway Over Pipelines	Three-sided/arch reinforced concrete culvert structures
3	Bridge Over Drainage Channel/Terrain	Roadway Over Drainage Channel/ Terrain	Prestressed/reinforced/three-sided/arch reinforced concrete structure
4	Bridge Over Roadway	Roadway Over Roadway	Prestressed/reinforced concrete structure
5	Bridge Over Rail	Roadway Over Railway Track	Prestressed/three-sided/arch reinforced concrete structure/reinforced concrete structure

5.3 Preliminary Design and Planning

5.3.1 Scoping

- During scoping/early planning phase of the project the A/E shall establish genuine consensus about the nature of the proposed project and what is to be accomplished regarding:
 - Project Objectives
 - Design Criteria
 - Feasible Alternates, and Reasonable Cost Estimate(s) for each.

5.3.2 Structure Geometry

- Alignment and Layout
 - Alignment and layout of structures shall be established based on the geometry of the feature the structure carries and crosses, and the structure's aesthetics design criteria of the project.



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- Structure's horizontal alignment for centerline and foundation setout points, shall be established in accordance with the structure's alignment and layout.
- Vertical alignment for Groups 3, 4, and 5 structures shall be established in accordance with the profile of the roadways they carry, and shall meet controlling vertical clearance requirements for the features the structures cross.
- Vertical alignment and profile for Groups 1 and 2 structures, profile and vertical clearance requirements shall be governed by the type of application and/or those of the authorities having jurisdiction over the structures.
- Horizontal and vertical alignments for all structures shall meet the horizontal and vertical clearance requirements of the geometric design criteria of the project.
- Structure's length shall be determined based on the roadway alignment, width of the feature crossed, geotechnical site conditions, economy, and aesthetic requirements of the project.
- Structure's width shall be determined based on the width of the roadway the structure carries and the specific requirements in the project objectives.
- Structures area shall be calculated based on abutment centerline to centerline length and structure's width.
- Vertical Clearance
 - Vertical clearance to sign supports and pedestrian overpasses shall be 500 mm greater than highway structure clearance and vertical clearance from the roadway to overhead cross bracing of through truss structures shall not be less than 5.5 m.
 - Structures over navigable waters shall have a minimum vertical clearance of 6.5 m above maximum navigable pool elevation or as determined based on the design vessel. Specified minimum clearance is estimated based on clearance requirements for common barges with tug boats, sailing boats, and yachts navigating similar waterways to those crossed by the structures. Water depth shall be no less than 4.5 m from normal pool elevation or as determined based on investigation of the specific site. Actual vertical clearance for a bridge over navigable waterway may be investigated based on, but not limited to, existing, upstream and downstream clearances, and type and size of vessels utilizing the waterway. The Entity shall make determination on increasing the specified minimum vertical clearances based on the outcome of the investigation. Ordinary high water elevation for non-tidal or mean high water for tidal areas shall be used when determining minimum vertical clearance. Water depth shall be determined from normal pool elevation in non-tidal waters or mean sea level in tidal areas.
 - Navigational clearances, both horizontal and vertical, shall be established in cooperation with the Kingdom Coast Guard and coordinated with other agencies having jurisdiction over the structure.
 - Reduction in vertical clearance due to support settlement shall be accounted for in the vertical clearance calculations, if such settlement exceeds 25 mm.
- Hydraulic Clearance
 - Hydraulic structures falling under Group 1 shall be designed such that adequate opening is provided for a 100-years design flood and for the passage of debris. A minimum freeboard of 300 mm for the 100-years flood shall be considered as satisfying normal hydraulic clearance requirements for Saudi Arabia. The freeboard may be increased to 750 mm for sites where the risk of debris clogging the structure is high. This requirement follows common practice in the US which calls for a minimum of 600 mm of freeboard, and allowing for an additional 150 mm for sand/debris depositing in the bottom of the culvert.
 - The minimum freeboard may be increased, based on additional investigation at the site's history of debris, changes in water surface elevations, consequence of debris clogging, potential damage, and the degree of difficulty of performing necessary repairs.
- Structure Roadbed
 - Width

The full road cross section is to be carried over bridge structures. Concrete bridge railing shall be installed under the following scenarios:

 - At outer edges.
 - On all roads in the Industrial area and on freeways in the community area, where the median is at least 8 m wide, bridge railing shall be placed 1 m behind the side walk. This 1 m shall be constructed as a raised sidewalk, locally across the structure only,



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in which utility ducts/troughs may be provided for street lighting and emergency telephone cables.

- On community roads, other than freeways, the bridge railing may be located behind the normal 1 m sidewalk.
- Median Edge
 - On freeway bridges, railing shall be located immediately behind the 1 m paved shoulder.
 - On expressways, where the normal cross section has a raised median with no hard shoulder, the median curb shall be carried over the structure with the bridge railing located 1 m behind the face of the curb.
 - In case of collector roads or other situations with narrow medians, the median shall be decked unless directed otherwise by the Entity.
- Alignment at Structures
 - Super-elevation transitions almost always result in an unsightly appearance of the bridge and the bridge railing. Therefore, if possible, horizontal curves should begin and end a sufficient distance from the bridge so that no part of the super-elevation transition extends onto the bridge.
 - If the super-elevation transition is unavoidable because of alignment and/or safety considerations, the AE and or EPC Contractor shall prepare special rendering of the structure with proposed treatment to reduce the super-elevation impact on the structures' aesthetics.
- Depressed grade line under structures

It frequently simplifies bridge design if the low point in the grade line is set a sufficient distance from the intersection of the centerlines of the structure and the highway so that drainage structures clear the structure footings.
- Grade line on bridge decks

Vertical curves on bridge decks shall provide a minimum fall of 70 mm per 100 m. The flattest allowable tangent grade shall be 0.12%, but on long bridges where drainage is confined to the bridge deck, this shall be increased to 0.25%.
- Structures Over Existing Roads

Every effort shall be made to phase work in such a way that traffic may be re-routed away from bridges which have to be constructed over existing roads. Alternatively, and subject to available right of way (ROW), the A/E may include temporary details in the Contract. As a last resort, where falsework has to be erected over traffic during construction, the following criteria shall be followed:

 - The minimum width of traffic opening through falsework for various lane and shoulder requirements is shown in TABLE 5.1.B

TABLE 5.1.B: FALSEWORK SPAN AND DEPTH REQUIREMENTS

Facility to be Spanned	Minimum Width of Traffic Opening (m)	Opening Width Provided for:	Resulting Falsework Normal Span ²	Minimum Depth Required for Falsework ¹
Freeway	7.6	1 Lane + 2.4 m & 1.5 m Shoulders	9.8 m	0.5 m
	11.3	2 Lanes + 2.4 m & 1.5 m Shoulders	13.4 m	0.7 m
	14.9	3 Lanes + 2.4 m & 1.5 m Shoulders	17.1 m	0.8 m
	18.6	4 Lanes + 2.4 m & 1.5 m Shoulders	20.7 m	1.0 m
Non-Freeway	6.1	1 Lane + 0.6 m & 1.2 m Shoulders	0.5 m	0.6 m
	9.8	2 Lanes + 0.6 m & 1.2 m Shoulders	11.9 m	0.7 m
	12.2	2 Lanes + 0.6 m & 1.2 m Shoulders	14.3 m	0.8 m



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	15.8 19.5	2 Lanes + 0.6 m & 2.4 m Shoulders 3 Lanes + 0.6 m & 2.4 m Shoulders 4 Lanes + 0.6 m & 2.4 m Shoulders	18.0 m 21.6 m	1.0 m
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¹ Includes 2.1 m for 2 temporary metal beam guardrails.

² No temporary railing provided.

- When metal beam guardrail is used to protect the false work, space must be provided for its bending/deformation as per the Kingdom - Highway Design Manual.
- In special cases, where existing restraints make it impractical to comply with the minimum widths of traffic openings set forth in TABLE 5.1.B, a lesser width may be used if approved by the Entity.
- The minimum temporary vertical clearance shall be 4.5 m.
- The use of temporary vertical clearances less than 4.5 m shall require approval by the Entity.
- To establish the grade of a structure to be constructed with a falsework opening, allowance must be made for the depth of the falsework.
- Where vertical clearances, either temporary or permanent, are critical, close coordination shall be required during the early design stage when the preliminary grades, structure depths and falsework depths may be adjusted without incurring major design changes.
- Because the width of traffic openings through falsework may significantly affect costs, special care shall be given to determining opening widths. The following shall be considered:
 - Staging and traffic handling requirements.
 - The width of approach roadbed at the time the bridge is constructed.
 - Traffic volumes.
 - Controls in the form of existing facilities.
 - MOT requirements.
- Practical problems of falsework construction:
 - After establishing the opening requirements, a field review of the bridge site shall be made to ensure that existing facilities (drainage, other bridges or roadways) are not in conflict with the falsework.
 - Advance warning devices shall be specified or shown on the plans. Such devices may consist of flashing lights, overhead signs, over-height detectors, or a combination of these or other devices.
 - Placement and removal of falsework requires special consideration. During these operations, traffic shall either be stopped for short intervals or diverted away from the span where placement or removal operations are being performed.
- Railing
 - General
 - Concrete safety bridge railing shall be used on all bridges as per MOT and AASHTO standards.
 - Approach Railings
 - Approach railings shall be provided at the ends of bridge railings, exposed to approach traffic. On divided highways, railings shall be placed to the left and right of approach traffic. On two way roadbeds, railings shall be placed on both sides of each end of the structure.
 - Metal beam guardrail, with cable anchor breakaway, shall be used for bridge approach railing. However, concrete "safety shape" rail may be used for better appearance where long structures/viaducts are involved and the structure has concrete bridge railing.
 - When long runs of guardrail (such as embankment guardrail) precede the bridge, the guardrail shall connect to the bridge railing and thus serve the approach railing function. Approach railings shall be flared at their exposed end.



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- Physical connection shall be provided between approach rails and bridge rails to prevent vehicles from deflecting the guardrail and continue driving onto the end of the more rigid bridge railing.
- Drainage
 - Transverse drainage of the bridge roadway shall be accomplished by providing a suitable crown in the roadway surface and longitudinal drainage shall be accomplished by camber or gradient. Water flowing downgrade in a gutter section shall be intercepted and not permitted to run onto the bridge.
 - Short continuous span bridges, particularly overpasses, may be built without inlets and the water from the bridge roadway carried downslope by open and closed chutes near the end of the bridge structure. Longitudinal drainage on long bridges is accomplished by means of scuppers or inlets, of the required sizes and numbers to drain the gutters.
 - Downspouts, where required, shall be of rigid corrosion-resistant materials shall be provided with cleanouts. The details of deck drains shall be such as to prevent the discharge of drainage water against any portion of the structure and to prevent erosion at the outlet of the downspout. Overhanging portions of concrete deck shall be provided with a drip notch located 100 mm from the edge of the deck.
 - The number and size of deck drains shall be kept to a minimum and be consistent with hydraulic design requirements.
 - The minimum internal dimension of the downspout shall be not less than 300 mm.
 - Proper drainage details shall be provided behind abutment wingwalls such that runoff water is not collected at the back of the walls (behind the walls).
 - Proper drainage details shall be provided behind culvert end walls and wingwalls such that runoff water is not collected at the back of the walls. Grouted riprap 500 mm wide or concrete swale of similar width shall be provided at these locations.
 - Additional drainage considerations:
 - Provide a minimum 100 mm projection below the lowest superstructure component.
 - Location of pipe outlets shall be such that 45 degrees splash zone will not dampen structural components.
 - Use slots in parapets where practical and permissible.
 - Provide drain clean-outs.
 - Provide pipe drain bends no greater than 45 degrees.
 - Route bridge drainage runoff in a manner meeting safety and environmental requirements.

5.4 Structure Selection

5.4.1 Material

- Although concrete is the preferred material for the transportation structures, steel may be considered as an alternative material for certain structures. This section provides guidance on use of steel for these structures. Other factors related to consideration of steel for transportation structures include structure's relationship to the total project, aesthetics, geographical location, site accessibility, and constructability.
- Steel structures may be considered for the following situations:
 - For curved spans with mid-ordinate corrections exceeding 300 mm, if their advantages over prestressed/reinforced concrete construction could be established.
 - For spans with restricted clearances, if their smaller depth advantages over prestressed concrete is demonstrated.
 - For locations where either long piles or poor bearing capacity is anticipated, if their lighter weight advantages over prestressed concrete could be substantiated.
 - For pedestrian skyways between buildings, pedestrian bridges, and for carrying utility lines over terrain.
 - For spans on vertical curves, since the camber can be fabricated and controlled with greater accuracy, if advantages over prestressed concrete could be demonstrated. Accommodating



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curve correction by placing a variable depth deck slab, generally, is not desired as it results in considerable additional dead load and hence deeper structures.

5.4.2 Concrete Superstructure

- Precast or cast-in-place concrete units
 - Four-sided boxes have a maximum practical single cell span of approximately 7.5 m. Their concrete inverts may raise objections in sensitive fishing areas, where a natural stream bed is preferred. Various methods may be used to design these boxes which could be used for spans ranging from 3 m (single cell) to 30 m (multiple cells).
 - Three-sided units, with a frame or arch corner shape, have a maximum span of approximately 12 m. These units are usually supported on strip footings founded on rock or piles. A precast or cast-in-place full invert slab/footing unit may also be used.
 - Both of the above units shall be used with a minimum fill of 600 mm.
- Precast Arches
 - Precast arch units are generally available as proprietary systems of standard geometry designed for use with specified fill properties. Industry standards should be consulted for available arch sizes and limitations on customization of those systems.
 - Three-sided and precast arches units may be used for many of the same situations identified for large pipes. In order to obtain the necessary headroom for some cases, the units may be raised by supporting them on pedestals or conventional retaining walls.
 - Use of multi-cell units to convey waterways may not be appropriate when the risk of debris catching and accumulating at the intermediate piers is high.
- Spans Between 3 m and 30 m
 - Prestressed concrete voided slabs of standard AASHTO sections may be used to a maximum span of about 17.5 m. Prestressed concrete box units, concrete I-beams, bulb-tee sections are used for longer spans.
 - Prestressed box and voided slab systems, are generally designed with diaphragms provided within unit sections at each support to resist transverse rotations, displacements and cross sectional distortion. And designed to resist torsional moments and transmit vertical and shear forces from the superstructure to the bearings.
 - Prestressed box and voided slab structures must be analyzed for construction loads and forces that arise during jacking of the structure during bearing maintenance and replacement.
 - Intermediate diaphragms are required for box and voided slab structures. Diaphragm requirements and layout are described in this manual.
- Spans Between 31 m and 60 m
 - Modified prestressed concrete box beams (modified shapes of standard AASHTO sections) up to 1.4 m deep may be used for spans up to 30 m. Modified prestressed concrete box beams up to 2 m deep may be used for continuous arrangements for spans up to 45 m. Prestressed concrete I-beams and bulb-tee beams ranging from 1.4 m to 2.0 m in depth may be used for spans up to approximately 46 m. Composite steel plate girder systems can easily and economically span this range. Once the single span exceeds 50 m, alternate multiple span arrangements shall be considered. The cost of additional substructures must be compared to the greater superstructure cost.
 - Precast concrete beams are not recommended for spans over 50 m.
- Multiple Span Arrangements
 - For multiple span bridges, a continuous design shall be adopted whenever possible to eliminate deck joints. In the case of multiple simple span prestressed bridge, the deck slab shall be made continuous for live load over the intermediate supports.
 - If aesthetically acceptable, arrangements ranging from equal span viaduct type structures to proportionally increasing span ratios shall be evaluated during preliminary design.
 - Required beam depth for multiple span, prestressed box and voided slab structures is the same as for a single span with the identical span length.
- Spans Over 90 m



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- Multiple span arrangements in this range generally involve balancing superstructure and substructure costs to achieve an optimum design. Site restrictions often hamper efficient substructure placement.
- Long multiple span structures can utilize a variety of construction types and materials.
- Segmental box designs consisting of precast match cast or cast-in-place.
- Cable-stayed trapezoidal boxes.
- Deck arches.
- Segmental viaduct and variable depth units.

5.4.3 Steel Superstructure

- Spans less than 12 m
 - Prestressed concrete voided slab units and concrete decks with steel girders cover this entire span range. Conventional reinforced concrete slabs, however, are inefficient for spans greater than 7.5 m due to their excessive depth and heavy reinforcement.
- Spans Between 12 m and 60 m
 - Conventional composite design systems utilizing concrete decks and steel stringers may be used for the entire span range. At the lower end of the span range, rolled beam sections are typically used. Fabricated, welded plate girders are more likely to be used at the upper end.
 - Special prefabricated bridge panels with composite concrete decks and steel beams may reach spans approaching 30 m. They have the advantage of reduced field construction time.
- Span Between 61 m and 90 m

Single span bridges in this range have few options. For the majority of the cases only a thru or deck truss shall be considered. Plate girders may be used at the lower end of this span range. Special designs utilizing arches, slant leg rigid frames, and concrete or steel box girders are also viable options. These types of special structures are used to address limited member depths, aesthetics and compatibility with site conditions. The Entity will have a greater input into these larger structures. Constructability concerns and possible alternatives shall be discussed, in detail, with the Entity for structures in this span range.
- Multiple Span Arrangements

Continuous design using steel rolled beams or built-up plate girders takes into account the continuity over the interior support points. Based on the span arrangements and the span ratios, the largest span of a continuous layout may be equated to a smaller equivalent simple span. This reduces the required beam depth for the span. Poor continuous span ratios may result in uplift. Tie-down system and anchored end spans are two means of addressing uplift. Refer to TABLE 5.1.C.

TABLE 5.1.C. MULTIPLE SPAN ARRANGEMENTS

Number of Spans	Ratio of Spans	Equivalent Simple Span ¹	Span to Depth Ratios	
			Desired	Maximum ²
2	1.0 : 1.0	0.90 X 1.0 span	27.5	30
3	0.75 : 1.0 : 0.75	0.85 x 1.0 span	27.5	30
4	0.8 : 1.0 : 1.0 : 0.80	0.75 x 1.0 span	27.5	30
5	0.6 : 0.80 : 1.0 : 0.80 : 0.60	0.60 x 1.0 span	27.5	30

¹ For span arrangements with less efficient ratios, the equivalent factor may be adjusted proportionally upward (i.e., 0.85 up to 0.90, 0.75 up to 0.85 and 0.60 up to 0.75).

² Ratios greater than 30 may be used as long as the live load deflection criteria is not exceeded.

- Spans Over 90 m
 - Multiple span arrangements in this span range generally involves balancing superstructure and substructure costs to achieve an optimum design. Site restrictions will often hamper efficient substructure placement.
 - Long multiple span structures may utilize a variety of construction types and materials.
 - Thru or deck trusses with girder approach spans
 - Trapezoidal box beams



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- Variable depth girders ("I" shaped beams and box girders)
- Cable-stayed girders or box beams
- Deck or thru arches
- Suspension bridges.

5.4.4 Abutments

5.4.4.1 General

Abutments serve two principal functions. They support the bridge superstructure and retain earth of the roadway approach immediately adjacent to the bridge. Therefore, a bridge abutment combines the functions of a pier and a retaining wall.

- Cantilevered Abutment
 - Cantilevered abutments consist of a central stem supporting the bridge seat backwall and pedestals. A backwall on top of the stem and wingwalls on either side of the stem retains the fill behind the abutment. The stem and wingwalls rest upon a continuous footing that may be either soil or pile supported.
The structural reinforcing steel in a cantilevered abutment is designed to withstand the overturning forces that cause tension in the back of the stem and backwall. Also, design of footing reinforcement is required and depends on the type of foundation selected.
 - Cantilevered abutments have no limit on the skew angle; however, bridges with less skew perform significantly better than highly skewed bridges.
 - There is no limit on span for superstructure used with cantilevered abutments. The abutment shall be designed to support all applied superstructure loads. Thermal expansion of the superstructure shall be accounted for by the use of an expansion joint or appropriate jointless details.
 - There are three different forms of the cantilevered abutment:
 - When the abutment is placed so that the abutment has as little reveal above the ground surface as allowed, it is called a stub cantilevered abutment.
 - When the abutment has the largest possible reveal with respect to the clearances required for the feature crossed, it is called a cantilevered high abutment.
 - An abutment that falls between these two extremes is called a cantilevered semi-high abutment.
- Isolated Pedestal Stub Abutment
 - Isolated pedestal stub abutments have tall pedestals that rest directly on the footing and have no bridge seat. They have a backwall between the pedestals and wingwalls on each side to retain the fill. The footing may be either soil or pile supported.
- Spill Through Abutment
 - Spill through, or open, abutment consists of two or more vertical columns carrying a beam that supports the bridge seat and pedestals. The fill extends on its natural slope from the bottom of the beam through the openings in the columns. In an extreme form the spill through abutment is no more than a row of vertical piles driven through the fill and supporting a bridge seat and pedestals. The stem is usually provided with small wingwalls to keep the bridge seat free of soil. Spill through abutments are economical, however, they require proper drainage details be provided for the structure and approaches, to prevent water penetration and washout of the fill soil.

5.4.5 Wingwalls

- General
 - Wingwalls are retaining walls placed adjacent to the abutment stem to retain the fill behind the abutment. The orientation of the wall in relation to the centerline of bearings or centerline of the roadway determines the wingwall type.
 - When the wingwalls are parallel to the roadway, they are called U-wingwalls. U-wingwalls are used primarily in fill situations where there are obstructions or limited right of way on either side of the roadway to build a wide embankment. The length of the U-wingwall is determined



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by equating the point where the embankment slope meets the shoulder break (where the roadway shoulder changes slope at the embankment) elevation from the roadway. The intersection shall occur at the inside corner of the top of the wingwall. The elevation of the end of the U-wingwall shall be set at this intersection and stated on the plans.

- When the wingwalls are parallel to the centerline of bearings they are called in-line wingwalls. These wingwalls are used when the abutment is relatively short and there are no obstructions or right of way limitations on either side of the highway. The end of an in-line wingwall is located where the slope from the shoulder break meets the under-bridge embankment slope. The intersection shall occur at the rear corner of the wingwall. Elevation of the top of the wingwall shall be 200 mm higher than this intersection and stated on the plans.
- When the wingwalls are turned back towards the retained fill but not parallel to the roadway, they are called flared wingwalls. These wingwalls are used when the abutment fill would spill out too far for in-line wingwalls, but there are not enough restrictions to justify U-wingwalls. The end of a flared wingwall is located where the shoulder break from the roadway meets the under-bridge embankment slope. The intersection shall occur at the rear corner of the wingwall.
- Curved wingwalls shall be avoided whenever possible. If it is absolutely necessary to provide a curved wingwall, it is best to place a widened footing on a chord and only curve the top portion of the wall. Curved wingwalls should never be battered since the forming is extremely difficult.

5.4.6 Piers

1. 'Pier' is used here to refer to an intermediate support for a bridge superstructure, between the abutments, extending from below the ground surface to the bottom of the superstructure.
2. Piers may be required because of long spans, beam depth restrictions, or both. The pier may be a support point along a continuous superstructure, or it may be at the end of one simple span and the beginning of another. In either case, the pier must be designed to safely resist the dead, live, seismic and other loads introduced from the superstructure while resisting any loads acting on the pier from flood water, wind, and vehicular or ship impact.

- Pier Types

- Solid Piers

A solid pier (pier wall) consists of a solid mass of reinforced concrete, without overhangs, that is usually rectangular in plan. Solid piers are used primarily for river or stream crossings, low clearance bridges, bridges over divided highways with narrow medians, and where short columns on wide bridges would have high stress due to shrinkage. Solid Piers may also be used to meet crash protection requirements adjacent to railroads.

- Hammerhead Pier

With increasing pier height and narrow superstructures, the hammerhead pier becomes more economical by reducing the required amounts of material and formwork. Hammerhead piers consist of a single large column with a cap beam overhanging on either side. Both the column and cantilevered ends of the cap beam support the superstructure beams. When located in a waterway, pier protection may be required.

- Multiple Columns

When piers need to be tall and wide, a multiple column pier is usually the best choice. This pier type consists of two or more columns that may be either rectangular or circular. The columns are usually connected by a cap beam that supports the superstructure at points between the columns. For some highly skewed bridges with large beam spacing, it may be necessary to place individual columns under each bearing and to connect the top of the columns with a simple tie strut. When there are only two columns with overhangs, this pier is called a pi pier. Circular piers are aesthetically less attractive than rectangular piers, and are not recommended for use in residential areas.

- Free Standing Columns

This type of pier consists of free standing individual columns usually supporting a voided slab or box type continuous superstructure. Unlike multiple columns, free standing columns are not connected with a cap beam which transmits superstructure loads to the columns. Instead, superstructure loads are transmitted to the columns through an interior diaphragm embedded in the superstructure.



5.4.7 Cap Beams

- A feature of most multi-column piers is the presence of the cap beam. This cap beam is subject to many design considerations that are not applicable to any other type of pier. The width of the cap beam is governed by the necessary width to support the bridge bearings with sufficient cover for the anchor bolts and the required support length for the beams. When the simply supported end of a beam rests on a pier, seismic criteria dictates the support length required. Support length in the longitudinal direction shall be measured perpendicular to
- the centerline of bearings. Support length in the transverse direction shall be measured perpendicular to the centerline of the beam. Round columns require that the cap beam be at least 50 mm wider than the columns on all sides.
- For cap beam cantilever ends where the fascia beam loads fall within a distance "d" from the column face, the actual behavior of the cantilever end may not be compatible with beam theory and must be checked against the requirements of AASHTO, Special Provisions for Brackets and Corbels. An alternative method to analyze such cantilever ends is the strut and tie method described in the AASHTO LRFD Bridge Design Specifications. Both the Bracket and Corbel and the Strut and Tie methods recognize that direct shear is the primary behavioral mode instead of flexure, and is resisted by tension reinforcement across the shear plane. As a result of these methods, more reinforcement may be required in the top of the overhang than would be required if a normal cantilevered beam is assumed.

5.4.8 Foundations

- Substructure Location

When deciding where to locate the substructures, the AE shall identify all appropriate horizontal offsets, standards and requirements. Utilizing these constraints and the shoulder break length, the determination of whether a single or multiple span arrangements is the most appropriate shall be made. The available beam depth is factored in along with any special concerns such as:

- Sheeting requirements for staging and substructure construction. Cantilever sheeting design vs. tied-back sheeting vs. pile and lagging wall costs.
- Deep water cofferdam construction vs. shallower depths or causeway construction.
- Treatments such as high abutments with large reveal heights for masonry or brick treatments.
- Wetland or corridor encroachments - Longer spans would require additional beam depth. This might raise a profile and move the toe of slope out or require a retaining wall. Shorter spans may require more disturbance of the area, and also require retaining walls at the toe.
- Staging problems - includes interference between the existing and new features, such as substructures, beams and pier caps, as well as utilities that must remain in service.
- Utility Conflicts - The avoidance of utilities that would require costly relocations may further restrict the location of substructures. Pile driving and sheeting placement may be limited by overhead or underground interference.

- Foundation Assessment

The substructure design shall be based on available borehole logs for the bridge and earthworks. These logs shall be evaluated with regard to:

- Their location with respect to the proposed bridge, and shall be assessed by the A/E to confirm there is sufficient information to develop the substructure design.
- Where necessary the AE and/or the EPC Contractor shall specify additional exploratory holes to develop and/or validate the substructure design.
- The A/E shall review the borehole and supporting laboratory test data to confirm soil and rock profiles to develop the design ground model.
- The ground shall be assessed to determine the appropriate foundation type, constructability and temporary works.

- Foundation Selection

Water Crossings - The following criteria shall be applied to all structures crossing water:

- Unless founded on rock, all structures crossing water shall be supported on piles or have other positive protection to maintain the elevation at which the bottom of the substructure unit is founded. In concrete lined channels where there is no scour risk, this requirement may be waived with approval of the Entity.



Structural Design Guidelines

- The minimum pile length to pile diameter shall be > 12 .
- Piles shall be socketed into rock if a stilt effect is possible due to scour.
- Cofferdams shall be evaluated with regard to need, type, size, constructability and cost. Alternative types of construction such as causeways, caissons or drilled shafts shall be considered and compared to conventional cofferdam costs.
- The estimated maximum depth of scour shall be used to determine the overall structure stability.
- **Grade Separations**
 - Use of continuous structures will normally require unyielding foundations. Differential settlement is not acceptable since it may result in secondary stresses that may be detrimental to the structure.
 - In cases where the abutment or wingwall heights exceed 9 m, alternate system other than cantilevered, cast-in-place concrete wall systems shall be considered. This is especially true in fill areas. Several modular wall systems are available which may provide a more economical system.
- **Orientation, Configuration, and Details**
 - **Skew**
 - The orientation of the substructure units is greatly dependent upon the type of feature crossed. Whenever possible, the skew of the structure shall be kept at 30° or less.
 - Skews in excess of 30° may cause uplift problems, cracking of the concrete deck in the acute corners, and require larger bridge seats and pedestal bearing areas.
 - Sharp acute corners shall be avoided, and radial supports are preferred for curved structures. If possible, skews of 10° or less should be eliminated, unless it creates problems of misalignment with the feature crossed.
 - **Water Crossings**

Whenever possible piers should be aligned with the stream flow to avoid the creation of eddies and turbulence which could result in scour. The placement of abutments or piers should not result in pockets where water turbulence could increase the potential for scour. The following guidelines for substructures need to be considered:

 - Two piers close to each shore line may be more hydraulically efficient and economical to build than one deep water pier.
 - The pier shall be made solid to a height of 1 m above the maximum navigable elevation or 600 mm above the 100 year flood or the flood of record, whichever is higher. If the remaining height of pier above the solid stem is 5 m or less, the pier shall be made completely solid.
 - The upstream face of piers shall be rounded or V shaped to improve hydraulics and debris problems.
 - In cases where the wingwalls of an abutment are at or near the water's edge, the wingwalls shall be flared to improve the hydraulic entrance condition. If possible, the elevation at the end of the wingwall should be higher than design high water or as a minimum, the ordinary high water.
 - The wingwalls on the upstream side should be aligned to direct the flow through the bridge opening. For the ease of construction, the downstream wingwalls may be made mirror images. Scour protection should be provided in the form of rip-rap wherever risk of scour is identified.
 - **General Details**
 - U-wingwalls may be used when there is interference between the existing and the proposed structure or some other site restriction. They may also be used when a certain aesthetic effect is requested. Flared or in-line wingwalls are generally more cost effective. Corrosion environment for sheeting. Durability for precast.
 - When the length of a wingwall exceeds 8 m, use of an alternate type of wingwall system shall be investigated. MSE walls or other modular wall systems may prove to be more economical than a cast-in-place cantilever design. However, MSE walls shall never be used in proximity to a hydraulic environment where there is risk of scour or underpinning. Commercially available proprietary MSE wall systems specifically developed for use in marine environments may be used with Entity approval.



Structural Design Guidelines

- Special details such as below ground cast-in-place or masonry block sills may be used to support architectural stone or brick facings. If form inserts are used to obtain an aesthetic appearance, wall thickness must be increased by an amount equal to the relief of the insert.
- Narrow roadway medians will generally require the alignment of a median pier to approximate the skew of the roadway. In wider medians, 18 m or more, pier skews may be modified. In narrow highway medians where a pier will be subject to road spray, a solid pier shall be considered.

5.4.9 Bearings

Bearings allow controlled bridge movement, and thus reducing the stresses induced on the bridge superstructure and substructure.

- Design references for the design of bridge bearings are:
 - Bearing Design, Publication No. FHWA-IF-12-052-Vol. 15
 - AASHTO Bridge Design Specifications.
- Types of Bearings
 - Elastomeric Bearings
 - Plain elastomeric pads rely on friction at contact surface to prevent bulging. Pads are thin to prevent slip of pads under strain and therefore may accommodate small horizontal translation.
 - Steel Reinforced elastomeric bearings rely on steel reinforcing pads and contact surface friction to prevent budging. Steel reinforced elastomer may carry larger strains and rotations than unreinforced bearing pads.
 - Multi-Rotational Bearings
 - Pot bearings provide a contained elastomer disc to high loading pressures, causing the disc to behave as a fluid. Vertical force is transmitted through elastomeric disc via a piston. Horizontal loads are transmitted by contact of the piston face against the pot wall.
 - Disc bearings are stiff to compression and rotation forces but are free to bulge. Horizontal forces are distributed from a load plate to a center shear pin or restricting ring.
 - Mechanical Bearings
 - Mechanical bearings distribute vertical and horizontal forces through metal to metal contact. Most mechanical bearings provide a pin or knuckle to allow for rotation while restricting translation. Rockers, rollers or sliding type bearings are common types of bearings allowing required translation

5.4.10 Expansion Joints

Bridge expansion joints are designed to allow for continuous traffic between structures accommodating movement, shrinkage, temperature variations on reinforced and prestressed concrete, composite and steel structures. They stop the bridge from bending out of place in extreme conditions and allow enough vertical movement to permit bearing replacement without the need to dismantle the bridge expansion joint.

5.4.10.1 Types of Joints

- Small movement Joints:
 - Compression Seals

Compression seals are continuous manufactured elastomeric elements installed within an expansion joint gap to seal the joint against water and debris infiltration. Compression joints are held in place by utilizing wall friction of vertical surfaces
 - Silicone Sealants

Silicone sealants are durable watertight sealants that are efficient for rehabilitation and repair projects. System has less service life than compression seals but is easier to install and maintain.



Structural Design Guidelines

- Medium Movement Joints:
 - Sliding Plate Joints

Two overlapping plates attached to the superstructure on each side of the plate. Joints do not provide an effective barrier against water infiltration, however, they provide a smooth driving surface across joints. Corrosion protection/mitigation shall be considered when using sliding plate joints, and shall be used only with the approval of the Entity.
 - Strip Seal Joints

Elastomeric strip seal system consists of preformed gland mechanically locked into steel angles or members embedded in slab or abutment concrete. 180 mm block-out in concrete is required for installation.
 - Large Movement Joints
 - Steel Finger Joints

Are the most common type of joints and are installed in cantilever situations on bridges. Steel finger joints are designed to carry superimposed traffic loads. However, they do not provide an effective seal against water and debris infiltration. This type of joint shall only be used with Entity approval.
 - Modular Expansion Joints

Comprise a series of steel or concrete center beams oriented parallel to the expansion joint axis. Elastomeric strip seals or box-type seals attach to adjacent center beams, preventing infiltration of water and debris. The center beams are supported on support bars, which span in the primary direction of anticipated movement. The support bars are supported on sliding bearing mounted within support boxes. Polytetrafluoroethylene (PTFE) - stainless steel interfaces between elastomeric support bearings and support bars facilitate the unimpeded translation of the support bars as the expansion gap opens and closes. The support boxes generally rest on either cast-in-place concrete or grout pads installed into a preformed block out.

5.5 Principles and Guidelines

5.5.1 General

The principles and guidelines included in this section shall apply to all the structures in TABLE 5.0.A.

Concrete is the material of choice for transportation structures. As appropriate, superstructures and substructures shall be designed as reinforced or prestressed concrete members. Structures and components covered under this subsection include reinforced concrete bridges, pre-tensioned and post-tensioned concrete beams, unreinforced and reinforced concrete culverts, and reinforced concrete piers, foundations, retaining walls, spread footings, drilled shafts, driven pile foundations, and cut and cover tunnel structures. Although concrete is the preferred material for transportation structures, steel material might be more appropriate in some cases.

5.5.2 Depth/Span Ratios

The depth to span ratio for each structure is dependent on many factors. Some of these are span, type of construction, aesthetics, cost, and false work and vertical clearance limitations. For purposes of preliminary planning and design, the depth to span ratio listed below may be used in setting grade lines at grade separations:

- Highway Bridges:
 - Multiple spans 35 m or less, use 0.06.
 - Multiple spans over 35 m, use 0.045.
 - Single spans up to 55 m, use 0.045.
- Railroad Underpasses (not including the 0.6 m dimension between the top of bridge deck and top of track for ballasted rails):
 - Single spans up to 25 m, use 0.08.
 - Multiple spans 25 m or less, use 0.075.

5.5.3 Design Life



Structural Design Guidelines

All transportation structures covered under this section shall have a target minimum life of 75 years.

5.5.4 Skew

Maximum skew for Groups 3, 4, and 5 structures shall not exceed 30 degrees, unless restricted by extreme conditions at the structure's site. Any skew greater than 30 degrees shall require the Entity's approval. Severely skewed alignments may cause uplift, seismic design issues, and maintenance problems.

5.5.5 Abutments

Wingwall foundations shall match the abutment foundation type, and a pile supported abutment shall always have pile supported wingwalls, except when MSE wall is used in combination with a piled abutment.

5.5.6 Bearings

- Elastomeric bearings shall be considered first, and other types may be used if their advantages over elastomeric bearings are demonstrated during preliminary design. Pot bearings shall be considered as second best choice.
- Multiple span substructures shall have fixed type bearings at only one pier support and expansion types at all others. The fixed pier shall be centrally located, or close thereof, between the two expansion joints.
- Wide seats shall be provided at expansion span ends at abutments and piers to allow for large displacements without unseating the spans. The minimum seat width shall be the greater of 220 mm or that determined based seismic analysis.

5.5.7 Arrangement

- For single span bridges, simply supported or integral abutment structures shall be used.
- Multiple span bridges shall be made continuous for live load over interior supports, with the maximum span length meeting the requirements stipulated in this section and configurations meeting aesthetics requirements of the project.

5.5.8 Expansion Joints

The distance between any two expansion joints on the deck shall not exceed 90 m. Modular type joints are the expansion joints of choice for structures, unless dictated by design or advantages of other systems are demonstrated to ENTITY satisfaction.

5.5.9 Diaphragms

All Groups 3, 4, and 5 superstructures shall be designed with two end diaphragms and at least one intermediate diaphragm, depending on the structure's span length. For spans shorter than 17 m, at least one intermediate diaphragm shall be specified at the center of the span. For spans 17 m or longer, at least 3 intermediate spans shall be provided at span mid- and quarter points.

5.5.10 Piers

- Piers over navigable water shall be placed with their longitudinal axes parallel to the principal direction of water flow.
- The need to protect bridge piers from ship impact shall be determined based on investigation of the specific site for the probability of occurrence of such event.

5.5.11 Railing



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- Brush curbs/sidewalks with curbs shall be used directly in front of concrete barriers, guard fences, or traffic rails on all structures. Curb height shall meet or exceed height of approach roadway.
- Both bridge rails and transition rails on structures shall meet crash testing requirements of NCHRP Report 350 or others acceptable to the Entity.

5.5.12 Approach Slab

Approach slabs behind abutments shall be provided to guard against susceptibility of backfill soil material to settlement behind abutments and smooth the transition from structure to pavement and vice versa.

5.5.13 Environmental and Safety

- Corrosion Control
 - The transportation structures shall be designed to endure corrosive or marine environments or any other severe exposure conditions. Concrete protection shall be suitably addressed by controlling concrete and steel materials, cover thickness, and/or providing other protection methods. Concrete corrosion protection is included in this manual.
 - Exposed reinforcing bars, inserts, and plates intended for bonding with future extensions shall be protected from corrosion by concrete or other adequate covering acceptable to the Entity.
 - Anchorages, end fittings, couplers, and exposed tendons shall also be protected from corrosion by adequate means acceptable to the Entity.
 - Burning or welding operations in vicinity of prestressing tendons shall be carefully performed, so that tendons are not subjected to excessive temperatures, welding sparks, or ground currents.
 - Tendon wrapping, sheathing, or coating shall be continuous over entire debonded length, and shall prevent intrusion of cement paste during concrete placement.
- Elements Control
 - Closed box beam sections shall be provided with bottom vent openings of 25 mm diameter located at the lowest ends of the beams, to relief air pressure and prevent accumulation of water accidentally entrapped inside a box.
 - Structures in arid regions are expected to be influenced by the following three processes associated with wind action on the topography of such regions: deflation, abrasion, and dunes. Deflation is the lifting or rolling and subsequent removal of loose, dry sediments (fine silt to coarse sand) by wind action. As the wind-driven silt and sand impact an exposed surface of the structure it creates a form of natural sandblasting effect called abrasion. Dunes are formed when a wind carrying a load of sediment encounters an obstructing barrier, the wind velocity decreases and the sediment is subsequently deposited in the form of a hill of sand on the lee side of the barrier. Design and construction of structures in arid regions shall incorporate, as reasonably practicable, provisions to mitigate the adverse effects of deflation, abrasion, and dunes on the structures and their maintenance. An example of such provisions is increasing culvert depth to account for sand accumulation on inlet.
- Noise Control
 - The effect of highway noise within urban areas shall be mitigated by providing sound barrier systems, designed to meet Entity's requirements for noise abatement at the bridge site.
- Safety
 - Structures over rail shall be designed with provisions to protect their substructure elements from being impacted by a derailed train. Such provisions are included in AREMA.
 - Structures shall be designed to withstand the forces induced in structural members as a result of accidental truck impact. The members covered under these requirements include deck cantilevers due to accidental impact on concrete barrier, and pier bents consisting of two columns or less, including hammer heads, laying within less than 9 m from the edge of a roadway and not protected by other means from accidental truck impact. The impact force and point of application on a pier shall be as specified for traffic barriers.
 - Piers in navigable waters shall be protected from ship impact whenever probability of occurrence of such an event is established. The reference document on this is the AASHTO Guide Specifications and Commentary for Vessel Collision Design of Highway Bridges, 2nd Edition, 2010 Interim.



5.6 Design Standards and Requirements

5.6.1 General

- Purpose
 - This section mandates the standards and design requirements for the structures to meet the requirements specified herein for durability, strength, stiffness, stability, and serviceability to ensure long and safe operation of highway vehicles on those structures.
- Applicability
 - This section shall apply to all transportation structures, except those excluded in Subsection 5.1.2
 -

5.6.2 Design Standards

- Main Standards
 - Design and construction of all applicable transportation structures shall be based upon the requirements of this section and existing structures standards; as stated in this section. Where the requirements stipulated in any reference document are in conflict with the requirements of this section, the stricter shall govern unless otherwise noted herein and shall require the Entity's approval. The AASHTO Standard Specifications and MOT are the main standards for design and construction of transportation structures.
- Authorities Standards
 - Design and construction of Groups 1 and 2 structures, as applicable, shall be based upon the design standards of the authority having jurisdiction over the structures.
- Alternative Standards
 - In the absence of appropriate standards, because of unconventional design or introduction of uncommon features, alternative standards may be proposed. However, documents and evidence in support of the proposed standards must be submitted to the ENTITY for review and approval.
- No appropriate Standards
 - Where no appropriate standards exist (e.g. due to the introduction of new technology, components or a novel application of such) then risk assessments shall be carried out, supported by experimental and development data, before the component or technique is adopted for Entity use.

5.6.3 Analysis Methods

- Member forces, stresses, and deformations under the design loads specified in this section shall be obtained through recognized elastic analysis methods accepted by the Entity.
- Inelastic analysis methods shall only be used where noted in this section, or required/recommended in the design standards referred to in the section.
- Soil structure interaction shall be considered in the design of flexible buried structures, such as proprietary precast arch systems.

5.6.4 Design Methods

- Design of transportation structures shall be based on the following methods:
 - Reinforced concrete structures - Load and Resistance Factor Design Method (LRFD)
 - Prestressed concrete structures - Service Load Design Method with check for Ultimate Strength
 - Abutments, capbeams, pilecaps, and piers - Load & Resistance Factor Design Method with check for Serviceability.
 - Foundations - Service Load Design Method
 - Drilled shafts - Service Load Design Method



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- Driven piles - Service Load Design Method
- Steel structures - Load and Resistance Factor Design Method
- Groups 1 and 3 structures over drainage channels shall be designed with attention to neighboring drainage structures, to prevent potential for channel overflow and flooding.
- Groups 1 and 3 structures over drainage channels shall be sized based on hydraulic design demand and specified freeboard. Selection of unreinforced culvert structures sizes shall also be based on hydraulic design, and not on height of the fill above the culvert.
- Cut and cover tunnel structures shall be designed in accordance with FHWA publication - FHWA - NH1-10-034, "Technical Manual for Design and Construction of Road Tunnels".

5.6.5 Strength Requirements

- Steel
 - Reinforcing Steel
 - Reinforcing steel used for constructing transportation structures substructures shall as per the requirements of Subsection 5
 - Minimum steel yield strength = 420 MPa
 - 2) Prestressing Steel
 - Prestressing steel used for constructing transportation structures shall be 12.5 mm diameter "Uncoated Seven-wire high Tensile Cold Drawn Low Relaxation strand for Prestressed Concrete" as specified in ASTM A416, Grade 270 with $f_u' = 1860$ MPa.
 - Use of 15.24 mm strands shall be allowed for cast in place post-tensioned members only.
- Concrete
 - Reinforced Concrete Applications:

Concrete strength used for constructing reinforced concrete transportation structures shall have the following minimum specified cylinder strength:

 - Decks except barriers $f_c' = 40$ MPa
 - Abutments $f_c' = 35$ MPa
 - Piers except footings $f_c' = 35$ MPa
 - Drilled shafts $f_c' = 35$ MPa
 - All others $f_c' = 27.5$ MPa
 - Post-Tensioned Concrete Applications:

Concrete strength used for constructing post-tensioned concrete transportation structures shall have the following cylinder strength:

 - Min. initial $f_c' = 28.5$ MPa
 - Min. final $f_c' = 35$ MPa
 - Max. final $f_c' = 41$ MPa
 - Pre-Tensioned Concrete Applications:

Concrete strength used for constructing prestressed concrete transportation structures shall have the following minimum cylinder strength:

 - Min. initial $f_c' = 28.5$ MPa
 - Max. initial $f_c' = 31.4$ MPa
 - Min. final $f_c' = 35.3$ MPa
 - Max. final $f_c' = 41$ MPa

Use of higher concrete strength than those specified in this section shall require approval of the Entity.

5.6.6 Concrete Cover Requirements

The following minimum concrete clear cover shall be provided:

- Concrete exposed to salt water & splash zone 75 mm
- Concrete of all substructure elements in contact with earth soil 75 mm.
- Concrete of all substructure elements exposed to weather 75 mm.



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- Superstructure cast-in-place concrete exposed to weather 50 mm.
- Inside faces of post-tensioned concrete boxes 50 mm.
- Prefabricated superstructure elements, outside 50 mm
- Prefabricated superstructure elements, inside faces 40 mm.

5.6.7 Design Loads

The transportation structures shall be designed for all the loads listed under this section.

5.6.7.1 Standard Loads

The transportation structures shall be designed for the applicable of the following loads:

- Dead Load and Superimposed Dead Load (D)
- Live Load (L)
- Impact Load (I)
- Wind Load on Structure (W)
- Wind Load (WL)
- Centrifugal Force (CF)
- Longitudinal Force from Live Load (LF)
- Earth Lateral Load (EH)
- Longitudinal Force due to Friction or Shear Resistance at Expansion Bearings (F)
- Other Forces (Rib Shortening, Shrinkage, Temperature and/or Support Settlement) (OF)
- Earthquake Forces (EQ)
- Stream Flow Pressure (SF)
- Buoyancy (B)
- Prestressing Forces (PS).

Members of the structure shall be designed for the combination of loads and forces that can occur simultaneously to produce the most critical design conditions as specified in the standard codes. In addition, transportation structures shall also be designed for the non-standard loads specified in this section.

- Dead Load (D)
 - Dead load shall consist of the structure's estimated self-weight and the superimposed dead load it supports, such as weigh of concrete deck, diaphragms, utilities, and rail system. The unit weights below shall be used to calculate dead load on structures.
 - Steel 78 kN/m³
 - Reinforced Concrete 24 kN/m³
 - Pre-stressed Concrete 24 kN/m³
 - Earth-Fill 19 kN/m³
 - Asphalt Concrete 22 kN/m³
 - Water 9.81 kN/m³
 - Structures designed with concrete wearing surface for riding surface shall be designed for an additional future wearing surface weight calculated based on 7.5 kg/m³.
 - Superimposed load due to lighting poles, utility lines, fences, noise barriers, etc. carried on a structure shall be calculated based on specific materials volumes and unit weights.
 - The minimum superimposed dead load due to waterproofing and protective covering shall be 1 kN/m².
- Live Load (L)
 - Groups 1, 2, and 3 Structures
Groups 1, 2, and 3 culvert-type transportation structures shall be designed using the MOT live load models.
 - Groups 3, 4, and 4 Structures



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Groups 3, 4, and 5 transportation structures shall be designed using the MOT live load models and the standard AASHTO bridge design requirements for distribution of live load.

- Configuration for the MOT truck is similar to that of the HS-20, however, total gross weight for the MOT truck is much higher than that of the HS-20.
- All structures laying on a Module Path shall be designed based on the live load criteria specified by the Entity.
- Railing and Sidewalks Live Load
 - The minimum live load on bridge sidewalks shall be as specified in the AASHTO Standard Specifications.
 - In addition to standard live loads on traffic lanes, one lane structures with sidewalks shall be analyzed for incidental truck traffic on the sidewalk.
 - Lateral loading on railing from pedestrian traffic shall be 1.5 kN/m applied at the top of the rail.
- Governing Live Load (L)
 - Design live load for Groups 1 to 5 shall include various loading scenarios to maximize the load effects on the member to be designed. This shall include, eccentric loading, alternate lane loading, alternate span loading, and eccentric wind loading.
 - For bridges on curves, provision shall be made for the increased proportion of the load carried by main structural members due to eccentricity of the load.
- Distribution of Live Load
 - For Groups 1 to 5, live load distribution shall be based on AASHTO Standard Specifications.
 - In line girder analysis, live load for Groups 3, 4, and 5 shall be distributed in accordance with the AASHTO Standard Specifications requirements.
- Impact Load (I)
 - Impact load for Groups 1 to 5 structures shall be calculated based on the AASHTO Standard Specifications requirements.
 - The span length L in AASHTO impact factor equation, defined as the length of the effective free span between columns or supports, shall be determined as follows:
 - For simple structures, as the length of the span analyzed for positive moment,
 - For continuous structures, as the average length of the neighboring spans analyzed for negative moment.
 - For continuous structures, the impact value calculated for the shortest span shall be applied for the remaining spans in the structure.
 - Impact load shall not be included in the design of foundations, abutments, and other earth retaining structures.
- Wind Load

The basic wind speed used for determining wind load on structures and live load shall be provided by the Entity based on actual location of project.

 - Wind Load Background
 - If an increase in the design wind speed is accepted by the Entity, the increased wind speed shall be recorded on the design documents and shown on the plans.
 - The wind loads in the next sections are based on AASHTO, AREMA, and ACI 358.
- Wind Load on Structure (W)
 - Wind Load on Superstructure

Wind pressures on structures shall be included as part of the W loads as follows:

 - For structures where the bottom of the beams is located at a height (H) not exceeding 9.0 m above natural ground, fill or water level, a uniform transverse wind pressure of 2.36 kN/m², and a longitudinal wind pressure of 0.59 kN/m² shall be applied simultaneously on the superstructure. The pressures shall be applied at the exposed area of the superstructure projected upon a vertical plane running parallel to the longitudinal axis of the structure. For taller structures of height exceeding 9.0 m, the above specified pressures shall be as follows:

H = 9.0 m to 17.0 m:



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Transverse Wind Pressure 2.65 kN/m²
Longitudinal Wind Pressure 0.69 kN/m²

H = 17.0 m to 25.0 m:

Transverse Wind Pressure 2.9 kN/ m²
Longitudinal Wind Pressure 0.74 kN/ m²

- For structures higher than 25.0 m, wind pressures shall be determined on a structure by structure basis, as specified under adopted design codes. For special structures, the Entity might request further investigation of wind loads using methods other than those specified under adopted design codes.
- The resultant of transverse wind pressures shall be assumed to act in any transverse direction, acting through the centroid of the exposed area running parallel to the longitudinal axis of the structure.
- In the design of the substructure, an additional wind load shall be considered as an upward force in the form of a lineal load applied at the windward quarter point of the transverse width of the superstructure, measured from the upwind surface. The magnitude of this vertical force shall be 0.98 kN/m² of the exposed plan area of the structure.

- Wind Load on Substructure

Wind upon the substructure shall be included in load as follows:

- The substructure shall be designed to withstand the preceding loads from the superstructure in addition to live load. Further, a uniform and perpendicular wind pressure of 1.92 kN/m², acting in any direction, shall be applied acting at the centroid of the exposed face of the substructure projected onto a vertical plane.

- Wind Load on Live Load (WL)

- For traffic on structures where the height (H) does not exceed 9.0 m above grade, natural ground, fill or water level the wind on live load (WL) shall consist of a transverse wind load of 1.45 kN/m and a longitudinal wind load of 0.58 kN/m. These loads shall be applied simultaneously. The transverse force shall be applied to the superstructure as concentrated loads acting through a plane located 1.8 m above the top elevation of the superstructure. The longitudinal force shall be applied to the superstructure as a uniformly distributed load along the length of the span, acting within a horizontal plane located 1.8 m above the top elevation of the superstructure. For structures taller than 9.0 m, the transverse and longitudinal values of WL shall be as follows:

H = 9.0 m to 17.0 m:

Transverse wind pressure 5.31 kN/m
Longitudinal wind pressure 1.33 kN/m

H = 17.0 m to 25.0 m:

Transverse wind pressure 5.75 kN/m
Longitudinal wind pressure 1.42 kN/m

- For traffic on structures higher than 25.0 m, wind pressures shall be determined on a structure by structure basis, as specified under adopted
- design codes. For special structures, Entity might request further investigation of wind loads using methods other than those specified under adopted design codes.
- The above loads shall be considered in the design of substructure elements that support one single lane of traffic.
- For the design of substructure elements that support two lanes, the loads shall be increased by 30 percent when two lanes are loaded.

- Centrifugal Force (CF)

- On curves, structures shall be designed for a horizontal radial force (centrifugal force/CF) determined as the percentage of the live load, without impact, in all traffic lanes obtained as described below (AASHTO).

$$C = 7.865 \times 10^{-3} S^2 / R$$

where:

C = Centrifugal force in percentage of the live load

R = Radius of curvature (m)

S = Permissible speed (km/hr)



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- α = Angle of inclination of the back face of the wall with respect to horizontal
 δ = Wall friction angle

- According to AASHTO Section 3.11.5, the earth pressure coefficients adopted in design are dependent on the wall type and degree of movement. The earth pressure coefficients further depend on soil types (granular or cohesive), consolidation state, etc. Rankine equation may not be appropriate depending on the above, sloping ground, etc. The A/E shall be able to identify such limitations on Rankine equation, and recommend alternative methods to Entity for approval should they arise.
- Shear Resistance at Expansion Bearings (F)
 - Structures shall be designed with provisions to accommodate forces due to friction or shear resistance at expansion bearings.
- Other Forces (OF)
 - The transportation structures shall be designed to resist all applicable forces due to concrete shrinkage (S)), settlement of supports, rib shortening (R), erection, or any other loads expected to act on the structure and not included in this manual.
- Thermal Forces (T)
 - Forces and deformations resulting from temperature variations shall be accounted for.
 - The maximum expected temperature differential and coefficients of thermal expansion should be considered as follows (A/E shall verify project specific values):
 - Concrete:

Temperature Differential	70° C between max. and min.
Expansion Coefficient	1.08x10-5 cm/(cm-°C)
Temperature Rise	40° C
Temperature Fall	30° C
Expansion Coefficient	1.17x10-5 cm/(cm-°C)
 - The 40°C increase and 30°C decrease in temperature assumes that the stress-free temperature (temperature at which the structure is cast) is around 30°C.
 - Thermal forces in concrete box girder bridges due to temperature differential between the top of the deck and bottom slab shall be based on a temperature gradient of 20° C.
 - Air humidity to be considered in the design shall be 70 percent.
- Earthquake Forces (EQ)
 - The transportation structures carrying highway loads shall be designed for seismic loads based upon the MOT requirements. Structures designed as such shall satisfy the specified performance criteria to ensure safety of the traveling public and minimize the costs of damage, and loss of use caused by potential earthquakes.
 - The soil supporting the transportation structures shall be analyzed for liquefaction hazard and, as appropriate, mitigation measures shall be taken.
- Stream Flow Pressure (SF)
 - All piers and other portions of structures which are subject to the force of flowing water or drift shall be designed to resist the maximum stresses induced thereby.
 - The effect of flowing water on piers and drift build up, assuming a second-degree parabolic velocity distribution and thus a triangular pressure distribution shall be computed using the following equation:
$$P = KV^2$$

Where:

P = Average stream pressure in Pa

K = A constant, being 725 for all piers subjected to drift build up and square-ended piers, 360 for circular piers, and 260 for angle-ended piers where the angle is 30 degrees or less.

V = Average water flow velocity in m/sec.
 - The maximum stream flow pressure P max, shall be computed using the above equation as twice the average stream flow pressure, Pavg. Stream flow pressure shall be a triangular distribution with P max located at the top of water elevation and zero pressure located at the flow line.



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- The stream flow forces shall be calculated as the product of the stream flow triangular pressure distribution by the exposed pier area. If the corresponding top of water elevation is above the low beam elevation, stream flow loading on the superstructure shall be investigated. Then the stream flow pressure acting on the superstructure shall be taken as P_{max} with a uniform distribution. When stream flow is not normal to the pier, directional component of the pressure shall be investigated.
- When it is anticipated that the flow area under a structure will be significantly blocked by drift build up, increases in high water elevations, stream velocities, stream flow pressures, and the potential increases in scour depths shall be investigated.
- Buoyancy (B)
 - Design of foundations is negatively impacted by buoyancy. The foundation structures shall be designed assuming the negative effects of buoyancy, unless water below the foundation level is effectively removed.
- Prestressing Forces (PS)
 - Design of transportation structures shall consider the forces created in those structures due to prestressing. Those shall include 1) primary forces occurring in any prestressed structure and secondary forces occurring in prestressed concrete continuous structures and 2) forces arising during construction due to temporary restraint of post-tensioned members. The latter shall be considered under erection loads during construction. Movement due to shortening during prestressing shall never be obstructed.

5.6.7.2 Nonstandard Loads

- In addition to the loads defined herein, Entity may request that Groups 3, 4, and 5 highway structures be designed for loads other than those previously defined to assess ultimate strength or stability of the structures.
- Construction Loads

All transportation structures shall be designed to safely and adequately resist construction loads specified under adopted design codes.

5.6.8 Deformation Limits

- Flexural members of bridge structures shall be designed to have adequate stiffness to limit deflections or any deformations which may adversely affect the strength or serviceability of the structure at service load levels. Deflection of main structural flexural members carrying live load shall not exceed $L/800$ where L is the member's span length.
- The transportation structures shall be designed for a minimum of 25 mm vertical differential settlement at any single pier foundation. Based on geological and geotechnical assessment of the structure's site, Entity may change this differential settlement requirement.

5.6.9 Fatigue

Groups 3, 4, and 5 shall be verified to have adequate fatigue life under highway traffic. The aim of performing fatigue-safety verification is to demonstrate that the fatigue effects due to traffic loads will not impair the safety of the highway bridge during its intended service life. Fatigue requirements specified under AASHTO Standard Specifications may be used for adequate fatigue life verification.

5.6.10 Bearings

- All bridge bearings shall be designed and constructed according to AASHTO and as specified in this manual. Bearings articulation shall be shown on plans and be consistent with the structure's kinematics under applicable design loads.
- Uplift

Design of the transportation structures shall include provisions for adequate attachment of superstructure members to the substructure to resist uplift. Anchorage or tie down elements shall be



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designed to provide 150 percent of the uplift forces calculated under Group I loading and 125 percent of that calculated under all other service load combinations of the AASHTO. Anchorage devices shall be designed for a minimum force of 100 kN per beam support location for Group I where uplift is identified.

- Uplift requirements mandated under the seismic design criteria shall govern over those specified in this section.

5.6.11 Concrete Box Culverts

- Concrete box culverts shall be fully designed and constructed in accordance with AASHTO and as amended by this manual.
- A culvert shall be defined as any structure, whether of single or multiple-span construction, with an interior width of 6.0 m or less, measured horizontally along the center line of the roadway from face-to-face of abutments or sidewalls. Structures spanning more than 6.0 m along the centerline of the highway shall be considered bridges. More complex hydraulic and design analysis is generally required for bridge-size culverts. The information in this section shall apply to both culvert and bridge size culverts.
- Hydraulic analysis of culverts is generally based on the span length, and any sophisticated backwater analysis program shall be used to determine the size and shape of culvert structures.
- Hydraulic analysis shall be performed on all culverts over drainage or seawater cooling channels, including the standard un-reinforced culvert structures.
- Four-sided (box), three-sided, and arch types of concrete culverts are often provided as proprietary products with adjustable basic geometries, and designed using specialized software. A/E proposing such products shall include in the submittal to Entity design basis report, sample calculations, and foundation reactions for the proposed system.
- The maximum clear span (the perpendicular distance between the inside face of the sidewalls for non-skewed culverts, or for the perpendicular distance between the centerlines of the sidewalls for skewed culverts) for a cast in place concrete box culvert shall not exceed 7.3 m.
- Before a final determination is made to use a large concrete culvert, the use of a short-span bridge with laid-back slopes and integral abutments shall be investigated.

5.6.12 Concrete Superstructure

Design and construction of concrete superstructures shall be based upon the standards and specifications included in this section. Concrete superstructures shall be designed to resist all applicable standard and nonstandard loads at the required performance levels mandated by AASHTO and amended by this manual.

5.6.13 Concrete Deck

- For multispan structures, the concrete deck shall be designed to be continuous for live load, and the top of the deck shall be appropriately reinforced to locally resist all applicable standard and nonstandard loads specified in this section.
- On skewed decks, main deck reinforcement shall be placed normal to the girders/bridge centerline when the skew angle does not exceed 30 degrees.
- For skew angles greater than 30 degrees, main deck reinforcement shall be placed parallel to the skew at the obtuse triangles formed at the ends of the deck, and parallel to the girders/bridge centerline past the areas of the triangles.
- Design of expansion joints
Joint design shall be based on:
 - Bridge Shrinkage Effects
 - Thermal Effects
 - Bridge Geometry.

5.6.14 Deck Drainage



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Deck drainage shall be based on proper calculations of storm water runoff, and can be accomplished by sloping the top of the pavement transversely by not less than 1.0 percent to direct the runoff to brush curbs and collecting the water at low points located close to the lower end of the span within the fascia beams of the structure. A properly designed collection system, consisting of scuppers and downspouts shall be used to dispose off the runoff water, with the pipes descending down the nearest pier and the water discharged away from the structure. Scuppers or inlets shall be of corrosion resistant materials, of size and number that adequately drain the structure, shall be provided. Downspouts also made of corrosion resistant material, not less than 100 mm in the least dimension, and having cleanouts, shall be provided to prevent discharge of water against any portion of the structure and detailed to prevent soil erosion at ground level.

5.6.15 Piers

- Bridge piers shall be designed for expected loads from the structure, wind load, stream flow pressure, longitudinal forces due to traffic, earthquake, thermal forces, torsional forces, and any additional forces that might act on them. Additionally, piers shall be designed to meet the requirements on deformations and stiffness specified in this manual.
- Design of piers shall be based on load factor design method and in accordance with the reinforced concrete design section of the AASHTO and checked for serviceability.
- Pier Protection
- In order to limit damage by the redirection and deflection of highway traffic and equipment, piers supporting bridges over highways shall be protected by a reinforced concrete crash barrier or wall. Protection of piers shall be provided as outlined in the Standard Details, which bases protection strategy on median width, roadway classification, and area (residential or industrial).

In general, crash walls for piers are provided unless the pier has a heavy built - have a cross-sectional area equal to or greater than that required for the protective crash wall and the larger of its dimensions is parallel to the roadway.

- Crash walls for piers generally specified of a minimum height above the top surface of the roadway and width.
- For a pier made of two or more columns, the crash wall usually connects the columns and extends parallel to the roadway at least 300 mm beyond the outermost columns, and 150 mm beyond the face of the column facing traffic.
- The crash wall could be anchored to the footings and columns, if applicable, with adequate reinforcing steel.

5.6.16 Approach Slab

Transition approach slabs behind abutments shall be provided to guard against susceptibility of backfill soil material to settlement and smooth the transition for the ride as it changes from a rigid to a flexible and vice versa, such as between a concrete superstructure and an embankment. In the case of bridge abutments, a subsurface approach slab shall be adequately designed and reinforced with a varying thickness over a distance away from the abutment.

5.6.17 Fill Material

The following values shall be used to estimate lateral soil pressure, unless instructed otherwise by the Geotechnical Design Report:

Weight of Fill Material : 1,900 kg/m³
Angle of Internal Friction : 30 degree

5.6.18 Highway Surcharge

Surcharge load on earth retaining structures due to truck traffic shall be determined based on MOT loading, and total surcharge load on the structures shall also include that contributed by adjacent foundations and structures. Highway surcharge load due to traffic shall be calculated as an equivalent surcharge load due 600 mm soil overfill.

5.6.19 Abutments

- Abutments shall be designed to support loads applied by the bridge superstructure and sustain those exerted by the retained earth of the highway/roadway approach immediately adjacent to the bridge.



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- A/E shall pay special attention to abutment behavior and design of elements when the abutment is analyzed as part of 3-D model including the wingwalls. In such cases, traditional analysis and design methods of the abutment are no longer valid.
- Design of bridge abutments shall be such that the resultant of all loads acting on the abutment is located within the middle one third of the footing, when the abutment is not resting on rock or piles. A factor of safety against overturning of 1.7 shall be used. For abutments bearing on rock, the resultant may be located within the middle one half of the footing, and a factor of safety against sliding of 2.0 at the base of the footing shall then be used.
- Piled integral abutments shall be supported on a single row of piles.
- Abutments supporting multiple span structures shall have the stem and wingwalls designed to rest upon a continuous footing that can be either soil or pile supported.
- Appropriate provisions for drainage shall be provided at the back of abutments, for back fill materials to be analyzed using its dry fill properties in the design of the abutment.
- Abutments shall be designed based on load factor design method and checked for serviceability.

5.6.20 Retaining walls

- Design of reinforced concrete retaining walls shall be based on the lateral earth pressure and surcharge load calculated based on standard methods, and shall meet acceptable design and stability requirements. A retaining wall structure shall be properly designed to ensure that it will not fail by overturning, sliding, excessive settlement, excessive bearing pressures, or overloading of piles, and shall possess adequate strength to resist applied earth pressure, live load, and surcharge load.
- The passive earth pressure of the soil in contact with the face of the retaining wall shall consider the effects of unplanned and planned excavation works, such as installation of new services and maintenance of existing services when calculating wall stability. Unless otherwise approved by Entity, the passive earth pressure shall be neglected when computing the wall resistance against sliding. Cantilever retaining walls shall be used for a maximum height of 9 m, and counterfort walls shall be used for structures in excess of 9 m in height.
- Use of cantilevered sheet pile retaining walls shall be limited to temporary construction work. These walls are generally efficient for wall height in the range 2-5 m. For temporary construction when wall heights is in excess of 5 m, tied back sheet pile and tied back soldier pile or lagging can be used.
- Mechanically Stabilized Retaining shall be used, as appropriate, as alternate systems to traditional retaining walls.

5.6.21 Wingwalls

- Wingwalls, retaining wall structures adjacent or abutting a bridge abutment, shall be designed based on the stipulation in the previous section for retaining walls, and for the types and requirements included in this section. Wingwalls used in the transportation structures shall be limited to the three types: U-wing walls, in-line wingwalls, and flared wingwalls. Selection of a wingwall type is dictated by the conditions at the site, including clearance and right of way constraints.
- Wingwall foundation shall match the abutment foundation requirements (pile-supported abutments shall have pile-supported wing walls, for example, except when MSE wall is used in combination with a piled abutment).
- The elevation of the top of the wingwall shall be 250 mm higher than the fill level and be shown on the plans.
- For integral abutments, in-line wingwalls cantilevered from the abutment are the preferred arrangement. Flared wingwalls cantilevered from the abutment may also be used on a case by case basis, especially at stream crossings where the alignment and velocity of the stream increase risk of in-line walls to scour.

5.6.22 Cut and Cover Tunnel Structures

- The transportation tunnel structures constructed by cut and cover methods shall be designed as reinforced concrete box-type earth-retaining structures which are not free to yield significantly. In addition to the weight of the basic structure, dead load for these structures shall include weight of



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secondary elements supported by the structure and the earth cover gravity load acting on the roof structure.

Cut and cover tunnel structures are generally less than 12 meters deep below grade, and constructed using open excavation, with temporary support of the excavation during construction operations. Round or horseshoe shaped structures are often used for efficiency, and rectangular configuration may also be utilized.

- The following loading scenarios for structures shall be investigated at working stress levels, and additional loading scenarios shall be investigated as deemed necessary based on the specific site and loading conditions (construction and permanent loads): Vertical and long-term horizontal loads; vertical long term on one side and short term horizontal load on the other side applied simultaneously.
- For structures subjected to unequal lateral pressure, analysis for axial, shear, and moment effects shall consider the top slab as being both restrained and unrestrained against horizontal translation; and vertical load and short-term horizontal load, neglecting ground water pressure on both sides. Cut and cover tunnels shall also be designed for hydrostatic pressures, including uplift/flotation and provision of piles to resist uplift and/or drainage measures.
- The analysis shall consider variations in the stiffness and elastic properties of the supporting subgrade soil. Compression forces shall not be considered in the shear design of the top slab and invert.
- Ventilation shaft structures shall be designed similar to cut and cover structures, and installed utilizing similar construction methods requiring support of excavation with soldier piles or sheet piles.

5.6.23 Retaining Wall Drainage

The fill material behind abutments, wingwalls, and retaining walls shall be effectively drained using weep holes placed at a maximum spacing of 8 m. The water behind the wall may be collected using a filtering system of coarsely-graded soil with water receptors behind the wall at the weep hole locations. Counterfort retaining walls shall have at least one weep hole for each pocket formed by the counterforts. Location of weep holes shall be established such that their invert is at 150 mm above finished grade or low water in the case of stream bridges. Back-fill material may also be drained by means of pipe drains or gravel drains, or by perforated drains.

5.6.24 Waterproofing of Structures

- Waterproofing of the structures shall be based on the recommendations of the corrosion protection subsection 7.
- Waterproofing methods, details, and application on structural members shall follow standard specifications and details.

5.6.25 Foundation

- Geological and geotechnical investigation at the bridge site shall be performed to provide the soil parameters and soil stratification information for foundation design. Soil parameters shall be determined based on recognized standard laboratory testing methods and field testing. The soil parameters and stratification information shall be investigated for the expected load effects transmitted to the foundation from the structure, foundation deformation limits, and site restrictions to determine the most suitable foundation type for the bridge site.
- Shallow foundations shall be spread or combined footing type, on treated or untreated soil to improve soil properties. Deep foundation shall be of driven piles, cast in place drill shafts, or any other type of foundation involving piles.
- Footings and piles shall be designed to keep maximum soil stresses within allowable limits. To prevent uneven settlement, the footings shall be designed such as to maintain uniform stresses in the soil and on piles.
- Long-term differential settlement between adjacent piers on any transportation structures shall not exceed $1/2750$ of the sum of the adjacent spans lengths or any other limit set by the Entity based on the results of the site geotechnical investigation.
- Design of foundations, including spread footings, drilled shafts, and driven piles shall be based on service load method.
- Pile shall be used for foundation at any structures site where scour risk is identified.



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- Pile foundations supporting fixed columns shall be battered, if necessary, to provide adequate resistance for longitudinal forces on the structure.

5.6.26 Load Combinations

5.6.26.1 Service Load Design:

The various groups representing all the various combinations of loads and forces to which a structure may be subjected are included in the AASHTO Standard Specifications. Components of the structure and foundation shall be proportioned for the applicable loads and group of loads that produce the most critical design condition.

Service load design shall be based on the groups in the AASHTO, and the allowable overstress limits shown in the table (allowable percentage of basic unit stress is referred to as "Allowable overstress").

5.6.26.2 Load Factor Design:

The loading group combinations for Load Factor Design are included in the AASHTO Standard Specifications. The factors are only intended for designing structural members based on the load factor method.

When designing for foundations (soil pressure, pile loads, etc.), the actual loads shall not be increased by the factors in the table. The factors are not intended to be used when checking for foundation stability (safety factors against overturning, sliding, etc.) of a structure. The factors in the code represent usual conditions and should be increased, if it is judged that predictability of loads is different than that anticipated by the specifications.

5.6.27 Temporary Structures

Temporary structures, including false work, and shoring systems consisting of cantilevered sheet piling, anchored sheet piles, cantilevered and anchored soldier beams with lagging, braced excavation, and cofferdams, shall be designed and constructed in accordance with AASHTO requirements for temporary structures.

5.7 Aesthetics

5.7.1 General

Bridges have more than just transportation functions. They also function socially, visually and symbolically as significant elements in their communities and environments. Every project will be different and will possess its own unique characteristics. Nevertheless, there will be some commonality in the steps that engineers may apply in considering aesthetic bridge design. Following these steps will help ensure a successful bridge that its owner and community will be proud of. Basic aesthetic features of bridge elements are included in this section.

5.7.2 Incorporation

Incorporated aesthetics in the design process from the early preliminary design stages and shall be submitted to the Entity for review and approval.

5.7.3 Aesthetic Design

As detailed on AASHTO BAS-1, the following steps shall be executed in the Aesthetic Design of Bridges:

- Site Goals.
- Develop a Design Vision.
- Engineering Study.

5.7.4 References

- AASHTO BAS-1 Bridge Aesthetics Source Book, 1st Edition.
- AASHTO LRFD Bridge Design Specifications.



5.7.5 Design Guidelines

5.7.5.1 Horizontal and Vertical Geometry

Before there is a concept for a bridge, the roadway geometry creates a ribbon in space that can be either attractive or unattractive. The geometry establishes the basic lines of the structure, to which all else must react. A graceful geometry will go a long way toward fostering a successful bridge, while an awkward or kinked geometry will be difficult to overcome.

5.7.5.2 Superstructure Type

The superstructure type defines the structural system used to support the bridge self-weight and applied loads. It may be an arch, girder, rigid frame, truss or cable-supported type structure. The most memorable aspect of the structure is determined when the overall shape of the structural members is established.

- Multiple girder systems such as steel plate or box girders, prestressed concrete girders and concrete box girders are common structural systems for everyday bridges.
- Arches or rigid frames are occasionally used in situations where visual features, atypical site conditions or project requirements make their use appropriate.
- Cable-supported bridges are often used in special situations where visual impact is important or where site conditions require long span solution.
-

5.7.5.3 Abutment Placement and Height

Abutment placement and height determine how a bridge begins and ends and, for shorter bridges, how the structure is framed. The abutment placement also establishes the shape of the end-span opening, which may have a significant influence on what can be seen beyond the structure and how well the structure relates to adjoining uses.

- An abutment is where a bridge touches the ground and the transparency of the structure transition to the mass of the surrounding walls or topography. Abutments may have an important symbolic function, as these are the points where travelers begin and end their passage over a bridge. This is particularly true when pedestrian traffic crosses a bridge. Abutments frame the landscape or cityscape behind the bridge much like a picture frame defines the view of the picture it encloses. Depending on the under clearance and superstructure width, spaces under bridges may be very dark even during daytime. Security or maintenance considerations may influence abutment type selection.
- Stub-type or flow-through end bent abutments are located at the top of an approach embankment or at the top of a cut slope. From a visual perspective, the spaces adjacent to stub abutments are often slivers that are dark and distant to the observer. This may not be desirable on bridges where security or maintenance considerations may discourage the creation of spaces that are not easily viewed from a distance.
- Mid-height abutments are typically located within the limits of the side slopes and have a vertical surface whose height is a significant percentage of the overall bridge opening. This abutment type may better frame the view beyond the bridge and be more suitable for use on bridges in close proximity to the public, such as over recreational trails.
- Full-height abutments extend from the ground line to the bottom of the superstructure. They are typically more massive than other abutment types and often create a very strong definition of the bridge ends. This may be desirable for gateway bridges or for locations where framing the view of the background is important. They may also provide for improved security beneath urban bridges.

5.7.5.4 Superstructure Shape (including parapets, overhangs and railings)

The superstructure shape establishes the form of the structural members, including deck overhangs, parapets and rails. The superstructure may be shaped to respond to the forces on it, and the shapes of these elements and the shadows they cast determine the intrinsic interest of the structure.

5.7.5.5 Pier Shape



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The pier shape defines the form and details of the piers. From many viewpoints, particularly at oblique angles to the structure, the shapes of the piers will be a major influence on the impression created. Majority of workhorse bridge piers are structural frames consisting of circular or rectangular columns with a cap beam, which supports the superstructure girders. Typically, the exterior columns are inset from the fascia girder for reasons of structural efficiency, and the cantilevered portions of a cap beam are often tapered to reduce the depth and mass at the ends.

5.7.5.6 Abutment Shape

Abutments may become visually massive structures or secondary structures, depending on the nature of the grading at the bridge ends and the bridge layout geometry. Abutment shapes are typically more visually important on shorter bridges than on longer bridges, since an observer is more likely to view a short bridge in its entirety. From viewpoints near the ends of longer structures, the shape and detail of the abutment will also be important. For structures involving pedestrians, the provisions made for them at the ends of the bridge can be among the most memorable aspects of the structure.

5.7.5.7 Color

Colors have a long history of application on bridges due to their large visual impact with a correspondingly low cost relative to that associated with other bridge features and treatments. The colors of uncoated structural materials as well as coated elements and details need to be considered. Color, or lack thereof, will influence the effect of all the decisions that have gone before. It provides an economical vehicle to add an additional level of interest.

5.7.5.8 Texture, Ornamentation and Details

Texture, ornamentation and details are elements that can add visual interest and emphasis. Structural elements, such as stiffeners and bearings, may serve this function. Indeed, traditional systems of architectural ornamentation started from a desire to visually emphasize points where force is transferred, such as from beam to column through an ornamental capital. Patterns of grooves or insets and similar details are other examples.

5.7.5.9 Lighting, Signing and Landscaping

Though not actually part of the structural system, these elements may have great influence on the aesthetic impression a bridge makes.

6.0 FOUNDATIONS AND EARTH RETAINING STRUCTURES

6.1 General

6.1.1 Introduction

This section mandates the principles, guidelines, and requirements for design and construction of the foundation and earth retaining structures, and provides the minimum technical requirements to be adopted by the A/E to enable safety, quality, and cost effectiveness in the design and construction of foundation structures that meet the needs and expectations of the Entity.

6.1.2 Scope

The scope of this subsection is to provide guidance on design and construction of foundation and earth retaining structures, constructed of concrete and steel materials. This scope is limited to building and non-building type structures and systems. The design requirements provided herein, or cited by reference, are based on the MBC, industry standards, and best Entity practices.

6.1.3 Applicability

The principles, guidelines, and requirements included in this subsection shall govern design of and construction of foundations and earth retaining structures for all building and non-building structures and systems.

6.1.4 General Requirements

- Foundations and retaining walls shall be designed based on the allowable soil pressure recommended in the GDR.



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- Foundations shall be designed with due consideration of the fact that soil cannot be engaged in tension. However, a region of zero pressure in a foundation design is acceptable, providing that stability of the footing is confirmed.
- The highest elevation of the water table shall be as provided in the GDR. Soil condition, dry or saturated and the need to consider buoyancy in the analysis shall be based on this elevation.

6.1.5 Codes

Design and construction of all foundation and earth retaining structures shall be based on the requirements of this section and existing standards; these shall be from the MBC. Analysis of these structures shall be based on standard methods acceptable to Entity and the soil parameters values recommended in the GDR for the specific structure's site.

6.2 Design Requirements

6.2.1 Bearing Pressure

- Foundations and retaining walls shall be designed using an allowable soil pressure and soil parameters recommended GDR.
- Foundations shall be designed with due consideration of the fact that soil cannot be engaged in tension. Regions of zero pressure are acceptable providing that stability is maintained.

6.2.2 Water Table

- The highest elevation of the water table shall be as provided in the GDR.
- For structural design, water table elevation shall be at the elevation provided in the GDR or at the finished grade elevation, whichever is higher.
- Structures shall be designed for the most severe ground water conditions, including the condition of no ground water.
- For retaining walls, the ground water on the toe side and the soil on top of the toe shall be ignored in structural design and in the overturning, sliding, and buoyancy stability calculations.

6.2.3 Buoyancy

- In the design of foundations, retaining walls, pits, pipes, and buried structures, the upward buoyant force of ground water shall be taken as the volume of water displaced by the structure and air space multiplied by the density of water. Interactions of structural systems shall be considered, such as empty pipeline buoyant reactions on walls.
- The dead weight of the structure shall be considered in the resistance to buoyant force calculations. Soil shall not be considered unless it is directly supported by the foundation and it is certain that the soil would not be removed. Soil wedges shall not be considered in the design. For soil that is directly supported by the foundation and that could possibly be removed, the weight of water may be substituted for the weight of the soil.
- For structures wherein water is expected on the inside of the structure, such water shall be ignored in the calculation of the resistance to buoyant force.
-

6.2.4 Hydrostatic Pressure

- For retaining, basement, tank, and pit walls, hydrostatic pressure shall be considered in the design of the wall elements.
- Base slabs of basements, tanks, and pits shall be investigated for upward shear and bending due to hydrostatic pressure. The hydrostatic pressure shall be based on the water table being at the finished grade elevation.
- Water-stops shall be provided as specified in the specifications and at the locations shown on the drawings.



6.2.5 Hydrodynamic Pressure

If hydrodynamic pressure due to flowing water is possible, then this pressure shall be considered in the structural design of impacted elements.

6.2.6 Adjacent Loads

Where footings are placed at varying elevations, the effects of adjacent loads shall be considered in the foundation design.

6.2.7 Existing Construction

- New footings shall not be placed in locations which would increase soil pressure on existing structural elements. Where the situation is unavoidable, the existing foundation shall be evaluated for the impact of the new foundation, and the new foundation system shall be configured to have the least negative effect on the existing foundation.
- The effect on existing structures of surcharges relating to service and construction loads shall be considered in the design. Limits shall be indicated on the construction drawings that define the zones in which cranes and heavy equipment may not operate. Where the condition is unavoidable, the AE and or EPC Contractor shall provide an engineered solution and submit to Entity for approval.

6.2.8 Founding Depth

- Unless a deeper depth is established as a result of the geotechnical investigation, the minimum depth for shallow foundations shall be based on the recommendations of the SBC 303, Chapter 5; min footing depth not less than 1.2 m below natural ground for cohesionless soils, 1.5 m for silty and clay soils, and 0.6 to 1.2 m for rocks depending on quality and strength of rock.
- For strip footings supporting walls of light-frame construction, foundation width and thickness shall be as provided in the MBC.

6.2.9 Stability

- General
 - Stability calculations shall be based on service loads.
 - Except for retaining walls, soil shall not be considered unless it is directly supported by the foundation and it is certain that the soil would not be removed. Soil wedges shall not be considered.
 - For tanks, vessels, bins, etc., both cases (empty and with content) shall be considered for all stability analysis. Structure shall be designed for the most significant effect from the two cases.
 - Overturning and sliding stabilities shall be evaluated with and without the effects of buoyancy.
- Factor of Safety for Overturning
 - The factor of safety for overturning shall not be less than 1.5.
 - For irregular or special-use structures where loads other than wind and seismic contribute significantly to the overturning effect, a higher factor of safety shall be considered.
 - Weights of equipment that can be removed shall not be considered in the overturning resistance.
- Factor of Safety for Sliding
 - The factor of safety for sliding shall not be less than 1.5.
 - A value of 0.40 shall be used for the coefficient of friction, unless specified otherwise in the GDR.
- Factor of Safety for Buoyancy
 - The factor of safety for buoyancy shall be at least 1.2 for the highest anticipated buoyant force effects. Where the dead weights calculated are well established, such as for concrete components, this factor may be reduced to 1.1.



6.3 Foundation Structures Types and Selection

6.3.1 Shallow Foundation

- Ground supported concrete mat, combined, isolated, and strip foundations are recommended where the soil at shallow depths has sufficient bearing capacity for the applied structural loads.
- Shallow foundations shall be configured such that the gravity load bearing pressures for all foundations will produce uniform settlement of the structural system. Combined foundations shall be configured such that the dead load bearing pressure is approximately uniform.
- For foundations that support a lateral force resisting system of a structure, all tensile and shear forces shall be resisted by the foundation and transferred to the ground through a well-defined load path. Any uplift shall be resisted by concrete mass and soil, if it could not be removed.
- Shallow foundations shall be reinforced to resist the maximum loads required by design. Steel reinforcement in shallow foundations shall be hooked only if required by analysis.

6.3.2 Deep Foundation

- Deep Foundations are recommended when there are large design loads, poor soil at shallow depth, or site constraints. Piles are generally driven into the in-situ ground; other deep foundations are typically installed using excavation and drilling. Deep foundations may be composed of either treated timber, reinforced concrete, or pre-stressed concrete. A pile cap shall be used when the required loads exceed single pile capacity recommended in the GDR. Pile caps and isolated piles are typically connected with grade beams to tie the foundation elements together. Lighter structural elements are usually supported on the grade beams, while heavier elements bear directly on the pile cap.
- There are different terms used to describe different types of deep foundations as follows:
 - Driven Piles
 - Drilled shafts or caissons
 - Helical or Screw piles
- Pile Types are as follows:
 - Concrete Driven Piles
 - Precast / Pre-stressed concrete round reinforced shafts ranging in size from 150 mm to 600 mm.
 - Depths of soil embedment are optimal when greater than 5 m and may range in depth to over 30 m.
 - Concrete piles are typically designed with steel reinforcing bars and/or prestressing tendons to develop the strength required for handling and driving, and to provide required bending resistance.
 - Long piles may be difficult to handle and transport. Pile joints may be used to join two or more short piles to form one long pile. Pile joints may be used with both precast and pre-stressed concrete piles.
 - Treated Timber Driven Piles
 - Timber piles shall not be used unless specific authorization by the Entity is provided.
 - Timber piles have significantly less strength than steel or concrete piles.
 - Timber piles are more durable than steel piles in a corrosive environment.
 - Steel Driven Piles
 - Structural Steel piles are subject to severe corrosion and shall be used only with Entity authorization.
 - Steel piles are most economical for depths greater than 5 m and may range in depth to over 30 m.
 - Wide flange and Pipe profiles provide the most economical sections for use as piles.
 - See corrosion protection Subsection 7 for Corrosion Protection requirements.
 - Drilled Piers/Caissons
 - Drilled piers range in size from 450 mm to 2000 mm. Drilled shafts have the ability to generate large passive pressure forces based on their diameter and depth of embedment and should



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be considered for sign, flag pole and high mast lighting foundations due to their significant lateral load capability.

- Soldier Piles
 - Soldier pile systems are utilized extensively in temporary works such as support of excavation during project construction phases.
 - Other applications of Soldier Pile systems are not allowed and require authorization by the Entity.
 - Soldier pile systems are constructed of wide flange steel H sections spaced about 2 to 3 m apart and are driven prior to excavation. As the excavation proceeds, horizontal timber sheeting (lagging) is inserted behind the H pile flanges.
 - Horizontal earth pressure is generally attracted to the soldier pile locations because of their relative rigidity in comparison to the lagging. Soil movement is minimized by maintaining the lagging in firm contact with the soil.
- Helical Piles
 - Helical piles are subject to severe corrosion and shall be used only with Entity authorization.
 - Helical piles are a steel screw-in piling and ground anchoring system used for building deep foundations.
 - Helical Piles are manufactured using varying sizes of tubular hollow sections for the pile or anchor shaft.
 - The pile shaft transfers the structural load into the pile. Helical steel plates are welded to the pile shaft in accordance with the intended ground conditions, and transfer the shaft load into the soil. Helices may be press formed to a specified pitch or simply consist of flat plates welded at a specified pitch to the pile's shaft.
 - Helical piles may be installed at reduced cost and time of installation as compared to competing pile systems.
 - Helical piles can be installed in low overhead situations where there is insufficient access for pile driving equipment.
- Auger-Cast Piles
 - Auger-cast piles require specific soil and geotechnical parameters to be utilized effectively and shall be used only with Entity authorization.
 - Auger-cast piles are formed by drilling into the ground with a hollow stemmed continuous flight auger to the required depth or degree of resistance. No casing is required. A cement grout mix is then pumped down the stem of the auger. While the cement grout is pumped, the auger is slowly withdrawn, conveying the soil upward along the flights. A shaft of fluid cement grout is formed to ground level. Reinforcement may be installed after removal of the auger.
 - Auger-cast piles cause minimal disturbance, and are often used for noise and environmentally sensitive sites.
 - Pile Testing
 - All pile projects shall have load testing and inspection per the requirements of the MBC.
 - Dynamic pile testing shall be required for all driven piles.
 - Load testing shall be performed in accordance with ASTM D1143 and ASTM D3689 for piles which have been augured or drilled.

6.4 Earth Retaining Structures Types and Selection

Earth retaining structures shall be designed based on the GDR recommendations for the specific type of structure and acceptable analysis and design methods included in the Volume 6, Chapter 7, Section 11 (EPM-KE0-GL-000002 Geotechnical guideline).

6.5 Construction Requirements

6.5.1 Foundations



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The top elevation of pedestals supporting steel bases such as structural columns, pipe supports, and equipment shall be at least 150 mm above finished grade level.

6.5.2 Retaining Walls

- Accumulation of water behind retaining walls shall be prevented by providing a drainage system consisting of adequately spaced weep holes and coarse gravel filter to collect the water behind the wall.
- The depth of backfill material in front of a retaining wall shall be at least 600 mm from the bottom of the footing and at least 300 mm from the top of the footing.

7.0 CORROSION PROTECTION

7.1 General

7.1.1 Introduction

- Concrete and steel structures in Saudi Arabia and particularly, when located close to sea, are subjected to one of the most severe exposure conditions in the world, and therefore, require special considerations in design, detailing, and construction to achieve the acceptable standards for protection and long term durability required by the Entity.
- This subsection covers the corrosion protection guidelines for the Entity facilities during design, construction, and operation and maintenance stages, to achieve long service life, durability, and low maintenance cost.

7.1.2 Scope

- The scope of this subsection is to provide the principles, guidelines, and requirements for corrosion protection of facilities and systems constructed of concrete and steel materials. The facilities and systems covered under this subsection include reinforced concrete and steel structures including buildings, bridges, culverts, water storage tanks, wastewater handling structures, pipelines, pipe supports, pipe racks, drainage channels, and others.
- The requirements provided herein, or cited by reference, are based on the Saudi Building Code, industry standards, and best practices adopted by the Entity for over four decades, as applicable for certain regions of the Kingdom of Saudi Arabia.

7.1.3 Applicability

The principles, guidelines, and requirements in this subsection shall apply to all facilities and systems included in the above scope. For structures and systems not specifically mentioned in the scope, the A/E shall direct questions on applicability to the Entity.

7.1.4 General Requirements

7.1.4.1 For non-building structures not listed, specifications and construction details shall be generated by the A/E, subject to ENTITY's approval.

7.1.4.2 Although this subsection covers certain materials and special considerations for those materials when used in particular applications, the category of structures "other than buildings" includes possible applications for virtually any material type.

7.1.4.3 Exposure Conditions

- Saudi Arabia Industrial Cities



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The exposure conditions for reinforced concrete and steel structures in Saudi Arabia are severely corrosive. The parameters which are relevant to performance of concrete and steel structures are listed herein. The Entity shall be provided the project specific information based on local exposure conditions.

- According to the Soil Corrosivity Survey Report conducted under Contract No. 001-T20 in 1981, the characteristics of the soil conditions of Saudi Arabia's Industrial cities are as follows:
 - About 63% of the area is covered with sabkha (flat and very saline areas of sand or silt lying just above the water-table).
 - Chloride content in soil exceeds the critical value for corrosion at 21% of the area.
 - Sulfate content in soil exceeded the critical value for sulfate attack for concrete at 52% of the area.
 - Soil resistivity at 3 m depth was lower than 500 ohm-cm at 18% of the area.
- According to the Report on Characterization of Soil and Groundwater Conditions in Saudi Arabia 2 conducted under Contract No 202-T03, Task 10, the characteristics of the soil conditions of Saudi Arabia industrial cities are as follows:
 - The soil conditions above the groundwater table are very severely to moderately corrosive.
 - The soil conditions below the groundwater table are very severely to severely corrosive.
 - Only 6% of the area is covered with sabkha.
 - Chloride content in soil exceeded the critical value of 0.1% for corrosion of reinforcing steel at 15% of the area. The chloride concentration in soil varied from 0.01 to 0.6%.
 - Sulfate content in soil exceeded the critical value of 0.1% for sulfate attack of concrete at 15% of the area. The sulfate concentration in soil varied from 0.01 to 0.6%.
 - Soil resistivity at 5 m depth was lower than 1000 ohm-cm at 25% of the area.
 - The depth of groundwater table varies from 0.3 to 5.8 m from the finished ground level (after the proposed filling).
 - Chloride and sulfate contents in groundwater are more than the critical values for concrete deterioration. The chloride and sulfate concentrations in groundwater varied from 0.05 to 1% and 0.02 to 0.38% respectively.

The atmospheric conditions in Saudi Arabia are characterized by high day-time temperatures during summer, high humidity in winter season, high temperature difference between summer and winter seasons, high temperature and humidity fluctuations during day and night in summer season, high winds and sandstorms, and atmosphere heavily laden with salt and dust. The average minimum and maximum temperatures are 8°C and 46°C respectively.

7.1.5 Codes and Standards

- Industry Standards
 - Saudi Building Code, Chapter 4.
 - American Concrete Institute, ACI 214R Evaluation of Strength Test Results of Concrete.
 - American Concrete Institute, ACI 224R Control of Cracking in Concrete Structures.
 - American Concrete Institute, ACI 305 Hot Weather Concreting.
 - American Concrete Institute, ACI 318M Building Code Requirements for Structural Concrete and Commentary.
 - American Society for Testing and Materials, ASTM C76 Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe.
 - American Society for Testing and Materials, ASTM C150 Standard Specification for Portland Cement.
 - American Society for Testing and Materials, ASTM C618 Standard Specification for Coal Fly ash and Raw or Calcined Natural Pozzolan for use in Concrete.
 - American Society for Testing and Materials, ASTM Standard Test Method for Water-Soluble Chloride in Mortar and Concrete.



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- American Society for Testing and Materials, ASTM C1240 Standard Specification for Silica Fume Used in Cementitious Mixtures.
- American Association of State Highway and Transportation Officials, AASHTO T277 Standard Method of Test for Rapid Determination of the Chloride Permeability of Concrete
- American Water Works Association, AWWA C105 Polyethylene Encasement for Ductile-Iron Pipe Systems.
- American Water Works Association, AWWA C151 Ductile Iron Pipe, Centrifugally Cast.
- American Water Works Association, AWWA C301 Prestressed Concrete Pressure Pipe, Steel-Cylinder Type.
- American Water Works Association, AWWA C303 Concrete Pressure Pipe, Bar Wrapped, Steel-Cylinder Type.
- Society for Protective Coatings, SSPC SP-5 White Metal Blast Cleaning.
- Society for Protective Coatings, SSPC SP-10 Near-White Blast Cleaning.
- Royal Commission Issued Reports
 - Report on "Characterization of Soil and Groundwater Conditions in Saudi Arabia 2", Contract No. 202-T03, Task Release No. 10, 2006.
 - Report on "Corrosion Control Guidelines for Concrete Structures in Saudi Arabia 2", Contract No. 202-T03, Task Release No. 10, 2006.
 - Report on "Corrosion Control Guidelines for Concrete Structures in Ras Al-Khair Industrial City (RIC)", Contract No. 027-T01, Task Release No. 2, 2013.
 - Report on "Soil Corrosivity Study, Contract No. 001-T20, by Research Institute, King Fahd University of Petroleum and Minerals for Royal Commission, Saudi Arabia Project, 1981.
 - Report on Geotechnical Investigation for Site Development of Area B in Ras Al-Khair Industrial City conducted under Contract No. 001-T01, Task Release 54, January 2013.
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7.2 Commissioning

Commissioning for corrosion protection shall be performed during or after construction, depending on the structural systems or elements, to verify that the new/rehabilitated systems or elements meet the corrosion protection requirements of this subsection.

7.3 Protection of Concrete Structures

7.3.1 General

The guidelines provided herein include all reinforced concrete structures.

7.3.2 Forms of Concrete Deterioration

- Reinforcement Corrosion

This is the most predominant type of deterioration of concrete structures in Saudi Arabia. Chloride salts from soil, groundwater, seawater, and other sources ingress into concrete and cause breakdown of the protective oxide film on reinforcing steel and cause onset of active corrosion. Accumulation of corrosion products, which occupy more volume than the steel, cause tensile stresses in the cover concrete. When these tensile stresses exceed the tensile strength of concrete, the cover concrete suffers cracking, delamination, and spalling. This causes loss of serviceability and may lead to a reduction in the structural capacity of the reinforced concrete member.
- Sulfate Attack

Sulfate attack is caused in concrete exposed to soil, groundwater and seawater by chemical reaction between hydrated cement and sulfate ions. Sulfate attack results in formation of expansive products which cause expansion of concrete leading to cracking. Sulfate attack can also cause progressive loss of strength and mass due to deterioration in the cohesiveness of the cement hydration products.
- Salt Crystallization

This is caused in concrete exposed to wetting and drying by groundwater and seawater. It is caused by ingress of salts into concrete which crystallizes on drying leading to progressive crumbling or



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scaling of concrete. Salt crystallization leads to erosion of concrete surface and exposes the aggregate.

- Thermal Cracking

Cracking of concrete may be caused due to plastic shrinkage in freshly poured concrete or drying shrinkage in hardened concrete. Plastic and drying shrinkage are physical phenomena and cause tensile strain in concrete. When the associated tensile stress in concrete exceeds its tensile strength, cracking occurs.

7.3.3 Exposure Conditions

Concrete structures exposed to the following conditions shall be considered as severe exposure:

- Below ground and up to half meter above ground level
- Seawater and spray from seawater (splash zone, tidal zone and structures located within 500 m from the seashore)
- Interior of chambers (valve chambers, manholes etc.)
- Wastewater and chemicals

Concrete exposed to atmosphere and interior of air conditioned areas shall not be considered as exposed to severe conditions.

7.3.4 Guidelines and Examples for Protection of Concrete Structures

- General

Design and construction of durable concrete structures involve selection of adequate materials, adoption of proper design and construction techniques and provision of additional protection measures, as required, to prolong the service life to the design service life.

- Material Selection

- Cement Type

The SBC recommends ASTM C150 Type I cement with mineral admixture for concrete exposed to very severe chloride exposure and ASTM C150 Type V cement with mineral admixture for concrete exposed to very severe sulfate exposure. Similarly ACI 318 recommends ASTM C150 Type V cement with pozzolan or slag for concrete exposed to very severe sulfate exposure.

Cement with a high tricalcium aluminate (C3A) content is more resistant to chloride exposure than that with a low C3A content. This is due to the influence of C3A in binding more chlorides and reducing chloride diffusion coefficient of concrete. Mineral admixtures increase resistance to reinforcement corrosion as well as sulfate attack due to improvement in impermeability of concrete.

Type of cement for different exposure conditions shall be as follows:

- For reinforced concrete exposed to severe conditions, use ASTM C150 Type I with mineral admixture.
 - For reinforced concrete not exposed to severe conditions, use ASTM C150 Type I cement without mineral admixture.
 - For unreinforced concrete exposed to severe conditions, use ASTM C150 Type V cement with mineral admixture.
 - The mineral admixture shall be silica fume conforming to ASTM C 1240. Class F fly ash conforming to ASTM C 618 may be used as an alternative.

- Water Cementitious Materials Ratio

- The maximum water-cementitious materials ratio for all concrete shall be limited to 0.40.
 - Water-cementitious material ratio is the ratio of water to the sum of cement and mineral admixture. The SBC recommends maximum water-cementitious material ratio of 0.4 for concrete exposed to very severe chloride exposure and 0.45 for concrete exposed to very severe sulfate exposure. ACI 318 recommends maximum



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water-cementitious material ratio of 0.45 for concrete exposed to very severe sulfate exposure.

- Compressive Strength
 - The minimum specified compressive strength for reinforced concrete exposed to severe conditions shall be 35 MPa.
 - A lower strength may be specified for un-reinforced concrete.
 - The SBC requires minimum compressive strength of concrete of 35 MPa for concrete exposed to very severe chloride exposure and 30 MPa for concrete exposed to very severe sulfate exposure. ACI 318 recommends minimum 28-day compressive strength of 35 MPa for corrosion protection of reinforcement in concrete exposed to moisture and chlorides from de-icing chemicals, salt water, brackish water, seawater, or spray from these sources.
- Cement Content
 - A lower cement content value may be used for unreinforced concrete.
 - Minimum cement content requirement is governed by maximum water cementitious material ratio, minimum compressive strength and workability. For a required water cementitious material ratio and compressive strength, a certain amount of cement is required to obtain a workable concrete mix.
 - The SBC recommends minimum cementitious material (cement plus mineral admixture) content of 370 kg/m³ for concrete exposed to very severe chloride exposure and 350 kg/m³ for concrete exposed to very severe sulfate exposure.
- Design
 - Cover
 - For concrete exposed to severe conditions, the minimum cover shall be 75 mm.
 - The cover over the reinforcing steel plays a very important role in protection of reinforcement against corrosion. ACI 318 specifies a minimum cover of 75 mm for concrete cast against and exposed to earth.
 - 2) Crack Control
 - The minimum crack width shall be 0.15 mm for structures exposed severe conditions and 0.30 mm for superstructures exposed to atmosphere.
 - One of the major causes of concrete deterioration in otherwise durable concrete is cracks. The cracks allow ingress of chlorides at an accelerated rate through concrete cover. Cracks are caused by stresses in concrete due to drying shrinkage, loads, and settlement.
 - ACI 214R "Control of Cracking in Concrete Structures" provides a general guide for tolerable crack widths in reinforced concrete for different exposure conditions. A tolerable crack width of 0.30 mm is recommended for concrete structures exposed to humidity, moist air, and soil, and 0.15 mm for structures exposed to seawater and seawater spray.
 - The above crack width limits shall be used for the design. However, ACI 224R cautions that these values of crack width are not always a reliable indication of the corrosion and deterioration to be expected. In particular, a larger cover, even if it leads to a larger surface crack, may sometimes be preferable for corrosion control in certain environments. Thus, engineering judgment must be exercised on the extent of crack control to be used. ACI 224R also provides recommendations for controlling cracks in different structural members.
 - Reinforcement Detailing

Good detailing helps in minimizing reinforcement corrosion risk. Using a large number of smaller diameter bars is preferable to small number of larger diameter bars. The maximum spacing between the bars shall be limited to 300 mm. Large diameter bars shall be avoided in thin sections.
- Construction Practice
 - Curing
 - Curing is essential to develop the potential properties of concrete. Concrete containing mineral admixtures is more sensitive to curing. Strength development of fly ash blended cement concrete is slower than plain concrete and hence, a prolonged



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curing period is required. Silica fume blended cement concrete has higher potential of cracking due to plastic shrinkage and its strength development is sensitive to early curing. Therefore, efficient curing during early days is required. The rate of strength development of concrete containing silica fume is either equal to or better than concrete without silica fume.

- The minimum curing period shall be 14 days for all reinforced concrete with and without silica fume. However, the minimum curing period shall be extended to 21 days for concrete containing fly ash as mineral admixture.
- Hot Weather Concreting

Precautions shall be taken for concreting during hot weather. Recommendations provided by ACI 305R "Hot Weather Concreting" shall be followed. The temperature of concrete at delivery shall be limited to 30°C.
- Chloride and Sulfate Limits
 - The SBC and ACI 318 recommend maximum water soluble chloride ion content, as measured in accordance with ASTM C1218, of 0.15% by weight of cement for reinforced concrete exposed to very severe chloride exposure. This limit is reduced to 0.06% for pre-stressed concrete.
 - Sulfate (SO₃) content of cement allowed by ASTM C150 is 3% for Type I cement with C₃A content of 8% and less, and 3.5% for C₃A content of more than 8%. This is equivalent to about 4% of SO₄ content. Therefore, SO₄ content of hardened concrete shall be limited to a maximum of 4% for all concrete (reinforced and unreinforced).
- Chloride Permeability

Chloride permeability, as measured by procedures described in AASHTO T277, is a convenient quality control test for concrete durability. Typical values of chloride permeability for 0.40 water cement ratio concrete made with ASTM C150 Type I cement varies from 3500-5000 Coulombs. These values for 10% silica fume concrete range from 500-1000 Coulombs. Therefore, the maximum chloride permeability for plain, fly ash, and silica fume concrete shall be 4,000, 2,000, and 1,000 Coulomb respectively.
- Mass Concrete
 - Excessive cracking that occurs as a result of improper casting and curing of mass concrete significantly increases the ingress of corrosive contaminants. The presence of cracks can rapidly accelerate the deterioration process.
 - The configuration of structural elements with proportions that qualify as mass concrete shall be avoided. Engineering shall employ "strut and tie" or "truss analogy" techniques, where applicable, to keep member sizes below the mass concrete threshold.
 - Any concrete structural element for which the least dimension exceeds 1 m shall be considered mass concrete and shall be subject to the requirements of this subsection. The presence of mass concrete shall be declared in the general concrete notes and specifically identified on the plans of the construction drawings. Instructions for casting and curing the mass concrete shall be provided in the notes.
 - Mass concrete is defined by ACI Committee 207 as "any volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat from hydration of cement and attendant volume change to minimize cracking."
 - Casting and curing of mass concrete elements shall comply with the recommendations and provisions of ACI 207.1R, 207.2R, and 207.4.
- Additional Protection Measures

Depending on the design service life requirement, it may be necessary to provide additional protection systems. Some of the commonly used measures are using fusion bonded epoxy (FBE) coated reinforcement, concrete surface coating, tanking, and cathodic protection. The A/E and/or EPC Contractor shall assess the exposure conditions and the design life and decide upon the required additional protection measures.

7.3.5 Summary of Guidelines for Protection of Concrete Structures



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- The guidelines on water-cementitious material ratio, compressive strength, cement content, cover, crack control, reinforcement detailing, curing, hot weather concreting, chloride and sulfate limits, and chloride permeability shall be followed for all concrete as discussed in the above sections.
- A summary of the guidelines for protection of concrete structures is given in TABLE 7.1.



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TABLE 7.1 SUMMARY OF GUIDELINES FOR PROTECTION OF CONCRETE STRUCTURES

Important Note: A/E shall propose coating systems based on project specific.

S. No	Structure	Exposure Condition	Cement Type	Type of Reinforcement	Additional Protection
1	Superstructures (located over 500 m away from seashore)	Atmosphere	TYPE I	Uncoated	NONE
2	Superstructures (located within 500 m from seashore)	Atmosphere	TYPE I Plus Mineral Admixtures*	Uncoated	Concrete Surface Coating
3	Superstructures	Interior of air-conditioned areas	TYPE I	Uncoated	NONE
4	Foundation of buildings, bridges, culverts and other structures (buried and up to 0.5 m above ground/finished floor level)	Buried (soil / groundwater)	TYPE I Plus Mineral Admixtures*	FBE Coated	Waterproofing Membrane
5	All Reinforced Concrete	Immersed in seawater and Spray from seawater (splash, tidal & atmospheric zones)	TYPE I Plus Mineral Admixtures*	Uncoated	Impressed current cathodic protection
6	Pipe Supports	Partially buried & exposed to atmosphere	TYPE I Plus Mineral Admixtures*	FBE Coated	Waterproofing membrane for buried concrete up to 150 mm above ground level and concrete surface coating for exposed concrete
7	Piles	Buried (soil / groundwater)	TYPE I Plus Mineral Admixtures*	FBE Coated	NONE
8	Chambers and manholes	Interior of non-air-conditioned areas	TYPE I Plus Mineral Admixtures*	FBE Coated	Concrete Surface Coating
9	Interior of chambers handling wastewater and chemicals	Wastewater/chemicals	TYPE I Plus Mineral Admixtures*	FBE Coated	Concrete Surface Coating
10	Tanks (internal)	Potable/reclaimed water	TYPE I Plus Mineral Admixtures*	FBE Coated	Concrete Surface Coating
11	Tanks (bottom & external)	Potable/reclaimed water	TYPE I Plus Mineral Admixtures*	FBE Coated	Waterproofing membrane for buried concrete up to 150 mm above ground level and concrete surface coating for exposed concrete
12	Unreinforced concrete (mud-mat, anchor blocks etc.)	All conditions	TYPE V Plus Mineral Admixtures*	NONE	NONE

* Mineral admixture shall be 7% silica fume conforming to ASTM C1240 as cement replacement



7.4 Protection of Steel Structures

7.4.1 General

The guidelines provided herein include steel framed structures (such as buildings, pipe racks, bridges etc.), tanks, vessels, and piles.

7.4.2 Forms of Corrosion of Steel

7.4.2.1 Galvanic Corrosion

Galvanic corrosion occurs when two dissimilar metals come in contact in a conducting corrosive environment. The corrosion is stimulated by the potential difference that exists between the two metals. The more active metal acts as anode and the other acts as cathode.

Galvanic corrosion can be minimized by selecting suitable metal couples in system design. If sufficient experience is not available to select compatible couples, the selection may be confirmed through laboratory testing. Wherever dissimilar metals are used, they shall be separated electrically with an electrical insulator. When insulation is not practical, the area ratio method may be used in the design. Coating the cathode only, or coating both the anode and the cathode, is generally preferable to avoid the unfavorable area ratio effect in a galvanic corrosion situation.

7.4.2.2 Pitting

Pitting corrosion is localized accelerated dissolution of metal that occurs as a result of a breakdown of the otherwise protective passive film on the metal surface. Pitting can be avoided/minimized by coating the metal surfaces, periodic cleaning and designing shapes that prevent liquids or solids to collect.

7.4.2.3 Crevice Corrosion

Crevice corrosion refers to corrosion occurring in confined spaces to which the access of the working fluid from the environment is limited. These spaces are generally called crevices. Examples of crevices are gaps in contact areas between parts, under gaskets or seals, inside cracks and seams, in spaces filled with deposits, and under sludge piles. Crevice corrosion can be avoided by minimizing and sealing crevices and cavities where the metal is susceptible to corrosion. The use of double butt or double lap weld joints, continuous welds, or nonporous filler materials is recommended to seal the crevice openings.

7.4.2.4 Intergranular Corrosion

Intergranular corrosion, also known as intergranular attack, is a form of corrosion where the boundaries of crystallites of the material are more susceptible to corrosion than their insides. This situation can happen in otherwise corrosion-resistant alloys, when the grain boundaries of the corrosion-inhibiting elements are depleted, such as chromium by some mechanism. To minimize the effects of intergranular corrosion, the base metal and weld filler material shall be selected to be compatible with the specific environment. Laboratory tests, if necessary, may be specified as part of the materials selection process. Additionally, a qualified corrosion or metallurgical engineer shall be consulted on the need of other control measures such as stress relieving and heat treatment of susceptible metals.

7.4.2.5 Stray Current Corrosion

Stray current corrosion, also called interference corrosion, is corrosion caused by direct current from an external source that travels through paths other than the intended circuit. Accelerated corrosion may result if the current is collected by a structure and discharges to the soil. Preventive measures include electrical insulation of the structure, equipotential bonding, shielding, or cathodic protection.

7.4.3 General Guidelines for Corrosion Control of Steel

7.4.3.1 General

Steel structures shall be designed to resist the exposure conditions to achieve the intended design service life of the structure. The most commonly used method of design and construction of durable steel structures involve material selection, protective coatings, cathodic protection, and environment treatment.



7.4.3.2 Material Selection

Material selection shall consider the service conditions to which the structure will be exposed to and shall involve a qualified metallurgical engineer. Suitable corrosion protection techniques shall be selected by a qualified corrosion control and coatings specialist.

Following guidelines shall be followed in selection of materials:

- **Materials Selection Process**
Most corrosion patterns are not uniform but highly localized. Therefore, it is important that all materials be evaluated on maximum penetration rates especially when considering structures containing products. Care shall be taken when substituting more noble alloys; while general corrosion rates are substantially lower, the mode of failure can be catastrophic (i.e. stress corrosion cracking, hydrogen embrittlement, etc.).
- **Galvanic Corrosion**
When selecting materials for various components of a unit (ex. body and trim materials for valves or connecting pipework), care shall be taken to ensure use of galvanically compatible materials. Electrical insulators and insulating sleeves shall be used to separate dissimilar metals from each other. In cases where providing insulation is not feasible, more noble metals shall be used for joining or fastening.
- **Ferrous Alloys**
Ferrous alloys that are buried in soil or exposed to marine environment are expected to corrode at higher rates. Therefore, such ferrous alloys shall be protected against corrosion by coating or cathodic protection.
- **Galvanized Steel**
Galvanizing alone cannot be expected to provide adequate protection for metals in outdoor, buried, or submerged applications. Particular attention shall be given to conditions where galvanized components are electrically continuous with a large structure, since the galvanizing will provide very little advantage. Wherever galvanized steel is buried in soil or exposed to the splash zone or below, it shall be protected against corrosion by coating or cathodic protection.
- **Aluminum**
Aluminum shall not be buried, embedded in concrete, or submerged in brine or chlorinated water.

7.4.3.3 Protective Coatings

Application of protective coatings is the most commonly used method for corrosion protection of steel structures. Coatings may be used in conjunction with other methods, such as cathodic protection. Discussion on protective coatings is provided in detail the following sections.

7.4.3.4 Cathodic Protection

Cathodic protection is one of the most commonly used methods for corrosion protection of steel structures exposed to aggressive conditions. Discussion on cathodic protection is provided in detail the following sections.

7.4.3.5 Environmental Treatment

The treatment of environment shall be viewed as part of an overall strategy to enhance the performance of a system. Several control methods may be adopted, depending on the type and function of the systems. Typical treatment methods are oxygen removal, pH adjustment, dehydration, water removal, velocity control, sludge removal, temperature control, pressure control, addition of inhibitors, use of biocides and bactericides, entrained solid removal, etc.

7.4.4 Guidelines for Corrosion Control of Steel Structures

- **General**
 - Steel structures exposed to atmosphere shall be protected by hot dip galvanizing or protective coating. The most suitable coating is epoxy with a top coat of polyurethane.
 - Buried steel structures shall be protected by protective coating and cathodic protection.



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- Steel structures immersed in potable and reclaimed water shall be protected by protective coating, the most suitable coating being epoxy.
- Steel structures exposed to seawater or other corrosive environment shall be protected by protective coating plus cathodic protection.
- Stainless steel structures exposed to seawater shall also be protected with cathodic protection.
- Steel Framed Structures
 - Structures shall be designed to eliminate or minimize crevices and features that trap and hold dust and water. All crevices shall be suitably sealed.
 - Steel framed structures shall not be buried and shall be protected against atmospheric corrosion by protective coatings. The most suitable coating is epoxy with a top coat of polyurethane.
 - Steel members shall be embedded in concrete foundation. A base plate with anchors into the concrete foundation shall be used. The exposed anchor bolts shall also be coated with the protective coating.
 - Provision shall be made for inspection and re-coating of the structures after the design life of the coating is exhausted.
- Tanks and Vessels
 - Tanks and vessels shall be protected internally as well as externally.
 - Design of vessels shall include eliminating or minimizing crevices. All crevices shall be suitably sealed.
 - Internal of potable and reclaimed water storage steel tanks shall be protected by protective coatings. The most suitable coating is epoxy.
 - Internal of vessels handling corrosive media (other than potable and reclaimed water) shall be protected by coating plus cathodic protection.
 - External of potable and reclaimed water storage steel tanks shall be protected by protective coatings. The most suitable coating is epoxy with a top coat of polyurethane.
 - Tank bottoms (underside of the tank floors) shall be protected by impressed current cathodic protection to avoid corrosion due exposure of the steel to soil.
- Steel Piles, if approved by the Entity
 - Steel piles and the steel casing pipe driven in soil of cased concrete piles shall be protected by protective coating and cathodic protection (coating is prone to damage during driving). Piles exposed to atmosphere shall be protected by protective coating.
 - Steel piles driven in seabed shall be protected by protective coating and cathodic protection. The cathodic protection shall be provided to the buried as well as immersed portions of the piles.
 - Piles in the splash zone shall be corrosion protection tape or protective coating or cathodic protection (jacket-type system). Piles exposed to atmosphere shall be protected by protective coating.
- Other Steel Structures
 - Suitable corrosion protection shall be provided for steel structures exposed to corrosive environments.
 - Light poles shall be protected by hot dip galvanizing. The base plates shall be protected by protective coating, epoxy being the most suitable coating.
 - Metallic structures in seawater intake and discharge structures shall be protected by protective coating plus cathodic protection.

7.5 Protection of Pipelines

7.5.1 General

Buried pipelines in Saudi Arabia Cities are subjected to one of the most severe exposure conditions in the world and therefore, require adequate corrosion protection and provisions for inspection during service. The guidelines provided herein include ductile iron, prestressed concrete cylinder, reinforced concrete, and carbon steel pipes.



7.5.2 Non-metallic Piping System

Non-metallic piping systems shall be considered for use wherever applicable. All factors, such as service, exposure conditions, life, cost (initial and life-cycle cost), maintenance requirements, and other factors shall be considered for selection of the piping system.

7.5.3 Guidelines for recommended Corrosion Control of Pipes

Note: A/E shall select corrosion control of pipes based on project specific.

- Ductile Iron Pipes (conforming to ISO 2531 and AWWA C151)
 - Ductile iron pipes are recommended for potable, reclaimed and sea water. They shall not be used for wastewater.
 - Ductile iron pipes have been successfully used and have good track record in Saudi Arabia Industrial City.
 - Ductile iron pipes and fittings shall be lined internally with high alumina cement mortar applied centrifugally and sealed with 400 micron thick epoxy coating.
 - Buried ductile iron pipes and fittings shall be protected externally by pure metallic zinc at the rate of 200g/m² and covered by a bituminous paint of 120 microns. Additionally, the pipes and fittings shall be wrapped in polyethylene sleeving conforming to ISO 8180 and AWWA C 105. The sleeve is made of a tubular film of 200 micron thick low density polyethylene slipped over and snugly fitted to a pipe at the time of laying. The sleeve is fitted to the pipe by means of adhesive plastic tape at each end and intermediate tie fasteners.
 - Cathodic protection is not required for internal nor external protection of ductile iron pipes.
- Prestressed Concrete Cylinder Pipes (PCCP) (conforming to AWWA C301)
 - PCCP are recommended for potable, reclaimed and sea water service and are suitable for large diameter pipes. They shall not be used for wastewater.
 - PCCP shall be protected internally by 400 micron thick epoxy coating.
 - Buried PCCP shall be protected externally by 400 micron thick coal tar epoxy plus cathodic protection.
- Concrete Cylinder Pipes (CCP) (conforming to AWWA C303)
 - CCP are recommended for potable, reclaimed and seawater service and are suitable for large diameter pipes. They shall not be used for wastewater.
 - CCP shall be protected internally by 400 micron thick epoxy coating.
 - Buried CCP shall be protected externally by 400 micron thick coal tar epoxy plus cathodic protection.
- Reinforced Concrete Pipes (RCP) (conforming to ASTM C76)
 - RCP are recommended for storm drains and culvert pipes.
 - RCP shall be protected internally and externally by 400 micron thick coal tar epoxy coating.
- Carbon Steel Pipes
 - Carbon steel may be used for potable, reclaimed and sea water service.
 - Carbon steel pipes shall be protected internally by cement mortar lining and 400 micron thick epoxy coating.
 - Buried carbon steel pipes shall be protected externally by epoxy or polyethylene coating plus cathodic protection.

7.6 Protective Coatings

7.6.1 General

Protective coating is one of the most commonly used corrosion control methods. Protective coatings are used for steel as well as concrete structures. Supplemental protection, such as cathodic protection, may be required for coated steel structures. A typical coating system includes primer, intermediate coat and top coat. All components of the coating system shall be compatible and shall be obtained from the same manufacturer.



7.6.2 Coating Selection Criteria

Protective coating systems design shall take into consideration the following factors:

- Location: Whether seacoast, inland, industrial, or rural.
- Climate: Temperate, humid, dry, wetting, and drying.
- Type of Service: Exterior/interior or immersed.
- Service Life: Level of performance desired, life of protection or time to first maintenance, and color/gloss retention.
- Surface Preparation: Types and condition of substrate, degree of cleanliness, and anchor profile.
- Chemical Exposure: Severe/moderate/mild and immersed.
- Physical Requirements: Impact resistance, flexibility, abrasion resistance, adhesion, and hardness.
- Compatibility: Lifting/hiding power.
- Curing Schedule: Minimum temperature required, pot life restriction, and re-coat limitation.
- Application Methods: Spray, brush, roller, field or shop application, and thinner required.
- Economics: Initial cost and cost of maintenance.

7.6.3 Coating Systems for Various Structures

Recommended coating systems for various reinforced concrete and steel structures are given in TABLE 7.2.

- Concrete surfaces shall be cleaned prior to coating to remove loose material, oil, grease, and dust. Imperfections in the surface shall be filled with epoxy filler. The coating system shall comprise penetrating epoxy sealer, intermediate and top coat.
- Steel surfaces shall be prepared by grit blasting to the required finish (SSPC SP 5 for internal surfaces and SSPC SP10 for external surfaces). Pits and surface imperfections shall be filled with epoxy filler. The coating system shall comprise zinc phosphate epoxy primer, intermediate, and top coat.
- The coating shall be tested for dry film thickness, pin holes, and adhesion.



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TABLE 7.2 RECOMMENDATIONS ON COATING SYSTEMS FOR VARIOUS STRUCTURES

Important Note: A/E shall propose coating systems based on project specific. This Table serves only as a reference

S. No	Type of Structures	Exposure Condition	Recommended Preparation	Recommended Coating Surface System
1	Reinforced Concrete Structures within 500 m from seashore	Marine	Clean surface and fill imperfections with epoxy filler	Epoxy sealing primer Amine cured epoxy (2 coats, 400 micron DFT) Re-coatable polyurethane (1 coat, 60 micron DFT)
2	Reinforced Concrete Pipe Supports	Exterior (above ground)	Clean surface and fill imperfections with epoxy filler	Epoxy sealing primer Coal tar epoxy (2 coats, 400 micron DFT)
3	Reinforced Concrete Chambers and Manholes	Interior	Clean surface and fill imperfections with epoxy filler	Epoxy sealing primer Coal tar epoxy (2 coats, 400 micron DFT)
4	Reinforced Concrete Chambers Handling Wastewater and Chemicals	Interior	Clean surface and fill imperfections with epoxy filler	Epoxy sealing primer Coal tar epoxy (2 coats, 400 micron DFT)
5	Concrete Tanks	Interior	Clean surface and fill imperfections with epoxy filler	Epoxy sealing primer MIO epoxy (2/3 coats, 400 micron DFT)
		Exterior	Clean surface and fill imperfections with epoxy filler	Epoxy sealing primer MIO epoxy (1/2 coats, 200 micron DFT) Re-coatable polyurethane (1 coat, 60 micron DFT)
6	Structural Steel	Atmosphere	SSPC SP-10	Epoxy zinc phosphate Primer (75 micron DFT) MIO epoxy (1/2 coats, 200 micron DFT) Re-coatable polyurethane (1 coat, 60 micron DFT)
7	Piles	Buried Seawater (submerged & exposed)	SSPC SP-10	Epoxy zinc phosphate primer (75 micron DFT) MIO epoxy (213 coats, 400 micron DFT)
8	Steel Tanks	Interior (potable & reclaimed water)	SSPC SP-5	Epoxy zinc phosphate primer (75 micron DFT) MIO epoxy (2/3 coats, 400 micron DFT)
		Exterior	SSPC SP-10	Epoxy zinc phosphate Primer (75 micron DFT) MIO epoxy (1/2 coat, 200 micron DFT) Re-coatable polyurethane (1 coat, 60 micron DFT)

7.7 Cathodic Protection

7.7.1 General

Cathodic protection design, installation, and commissioning shall be carried out by qualified engineers and contractors. Various factors to be considered prior to design of a cathodic protection system are type of structure to be protected, electrolyte resistivity, presence of other facilities and cathodic protection systems and stray current, right of way for locating cathodic protection hardware, availability of ac power, and other factors. Design information provided shall include design calculations, material and installation specifications, commissioning requirements and provisions for monitoring. All cathodic protection systems shall be monitored by the installation contractor for one year prior to handing over the system to the Entity.



7.7.2 Cathodic Protection Systems Design Guideline

Important Note: A/E shall select cathodic protection system and applicable criteria based on project specific conditions.

- Reinforced Concrete
 - Design current density for new reinforced concrete should at least be 5 mA/m² of steel reinforcement area.
 - Design current density for existing reinforced concrete should at least be 20 mA/m² of steel reinforcement area.
 - Protection criteria should be an instant off potential of -720 mV or more negative with respect to silver-silver chloride electrode or potential decay of at least 100 mV over a period of 24 hours or 150 mV over extended period of time.
- Steel Structures
 - Design current density for tank bottoms, buried piles, and buried bare pipelines should at least be 20 mA/m² of steel area. For coated steel piles and pipes, the value shall depend on the type of coating; a value of 0.1 to 1 mA/m² can be adopted.
 - Design current density for bare steel piles exposed to seawater should at least be 150 mA/m² (initial) and 70 mA/m² (mean) of steel area. For coated steel, the design current density can be based on a coating breakdown factor of 10%.
 - Protection criteria for steel exposed to soil and seawater should be an instant off potential of -800 mV or more negative with respect to silver-silver chloride electrode.

7.7.3 Cathodic Protection Systems for Different Structures

- Reinforced Concrete
 - For new reinforced concrete, mixed metal oxide coated titanium expanded mesh ribbon anodes from a qualified manufacturer with sufficient track record shall be used. The anodes shall be placed in the cover concrete or between two layers of the reinforcement. Titanium conductor bar shall be used for current distribution.
 - For existing reinforced concrete, mixed metal oxide coated titanium mesh anodes from a qualified manufacturer with sufficient track record shall be used. The anodes shall be placed on the existing concrete surface and covered in a cementitious overlay. Titanium conductor bar shall be used for current distribution.
 - The structure shall be divided in zones of suitable sizes and each zone shall be fed from a dedicated power supply channel.
- Steel Tanks and Vessels
 - For new tanks, mixed metal oxide coated titanium ribbon anodes from a qualified manufacturer with sufficient track record shall be used. The anodes shall be placed in soil under the tank in the form of parallel strips running in one direction. Titanium conductor bar shall be used for current distribution and shall be placed perpendicular to the anodes.
 - For existing tanks, mixed metal oxide coated titanium tubular or high silicon cast iron anodes from a qualified manufacturer with sufficient track record shall be used. The anodes shall be placed in drilled holes around the tank. The depth of the anodes shall be determined in the design calculations.
 - Each tank shall be fed from a dedicated transformer rectifier or a dedicated channel of a multi-channel transformer rectifier.
- Steel Pipelines
 - For new and existing pipelines, different types of anodes can be used. The type of anode shall be manufactured by a qualified manufacturer with sufficient track record.
 - Use of deep well anodes may be used for cross country pipelines, however, distributed anodes shall be used for pipelines inside plants and if other structures exist in the vicinity of the pipeline.
- Steel Piles
 - For new and existing steel piles buried in soil or submerged in seawater, sacrificial or impressed current anodes may be used. Sacrificial aluminum anodes shall be preferred for



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piles in seawater. The impressed anodes may include mixed metal oxide coated titanium tubular anodes for seawater, and mixed metal oxide coated titanium tubular and high silicon cast iron anodes for soil.

7.7.4 Monitoring of Cathodic Protection Systems

- All cathodic protection systems shall be regularly monitored to ensure proper functioning of the systems and to establish upgrade needs.
- The frequency of monitoring for sacrificial anode systems shall be six months. The monitoring shall include measuring anode current and structure-to-soil potentials.
- The frequency of monitoring for impressed current systems shall be as follows:
 - Monthly: Inspect condition of the hardware and measure transformer rectifier output.
 - Semi-Annually: Inspect condition of the hardware, measure transformer rectifier output and structure-to-soil potentials (on, instant-off and decay).
 - Three-years: Conduct complete system check including analysis of the monitoring data for the previous period.

8.0 ATTACHMENTS

1. Calculations Guidelines and Requirements
2. Specific Drawings Guidelines and Requirements



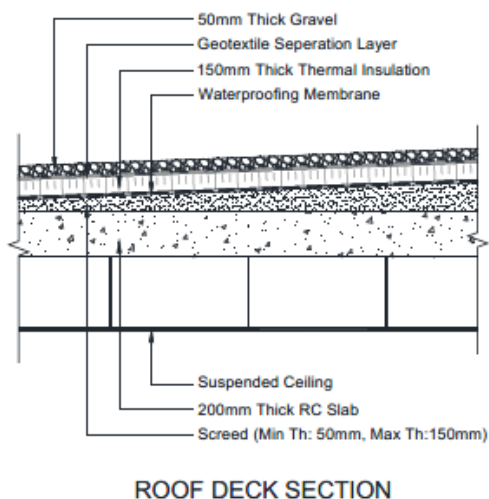
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Attachment 1 - Calculations Guidelines and Requirements

A. General

B. General Items & Design Criteria

1. The A/E must prepare calculations to support the design of the structural system and connections. The calculations should contain a table of contents or index and must clearly show and delineate service loads, factored loads, and factored load combinations. The structural calculations should be dated, legible and retained in a project file.
2. Analysis and design calculation package shall be provided with direct contact information of Design Engineer and Lead Structural Engineer in order to enable the Entity to discuss issues directly with them.
3. Prepared package shall be free from vague statements, self-explanatory and conclusive.
4. Provide linkage between Drawings and calculations for all structural members and connections. This can be with clear location descriptions in the calculations.
5. A discussion and description of the design basis including assumptions and clarification for why these assumptions used in design.
6. List of Building Codes, Standards and Specification (including their editions) for the materials used in design. Providing irrelevant codes, standards and specification will cause rejection of submittal.
7. Geotechnical report information, design criteria and correct reference to Geotechnical Report.
8. Limitations of deflection for structural elements and lateral drift limitations for entire structure.
9. Documentation of Design Loads:
 - a) Dead Loads: Dead loads shall include self-weight of all items of permanent nature that will act continuously throughout the service life of the building. Dead Load shall be well itemized for each type of assembly including with proper sketch, for example;



Roof Dead Load

50 mm Thick Gravel	xxx kPa
Geotextile	xxx kPa
150 mm Thick Thermal Insulation	xxx kPa
Waterproofing Membrane	xxx kPa
Screed (Ave. Thick: $[50+150]/2=100$ mm)	xxx kPa
200 mm Thick RC Slab	xxx kPa
MEP Allowance	xxx kPa
Suspended Ceiling	xxx kPa
TOTAL Roof Dead Load	xxx kPa

- b) Live Loads: Structural Engineer shall list live loads for each location where purpose of use differs.
- c) Wind Loads: Structural Engineer shall document all parameters required for wind load calculation for Main Wind Force Resisting System and Components & Cladding.

Parameters shall include:

- Design wind speed
- Exposure category
- Risk Category
- Importance Factor



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All parameters shall be clearly identified and referenced to relevant sections of codes and standards.

- d) Seismic Load: Structural Engineer shall document all parameters required for seismic load calculation for the structure including:
- Risk Category
 - Importance Factor
 - Lateral Load Resisting System
 - Response Reduction Factor (R)
 - System Overstrength Factor (ϕ)
 - Deflection Amplification Factor (C_d)
 - Site Class (Should be referenced to Geotechnical Report)
 - Site Coefficients
 - Mapped Spectral Response Accelerations
 - Spectral Response Coefficients

All parameters shall be clearly identified and referenced to relevant sections of codes and standards.

- e) Temperature Load: Consideration for loads and effects of contraction or expansion from temperature changes shall be clearly documented.
- f) Equipment Loads: All MEP equipment planned to be used in structure shall be listed with their location and operating weight.
- g) Structural Engineer shall clearly list all other loads including with locations to be applied, magnitude and explanation for resource of loads.
10. Load combinations used in design shall be clearly documented.
11. Structural Engineer shall list all fire rating requirements throughout the structure.
12. Consideration and information for Buoyancy and Flood shall be documented.

C. Gravity Design

1. Analysis and Design of the Primary Structural Components. This design should document the location, tributary area, span, loading and controlling condition, load combination for each member designed. Also effects of temperature loads shall be identified.
2. Structural Engineer shall provide list for used material and their grades used in design for each structural components.
3. Calculations should note the final member size as shown on the plans, including the support condition. Structural Engineer shall also note any eccentric loading conditions which creates torsion effect on member and design member accordingly.
4. All design calculation shall be conclusive, highlighted that Resistance of member satisfactory against analysis results. Also each step of design shall be referenced to related design standards or codes.
5. Deflection of member shall be checked against allowed deflection criteria.
6. Calculations for design of the connections between the Primary Structural Components.
7. Calculation for design of the connection between Secondary and or non-structural elements to primary structural components.
8. If vendor supplied elements used in design, Structural Engineer should still provide full analysis and design calculations as explained here in.

D. Lateral Design

1. Factors used in determining overall wind load should be indicated as required in section B.9.c of this appendix.



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2. Factors used in determining base shear should be indicated in addition to the required seismic design criteria required in section B.9.d of this attachment.
3. Clearly defined type of Lateral-Force-Resisting System used and which Primary Structural Components are part of the system.
4. Analysis and design results should be submitted with a sketch showing geometry, loading, boundary conditions, etc.
5. Design of Primary Structural Components relating to the Lateral Force Resisting System. These components would include, but are not limited to, diaphragms, collectors, drag struts, out-of-plane anchorage and connection design.
6. Design of Secondary Structural and Non-Structural Components and their connections to Primary Structural Components shall be provided.

E. Footing & Foundation Design

1. Clearly documented horizontal and vertical service loading on pile, pile group or foundation.
2. Design of the primary footing and foundation components.
3. Calculation or reference for sub grade modulus (k_s) used in design.
4. Information and reference about Allowable Bearing Pressure for soil shall be provided.
5. Provide footing schedule including with information for, size, service loads, reinforcement, bearing pressure, estimated settlement, etc.
6. Design of Secondary Structural Components required at the interface between foundation and structure above. These components would include base plates, anchor bolts and embed plates.
7. Effects of lateral loading including uplift, overturning and shear transfer to soil must be included.
8. Effects of buoyancy and flood should be included in foundation design.
9. The requirements for engineered fill or other specific placement criteria should be noted in the calculations and on the plans.
10. Unless otherwise approved by Entity, "assumed" soil properties (bearing pressure) shall not be used in the design. Where assumed parameters have been approved then field verification shall be undertaken, as determined by the size and complexity of the project. The Entity shall approve all proposals for site validation, field records and analysis shall be submitted to the Entity prior to the commencement of work to demonstrate site conditions can support the specified foundation design, similar to a deferred submittal.

F. Computer Aided Design

In addition to the requirement listed in Volume 6, Chapter 6 (EPM-KE0-PR-000008 CAD Standards Procedure), the followings are additional requirement for use of computer software in analysis and design.

1. For computer software that has built-in algorithms to implement the provisions of particular versions of model or material building codes, an analysis of the methodologies of the selected building code and the building code used in the software shall be performed to ensure consistency of methodology. The methodology of the software shall be reconciled with the selected building code(s) either through the use of modified input data or through the use of modified load factors within the load combinations, or both.
2. The method of reconciliation of the building code selected for design and the building code implemented in the software, as well as the determination of the modified input data and/or load combination factors that are utilized shall be included in the design basis reports and in the calculations. Notes shall be included as comments in the software input that describe why the input information and/or load combination factors are different than the normal values.
3. 3D structural skeleton of total structure shall be provided (All four isometric views).
4. Structural Engineer shall itemize all input variables and provide clear explanations for each variable (Loads, load combinations, defined section name, properties and modifications, etc.). Acronyms and abbreviations used in software shall be listed.



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5. Plan view (including with grid lines and dimensions) for each level of structure showing each applied area loads and area section names.
6. Elevation view at each gridline showing each applied line loads and frame section names.
7. Plan view showing location and section name of lateral load resisting system(s) at each level of structure.
8. If software used has auto lateral load calculation function, list all input variables for wind and seismic parameters with clear explanations.
9. If hand calculation method used for lateral loads, provide comprehensive calculation of loads and show how and where loads applied to structure. Structural engineer shall also provide calculation for fundamental period of structure.
10. Information about assigned diaphragm shall be provided including with location of connection for diaphragm to lateral load resisting system.
11. Output summary for lateral loads including but not limited to following information:
 - a) Story shear shown on elevation view of structure
 - b) Base shear
 - c) Drift for each level of structure
12. Structural Engineer shall provide analysis and design outputs for each primary structural member (beams, columns, slab, foundation, shear walls, etc.). Design outputs should be conclusive and results should be highlighted.
13. Most of structural analysis and design software in market performs only macro level analysis and design, meaning, detailed analysis of connections, checks for code requirements, etc. are left Structural Engineer to design either with hand calculations or other software approved by Entity.

Therefore, Structural Engineer shall provide comprehensive report including but not limited to the following:

- a) Beam-Column, Slab-Column Joint Design
- b) Punching shear checks for flat slabs and footings
- c) Code requirement checks for size of elements, grades, etc.
- d) Steel column — concrete foundation connection including with base plate, anchor bolt designs.
- e) Cladding connections to primary structural members
- f) Corbel, Ledge designs
- g) Diaphragm design



Attachment 2 - Specific Drawings Guidelines and Requirements

A. General

In addition to the general requirements listed in Volume 6, Chapter 6 (Project Submission Standard and Requirements) of White Book, structural drawings shall also include the specific information provided in this appendix.

B. General Items

1. Date & Purpose of each issue;
2. Applicable design and construction codes, standards and bylaws governing the work;
3. Materials to be used, including standards and grades;
4. Description of the lateral load resisting system under General Notes / Seismic section;
5. Provisions for future extensions, if applicable;
6. Sequence of work, if this is critical to the function of the finished structure;
7. Expansion, construction and control joint locations and details;
8. Existing structural drawings, condition surveys and special reports prepared by others, when necessary;
9. Structurally derived dimensions (generally, grid line and overall building dimensions should preferably be shown, or the architectural drawings, to avoid the duplication of dimensions and possible errors);
10. Design criteria giving the appropriate information for all vertical and horizontal loads, designating them as live or dead and specified or factored;
11. Design criteria shall include Seismic and Wind load information. Wind load shall be clearly identified for MWFRS and Components & Claddings. Include pressure diagrams if appropriate, and
12. Location and specification of temporary shoring / bracing if required.

C. Foundation Plans

1. Grid lines and grid line dimensions as well as overall dimensions and structurally derived dimensions;
2. Type, sizes, details and locations of foundations for columns, walls, piers, special equipment and other structural load bearing components;
3. Drainage and dewatering requirements, if critical to the structural design;
4. The anticipated bottom elevation of foundations;
5. Sub-grade preparation for slabs-on-grade, as well as the thickness, reinforcing and elevation of the slabs-on-grade;
6. Waterproofing details for foundations, if required;
7. Design soil or rock bearing values, with reference to pertinent geotechnical reports;
8. The location of existing adjacent services, foundations and site information made known to structural Engineers by others, which may conflict with structural footings or foundations;
9. In addition, where underpinning and/or shoring is specified to be designed by others, structural engineers should indicate on the drawings the areas to be underpinned or shored, the maximum allowable deflections and settlements, and other restrictions or criteria. When structural engineers are designing underpinning, they should indicate on the drawings adequate details and construction sequences, and
10. Foundation for vendor supplied structures: Structural engineer shall provide full design drawings for foundation and capacity table for the foundation.

D. Framing Plans of Floors, Roofs Walls and Ancillary Structures



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1. Grid lines and structurally derived dimensions, dimensions to outside of structural floor plate from grid or overall dimensions of floor plate;
2. Size and location of all structural framing components for the Building Structure must be shown for each direction and at all levels of structure;
3. Indicate location of each lateral force resisting component such as, but not limited to, lateral bracing, shear walls, moment frames.
4. Location and magnitude of additional loads, such as mechanical unit, considerably heavy architectural features, special equipment, etc. The drawing must indicate whether loads noted are service or factored loads;
5. Slopes and depressions or references to drawings by others that show that information;
6. Locations, sizes and framing details or reinforcing around openings on structural members;
7. Reference elevations of floors or roof(s);
8. Reinforcing bar sizes and spacing for concrete members;
9. Conditions at change of elevation of the structure, conditions at intersections of different structural materials, and at interaction of structural and non-structural components;
10. Direct forces, moments, shears or torsion required for the preparation of shop and detail drawings;
11. Standards to which detailing should conform;
12. Sufficient detail cuts, references to schedules and specific information identifying the Structural Components.
13. Connections between similar materials and materials manufactured offsite are generally designed by the supplier's engineer. Therefore, structural engineer shall differentiate between live and dead and specified and factored loads, to avoid possible confusion.
14. Framing plans for vendor supplied structures: Structural engineer shall provide schematic frame plan with adequate sizing of all structural members, however, Structural engineer shall also provide note to clarify that shown design on framing plan is indicative and it is vendor's responsibility to provide full design.

E. Column Information Showing

1. Elevations of top and bottom of columns;
2. Member sizes;
3. Reinforcing steel details for concrete columns;
4. Proposed splice locations for structural steel and concrete columns, and
5. Column axial loads and bending moments to be resisted.

F. Sections and Details

1. Elevations, sections, and details are to be at an appropriate scale to portray the relationship of structural elements to each other and their interconnection(s). Sections and details are to be in sufficient number to show all non-typical conditions, their locations and extent.
2. Primary Structural Component connections required to transfer gravity load from roof to floor to foundation must be detailed. These connections would include, but are not limited to, joist to beam or wall, beam-to-beam, beam to column and column to foundation.
3. Structural detailing of Secondary Structural Components such as parapets, fascias and canopies must be included in the structural drawings.
4. Details must be shown for all lateral force resisting connections. These types of connections are; diaphragm shear transfer, out of plane anchorage, bracing connections, moment frame connections and force transfer to foundations.
5. Typical details should be used where appropriate, however, care should be taken to determine that details noted as "typical" are applicable to the condition being portrayed and that their locations and extent are explicit.



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G. Other Information

1. Structural details of masonry bearing and shear walls, including details of reinforcing, support of loads, lintels and grouting procedures.
2. Structural details of reinforced concrete elements, openings in members, change in floor elevations, sufficiently detailed to enable others to prepare shop drawings.
3. Elevations and details of custom designed trusses, including direct forces, moments, shears and torsion to be resisted by each member.
4. Subgrade preparation for slabs on grade, based on the geotechnical engineer's recommendations, and slabs on earth thickness and elevation of main slab. Drawings should also make reference to other contract drawings for such additional details as recesses, depressions, pits.
5. Design loadings, details of reinforcing steel, if any, and the location and details of control and expansion joints.