DENVER INTERNATIONAL AIRPORT

DESIGN STANDARDS MANUAL

Structural

Design, Engineering and Construction

Revised: Q2 2025

Printed in the United States of America

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Summary of Revisions

The following tables list revisions to the Structural DSM.

2025 Revisions

Second Quarter

Reference	Revision Description
2.2.6.Documentation Requirements	Updated information
4.0.2.Live Load	Added information
4.0.6.4.Electrical & Communication Rooms	Updated information

2024 Revisions

Fourth Quarter

Reference	Revision Description
1.2 ORAT Requirements	New ORAT Requirements section
Throughout	Accessibility improvements

2023 Revisions

Fourth Quarter

Reference	Revision Description
1.2.1 Applicable Standards	Added applicable standard
1.4 References	Added reference
3.2.2.1 Cast-In Place Concrete for Structured Parking	Added section
4.0.6.1 Fire Lane Loads	Added information on consulting Denver Fire Department
4.2.5 Structured Parking	Moved section from 4.2.5.2 Garage Roofs here to be more inclusive to all parking areas
4.2.5.1 Vehicular Loading	Added information on consulting Denver Fire Department

Second Quarter

Reference	Revision Description
4.0.6.12 Vibration Criteria	Added Vibration Criteria table

Revision Notation: Revisions made to this Manual during this revision cycle are annotated as shown in the example below:

A vertical line in the left-hand margin is used to annotate paragraphs that have been added or revised in the current publication. Revisions may include items such as new requirements, clarifications of existing requirements, or removal of requirements that no longer apply to projects. Revision annotation is applied to each publication individually; revisions made in past publications are not annotated in subsequent publications.

Purpose of Design Standards Manuals

The DEN Design Standards have been developed to ensure a unified and consistent approach to the thematic and technical design for DEN. These standards are for use and strict implementation by all consultants under contract to DEN, to tenants, and all other consultants under contract to any other entity for the design of projects at DEN.

The Standards Manuals are working documents, which will be revised and updated, as required, to address the general, conceptual, design, and technical standards for all areas of design for DEN.

This Design Standards Manuals (DSM) for DEN has been prepared for use by competent, professionally licensed architectural and engineering consultants under the direction of DEN Maintenance and Engineering or tenants of DEN.

The Design Standards shall not be quoted, copied, or referenced in any bidding or construction contract documents. Content contained in this Manual shall not be copied in any bidding or construction documents, except where specifically instructed to do so. All information contained in these standards must be fully explained and shown in all bidding and contract documents.

The Design Standards Manuals are intended to be used as a whole, as each manual is complimentary to the other DSMs. To understand the overall thematic and design standards for DEN, the applicable manuals must be utilized together and not separated from the Design Standards Manuals.

The Consultant shall not reproduce, duplicate in any manner, transmit to other consultants or other entities, or use in conjunction with other projects without the express written consent of DEN.

NOTE: This document is optimized for duplex (double-sided) printing.

VARIANCE FROM DEN DESIGN STANDARDS MANUALS

Requests for non-conformance or variance from DEN Design Standards manuals, for any DEN or Tenant Projects, must be formally submitted using the online DSM Variance Request form at the following website:

DEN DSM Variance Request

Variance requests may or may not be approved by DEN and response will be communicated to the requestor.

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Chapter 1 - General

1.0 General

This manual establishes minimum criteria by which the structural systems must be designed to provide protection of life, health, and property in the environments provided.

1.1 Abbreviations

The abbreviations included in the Table 1-1: Abbreviations are used throughout this manual:

Table 1-1: Abbreviations

Abbreviations	Definition
AAE	AA Engineers and Associates, Inc.
AASHTO	American Association of State Highway and Transportation Officials
AMRL	AASHTO Materials Reference Laboratory
ARFF	Aircraft Rescue and Firefighting Facility
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
CCRL	Cement and Concrete Reference Laboratory
CDOH	Colorado Department of Highways
DEN	Denver International Airport
EFP	Equivalent Fluid Pressure
EPA	Environmental Protection Agency
F	Bracing Strut Loads
F_{SB}	Factor of Safety Against Bottom Instability
H	Depth Below Ground Surface
HDPE	High Density Polyethylene
K	Lateral Earth Pressure Coefficient
K_a	Active Earth Pressure Coefficient
K_o	At-rest Earth Pressure Coefficient
K_p	Passive Earth Pressure Coefficient
l	Excavation Strut Spacing
L	Distance between Centers of Spread Footings, the Least Dimension of Mat Foundations, or Shortest Length of a Continuous Footing
m	Horizontal Distance Coefficient
n	Vertical Depth Coefficient

Table 1-1: Abbreviations (Continued)

Abbreviations	Definition
N_o	Cohesive Soil Strength Coefficient
NSP	Non-Swell Potential
NVLAP	National Voluntary Laboratory Accreditation Program
OSHA	Occupational Health and Safety Administration
pcf	Pounds Per Square Foot Per Foot Depth
PDA	Pile Driving Analyzer
P_H	Resultant Horizontal Earth Pressure
psf	Pounds Per Square Foot
PVC	Polyvinyl Chloride
P-Y	Load Versus Deflection, as used in Pile Lateral Load Modeling
q	Surcharge or Areal Load Pressure Intensity
Q_1	Line Load Intensity
Q_p	Point Load Intensity
R	Distance from Blast Point
SCS	U.S. Department of Agriculture Soil Conservation Service
USDA	United States Department of Agriculture
V_r	Maximum Particle Velocity
W	Weight of Explosive Charge
β	Retaining Wall Backfill Surface Inclination
β	Areal Load to Retaining Wall Inclination
Y	Earth Unit weight
Y_W	Unit Weight of Water
δ	Retaining Wall Roughness Coefficient
σ_h	Horizontal Earth Pressure
σ_H	Horizontal Pressure Due to Uniform Surcharge
ϕ	Friction Angle
ϕ'	Friction Angle Based on Effective Stresses

1.2 ORAT Requirements

The Operational Readiness, Activation, and Transition (ORAT) team at DEN plays a critical role in ensuring that DEN’s Design Standards Manuals integrate operational requirements throughout the design and construction phases. By collaborating closely with project teams, architects, and engineers, ORAT ensures that the DSMs align with the airport’s functional and operational needs. This alignment is achieved by gathering feedback based on operational expertise, identifying potential challenges in facility layouts, and ensuring that the final design facilitates a seamless transition to full-scale operations. Program and project design teams are expected to be familiar with the DEN ORAT Standards Manual (OSM) and actively participate in ORAT-led meetings, charrettes, workshops, trials, and testing at the request of the DEN Project Manager.

1.3 Structural Codes and Standards

Design to most recent adopted Building Codes and City and County of Denver Code Amendments (hereafter referred to as Building Code or Code). In certain cases, this DSM shall have more stringent requirements than building code. Designer will design to the more stringent of the two.

1.3.1 Applicable Standards

A. American Society of Civil Engineers (ASCE) ASCE/SEI 7

B. American Concrete Institute (ACI) ACI 318

C. American Institute of Steel Construction (AISC)

  a. Steel Construction Manual
  b. Code of Standard Practice
  c. Specification for Structural Joints Using ASTM A325 or A490 Bolts
  d. Engineering for Steel Construction, A Source Book on Connections

D. American National Standards Institute, Inc. (ANSI)

  a. A58.1 Minimum Design Loads for Buildings and Other Structures

E. American Welding Society (AWS) D1.1

  a. Structural Welding Code-Steel

F. American Water Works Association (AWWA)

  a. Standard for Steel Tanks, Standpipes, Reservoirs and Elevated Tanks, for Water Storage AWWA D-100-59

G. American Society of Testing Materials (ASTM)

  a. Standard properties of miscellaneous building materials

H. Portland Cement Association (PCA)

  a. Applicable Standards

I. Post-Tensioning Institute (PTI)

  a. Post-Tensioning Manual

J. Prestressed Concrete Institute (PCI)

  a. Applicable Standards

K. AASHTO LRFD Bridge Design Specifications

Miscellaneous standards for properties, manufacture and installation of specific items are not fully covered by the above standards.

1.4 Quality Assurance Program

The structural systems design shall be thoroughly coordinated by the Design Consultant with the work of all other trades. The contract drawings shall reflect a design as completely engineered as possible. Provide design loads for any connections that are to be designed by the contractor. Provisions for attachment of equipment to the structure are to be noted, and support points located.

If the design of structural steel elements results in components that require nondestructive testing, that requirement must be indicated on the drawings. Nondestructive testing should only be specified where visual inspection by a certified inspector cannot provide reasonable assurance of structural integrity. Procedures, techniques, acceptance criteria, etc., shall conform to AWS D1.1 structural welding code and the AWS B1.0 guide for nondestructive inspection of welds.

Refer to the Standards and Criteria DSM for the overall project quality control program. Note especially that the Design Consultants must submit a quality control program for review and approval prior to the commencement of the work. There are specific quality assurance procedures required during the preparation of calculations, drawings, and specifications.

1.5 References

The following reference sources were used in the creation of this manual:

1. Preliminary Geotechnical Investigation, City and County of Denver, New Denver Airport Site, #8901, AA Engineers and Associates, Inc., February 9, 1989.
2. Soil Survey of Adams County, Colorado, USDA Soil Conservation Service, October 1974.
3. Subsurface Investigation for Design and Construction of Foundations of Buildings, American Society of Civil Engineers (ASCE), 1976.
4. Pile Driving Analyser, Pile Dynamics, Inc., Cleveland, Ohio.
5. Kezdi, Arphad, Lateral Earth Pressure, in Foundation Engineering Handbook, J.F. Winterkorn and H.Y. Fang, editors, 1975.
6. Terzaghi and R.B. Peck, Soil Mechanics in Engineering Practice, 2nd Edition, John Wiley and Sons, NewYork, 1967.
7. Steel Sheet Piling Design Manual, U.S. Steel Corporation, 1970.
8. K. Terzaghi, Anchored Bulkheads, Transactions, ASCE Volume 119, 1954.
9. Foundations and Earth Structures, Design Manual 7.2, NAVFAC DM-7.2, Department of the Navy, Navy Facilities Engineering Command, May 1982.
10. Standard Specifications for Road and Bridge Construction, State of Colorado, State Department of Highways, Division of Highways, 1986.
11. Final Wind Speed Zones and Wind Induced Loads on the Video Board Report, Wind Tunnel Tests for DIA Hotel and Transit Center, CPP, Inc., December 20, 2017.
12. AISC Design Guide 11: Vibrations of Steel-Framed Structural Systems Due to Human Activity.

End of Chapter

Chapter 2 - Task Requirements by Phase

2.0 Task Requirements by Phase

During the design phase of new facilities or facility improvements at DEN and after the initial design scope development stage, submittals are required for review by the owner at the following stages of completion. The owner's comments, corrections, notations, etc., shall be revised by the Design Consultant and incorporated into the design before the next stage of completion is submitted. Refer to the Standards and Criteria DSM for the material included in each phase.

2.1 Schematic Design Requirements

Refer to the Standards and Criteria DSM.

This phase includes a preliminary one-line schematic design layout of the structural systems, alternative systems if appropriate, and a cost estimate refined to the 15% level. Conduct meetings with owner, facility users, and operators for design input.

2.2 Design Development Requirements

Refer to the Standards and Criteria DSM.

Perform design development tasks for the contract that shall include general areas of work for floors and roofs, floor framing, columns, bracing, foundations, and miscellaneous structures.

2.2.1 Calculations

Perform definitive structural calculations. They should include sizing for all main components and most secondary members exclusive of bracing and connections.

2.2.2 Plans and Elevations

A. Plans and elevations showing major components; general arrangements; and location of all major framing.

B. Location of doors, windows, stairs, and other openings.

C. Lateral force resisting systems. Define systems and locate diaphragms, braces, and moment resisting connections.

D. Layout of standards, schedules, and details.

E. Indicate scope of information to be provided in final design drawings.

F. Standard drawings, schedules, charts, and details.

G. Layout drawings indicating information to be supplied in subsequent phases. Include any information available currently to show concepts of construction details, materials, and overall structural systems.

2.2.3 Coordination Requirements

A. Coordinate overall plan and elevation views with Architectural Design Consultant.

B. Coordinate all access openings in floors and walls with Architectural Design Consultant.

C. Coordinate all floor and wall penetrations for ducts, pipes, conduits, etc. with mechanical and electrical Design Consultants.

D. Coordinate locations, sizes, and loadings from all equipment to structural system.

E. Meet with any other consultants at review meetings to verify direction and progress during design development work.

2.2.4 Geotechnical Specification Requirements

Outline specifications including brief technical descriptions of all system, members, and materials.

2.2.5 Cost Estimates

A. Prepare preliminary cost estimates on a per square foot or similar basis.

B. Preliminary cost estimate shall include a list of quantities of materials and unit prices.

C. Prepare cost estimates for alternative support systems, including schedule impacts of different systems.

2.2.6 Documentation Requirements

Design development documents to be completed for the structural systems shall include the following:

A. Preliminary Design Analysis Report. For information about this report, refer to the Standards and Criteria DSM.

B. Drawings shall be prepared using the current edition of Revit adopted by DEN. Refer to the Digital Facilities and Infrastructure (DFI) DSM.

Drawings shall include, but not be limited to, the following:

A. Foundation plan showing all footings, grade beams, walls, trenches, etc. Locate and orient columns and equipment foundations.

B. Structural floor and roof plans.

C. Types and dimensions of floors, including grating and floor plates. Define all major equipment supports, openings, framing systems.

D. Elevations and building sections.

E. Locate all floor levels, beams, columns, struts and framing around openings. Locate braces or moment resisting connections.

F. Standard drawings, details, schedules, and charts.

G. Show standard details selected at this phase for bracing, girt system, beam connections, concrete slab edges, handrails, ladders, stairs, etc. Provide format for schedules for columns, connections, foundations, etc.

2.3 60% Design Review

Refer to the Standards and Criteria DSM.

Tasks to be completed by the 60% completion level:

A. Rough draft of specifications.

B. Drawings **-** Plans should be at least 80% complete.

C. Elevations **-** Should be at least 70% complete.

D. Details **-** Should be at least 50% complete.

E. Schedules **-** Should be at least 70% complete.

F. Updated and completed calculations.

G. All notes, details, schedules and charts shown.

H. Identify, in tabular form, work required to complete drawings.

Note: A Final Design Analysis Report is required. Refer to the Standards and Criteria DSM.

2.4 Final (100%) Review

All work complete and checked. Submit for final review.

Refer to the Standards and Criteria DSM.

2.5 Bid Document Requirements

All comments and corrections from final review have been incorporated.

Refer to the Standards and Criteria DSM.

2.6 Bidding Period Requirements

Once the project is ready for bidding purposes, a complete set of project documents shall be submitted to the Owner along with any addenda.

Refer to the Standards and Criteria DSM for an explanation of the Design Consultant's responsibilities during bidding.

2.7 Construction Period Requirements

Refer to the Standards and Criteria DSM.

End of Chapter

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Chapter 3 - Structural Systems

3.0 Structural Systems

The structural system of each building, structure, or portion thereof shall be selected to support its own weight and that of all structural and nonstructural components attached to it. It must also resist all forces applied to it from pedestrian or vehicular traffic, wind, seismic movement, thermal movement, and all loads from equipment or other sources.

The structural systems shall be selected to provide a safe, healthy, and comfortable environment for all persons or equipment occupying or affected by their presence. They shall also be coordinated for a pleasing, unified appearance, efficient circulation of personnel and other traffic, and economical construction.

3.1 Foundations

Foundations for all structures are to provide a supporting platform on which to erect the structure. They shall resist all loads from the superstructure and all lateral or swelling forces from the soil without exceeding acceptable limits for bearing pressures, pile capacities, or settlement. Uplift of any part of a structure is also to be resisted by anchorage to the foundation.

A subsurface investigation will be required for each facility, and a report will be prepared that will include a recommended foundation system and design and construction parameters.

3.1.1 Shallow Foundations

Shallow foundations are those that are constructed a relatively short distance below grade and derive their support from bearing pressure on the underlying soil. Tops of slabs or mats will be located as required for ground floor or basement floor elevations. Footings subject to outside temperatures are to be located below frost penetration depth, a minimum of 3'-0 below ground surface. Soils investigations will be made to determine permissible bearing pressures.

3.1.2 Deep Foundations

Deep foundations shall be employed where shallow foundations do not provide satisfactory bearing capacity or resistance to settlement or heaving. Footings or mats are supported by piles or drilled shafts. Load-carrying capacity is provided by end bearing, skin friction, or a combination of both. Type of pile or shaft will be determined from soils investigation. Select type of deep foundation that will be most capable of supporting the imposed loads efficiently and economically.

3.2 Superstructure Types

3.2.1 Steel Structures

Steel structures are essentially frames that support floors, roofs, and walls of a building. Vertical loads from floors, roofs, and other structural components are supported on beams, joists, or trusses that are in turn supported by columns. Walls are supported by beams or by girts spanning between columns.

Lateral loads from wind, seismic or temperature movements, etc. are resisted by shear walls, diagonal bracing, or by moment resisting members and connections.

Materials used in steel structure shall be those with proportions and properties that provide the best performance in the overall design. The use of stainless, high strength or corrosion resistant steels may be warranted in special areas.

Members used in fabricating a steel frame may be rolled sections, factory built joists and joist girders, or custom designed and built up sections. Connections may be welded, bolted or a combination of both. Composite design may be used where required or economically advantageous.

Connections both bolted and welded, may be designed by the Design Consultant or the fabricator. If designed by the Design Consultant, they must be thoroughly detailed in the construction documents. If designed by the fabricator, the drawings must clearly define that responsibility and provide all the design loads, restrictions, and special provisions. Connections designed by the fabricator must be under the direct supervision of a professional engineer registered in the State of Colorado. The construction documents must specify that the fabricator furnish documentation, under a licensed professional engineer's seal and signature, that a professional engineer has designed the connections.

In either case, the Design Consultant must review and approve the connection details and retain responsibility for conformance with overall design requirements and information given in the construction documents. However, the review and approval by the Design Consultant do not relieve the fabricator and his professional engineer of their design responsibility.

3.2.2 Cast-In-Place Concrete Structures

Cast-in-place structures are essentially frames of reinforced concrete members, cast in their final position at the construction site. The typical structure is a moment resisting frame with connecting members placed to form monolithic joints. Reinforcing steel extends through joints to provide continuity between members.

Cast-in-place members and components may include, but are not limited to, foundations, columns, beams, floors, walls, tunnels, and machinery pedestals.

Construction joints may be used between successive pours. Extend reinforcing bars through joints to splice onto bars following placement.

Where appropriate, post-tensioning may be used with the cast-in-place construction. It may be used to limit deflections of long-span members, to develop frame action, to control cracking in slabs, etc.

Forms for concrete members are to be constructed of materials that have the strength to support the fluid concrete and any loads that may be applied during construction. Form surfaces that are in contact with the concrete must be of a material that will give the concrete a satisfactory finish. Reuse of forms can be achieved by designing members of the same sizes where practical.

Foundations are to be placed on the earth below them. Vertical sides of excavations may be used for forming where the earth can retain its excavated shape. Forming of sides is required for all exposed foundations.

3.2.2.1 Cast-In Place Concrete for Structured Parking

New structured parking shall be constructed of cast-in-place post-tensioned systems.

3.2.3 Precast Concrete

Precast concrete structures or members are those cast other than in their final position. They may be standard manufactured items or custom designed. Precast members may include, but are not limited to,

A. Floor and roof deck panels
B. Wall panels
C. Columns or posts
D. Beams
E. Other precast items are wall copings, door and window frames, stair segments, etc.

Precast members may be prestressed (pre-tensioned or post-tensioned) or non-prestressed. All are to be reinforced to give the members their desired strength and durability.

Attachment to other members of the overall structure is to be made by bolting, welding, anchoring by use of dowels into cast-in-place segments, or other approved methods.

Design of precast elements must include the forces due to removing sections from forms, lifting, transporting, anchoring, etc., in addition to those forces to be resisted after the element is incorporated into the framing system.

3.2.4 Tilt-Up Concrete

Tilt-up construction is a special case of pre-cast concrete. Wall panels are poured in beds or on the grade floor slab with embedded devices for attachment to the building frame. After curing, the panels are tilted to a vertical position and connected to the building. Tilt slabs may serve as the building frame or merely as a skin enclosing it.

Design of tilt-up elements must include the forces due to lifting, anchoring, etc., in addition to those forces to be resisted after the element is incorporated into the framing system.

3.2.5 Concrete Masonry Units (Concrete Blocks)

Concrete blocks are used for construction of both interior partitions and exterior walls. Depending on the size and use of the buildings, walls may be load bearing and provide the entire means of resisting vertical and lateral loads. Block walls may also be incorporated as shear walls to resist lateral loads in other types of building frames.

Depending on the size or use, concrete block walls may be reinforced or non-reinforced. Special purpose blocks are available for anchorage of various items, spanning openings, etc.

End of Chapter

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Chapter 4 - Structural Design

4.0 Structural Design

The structural systems of each building or portion thereof shall provide a safe environment for all persons and equipment occupying or affected by it. All forces which may be expected to act upon it shall be considered in designing and members proportioned to resist these loads without exceeding stresses, deflections, or other limits defined by the applicable codes and standards. Loads to be used in designing include, but are not limited to the following:

4.0.1 Dead Load

Dead load is defined as the weight of structure, supported structures and building components, and all stationary equipment and furnishings. Floor dead load includes ceilings and services hung from the floor.

4.0.2 Live Load

A. Temporary loading imposed by snow, traffic, machines, etc.

B. Live loads for small spaces, toilet rooms, corridors, etc. should be the same as the live load for the surrounding spaces if the surrounding live load is heavier.

C. Catwalks and equipment access platforms shall be designed for at least 40 psf live load. Lay-down areas may require substantially heavier loads.

D. Loads for rigging and construction equipment (lifts, transporting heavy equipment to other areas, etc) for current project.

Airports need to be flexible to accommodate various uses of space throughout the life of airport operations. Therefore, it is the responsibility of the Design Consultant to examine spaces that may be used for something other than for what they were initially intended. Use the higher loading requirement when it is reasonably justifiable. (i.e., airline office space, due to future remodeling, may become circulation corridor space. Therefore, design for 125 psf.) All assumptions should be listed in the Preliminary Analysis Report for comment and/or approval by PM.

4.0.3 Snow Load

Design for load specified in the proposed Denver Building Code Amendments. Roof loads shall account for roof slopes and potential accumulation of snow at valleys, parapets, roof structures, and offsets of roofs of uneven configuration.

4.0.4 Wind Load

Design for wind speed specified in the proposed Denver Building Code Amendments and exposure category C. Design pressures shall be calculated for individual structures on basis of shape, height, size, and locations as specified by ANSI A58.1, but not less than 30 psf for exterior walls and any interior partitions subject to jet blast.

Design for wind speed on the Hotel Plaza shall be increased by the factors specified in Figure 4-1: Local Design Wind Speed Zones- Hotel Plaza. Wind speed zones are presented as a ratio to site design wind speed. Numbers in parenthesis indicate local wind speeds in MPH.

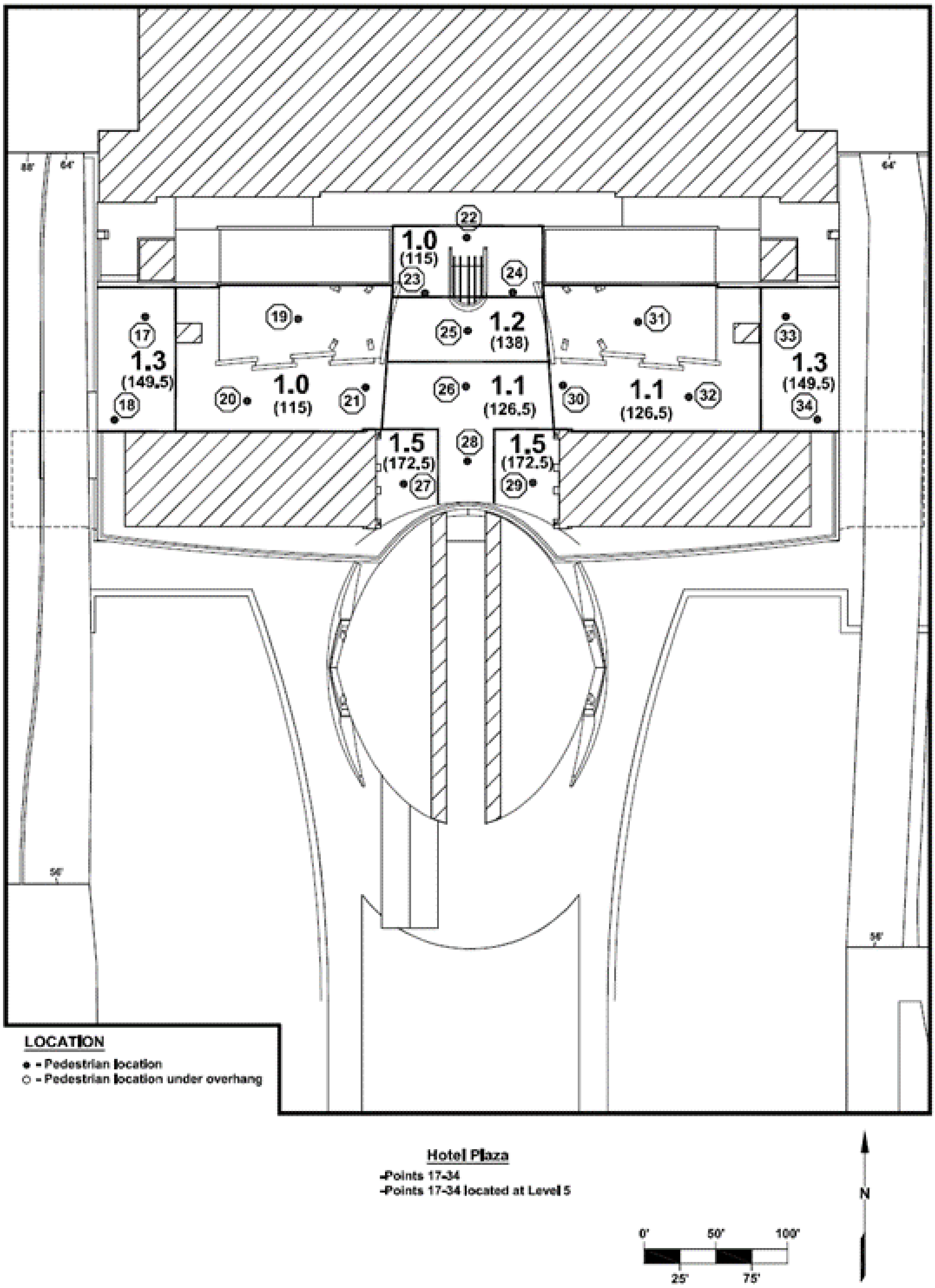

Figure 4-1: Local Design Wind Speed Zones - Hotel Plaza

4.0.5 Earthquake Load

Design for forces specified by ASCE 7 with minimum Seismic Design Category B.

4.0.6 Other Loads

4.0.6.1 Fire Lane Loads

Design for worst condition for AASHTO HL-93 or actual firetruck loads including tankers, and outrigger loads. Consult with Denver Fire Department for most current firetruck loads.

4.0.6.2 Mechanical Rooms

Design for actual equipment loads, but not less than 125 psf.

4.0.6.3 Elevators

Use loading data from manufacturer for specific elevators used with 100% impact.

4.0.6.4 Electrical & Communication Rooms

Design for actual equipment loads, but not less than 125 psf.

4.0.6.5 Lateral Loads

The Structural Design Consultant shall submit a plan showing the path of resistance for all lateral loads as part of the design development (35%) submittal.

4.0.6.6 Handrails and Railing Systems

Require contractor to design, engineer, fabricate, and install handrails and railing systems to withstand the following structural loads without exceeding the allowable design working stress of the materials for handrails, railing systems, anchors, and connections. Apply each load to produce the maximum stress in each of the respective components comprising handrails and railing systems.

4.0.6.7 Top Rail of Guardrail System

Capable of withstanding the following loads applied as indicated:

A. Concentrated load of 200 lbf applied at any point nonconcurrent, in any direction.
B. Uniform load of 50 lbf per linear foot applied nonconcurrent, in any direction.
C. Concentrated and uniform loads above need not be assumed to act concurrently.

4.0.6.8 Handrails Not Serving as Top Rails

Capable of withstanding the following loads applied as indicated:

A. Concentrated load of 200 lbf applied at any point nonconcurrent.
B. Uniform load of 50 lbf per linear foot applied nonconcurrent, vertically downward or horizontally.
C. Concentrated and uniform loads above need not be assumed to act concurrently.

4.0.6.9 Infill Area of Guardrail System

Capable of withstanding a horizontal concentrated load of 200 lbf applied to one square foot at any point in the system including panels, intermediate rails, balusters, or other elements composing the infill area.

Above load need not be assumed to act concurrently with uniform horizontal loads on top rails of railing system in determining stress on guard.

4.0.6.10 Glass-Supported Railing Systems

Capable of withstanding loads indicated for top rails and infill area of guardrail systems based on safety factor of 4, with each section of top rail supported by a minimum of 3 glass panels or by another means so that it remains in place should one panel fail.

4.0.6.11 Interior Walls and Partitions

Design to resist all loads to which they are subjected but not less than 5 psf applied perpendicular to the walls. Deflection shall not exceed L/360 of the span.

When the structural framing members, either concrete or steel, are left exposed as an architectural element, coordinate the finish of these members with the Architectural Design Consultant.

4.0.6.12 Vibration Criteria

Design all structural slabs to the following vibration criteria.

Table 4-1: Vibration Criteria

Occupancy Type Description	Acceleration Limit (%g)	Number of Walkers
Dining adjacent to general circulation	1.2	4
Dining seated inside formal restaurant	1.2	1
General Circulation	1.2	4
Mechanical	N/A	N/A
Mechanical Workshop	N/A	N/A
Office	0.5	1
Restroom	1.2	1
Retail	1.2	1
Seated Concourse Assembly Area	1.2	1
Storage	N/A	N/A
Vehicle Parking/Dining	N/A	N/A

4.0.7 Major Structural Components

4.0.7.1 Roofs

Roofs over all enclosed areas shall protect the interiors from the outside environment. Forces acting on the roof include the dead load of the roof and all structure and equipment supported, live loads including snow and traffic or other temporary forces, and wind effects. Any roof that may become a future floor shall be designed for a minimum uniform live load of 100 psf or greater load if required.

4.0.7.2 Walls and Partitions

All walls and partitions shall be designed to support their own weight and any building components or equipment supported by them. Lateral loads from wind or earthquake forces shall be applied as well as collision or other forces. Walls to be stiffened or provided with lateral support by girts as indicated.

4.0.7.3 Main Structural Framing System

All beams, columns, bracing, and other parts of the main load-resisting frame shall be designed to resist gravity, lateral, and thermal loads applied directly or through floors, roofs, and walls. Reactions from traffic or mechanical systems shall be included. Member types and sizes are to be selected to give a uniform appearance. Lateral loads are to be resisted by shear walls, diagonal bracing, moment-resisting members and connections, or combinations thereof.

4.0.7.4 Foundations

Design foundations to support structures on the underlying soil. All gravity and lateral loads are to be resisted without exceeding permissible loading or total or differential settlement limits determined from soils investigations. Uplift of any portion to be resisted by foundation. Foundations may be slabs on grade or piles, individual spread footings, or footings on piles or drilled shafts.

4.0.7.5 Floors

Floors are to be designed for the floor dead load plus uniform or concentrated live loads pertinent to given areas. Include loads from all equipment, furnishings, piping, lighting and structures supported upon or suspended from them. Design all stairs, ramps, escalators, and walkways for 100 psf, except as noted for individual zones or buildings.

4.0.7.6 Ground Transportation and Parking Lots

Ground transportation and parking lots that are exposed to weather shall be designed for snow removal equipment loads.

4.1 Passenger Terminal

4.1.1 Minimum Floor Live Loads

The Design Consultant is responsible for verifying all loads.

4.1.1.1 Ticketing Level

Design for 100 psf except for areas occupied by baggage conveyors or where baggage conveyors could potentially be hung from the floor minimum live load shall be 125 psf.

4.1.1.2 Baggage Claim

Design for 100 psf except for areas occupied by baggage conveyors and distribution equipment, including bag carousels. Design these areas for actual equipment loads, but not less than 160 psf. Any conditions, such as multiple levels of suspended conveyors that may exceed the additional 60 psf shall be investigated in detail by the Design Consultant.

4.1.1.3 Feature Piedmont (Observation Lounge)

Design for 100 psf.

4.1.1.4 Train Stations

A. Security (office, lockers, restrooms and showers)

   Design for 100 psf except where communications, mechanical, or other equipment exceeds this.

B. Exit and boarding platforms

   Design for 100 psf. With dead load, include weight of barriers or other structures supported.

C. Train support structures

   Design for dead load of structure, track and accessories, stops, etc. Live load to include weight of loaded train (to be supplied by manufacturer), impact, and any lateral and longitudinal loads resulting from the operation of the train.

4.1.1.5 Concessions and Service

Design for 100 psf in public areas and 125 psf in storerooms. Consider weights of vending machines, appliances, and miscellaneous equipment and increase live loads as required.

4.1.1.6 Restrooms

Design for the same load as the adjacent occupancy. For example, restrooms in ticketing areas shall be designed for 125 psf; in baggage claim areas, 160 psf.

4.1.1.7 Ground Transportation Levels

A. For areas usable by passenger cars only and height limitations do not allow busses or trucks, design for uniform live load of 50 psf or individual wheel loads of 2000 lbf acting on areas of 20 in^2, spaced 5 feet on center in any direction; whichever produces the greater stress.

B. For areas usable by busses and trucks and any area that may be used for busses and trucks in the future, design for lane loads or axle loads as specified by AASHTO latest edition Standard Specifications for Highway Bridges, with interim specifications. Design for HL-93 loads plus impact unless reduced loading is approved by the City and County of Denver.

4.1.1.8 Baggage System

A structural analysis shall be performed by the Design Consultant regarding the baggage system including both static and dynamic loadings.

4.1.1.9 Vibrating Loads

The Design Consultant shall address the problem of transfer of unacceptable vibrations to the public areas including hold rooms, waiting rooms, concession areas, observation lounge, restaurants, etc. Isolation joints, isolation dampers, absorbers or other means shall be used to control the transfer of vibrations from the baggage system, tug drive, conveyors, moving walkways, trains, or any other source.

4.2 Other Buildings – Minimum Floor Live Loads

4.2.1 International Concourse

Use same live loads as for corresponding use areas in Terminal. For areas where baggage conveyors could potentially be hung, follow the guidelines for the Terminal Ticketing Level. Comply with the requirements for the bag- gage system and vibrating loads stated in the Terminal section.

4.2.1.1 Public Access and Waiting Areas

Use 100 psf.

4.2.1.2 Train Stations

Use 100 psf on platforms, design train support structure for dead load of structure, track and accessories, stops, etc. Live load to include weight of loaded train (to be supplied by manufacturer), impact and any lateral and longitudinal forces resulting from the operation of the train.

4.2.1.3 Concessions and Services

Design for 100 psf in public areas and 125 psf in store rooms.

4.2.1.4 Restrooms

Design for live loads for the occupancy with which they are associated, but not less than 100 psf.

4.2.1.5 Escalators and Moving Walks

Design for at least 100 psf live load plus the added equipment loads. Dimensional requirements for end pits and the depth between the end pits shall be sized to accommodate all qualified escalator and moving walk systems. For moving walks, support points shall be provided at the column lines only. Any additional supports required for a particular moving walk system shall be provided by the manufacturer of that system.

4.2.2 Domestic Concourse

Use same live loads as for corresponding use areas in Terminal. For areas where baggage conveyors could potentially be hung, follow the guidelines for the Terminal Ticketing Level. Comply with requirements for the DCV bag- gage system and vibrating loads stated in the Terminal section.

4.2.2.1 Public Access and Waiting Areas

Use 100 psf.

4.2.2.2 Train Stations

Use 100 psf on platforms, design train support structure for dead load of structure, track and accessories, stops, etc. Live load to include weight of loaded train (to be supplied by manufacturer), impact and any lateral or longitudinal loads resulting from the operation of the train.

4.2.2.3 Concessions and Services

Design for 100 psf in public areas and 125 psf in storerooms.

4.2.2.4 Restrooms

Design for live loads for the occupancy with which they are associated, but not less than 100 psf.

4.2.2.5 Escalators and Moving Walks

Design for at least 100 psf live load plus the added equipment loads. Dimensional requirements for end pits and the depth between the end pits shall be sized to accommodate all qualified escalator and moving walk systems. For moving walks, support points shall be provided at the column lines only. Any additional supports required for a particular moving walk system shall be provided by the manufacturer of that system.

4.2.3 Control Tower

The FAA has specific requirements for FAA facilities. Refer to the FAA Web site and DEN or FAA PM for specific FAA requirements.

4.2.4 Hotel

4.2.4.1 Lobby, Meeting, and Public Assembly Rooms

100 psf

4.2.4.2 Sleeping Rooms and Corridors on Sleeping Floors

40 psf

4.2.4.3 Restaurants and Kitchens

100 psf

4.2.4.4 Concessions and Services

100 psf in public areas, 125 psf for storerooms.

4.2.4.5 Stairs, Corridors on Public Assembly Levels, and Miscellaneous Pedestrian Traffic Areas

100 psf.

4.2.4.6 Offices

50 psf + 20 psf partitions

4.2.4.7 Restrooms

Design for live loads for the occupancy with which they are associated, but not less than 50 psf.

4.2.5 Structured Parking

Provide positive slopes to ensure drainage. Consider the use of epoxy-coated reinforcing, micro silica concrete, and/or silane or siloxane sealer stored ucechloride penetration and corrosion of reinforcing in all slabs subject to freeze-thaw cycles and chemical deicing materials.

4.2.5.1 Vehicular Loading

A. For areas usable by passenger cars only, and height limitations do not allow buses or trucks, design for uniform live load of 50 psf or individual wheel loads of 2000 lbf acting on areas of 20 in^2, spaced 5 feet on center in any direction; whichever produces the greater stress.

B. For areas usable by buses and trucks, and any areas that may be used for buses and trucks in the future, design for lane loads or axle loads as specified by AASHTO- latest edition LRFD Bridge Design Specification with interim specifications. Design for HL-93 loads plus impact. For fire lane loading, consult with Denver Fire Department for most current loads & sizes of equipment that will access the site.

4.2.5.2 Garage Roofs

Garage roofs shall be designed for a non-reducible live load of 55 psf that includes snow and snow-removal equipment. Garage roofs that provide access for fire trucks shall be designed for the live loads required. Contact the Fire Department for specifications.

4.2.5.3 Stairs, Ramps, Etc.

100 psf

4.2.5.4 Restrooms

Design for live loads for the occupancy with which they are associated, but not less than 50 psf.

4.2.6 Parking Toll Plaza

4.2.6.1 Office, Restrooms, Locker Areas

50 psf

4.2.6.2 Store Rooms

125 psf.

4.2.6.3 Toll Collection, Communications, and Miscellaneous Equipment Live Loads as Provided by Manufacturers

4.2.7 Office Building

4.2.7.1 Offices

50 psf + 20 psf partitions

4.2.7.2 Restrooms

Design for live loads for the occupancy with which they are associated, but not less than 50 psf.

4.2.7.3 Lobby, Main Access Passageways, Stairs, Etc.

100 psf

4.2.7.4 Store Rooms (Light Storage)

125 psf.

4.2.7.5 File and Computer Rooms

File and computer rooms shall be designed for heavier loads based on weights of actual equipment to be provided, but not less than 125 psf.

4.2.8 Central Utility Plant

Central Utility Plant (CUP) houses equipment for providing chilled water and heating water to all the main airport buildings. Structural design to include loads for the support of all mechanical, electrical, and other equipment, floors, platforms, stairs, hoisting equipment and other items used. Loads for these items to be provided by manufacturers. Other loads not governed by specific equipment are detailed in the following paragraphs.

4.2.8.1 Offices

50 psf + 20 psf partitions and miscellaneous dead load.

4.2.8.2 Restrooms

Design for live loads for the occupancy with which they are associated, but not less than 50 psf.

4.2.8.3 Storage

125 psf or as required for heavy parts.

4.2.8.4 General Access Floors, Platforms, and Stairs

100 psf

4.2.8.5 Platforms Provided for Access to Equipment

As indicated for lay down or transport of heavy parts and equipment.

4.2.9 Maintenance Facility

4.2.9.1 Offices, Restrooms, and Lockers

50 psf

4.2.9.2 Storage

125 psf or larger loads such as 250 psf for heavy storage, based on specific supplies or equipment.

4.2.10 Air Cargo Facility (Handling and Short-Term Storage on Air Cargo)

4.2.10.1 Offices, Lockers, Restrooms

50 psf

4.2.10.2 Storage Areas

250 psf

4.2.10.3 Main Floor Landing

Design for traffic and storage loads from cargo handling equipment (forklifts, carts, tugs, cranes, etc.). Use design loads for specific items used.

4.2.11 Aircraft Hangars

4.2.11.1 Small Hangars

Maintenance performed on small aircraft from the ground floor or platforms and machines operating from the ground floor.

A. General Facilities (Offices, Restrooms, Lockers, Etc.)

   50 psf + 20 psf partitions and miscellaneous dead load.

B. Storage (Light)

   125 psf

C. Main Floor

   Design for loading from aircraft, highway type trucks, cranes, and miscellaneous vehicles used for transporting aircraft engines, airframe assemblies, and parts.

D. Roof System

   Design for roof loads, support of HVAC and other mechanical, electrical, or other suspended equipment and access catwalks and platforms.

4.2.11.2 Large Hangars

Design for all maintenance of large aircraft including inspection, repair, and major overhaul.

A. General Facilities (Offices, Restrooms, Lockers, Etc.)

   50 psf + 20 psf partitions and miscellaneous dead load.

B. Storage (Light and Heavy)

   Light 125 psf and heavy 250 psf.

C. Main Floor

   Design for loading from specified aircraft in applicable zones and from aircraft tugs in others. Provide jacking points in floor for supporting aircraft without wheels. Design covers for trenches, manholes, and pits for traffic load applicable in specific areas.

D. Roof System

   Design for usual roof loads support of HVAC and other mechanical, electrical, or other suspended equipment and access catwalks and platforms. Include loading to roof system from movable platforms providing access for servicing and overhaul of aircraft.

4.2.12 Flight Kitchens

4.2.12.1 General Facilities (Offices, Restrooms, Lockers)

50 psf + 20 psf partitions and miscellaneous dead load.

4.2.12.2 Pedestrian Traffic (Stairs, Main Entry and Exit Corridors)

100 psf

4.2.12.3 Kitchens

100 psf except where exceeded by loading from specific appliances, mechanical, or other equipment.

4.2.12.4 Storage

125 psf minimum or as required for storage of specific foods, utensils, or equipment.

4.2.12.5 Loading and Receiving Docks

Design for vehicular live loads from the largest trucks, tugs, tractors, or other vehicles which may use any specific area.

4.2.13 Snow Removal Equipment Facilities

4.2.13.1 General Facilities (Offices, Restrooms, Lockers)

50 psf

4.2.13.2 Storage

125 psf for light storage.

4.2.13.3 Storage

250 psf for heavy storage.

4.2.13.4 Main Floor Loads

Design for heaviest vehicles to be stored or serviced. Design for wheel loads directly on floor or supported by lifts or hoists. Servicing equipment and any mechanical or electrical equipment must be considered.

4.2.14 Aircraft Rescue and Firefighting Facility

Refer to 4.2.13.Snow Removal Equipment Facilities for loads.

4.2.15 Rental Car Support Facility

4.2.15.1 General Facilities (Offices, Restrooms, Lockers)

50 psf

A. For areas usable by passenger cars only, and height limitations do not allow busses or trucks, design for uniform live load of 50 psf or individual wheel loads of 2000 lbf. acting on areas of 20 in.^{2}, spaced 5 feet on centers in any direction; whichever produces the greater stress.

B. For areas occupied by equipment used in cleaning, repairing, lubricating and refueling automobiles, design for actual weights of these items, but not less than 100 psf.

4.2.15.2 Storage (Light)

25 psf

4.2.16 Auto Service Station

4.2.16.1 General Facilities (Office, Restrooms)

50 psf

4.2.16.2 Garage and Servicing Areas

A. 100 psf or 2000 lbf wheel loads acting on areas of 20 in^2, spaced 5 feet on center in any direction; whichever produces the greater stress.

B. If truck servicing is provided, increase loads for vehicles included. Areas supporting any servicing or building equipment to be designed for their support if the loads exceed the vehicle loads.

C. For areas occupied by equipment used in cleaning, repairing, lubricating and refueling automobiles, design for actual weights of these items, but not less than 100 psf.

4.2.16.3 Storage

125 psf for supplies, parts, etc. plus parking for towed cars.

4.2.17 Aircraft Fueling Control Facility

4.2.17.1 General Facilities (Office, Restroom, Lockers)

50 psf

4.2.17.2 Control and Monitoring Center, Small Repair Area

100 psf

4.2.18 General Aviation Facilities (Small Aircraft Services)

4.2.18.1 General Facilities (Offices, Restrooms)

50 psf

4.2.18.2 Business Offices, Concessions, and Services

100 psf

4.2.18.3 Storage Areas

125 psf

4.2.18.4 Maintenance Areas, Small Aircraft

Design for heaviest aircraft or maintenance vehicle to be stored or serviced, but not less than 250 psf.

4.2.19 Communications Center

4.2.19.1 General Facilities (Offices, Restrooms)

Design for heaviest aircraft or maintenance vehicle to be stored or serviced, but not less than 250 psf.

4.2.19.2 Access Passageways, Stairs, Etc

100 psf

4.2.19.3 Telephone Switchgear and Equipment

250 psf

4.2.20 Security Guard House

4.2.20.1 Office and Restroom

50 psf

4.2.21 Aviation Museum

4.2.21.1 General Facilities (Office, Restrooms)

50 pcf + 20 psf partitions and miscellaneous dead load.

4.2.21.2 Pedestrian Traffic Areas, Stairs, Exits, and Entries

100 psf

4.2.21.3 Counters, Display Cases, Etc.

100 psf

4.2.21.4 Support for Large Displays (Aircraft, Etc.)

Design floors for large uniform or concentrated loads exceeding nominal uniform loads in all display areas. Design roof for suspension of aircraft. Location and magnitude of loads to be determined by weight of aircraft to be accommodated.

4.2.22 Warehouse Facility

4.2.22.1 General Facilities (Offices, Restrooms)

50 psf

4.2.22.2 Storage Areas

Load to be determined from proposed use, but never less than 250 psf.

4.2.22.3 Main Floor Loading and Truck Docks

Check design for traffic and storage loads from handling equipment (forklifts, carts, tugs, cranes, etc.).

4.2.23 Bulk Storage Facility

Special structure for storage of bulk sand and salt.

A. Design walls for lateral loads from sand and salt at rest, as well as dynamic loads, due to filling of bunkers and impact from front-end loaders.

B. Provide treatments or coatings as may be appropriate for abrasion and corrosion.

4.3 Miscellaneous Structures Other Than Buildings

The Design Consultant is responsible for verifying all loads. Check all aircraft loads, tug loads, firefighting, and ARFF equipment, etc.

4.3.1 Pedestrian Bridges

The minimum live load for the bridge deck shall be 100 psf. Where use by small vehicles is anticipated increase live loads accordingly.

4.3.2 Highway Bridges

Contact the DEN Project Manager for project specific requirements.

4.3.3 Aircraft Bridge Structures

Including all bridges, tunnels, culverts and other structures supporting aircraft on runways, taxiways, or aprons.

Contact the DEN Project Manager.

4.3.4 Lighting and Sign Supports

Design lighting and sign supports, including poles, sign bridges, arms, and foundations for loads and criteria from following the latest edition of the AASHTO specification: Standard Specification for Structural Supports for Highway Signs, Luminaries, and Traffic Signals.

4.3.5 Retaining Walls

A. Retaining wall design shall be in accordance with applicable codes. For walls related to roadways use AASHTO and for others follow IBC.

B. Design for lateral soil and surcharge pressures and for any other loads supported by walls.

   a. Effect of wall movement from expansive soil pressures shall be included.
   b. Use safety factors against sliding and overturning as specified by applicable codes, but not less than 1.5.
   c. Provide drains on high sides to prevent excessive pressures in saturated backfill.
   d. Drains may be perforated pipe or gravel wrapped in geofabric.
   e. Provide weep holes at frequent intervals, generally less than 8 feet.

4.3.6 Tunnels

Contact the DEN Project Manager.

4.3.7 Metal Structures on Concrete Slab

When design requires detailing of, or modification to metal structures resting on concrete slabs on grade, utilize a detail similar to Figure 4-2: Example of Base Connection Detail- Metal Structure on Concrete Tab at the base connection. All design loading as outlined in applicable codes shall be followed to design and size the members to be used.

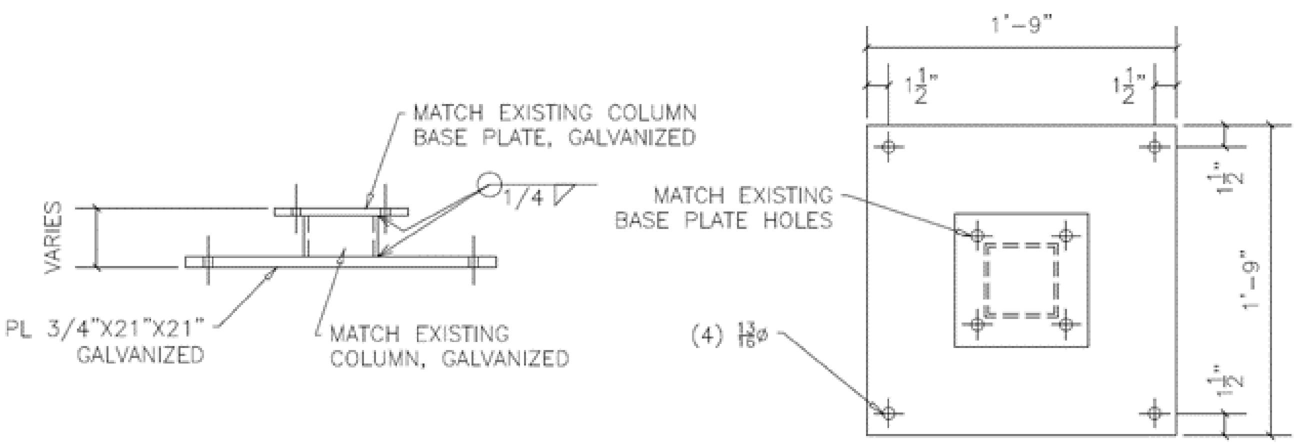

Figure 4-2: Example of Base Connection Detail - Metal Structure on Concrete Tab

End of Chapter

Chapter 5 - Geotechnical

5.0 Geotechnical

In this report, Geotechnical Criteria for design of structures at DEN are presented. Design of foundations for structures at the DEN will require site-specific evaluations of appropriate foundation types and supporting capacities, as well as estimates of settlement or heave, and other geotechnical considerations.

5.1 Geotechnical Conditions General

Site-specific subsurface exploration should be performed at all proposed structure locations. Criteria for the explorations are presented in subsequent sections of this report. The following subsections include discussions of general subsurface conditions and the other site-specific considerations, which should be addressed during foundation designs for DEN structures.

5.1.1 Subsurface Conditions

A Preliminary subsurface exploration was conducted at the DEN site by AAE[1] . One hundred thirty-three borings were drilled. This subsurface information should be used in planning subsurface explorations for structures. The complete AAE preliminary exploration report is available from City and County of Denver.

The AAE borings generally encountered clay and silt soils overlying weathered claystone, siltstone, and sandstone bedrock. Depth of the natural soils was generally reported to vary between 5 and 20 feet. Localized groundwater was reported.

5.1.2 Swelling Soils

Clay and weathered claystone bedrock with swell potential were reported by AAE (*PGI*). Samples exhibited varying swelling characteristics, as swell percentages up to about 5 percent and swell pressures up to about 15,000 psf were noted.

The reported swell characteristics should not be used directly for structural design purposes, except for facilities at locations where the specific data were obtained. Rather, subsurface explorations should be planned to evaluate the structure-specific occurrence of swelling soils and weathered bedrock.

5.1.3 Erosion Potential

Surficial soil types reported at the DEN site by AAE included clay, silt, and sand (*PGI*). Each of these soil types is potentially highly erodible by wind and water. Construction sequencing and architectural detailing should take into consideration the potential for erosion and the associated fugitive dust potential. Appropriate measures should be implemented during design of structures and landscaping to control potential erosion problems at DEN building sites.

5.1.4 Frost Susceptibility

Soils reported at the DEN site by AAE (*PGI*) included clay, silt, and sand soils that may be moderately to highly frost susceptible. Of the reported soils, silts generally exhibit the greatest heave tendencies upon freezing.

Subsurface explorations should assess the occurrence of frost susceptible soils. Generally, non-frost susceptible soils should be used within 3 feet of the ground surface, particularly beneath paved surfaces.

1Preliminary Geotechnical Investigation, City and County of Denver, New Denver Airport Site, #8901, AA Engineers and Associates, Inc., February 9, 1989, (hereafter cited in text as PGI).

5.1.5 Groundwater

Groundwater was reported in some borings at the DEN site by AAE (*PGI*). Groundwater was encountered in drainages and as localized perched groundwater tables. Future regrading, coupled with landscape watering and altered run-off characteristics, could create localized perched groundwater tables at almost any DEN location. It is possible that the resulting increased moisture contents could result in heave of potentially swelling clays and weathered bedrock.

Structure specific subsurface explorations should evaluate the existing groundwater conditions at building sites, and the potential for development of perched groundwater tables. Building plans should account for the potential effects of perched groundwater tables and the generally increasing moisture contents of subsurface materials.

5.1.6 Soil Reactivity

General information on the chemical reactivity of subsurface soils at the DEN site is available from the SCS[2]. SCS soil information is for the upper 5 feet of a soil profile, and, as such, has limited application for engineering purposes. However, SCS data presently represents the most readily available information at the DEN site.

In general, shallow soils at the DEN site are reported to have low potential for concrete attack and a high potential for steel corrosion. Site-specific soil reactivity data should be developed during building subsurface investigations.

Soil reactivity should be accounted for as it pertains to foundation attack. Appropriate cement types should be used in concrete in contact with subsurface materials. The potential for loss of section needs to be evaluated for steel foundation elements. Effects of soil reactivity on buried utilities must also be considered during design on a facility-by-facility basis.

5.2 Subsurface Investigations

5.2.1 General

Site-specific subsurface investigations should be performed prior to foundation design at each DEN structure. Subsurface investigations should include, as appropriate, geotechnical borings, field testing, material sampling, groundwater monitoring, and other testing and/or procedures. The subsurface investigations should be planned to gather site-specific information pertinent to particular foundation designs. A general discussion of the philosophy of the subsurface investigations is presented in a 1976 ASCE paper2.

5.2.2 Site Reconnaissance

A reconnaissance of site surface conditions should be performed as part of subsurface investigations. The reconnaissance should include as appropriate, but not necessarily be limited to, a review of: topography, vegetation, existing structures, roadways, utilities, and surface water.

5.2.3 Preliminary Subsurface Investigations

Preliminary subsurface investigations are appropriate for large or heavily loaded structures and/or where significant variations in subsurface conditions are anticipated. The information obtained by preliminary subsurface investigations should be utilized in preliminary foundation system design and site preparation planning, and to plan final subsurface investigations.

Preliminary investigations should include borings with field and laboratory testing. Although, the scope of preliminary investigations may vary by structure, typically about 25 percent of the total anticipated borings would be included. The borings should be logged, sampled, and subjected to field tests in a manner consistent with final sub- surface investigation borings. The preliminary borings should be distributed in a logical pattern across the site area to be integrated into a final subsurface investigation.

2Soil Survey of Adams County, Colorado, USDA Soil Conservation Service, October 1974.

5.2.4 Final Subsurface Investigations

5.2.4.1 General

Final subsurface investigations should be performed during the design of all DEN structures. Final subsurface investigations should provide detailed information on the subsurface conditions and material properties pertinent to foundation design and site preparation. Final design investigations should include, as appropriate, geotechnical borings, field tests, sampling, and groundwater observations.

Borings for final subsurface investigations should be arranged in a pattern to explore conditions throughout the site, as well as areas of special concern (e.g., areas with high foundation loads, or anticipated unfavorable sub- surface material properties).

5.2.5 Boring Locations and Depths

The number of borings should be developed based on the structure size and complexity. However, borings should normally be at a spacing not exceeding approximately 150 to 180 feet.

The depth of borings should be based on site conditions encountered but should extend through the zone of anticipated foundation installation, and to firm bearing materials, such as weathered bedrock. For example, borings should generally extend at least 10 feet below anticipated bottoms of deep foundations, such as driven piles or drilled piers (caissons).

5.2.5.1 Sampling and Field Testing

Sampling should be performed during boring programs to gather samples adequate for laboratory testing programs designed to provide foundation design information. Field testing should include Standard Penetration Tests and/or relatively undisturbed sampling attempts. The minimum sampling or field testing interval should be 5 feet. Relatively undisturbed samples to be tested for strength, consolidation, or density properties should be obtained with tube-type samplers to minimize sample disturbance (i.e., California Tubes, Shelby Tubes, etc.).

Relatively undisturbed samples should be retained and transported in a manner that will protect the in-situ moisture and density, strength properties, etc.

All changes in strata should be recorded and various subsurface materials described on the boring log (descriptions should be verified by laboratory testing). All field test results and sampling locations should also be noted.

5.2.5.2 Groundwater

Groundwater levels should be recorded in all borings. Piezometers should be installed at locations where ground-water is encountered, or any location where surface features may indicate shallow groundwater (for example, near drainage ways, water bodies, and irrigation systems). Groundwater levels should be monitored at the time of drilling, 24 hours later, and/or until they stabilize. A complete record of groundwater levels and times of measurement should be maintained.

5.2.5.3 Reporting

Subsurface investigation reporting should include a complete description of surface and subsurface conditions encountered, with emphasis on the effect of these conditions on design and construction of structures.

The report should include copies of all boring logs with sampling, field test information, groundwater elevations, and all laboratory test results.

The final report should also include results of engineering analyses, discussions of special areas of concern, final foundation design recommendations, site preparation recommendations, and construction detail recommendations.

5.2.6 Alternative Methods

Alternative methods of subsurface exploration may be used at the DEN site as supplements to boring programs. These methods may include, but are not limited to:

A. Geophysical methods such as seismic refraction, electrical resistivity, electrical conductivity, ground penetrating radar, geomagnetic, and gravitational methods.

B. Geotechnical methods such as static cone penetrometer, flat plate dilatometer, pressure meter surveys, etc.

These methods may be considered for augmentation of, but not in lieu of, geotechnical boring, sampling, and testing programs. Results of the alternate exploration methods must be correlated with results of the geotechnical boring programs.

5.3 Laboratory Testing

5.3.1 General

Representative samples of soil and bedrock materials obtained during subsurface investigations should be subjected to pertinent laboratory testing. The following subsections provide criteria for laboratory testing including test types, test methods, test programs, quality control, and sample retention.

5.3.2 Test Types and Methods

Laboratory testing of material samples associated with foundation investigations for DEN Structures should be conducted to investigate specific, pertinent material properties. Test methods should conform to the most recent version of ASTM or other appropriate standards. The test types and associated test methods shown in Table 5-1: Test Types and Methods are among the geotechnical laboratory tests typically assigned for foundation investigation.

Table 5-1: Test Types and Methods

Description	Method
Method for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants	D421
Method for Particle-size Analysis of Soils	D422
Test Method for Shrinkage Factors of Soils	D427
Test Methods of Moisture-Density Relations of Soils and Soils and Soil-Aggregate Mixtures, using 5.5-lb (2.46-kg) Rammer & 12-in (305-mm) Drop	D698
Test Method for Specific Gravity of Soils	D 854
Test Method for Amount of Material in Soils Finer then the No. 200 (75-um) Sieve	D 1140
Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures, using 10-lb. (4.54-kg) Rammer and 18-in. (457-mm) Drop	D 1557
Test Methods for Unconfined Compressive Strength of Cohesive	D 2155
Method for Laboratory Determination of Water (Moisture) Content of Soil Rock, and Soil-Aggregate Mixtures	D 2216
Method for Wet Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants	D 2217

Table 5-1: Test Types and Methods (Continued)

Description	Method
Test Method for Permeability of Granular Soils (Constant Head)	D 2434
Test Method for One-Dimensional Consolidation Properties of Soils	D 2435
Test Method for Classification of Soils for Engineering Purposes	D 2487
Test Method for Triaxial Compressive Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements	D 2664
Test method for Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression	D 2850 D 2850
Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens	D 2938
Test Methods for Moisture, Ash, and Organic Matter of Peat Materials	D 2974
Method for Direct Shear Test of Soils Under Consolidated Drained Conditions	D 3080
Test Method for Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression	D 3148
Test Method for One-Dimensional Consolidation Properties of Soils Using Controlled-Strain Load-ing	D 4186
Test Methods for Max. Index Density of Soils Using a Vibratory Table	D 4253
Test Methods for Minimum Index Density of Soils and Calculation of Relative Density	D 4254
Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils	D 4318
Test Method for Creep of Cylindrical Hard Rock Core Specimens in Uniaxial Compression	D 4341
Test Method for Calcium Carbonate Content of Soils	D 4373
Test Method for Creep of Cylindrical Soft Rock Core Specimens in Uniaxial Compression	D 4405
Test Method for Creep of Cylindrical Soft Rock Core Specimens in Triaxial Compression	D 4406
Test Method for pH of Soil for Use in Corrosion Testing	G 51
Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method	G 57
Chlorides, Methods 2, 3 and 13 from USDA Agricultural Handbook No. 60 (EPA 325.1, 325.2, 325.3)	
Sulfates, Method 14 from USDA Agricultural Handbook No. 60 (EPA 375.1, 375.2, 375.3, and 375.4)	
Conductivity, USDA Agricultural Handbook No. 60 (EPA 120.1)	

5.3.3 Test Program

Appropriate laboratory testing programs should be prepared and should include sufficient testing to define appropriate parameters related to:

A.Index properties

B.Natural moisture and density

C.Swell/collapse potential

D.Shear strength

E.Consolidation

F.Hydraulic conductivity

G.Chemical reactivity (as required by the Corrosion Engineer)

H.Other pertinent parameters

Laboratory testing programs for each foundation design will vary depending on factors such as structural loads, foundation types, and subsurface conditions.

5.3.4 Quality Control

Laboratory testing should be performed according to standard methods, utilizing standard equipment. In addition, laboratories conducting tests should have a current certificate of compliance such as from CCRL, AMRL, NVLAP, or Department of Army.

5.3.5 Sample Retention

Representative material samples obtained during subsurface investigations should be retained a minimum of 1 year after completion of the investigation. If possible, samples should be retained in a condition that will allow duplication of previously performed tests.

5.4 Foundation Deign Criteria

5.4.1 General

A wide variety of structures will be associated with DEN Facilities. Foundation designs for DEN structures should be based on site-specific subsurface investigations. Foundation designs should include consideration of structure requirements, possible foundation types, and the design criteria as set forth in the following subsections.

5.4.2 Structure Types

Structures at the DEN will range from small, lightly loaded structures, such as parking tollbooths, to large concourses, hotels, and hangars.

In terms of foundation design, the principal distinction between structures is the magnitude of foundation loads and the method that these loads are transmitted to foundations. This information should be obtained from the Design Engineer and provide the basis for foundation design.

5.4.3 Foundation Types

A variety of foundation types will be appropriate for supporting structures associated with DEN facilities. Foundation types will include shallow foundations and deep foundations. Selection of appropriate foundation type must consider structural requirements, foundation loadings, subsurface conditions, foundation performance criteria, constructability, and economic feasibility. The following subsections should serve as a guideline in the selection of foundation types. Selection of specific structural foundations should be based on the results of site-specific sub- surface investigations.

5.4.3.1 Shallow Foundations

Shallow foundations include spread footings and post-tensioned mats. Shallow foundations transmit structural loads to competent soil or bedrock layers at shallow depths beneath the structure base. Competent layers will be located at shallow depths at many DEN locations.

An important limitation on the use of shallow foundations at the DEN site will be the swell potential of the sup- porting soils or weathered bedrock. Plans to utilize shallow foundations must include a demonstration that the proposed foundation system will support anticipated loads and limit settlement or heave to allowable levels. Proposed shallow foundations must also be constructible and economically feasible.

5.4.3.2 Deep Foundations

Deep foundations such as driven piles and drilled piers (caissons) are used to transmit structural loads to competent soil or bedrock layers below the structure base. Loads may be supported by end bearing pressure, by side (skin) friction, or a combination of both. Piles may be driven, pre-drilled, or cast-in-place. Drilled piers (caissons) may be cast-in-place.

Plans to utilize deep foundations must include demonstrations that the proposed foundation system will support anticipated loads and limit settlement or heave to allowable levels. Deep foundations should also be constructible and economically feasible.

5.4.4 Design Criteria

Foundation designs should be developed for each structure based on site-specific foundation loadings and subsurface conditions. Selection of an appropriate foundation system should be based on the structure and its loadings, the nature and depth of bearing strata, overall site stability, comparative economics, and construction considerations.

Preliminary foundation designs and cost estimates may be based on standard engineering practices and the general recommendations in the following subsections.

5.4.4.1 Foundation Loads

Foundation design loads shall be a combination of structural loads and geotechnical loads.

A. Structural loads

Foundation loads shall be developed by the Design Engineer and shall include the unfactored dead loads and an appropriate combination of live and environmental loads. Typically, foundations are designed for full dead load and at least 50 percent of the live loads. Appropriate foundation loads should be calculated separately for each component of the foundation.

B. Geotechnical loads

Geotechnical loads should be estimated by the Geotechnical Engineer as the most severe combination of overburden, surcharge, uplift, downdrag, and lateral earth pressures. If groundwater is present, the geotechnical loads should consider the effective pressure loads plus hydrostatic loads and/or the total soil pressure loads. The Geotechnical Engineer should supply geotechnical loadings to the Design Engineer.

5.4.4.2 Shallow Foundations

Design of shallow foundations such as spread footings and mats should include consideration of bearing capacity, settlement, and resistance to lateral loads.

A. Bearing capacity

The capacity of the bearing strata to support design loads should be demonstrated based on subsurface material parameters developed from the subsurface investigations, laboratory testing programs, and standard engineering practices. A safety factor, calculated as the ratio of support capacity divided by applied structural loads should be equal to, or greater, than 3.0.

For planning purposes, minimum and maximum allowable (factored) bearing capacities for shallow foundations will likely be in the following ranges:

Table 5-2: Bearing Capacity Ranges

Material Type	Minimum Allowable Bearing Capacity (psf)	Maximum Allowable Bearing Capacity (psf)
Natural Soil	1,000	4,000
Bedrock	3,000	12,000

Estimated values less than the minimum values listed above should be considered grounds for neglecting the capacity of a stratum.

Estimated values greater than the above maximum values should not be used unless substantiated by site-specific geotechnical data.

B.Settlement/heave

Total and differential settlements and/or heave should be estimated based on standard engineering practices. Total estimated settlements should be calculated based on subsurface conditions, and the anticipated foundation loads. Differential settlement should be calculated based on subsurface conditions and soil-structure interactions.

Estimated settlements should be less than allowable limits as stipulated by the Project Manager. Alternately, a total settlement of 1 inch and differential settlement of L/360 (where L is the distance between centers of spread footings, the least dimension of mat foundations, or shortest length of a continuous footing) may be used for planning and estimating purposes.

Heave magnitudes and pressures should be estimated based on standard engineering methods and site-specific conditions. Air-dried swell/consolidation tests should be considered in estimating swell potential and swell pressure for all materials.

Estimated heave should be less than allowable limits set by Project Manager. Generally, allowable heave magnitudes would be similar to allowable settlement magnitudes. Structural dead loads and overburden loads may be considered as counteracting heave forces.

C.Resistance to lateral loads

Resistance to lateral loads for shallow foundations can generally be obtained from:

- Friction between the base of foundations and the underlying soils.
- Passive resistance against the sides of foundations and grade beams.

The soil/foundation friction coefficients and passive resistance should be evaluated based on the site-specific geotechnical conditions. For planning purposes, the following ranges of coefficients can be used:

Table 5-3: Friction Coefficients - Resistance to Lateral Loads

Friction Coefficient	Passive Resistance
0.3 to 0.6	200 to 350 pcf**

**Higher values may be available in weathered bedrock.*
***EFP in psf per foot of depth.*

Passive resistance should only be considered for soils permanently bearing against the foundation, and below depths of frost penetration.

5.4.4.3 Deep Foundations

Design of deep foundations such as driven piles and drilled piers (caissons) should include consideration of support capacity, minimum dead lead, settlement (including elastic shortening), resistance to lateral loads, and foundation installation methods.

A. Supporting capacity

Vertical support capacity for deep foundation can be derived from end bearing and/or side friction. Design supporting capacities should be developed based on site-specific geotechnical data.

For planning and preliminary design and estimating purposes, the following ranges of parameters may be used.

B. The following notes to apply to Table 5-4: Driven and Drilled Piers- Allowable End Bearing Capacities, Table 5-5: Drilled Piers- Allowable Side Friction, and Table 5-6: Driven Piers- Allowable Side Friction Angle Range and Cohesion.

Notes:

- Estimated values less than the minimum values listed above should be considered grounds for neglecting the capacity of strata.
- Estimated values greater than the above maximum values should not be used unless substantiated bysite-specific geotechnical data.

Table 5-4: Driven and Drilled Piers- Allowable End Bearing Capacities provides the minimum and maximum allowable (factored) end bearing capacities for driven piles and drilled piers.

Table 5-4: Driven and Drilled Piers - Allowable End Bearing Capacities

Material Type	Minimum Allowable Bearing Capacity (psf)	Maximum Allowable Bearing Capacity (psf)
Soil	N/A	N/A
Weathered Bedrock	20,000	40,000

Table 5-5: Drilled Piers- Allowable Side Friction provides the minimum and maximum allowable (factored) side friction for drilled piers.

Table 5-5: Drilled Piers - Allowable Side Friction

Material Type	Minimum Allowable Bearing Capacity (psf)	Maximum Allowable Bearing Capacity (psf)
Natural Soil	500	1,000
Bedrock	2,000	4,000

Table 5-6: Driven Piers- Allowable Side Friction Angle Range and Cohesion provides for minimum and maximum allowable (factored) side friction angles and cohesion for design of driven piles.

Table 5-6: Allowable Side Friction Angle Range and Cohesion

Material Type	Minimum Allowable Bearing Capacity (psf)	Maximum Allowable Bearing Capacity (psf)
Sand	28 to 35	0
Weathered Bedrock	10 to 28	700 to 4,000

C.Minimum penetration into bedrock

Deep foundation members should penetrate a minimum of 5 feet into the strata utilized in design. Drilled piers (caissons) should be a minimum of 16 feet in length.

D.Minimum dead load

Deep foundations should have sufficient embedment and/or support dead loads large enough to ensure that heave of soils either beneath the end or in contact with the shaft will not cause uplift of the foundation. Dead loads typically required on deep foundation embedded into potentially swelling mater- ials range from 10,000 to 20,000 psf of cross-sectional area. Site-specific conditions should be considered in selecting an appropriate design value.

E.Settlement

Settlement of deep foundations should be analyzed based on site-specific subsurface data and the structural properties of the deep foundation materials. For planning purposes for driven piles and drilled piers (caissons) designed and installed as described herein, settlements should be one-quarter inch, or less. The Design Engineer should add elastic compression of the pile/pier materials to the estimated geotechnical settlements.

F.Resistance to lateral loads

Lateral loads on deep foundations are generally associated with lateral structural loadings. Resistance of deep foundations to lateral loads is derived from lateral bearing of the foundation shaft on soils and/or weathered bedrock. Lateral load capacities of deep foundations should be estimated by use of p-y curves. Complete solutions for pile forces and deformations generally require computer simulations. For structures at the DEN site, a computer program should be used to model lateral loads on piles. The results of lateral load modeling should be reviewed by the Geotechnical Engineer.

G.Group action

For deep foundations to act as individual support members and realize their full capacity, the minimum center-to-center spacings must be at least 3 times the shaft diameter. End bearing and side friction for groups of deep foundation members spaced closer may be reduced and the potential for settlements or heave may be increased.

Support capacity reductions and settlement/heave analyses should be performed for deep foundation groups not meeting the minimum spacing cited above.

H.Installation criteria

Deep foundations should meet specified vertical and horizontal installation tolerances.

Pile driving should include verification of pile stresses and capacities with PDAs[3]. Exposed portions of driven piles should be inspected to verify they were not damaged during driving. Driven pile lengths should be modified during driving to account for actual subsurface conditions encountered.

Where caissons are to be installed beneath the groundwater table, specific dewatering and concrete placement methods must be specified by the Design Engineer. For example, casing may need to be set into the bedrock to cut off inflow. Alternatively, the piers should be large enough so that pumps can be installed to dewater the caisson hole immediately before concrete is placed. Concrete should be pumped into the bottom of the caisson. Under special conditions, as where caissons are to be installed through saturated sands, it may be necessary to use bentonite slurries to maintain open holes during drilling.

5.4.4.4 Subsurface Perimeter Drains

In potentially swelling soils, it is important to minimize changes in moisture content in soils beneath and adjacent to foundations. One method that can be beneficial is a properly installed and functioning subsurface perimeter drain.

The potential exists for perched groundwater table development. Additional lateral drains may be required in large and/or deep structures where the distance between subsurface perimeter drains may not be adequate for effective drainage. In addition, utility lines can transmit water below structure. The use of impervious collars on utility lines should be considered to minimize transmission of groundwater into structural areas.

Design and installation of subsurface perimeter drains should include consideration of at least the following:

A. Locations

Subsurface perimeter drains should be considered around the periphery of all structures unless the Sub- surface Investigation report specifically says drains are not required.

B. Installation requirements

Subsurface perimeter drains should be constructed with HDPE drainpipe, perforated PVC, or equivalent. The drain should be sized to transmit expected inflows, but in no case be smaller than 4 inches in dia- meter. Perforations should be sufficient to accept the expected inflow but should not exceed 1/4 inch dia- meter and should not be less than 1 square inch per lineal foot of drainpipe.

The drain pipes should be installed in gravel filled trenches, approximately 3 times the drainpipe diameter in width. To avoid clogging of the drain by fine-grained soils, the gravel encapsulating the pipe should be wrapped in drain *geofabric*.

Perimeter drains should be below the base of the lowest foundation level. Drain spacing and depth should be sufficient to maintain the cone of depression below the depth of facilities to be protected. Drains should slope uniformly and positively with a slope of at least 1 percent. The base of the drain excavation should also slope uniformly in the direction of the drain slope.

C. Discharge

All perimeter drains should discharge to a positive, frost-free outlet such as a frost-free gravity draining outfall and/or sump system. Preferably, the sumps should be inside the structure, for frost protection and ease of maintenance. Sumps should be equipped with pumps or prepared for future pump installation if water enters and rises in the sump.

In cases where sump failure could lead to flooding of floor areas, a back-up sump and an alarm system should be included in the design and construction of the subsurface perimeter drain system.

5.5 Slabs at Grade

5.5.1 General

Floor systems for the lowest levels of buildings and parking structures are generally constructed with concrete slabs. Ideally, these slabs are placed directly on underlying stable soils. In areas where the subgrade soils exhibit swell potential, special design considerations must be incorporated to prevent excessive heave, distortion, and/or cracking of the slab. The following slab design alternatives and design criteria should be considered for design of all lower level slabs.

5.5.2 Slab Design Alternatives

5.5.2.1 Slab-On-Grade

[3]Pile Driving Analyser, Pile Dynamics, Inc., Cleveland, Ohio.

A concrete slab placed directly on natural subgrade soils represents the simplest form of slab construction. Slab- on-grade construction is appropriate when subgrade soils exhibit adequate strength and have none or low swell potential. Slabs-on-grade should be separated from surrounding structural members. Adequate subgrade drainage is required.

5.5.2.2 Slab-On-Fill

A concrete slab may be placed directly on structural fill. Slab on fill construction is appropriate where NSP fill is used to replace inadequate soils, or the slab elevation is higher than existing ground surface elevations. Fill used to replace inadequate soils should be thick enough to replace or overcome natural soil inadequacies. In the case of swelling soils, this thickness should be adequate to replace the swelling layer or provide enough surcharge to limit heave due to swell. Fill beneath slabs should be compacted to specified criteria and adequately drained. Generally, it is impractical to consider replacement fills thicker than about 6 feet. Where replacement fills thicker than 6 feet are indicated, it is usually more economical to consider structural slabs.

5.5.2.3 Structural Slabs (Slab-On-Void)

Structural slab systems may be utilized which isolate slabs from subgrade soils and transfer floor loads to surrounding structural members. A structural slab system is appropriate when subgrade soil properties have swelling soils or are inadequate to support the slab and the inadequate soil cannot be sufficiently improved or replaced. In the case of swelling subgrade soils, adequate void space should be provided beneath the slab to prevent contact between the soil and slab in the event of swelling.

5.5.3 Design Criteria

5.5.3.1 Swell Potential Ratings

Swell potential of subgrade soils beneath slabs should be adequately assessed. Swell/Consolidation tests should be performed on relatively undisturbed representative samples of soil or weathered bedrock from beneath the proposed slab in all soil types to a depth of at least 10 feet. Judgement should be applied to appropriately categorize swelling conditions. The lateral distribution of test locations should be at a maximum frequency of 100 by 100 feet, or a minimum of 1 test per 10,000 square feet.

Swell potential tests shall be performed with overburden pressures that correlate with the anticipated overburden on a site-specific basis. Table 5-7: Swell Damage Risk Categories defines swell damage risk categories that may be used as a preliminary guideline for assessing appropriate slab design types.

Table 5-7: Swell Damage Risk Categories

Swell Potential (percent)*	Swelling Pressure (psf)	Swell Damage Risk	Possible Slab Design
0	0	None	Slab-on-Grade
0-1	1000	Low	Slab-on-Grade
1-5	1000-5000	Medium	Slab-on-Fill
3-20	5000-10000	High	Structural Slab
Over 20	Over 1000	Very High	Structural Slab

**Tests performed at natural moisture contents with 200 psf surcharge pressure.*

5.5.3.2 Slab Loadings

Slabs-on-grade and slabs-on-fill should be designed for differential heave loadings in addition to structural loadings. Calculations of expected heave should be made for:

- Slabs-on-Grade
- 4, 5, and 6 feet of Over-Excavation
- Structural Slabs

Consideration should be given to design of the slab for partial loss of support due to differential soil movements.

5.5.3.3 Excavation and Backfill

If a structural slab or slab-on-fill is utilized, the excavation and backfill operations should be performed according to the following recommendations.

The excavation should be to the depth specified in plans and specifications. Appropriate precautions should be taken to ensure stability of excavated slopes or cuts. The bottom of the excavation should be contoured to feed any free water into drainage systems. For slabs-on-fill, excavation should be deep enough to limit heave due to swell to acceptable levels. Backfill should be non-swell potential soils compacted to a degree of compaction consistent with anticipated slab use.

5.5.3.4 Doorways

Consideration should be given to thresholds and landings tied to foundation at doorways to avoid having swelling soils moving the landing.

5.5.3.5 Drainage

A subsurface drainage system should be constructed beneath all slab systems to remove all water from the area. The system should be at least 18 inches beneath the bottom slab elevation or at bottom of footing and sloped to promote flow into a collection system or a frost-free outfall. The system should be provided with a back-up system to prevent flooding beneath the slab in case of subsurface drainage system failure. The subsurface drainage may be a subsurface perimeter drain.

5.6 Lateral Earth Pressure Design Criteria

5.6.1 General

Lateral earth pressures will be exerted on retaining walls, basement walls, culverts, shoring, and other members supporting earth materials. These earth retaining structures must be designed to resist the forces imposed by the supported soil and groundwater.

5.6.2 Earth Retaining Structure Types

5.6.2.1 Rigid

Structural elements that resist earth pressures by their internal structural strength as rigid bodies and transmit the loads to foundations or other bearing elements with minimal elastic structural deformations are known as rigid type earth retaining structures. Rigid retaining structures may or may not yield, but do not deform. Typical rigid retaining structures include basement walls, reinforced concrete retaining walls, grade beams, wing walls, etc. Temporary bracing of normally flexible material (for example, steel with wood lagging) may act as rigid elements if constructed with sufficient restraints.

5.6.2.2 Flexible

Flexible earth retaining structures include sheet pile bulkheads, shoring, and other support elements that may deform as they restrain imposed loads. At the DEN, flexible bulkheads will likely be temporary being utilized only during the construction period.

Flexible supports differ from rigid earth retaining structures in that they can yield within acceptable limits to accommodate the forces imposed on them. Flexible systems include both free standing and tied-back soldier piles and lagging, sheet piles, etc.

5.6.3 Design Criteria

5.6.3.1 Loads

A. Lateral earth pressure

Lateral earth pressure is the pressure exerted by earth material against a structure. The magnitude of the earth pressure is determined by the physical properties of the earth materials, and the amount and direction of structure and earth displacements[4].

The three general conditions of displacement often considered in design of earth retaining structures are the active, passive and at-rest conditions, and are defined as follows:

a. The active case results when the restraint moves away from the supported earth. An example of active pressure would be against a cantilever retaining wall.
b. The passive case results when a structural element moves towards the restrained earth. An example would be where a footing or grade beam is used to resist lateral loads imposed on a structure.
c. The at-rest case occurs where there is no relative movement between earth and the restraint. Such a condition may occur against a stiff, unyielding wall, such as a deep basement wall.

To select the design lateral earth pressure, the Design Engineer will need to evaluate whether the active, at-rest or passive condition (or some intermediate condition) applies. Earth pressure data can then be developed con- sidering the physical properties of the earth material.

Generally, the earth materials are subdivided into two groups, cohesionless (sandy) and cohesive (clayey). Two general theories used to evaluate lateral earth pressure coefficients for cohesionless and cohesive soils are the Coulomb and Rankin methods, which are described in soil mechanics textbooks[5].

In practice, it is common for the geotechnical engineer to present lateral earth pressure recommendation in Sub- surface Investigation reports. Usually, the recommended earth pressures are given as EFP in psf pressure pcf. For sandy soils, recommended EFPs of 35 to 45 pcf are typical. For clayey soils, EFPs of 45 to 65 pcf, and greater may be recommended, depending on moisture conditions. Swelling clays may exert significantly greater pressures.

Even though lateral earth pressure recommendations are often presented as EFP's, these triangular pressure distributions theoretically apply only to free draining cohesionless soils. A triangular EFP may not be appropriate for design of deep, rigid structures, since stresses imposed by backfill compaction may not diminish if the structure does not yield or rotate. The resulting pressure distribution may be more rectangular than triangular. Rectangular pressures distributions are therefore often used for design of deep, rigid retaining structures. Design earth pres- sure distributions typically range from 20H to 25H psf (where H is the height of the wall in feet) for sandy soils to 30H psf, or more, for non-expansive clayey soils.

For many rigid, unyielding wall situations, the rectangular pressure distribution is more realistic than a triangular EFP based on at-rest earth pressure coefficients. However, the at-rest condition should be investigated, and utilized if it produces greater forces and bending movements in the retaining structure.

The at-rest earth pressure coefficients may be evaluated by the following relationship:

4 *Kezdi, Arphad, Lateral Earth Pressure, in Foundation Engineering Handbook, J.F. Winterkorn and H.Y. Fang, editors, 1975*

5 *Terzaghi and R.B. Peck, Soil Mechanics in Engineering Practice, 2nd Edition, John Wiley and Sons, New York, 1967.*

$$K_0 = 1 - \sin\emptyset '$$

Where /' is the effective angle of internal friction.

A special condition exists when earth materials with expansion potential are used in backfill. expansion potential exist or must be used at locations where resulting horizontal swell pressures can exert force on the retaining structure, design lateral pressures must be considered on a case-by-case basis by the Geotechnical Engineer in consultation with the Project Structural Engineer.

Passive resistance to lateral loads was discussed earlier in this section. For other passive pressure conditions, appropriate passive pressure coefficients and/or pressure distributions should be developed by the Project Geo- technical Engineer based on material properties, potential depth of frost penetration, and soil-structure inter- action considerations.

In summary, methods are available to develop lateral pressure distributions based on earth material properties and wall movements. These must be developed based on judgment and experience. Where possible, active and at-rest earth pressures should be minimized by placing drained cohesionless material (sand) in the earth pressure zone of influence and controlling compaction to minimize compaction stresses.

B.Surcharge Loads

In addition to the earth pressure exerted by the retained soil, structures should be designed for forces exerted by surcharges on the backfill. The loading cases of particular interest in the determination of lateral soil pressure are uniform surcharges, point loads, line loads parallel to the wall, and strip loads parallel to the wall.

For the case of uniform surface loading, conventional theories of earth pressure may be used to evaluate lateral pressures. For point, line and strip loads, the theory of elasticity (Boussinesq Analysis) modified by experiment provides acceptable solutions[6] .

a.Uniform surcharge

When a uniformly distributed surcharge is applied at the surface of the backfill, the vertical pressures at all depths in the soil are increased equally. Without the surcharge, the vertical pressure at any depth, h, would be Yh, where Y is the unit weight of the soil. When a surcharge of intensity q (force/area) is added, the vertical pressures at depth h become Yh + q.

The lateral pressure, σ_H, due to the uniform surcharge q, is equal to K_g.

The K value is either the active co-efficient, Ka, the at-rest coefficient, Ko, or the passive coefficient, K_p, depending upon whether the wall tends to move away from, or toward, the surcharge area. The uniform lateral pressure due to the surcharge is then added to the lateral earth pressures.

a.Point loads

The lateral pressure distribution on a vertical line on the retaining structure closest to a point load may be calculated. Away from the line closest to the point load, the lateral stress decreases.

a.Line loads

Continuous wall footings of narrow width, or similar loads, parallel to a retaining structure may be taken as line loads. For this case, the lateral pressure increases from zero at the ground surface, to a maximum value at a given depth, and gradually diminishes at greater depths. The lateral pressure distribution on a vertical plane parallel to a line load may be calculated.

a.Strip loads

Wider wall footings or other similar loads parallel to a retaining structure may be taken as strip loads. The lateral pressure distribution on the wall may be calculated.

C.Hydrostatic loads

Where retaining structures support an unbalance in hydrostatic water levels, such as where a water level exists in the backfill but not in front of the wall, the hydrostatic pressures must be carried by the wall.Hydrostatic pressures are equal to an equivalent fluid pressure of Ywh, where Yw is the unit weight of water, and h is the depth below the water level.

Below the hydrostatic water level, lateral earth pressures should be evaluated based on the buoyant weight of the earth material.

Because the hydrostatic loading condition is ordinarily more severe than the drained loading condition, it is desirable to prevent hydrostatic water levels in wall backfill. For basement walls and retaining walls, this can be accomplished by using free draining backfill material with proper subsurface drainage to carry water away from the base of the fill. Alternate methods including geodrains and geofabrics may also be considered.

Subsurface drainage may be accomplished by properly designed weep holes through retaining walls, or lateral drains at the base of basement walls leading to a positive outlet.

5.6.3.2 Resistance to Overturning

Retaining structures must be supported so as not to turn over under the earth pressure and surcharge loads. Basement and other structure walls are typically restrained by the structure. Freestanding walls need to be analyzed so the restraining moments are at least 1.5 times greater than the activating moments.

5.6.3.3 Resistance to Sliding

Retaining structures must be able to resist the horizontal thrust of the earth pressures and other loads. This can be done structurally for basement walls. For free standing walls, the sum of the available friction on the base of the wall and passive resistance at the toe of the wall must be at least 1.5 times the activating loads. Shear keys on the base of foundations often assist in resisting sliding forces.

5.6.3.4 Structural Requirements

Earth retaining structures must be designated to resist the imposed loads in accordance with the Building Code and other structural requirements.

5.7 Excavation Stability Design Criteria

5.7.1 General

Excavations at the DEN site may be either permanent or temporary, and braced or unbraced. In planning excavations, consideration must be given to the stability of the sides of the excavation. All excavations in which men will work must be braced, sloped back, or otherwise engineered to meet all the requirements of OSHA and all other regulatory agencies with jurisdiction over the project.

5.7.2 Excavation Types

5.7.2.1 Braced

When excavations extend into soil that will not stand stable at the required inclination, the sides of the excavation are usually braced. Narrow excavations are typically braced by struts that support one side of the excavation against the other. The struts hold sheeting, lagging, sheet piles, H-piles, etc. in-place against the face of the excavations. Where excavations are not narrow, the bracing may be by the structural strength of the bracing, as in sheet piles or

6*Steel Sheet Piling Design Manual, U.S. Steel Corportation, 1970.*

soldier piles extending into the subgrade below the excavation, by tiebacks into the supported soil, or rakers extending into the excavation.

5.7.2.2 Unbraced

Where excavations extend into competent materials, such as the weathered bedrock at the DEN site, excavations may not need to be braced. The need for bracing depends on the depth and duration of the excavation, and the strength and jointing of the weathered bedrock. It may be possible to construct fairly deep unbraced excavations into weathered bedrock for periods of time typically associated with structure construction activities.

5.7.2.3 Sloped

Where bracing is not appropriate or economical, the sides of an excavation may be sloped to a stable inclination. At a minimum, the slopes should meet OSHA and other regulatory agency requirements. The sides of sloped excavations should be analyzed using slope stability analysis procedures so that the sum of the forces and moments resisting movement should be at least 1.5 times the sum of the forces and moments tending to produce movement.

5.7.3 Design Criteria

5.7.3.1 Lateral Loads

Lateral loads on braced excavations will be the result of lateral earth pressures, surcharge, and hydrostatic loads.

5.7.3.2 Bracing

The bracing that transmits compressional forces from one side of the excavation to the other should be structurally designed to carry the earth pressure and other loads. Where expansive soils are to be retained, the Geotechnical Engineer should evaluate if additional earth pressures should be included in the design, or specify replacement backfill material.

5.8 Groundwater Control Criteria

5.8.1 General

Control of groundwater is a very important aspect of design and construction of structures at the DEN site, especially for locations underlain by potentially expansive soils and bedrock. The extent of groundwater control will depend on the depth of proposed excavations, the materials into which the excavations will extend, and the site-specific geohydrology. At a minimum, all structures should have subsurface perimeter drains.

5.8.2 Groundwater Occurrence

Based on the data presented in the AAE Preliminary Report (*PGI*), local perched groundwater tables may exist naturally at the DEN site. However, at most locations within the DEN site, there is the possibility of the development of locally perched groundwater tables, as site development proceeds. This is because at most locations, permeability deceases with depth until essentially impervious bedrock is encountered. Thus, water infiltrating into the ground from the surface, landscaped areas, leaking pipes, etc. will tend to migrate downward to the impervious bedrock layers and then mound up or dissipate laterally. At many structure locations, the required excavations will extend into low permeability material such as clay or weathered bedrock. Thus, as water seeps into the ground it may be trapped in the bath tub in which the structure is set. In addition, groundwater may be transmitted by sand and sandstone layers, and by subsurface soils in old drainageways.

Where existing drainages cross the site, there may be shallow groundwater tables within the flood plain soils. Preparation of such sites for structure construction should include provisions for surface and subsurface drainage to make the location suitable for the proposed construction.

5.8.3 Construction Dewatering

5.8.3.1 Infiltration Rate

At those locations where naturally occurring perched groundwater is encountered during construction, the infiltration rate should be estimated by the Design Engineer based on site-specific subsurface conditions. It is anticipated that most naturally occurring groundwater will be contained within and just above the surface of weathered claystone and sandstone bedrock. Within weathered claystone, the groundwater will be in joints and fractures. High infiltration rates would not be expected. In weathered sandstone, locally high infiltration could occur upon initial excavation. It is expected that in both weathered claystone and weathered sandstone, the infiltration rates will diminish with time to relatively low base rates as construction progresses.

Where excavations extend into alluvial materials in drainages, infiltration rates should be estimated based on the site-specific geohydrology.

5.8.3.2 Dewatering Techniques

There are many dewatering techniques available depending on the depth and geometry of the excavation and site geohydrological conditions. Dewatering techniques include such methods as deep wells and well points. However, given the site conditions prevalent at the DEN site, it is anticipated that simple ditch and sump type dewatering will be sufficient at most structure locations. This should be defined for each excavation by the Design Engineer.

The ditch and sump dewatering method consists of digging a collector ditch around the perimeter of the excavation, sloped to sumps from where the collected inflow is pumped from the excavation. If an open ditch is inconvenient, a geotextile lined gravel drain can be installed to carry water to the sumps.

Other simple techniques include trenches outside the excavation limits that extend to depths below the excavation limit, or into impervious weathered bedrock.

5.8.3.3 Water Disposition

Water obtained from dewatering systems should be discharged into an appropriate discharge collection system. Dewatering activities may require permitting from the Colorado Department of Public Health and Environment (CDPHE) and/or the City and County of Denver.

5.8.4 Long Term Control

5.8.4.1 Applications

Groundwater control should be considered for:

A. All structures extending below final exterior grades and/or below hydrostatic water levels.

B. Deep permanent excavations, including all excavations extending within 4 feet of weathered bedrock elevation.

C. Slopes cut into native subsurface materials.

Other locations where undesirable groundwater seepage may occur.

The purpose of long-term control of groundwater is to:

A. Maintain hydrostatic levels below the bottoms of basements, occupied space, excavations, etc

B. Control groundwater that emerges on cut slopes or prevent groundwater from emerging on cut slopes.

5.8.4.2 Infiltration Rate

Design infiltration rates should be established on a structure or site-specific basis by the Design Engineer. For planning and cost estimating purposes only, based on the general site specific data presented by AAE (*PGI*), it is expected that infiltration rates for most long term groundwater control systems will be low, probably as the order of 10 gpm or less for structures and 50 to 120 gpm or less for large slopes and other deep excavations, except for excavations into alluvial aquifers.

5.8.4.3 Typical Drain Sections

Drain sections will vary depending on the purpose and location of the drain and the type of structure/slope to be protected.

The following general principles apply to design of typical drain sections.

A. The drain must be deep enough to maintain the hydrostatic levels at or below design levels. That is, the drain depths must be sufficient to keep the groundwater mound between the drains below design levels.

B. Where there are no anticipated or potential permanent hydrostatic levels, but rather where intermittent perched water or other seepage may develop, the drain should extend through the zone of seepage to a depth sufficient to maintain potential hydrostatic levels below design levels.

C. The drain must slope continuously and positively to an outlet. Minimum drain slopes would typically be 1 percent, unless the Design engineer demonstrates the effectiveness of drains with lesser slopes.

D. The base of the drain excavations should slope continuously and positively to an outlet with a minimum slope of 1 percent, as described for the drain in Step 3, above.

E. The drainpipe should be sized to carry the maximum expected flow, with a factor of safety of 1.2 for less than 100 gpm and 1.5 for flows in excess of 100 pgm but should be a minimum of 4 inches in diameter.

F. The drainpipe should be embedded in washed drain rock (filter material per the applicable CDOH Standard Specification) that is encased in geofabric, or equivalent drain section, that will transmit water to the drain without transporting fines or other subsurface materials.

G. The drain must discharge to a positive outfall that does not freeze and has a capacity to accept the design inflow without backup.

5.8.4.4 Outfall

Drains that constitute portions of long-term groundwater control should discharge to positive, frost free outfalls. Outfalls may be gravity discharges to a surface water course, sumps in which discharge pumps may be placed, gravel drains, storm or sanitary sewers (if allowed by the sewer authority), etc.

A note of caution with respect to gravel drains, the Design Engineer must demonstrate that the drain has sufficient cross-sectional area to transmit the design flow with an appropriate factor of safety, and that the drain has a positive discharge.

Sump-pump discharges to a surface drainage shall extend at least 10 feet away from the structure and discharge to a swale with sufficient capacity to carry the flow. The outlet area must be armored against erosion due to the discharge velocity.

Other outfall details should be developed by the Design Engineer as needed to develop a properly designed and engineered facility.

5.9 Protection of Adjacent Structures

5.9.1 General

When proposed facilities are to be constructed adjacent to existing DEN facilities, steps should be taken to protect the existing facilities from excessive vibrations or displacements. The Design Engineer should assure that construction documents contain specific methods or performance standards for protection to adjacent structures.

5.9.2 Vibration

5.9.2.1 Occurrence

Impact energy from construction operations may produce vibrations on adjacent structures. The level of vibrations is a function of the impact energy, the distance from the impact to the existing facility, and the dynamic stress strain characteristics of the intervening soils. The level of vibration that an existing facility can accept depends on the type of structure and the structure use. Vibration effects are most critical when the existing facility contains vibration sensitive equipment such as computers, switchgear, etc. With respect to people occupying or working in the building, people in quiet office space will be disturbed more by vibrations than people in hall- ways, reception areas, etc.

Experience indicates that high energy construction procedures such as pile driving, ripper excavation and light blasting may produce problem vibrations.

It is assumed that all DEN structures will conform to current building codes and will be designed for the current Denver Building Code Seismic addendum.

5.9.2.2 Protection

To maintain vibrations within acceptable limits, strict limitations should be placed on high energy impact construction activities. For example, blasting should be closely regulated adjacent to existing structures. In addition, drilled piers should be considered in lieu of driven piles.

For planning purposes, it may be considered that to minimize the potential for damage, vibrations due to construction activity should be limited 1.0 in/sec at existing facilities. If the facility is occupied, construction activity should be performed to keep peak particle velocities at 0.5 in/sec or less. However, some facilities may have more stringent criteria. Acceptable vibration levels should be established on a structure specific basis by the Design Engineer. These studies should include preconstruction surveys of ambient vibration levels. In areas of critical concern, vibration monitoring should be conducted during the vibration-producing construction activities.

5.9.3 Excavation

5.9.3.1 Occurrence

Where construction of proposed facilities will require excavation adjacent to existing DEN structures, the existing facility may need to be protected against movements into the excavation. The effect on the existing facility will depend primarily on the geometry of the proposed excavation, and the type of foundation and floor slab system in the existing facility.

5.9.3.2 Protection

The best protection for existing structures is to plan proposed excavations so that existing floor slabs and foundations will be outside the zone of influence of the excavation. Where excavations must be performed within the zone of influence, existing foundations should be supported by underpinning or bracing as required to prevent unacceptable movements. Underpinning must be planned on a case-by-case basis by the Design Engineer.

To document the potential for actual damage due to excavation, a detailed pre-excavation survey should be per- formed on the condition of the existing structure, noting all cracks, displacements, etc.

5.10 Field Instrumentation

5.10.1 General

Field instrumentation should be installed and monitored as necessary to develop foundation design parameters and evaluate foundation performance. The need for field instrumentation should be evaluated on a structure-by-structure basis by the Design Engineer. Field instrumentation, such as simple piezometers, is routinely installed to measure groundwater levels. High quality monitoring wells should be installed if groundwater contamination is known or suspected.

Settlement monitoring is typically not performed at normal structure foundation locations. However, it may be considered where there are unusual or exceptionally large foundation loads, or where foundations are adjacent to the zone of influence of an adjacent excavation.

5.10.2 Groundwater

5.10.2.1 Monitoring Requirements

As previously noted, except in alluvial aquifers in drainages, groundwater at the DEN site is typically expected to exist as local perched groundwater tables. To assess the presence of groundwater on the zone affected by the proposed construction, groundwater levels should be evaluated as a part of all structure subsurface investigations. Groundwater levels should be noted in each boring at the time of drilling, and at later dates so that stabilized water levels can be evaluated. Simple standpipe piezometers should be installed in representative borings so that longer term groundwater measurements can be made.

A condition that may be encountered at the DEN site is localized confined aquifers. These may exist, for example, in weathered sandstone layers confined between weathered claystone beds. The water levels in the sandstone layer may be under artesian conditions. Where subsurface conditions encountered in borings suggest the presence of these locally confined groundwater zones, installation of sealed piezometers should be considered.

Where groundwater contamination is known or suspected, monitoring wells should be installed to evaluate the nature and extent of the contamination. The monitor well locations should be selected based on a site geohydrologic investigation.

5.10.2.2 Monitoring Techniques

As indicated above, the most basic type of ground water monitoring is to observe groundwater levels in open boreholes. Groundwater encountered during drilling should be noted on the boring logs, along with other observations that may indicate groundwater, such as very wet materials, water seeping into the boring, etc. Water levels should be measured in open boreholes 24 hours after completion of drilling, and up to 7 days after drilling, or until groundwater levels stabilize.

Simple piezometers may be constructed by installing slotted PVC pipe, or other similar materials, into open boreholes. The PVC pipe should be backfilled with properly graded sand to a depth above the static groundwater level. Groundwater levels should be observed 24 hours after installation, and periodically thereafter, as necessary to evaluate stabilized and/or changing ground water levels.

Where groundwater levels are to be measured in isolated portions of boreholes, sealed piezometers should be installed. Groundwater levels in sealed piezometers should be monitored as necessary to establish stabilized and/or changing water levels.

All piezometer standpipes, both sealed and unsealed, should be numbered and clearly identified in the field.

Monitoring wells installed to monitor groundwater contamination should be designed by the Design Engineer and comply with applicable EPA, CDOH, and other regulatory agency requirements. As groundwater characterization is usually a requirement of such groundwater studies, monitor wells should be of sufficient diameter (normally 4 inches minimum) so that water samples can be obtained.

5.10.2.3 Reporting

Groundwater data obtained during Subsurface Investigations should be reported in the subsurface investigation reports. Borehole groundwater data should be included in the boring logs. Piezometer data should be tabulated on tables indicating groundwater depths/elevations with dates of observations. Groundwater levels can also be presented graphically.

Groundwater data from monitoring wells should be presented in Geohydrological Reports to meet current EPA or CDPHE reporting requirements.

5.10.3 Settlement/Heave

5.10.3.1 Monitoring Requirements

As noted earlier, it is appropriate to monitor foundation settlement/heave at unusual or exceptionally heavily loaded foundations, or at foundations within or adjacent to the zone of influence of adjacent excavations. It may also be appropriate to monitor movement of slabs-on-grade supported on potentially expansive materials.

5.10.3.2 Monitoring Techniques

The simplest form of settlement/heave monitoring is to establish survey monuments on the foundation/floor slabs of interest. To facilitate future monitoring programs, it is very important to obtain elevations on the top of all as built foundations.

5.10.3.3 Reporting

Settlement/heave monitoring data should be reported as elevation survey data by the dates observed.

End of Chapter

Chapter 6 - Technical Specification Requirements

6.0 General

Designers are required to provide project specifications on all DEN projects in accordance with the Standards and Criteria DSM, Chapter 11. The project specifications should encompass all aspects of the project and be based on industry-standard construction methods and products, with content based on the DEN Standard Specifications (where available) or from an industry-standard guide specification.

6.0.1 How to Use DEN Standard Specifications

6.0.1.1 DEN Technical Requirements

The DEN Standard Specifications listed in this chapter have been developed to ensure project consistency and compliance with DEN policy and procedure. For sections available as DEN Standard Specifications, the designer must obtain and use these sections for their project.

6.0.1.2 DEN Technical Requirements

This provides DEN-specific requirements that must be included in nonstandard specifications for all DEN projects. An itemized list of DEN-specific technical specification requirements is provided, which may include general requirements, product requirements, and execution requirements. The designer shall incorporate these requirements into their project specification content as appropriate for the project scope. Requirements are provided in an outline format similar to construction specifications for ease of incorporation. Content may be copied directly from this chapter, with article/paragraph numbering and structure modifications as needed to ensure a cohesive document.

Note: This chapter is intended to be used as an aid to the development of a project specification and is not intended to represent a complete specification as presented.

The designer is responsible for developing a complete specification, incorporating the requirements, which encompasses all aspects of the project and complies with general specification requirements outlined in the Standards & Criteria DSM, Chapter 11. After incorporating the requirements listed herein, the project specification should be reviewed to ensure it is free of redundant and/or conflicting information.

6.0.1.3 Notes to the Designer

Notes to the designer are included throughout the chapter, shown in red highlighted text. These are provided for guidance and clarification of requirements and are intended for use only by the designer in development of their specification.

Notes to the designer shall not be incorporated into the final project specifications.

6.0.2 Specification Numbering

6.0.2.1 Numbering of Deliverables

Project deliverables should utilize Section names and numbers contained in the latest edition of MasterFormat Numbers & Titles at the time of project kickoff, which may vary from those in this chapter. It is the designer's responsibility to ensure that all applicable DEN requirements are reflected accurately in the appropriate sections of the project specifications.

6.0.2.2 Numbering Provided in this Chapter

Specification section names and numbers provided in this chapter are based on MasterFormat Numbers & Titles, 2014 edition.

6.0.2.3 Product and Manufacturer Listings

Where manufacturers and products are listed in this chapter, they represent approved manufacturers and/or products. Do not include additional manufacturers and/or products for that Article or paragraph without written permission from the DEN Project Manager.

For sections without manufacturer and/or products listed in this chapter, the designer shall select a basis of design based on current industry standards which comply with all applicable requirements in this and other DEN DSMs, the DEN Standard Specifications, and the Denver Building Code. Provide at least (2) acceptable alternatives to the basis of design for all products, for a total of (3) or more acceptable products, except where a sole-source selection has been approved in writing by the DEN Project Manager.

6.1 DEN Standard Specifications

Please contact the DEN Project Manager.

6.2 DEN Technical Requirements

Please contact the DEN Project Manager.

End of Chapter