SECTION 6 – STRUCTURAL DESIGN

SECTION 6 – STRUCTURAL DESIGN CRITERIA

6.1.0 STRUCTURAL DESIGN CODES, MANUALS & SPECIFICATIONS

Load Factor Design, Allowable Stress Design and Load Resistance Factor Design (LRFD) are acceptable design concepts upon written approval from RTD. The designer shall coordinate the specific design methodology with RTD's structural engineer prior to commencing with preliminary design calculations and layout. All structural designs shall be signed and sealed by a Professional Engineer registered in the State of Colorado. All revisions shall be reviewed, and signed and sealed by a Professional Engineer registered in the State of Colorado. Unless otherwise specified herein, the following codes, manuals or specifications as appropriate or codes, manuals or specifications of other local jurisdictions shall guide the structural design.

6.1.1 Building Codes

The most recent edition of: Uniform Building Code, International Building Code, City and County of Denver and State of Colorado, Structural Specialty Code and Fire and Life Safety Code, and local jurisdictional codes, as required.

6.2.0 EARTH RETAINING STRUCTURES

For earth retaining structures located either on caissons or other foundations, the AASHTO Specifications for Retaining Walls and CDOT design specifications shall be followed.

6.2.1 Geometry

Retaining wall layout shall address slope maintenance above and below the wall. Provide returns into the retained fill or cut at retaining wall ends where possible. Any residual wall batter should be into the fill. Design and construction shall consider surface and subsurface drainage. A drainage system shall be provided to intercept or prevent surface water from entering behind walls. A fence or pedestrian railing with a minimum height of 42 inches above a standing surface shall be provided at the top of walls 30 inches or higher.

6.2.2 Type

Metal walls, including bin walls and sheet pile walls, and recycled material walls will not be permitted for permanent retaining walls. Timber walls will not be permitted for permanent retaining walls unless prior approval by RTD. Wall types, proposed for use, shall have successfully been used in similar geotechnical locations and environmental conditions.

6.2.3 Design Requirements

Retaining walls shall be designed in accordance with the applicable standards and references outlined in this Design Criteria. The design of MSE and modular walls near or in bodies of water shall account for soft saturated soils and scour. All project walls near irrigation lines for landscaping shall account for the additional hydrostatic load due to a waterline break. The use of free draining backfill material and/or leak detection devices to reduce

hydrostatic loads on retaining walls shall be included. All wall systems shall be designed to have a minimum service life of 50 years.

6.2.4 Characteristics

Mechanically Stabilized Earth (MSE) Walls - Wall panels shall be constructed of reinforced concrete. Provide corrosion protection for prestressing or posttensioning steel.

Panel joints - shall accommodate differential settlement. Use section 206 of the CDOT – Standard Specifications for Road and Bridge Construction for backfill requirements.

Reinforcing - Cover to reinforcing steel shall be a minimum of 2 inches with forms and 3 inches without forms. All reinforcing, mild or prestressed shall be galvanized or epoxy coated in splash zones of adjacent roadways.

Modular Walls - Modular wall height shall not exceed 15 feet. A mechanical connection to the wall facing for soil reinforcement shall be provided; friction connections relying on gravity alone will not be acceptable.

Cast-in-Place Walls - Cast in place walls shall be designed and constructed in accordance with the current AASHTO Standard Specifications for Highway Bridges, CDOT design specifications and all interims through the present. Construction joint spacing shall accommodate differential settlement.

Anchored Walls - Anchored wall design and construction shall use FHWA RD-82-046, FHWA RD-82-047 and FHWA-IF-99-015 as guidelines. Anchors shall be encapsulated with plastic sheathing. Proof load tests for anchors shall be provided in accordance with the above FHWA guidelines. Shotcrete shall meet the aesthetic requirements set by RTD.

Soil Nail Walls - Soil nail walls may be used when top-down construction is warranted. Soil nail walls shall not be used if ground water seepage will be a problem. Design and construction shall use FHWA-RD-89-93, FHWA-SA-93-086 and FHWA-SA-96-069 as guidelines. Load testing for nails shall be provided in accordance with the above FHWA guidelines. Shotcrete shall meet the aesthetic requirements, including final finish, as established by RTD.

Soil Reinforcement - Soil reinforcement for MSE and modular walls shall be galvanized, epoxy coated steel or geogrids meeting creep requirements of AASHTO Standard Specifications for Highway Bridges. Design shall account for any item projecting through the soil reinforcement. Avoid placing culverts and utilities perpendicular to soil reinforcement within the reinforced soil mass. Soil reinforcement shall be protected from corrosion of metal due to stray electrical currents. Requirements for stray current control shall follow the project standards as defined by RTD.

Structural Diaphragm Walls - Structural diaphragm walls may be used when top-down construction is warranted.

6.3.0 CONCRETE

Structures designed to carry highway loadings shall be designed to current AASHTO and CDOT specification including the most current interims.

The use of lightweight concrete is not allowed for use in structural members.

Minimum allowable concrete strengths shall meet the requirements of Section 601 of CDOT - Standard Specifications for Road and Bridge Construction.

6.4.0 STRUCTURAL STEEL

Structures designed to carry or support highway loadings shall be designed to current AASHTO and CDOT Specifications including the most current interims.

6.5.0 PRESTRESSING STEEL

The maximum diameter for prestressing strands shall be 0.6 inches for a 2 inch minimum spacing and 0.5 inches for a 1-3/4 inch minimum spacing.

6.6.0 POST-TENSIONING STEEL SYSTEMS

Provide corrosion protection for the strands consisting of grout filled galvanized or nonmetallic ducts. Grout shall meet the requirements of Section 618 of CDOT Standard Specifications for Road and Bridge Construction. Prestressing systems shall be from PTI Certified plants.

6.7.0 REINFORCING STEEL

The use of epoxy coated reinforcing steel for all bridges, walls, tunnels and box culverts shall adhere to the requirements of Table 1, Subsection No. 8.1 of the CDOT Bridge Design Manual. The design category for anticipated level of de-icing salt application shall be "Low." Specific reinforcing steel for bridges, not covered herein, shall conform to the requirements of CDOT Standard Specifications for Road and Bridge Construction.

Abutments, pier columns, and superstructures exposed to splash from adjacent roadway shall use epoxy coated reinforcing steel conforming to the requirements of CDOT.

6.8.0 TIMBER

For timber structures other than structures subjected to highway loading, the National Design Specification for Wood Construction, by the National Forest Products Association shall be followed. Timber structures with over 20 feet of span length shall not be allowed for permanent structures.

6.9.0 TEMPORARY STRUCTURES

All materials for temporary structures both above and below ground shall be removed unless given specific permission from RTD to leave in place.

6.10.0 SLABS

Structural slabs shall be designed to handle all loading that may be potentially placed upon them. For slabs in areas handling pedestrian loading and snow loads, design shall include HS15 truck loading at a minimum. Reinforcing in areas exposed to weather and de-icing chemicals shall have galvanized or epoxy coated reinforcement. For slabs subjected to heavier loads, design shall include HS20 loading at a minimum.

6.11.0 PEDESTRIAN TUNNELS

Pedestrian tunnels shall provide a minimum width of 20 feet for pedestrian movement. Pedestrian tunnels shall be well lit and provided with security cameras in accordance with Section 12 of this Manual.

See RTD Light Rail Design Criteria.

6.12.0 PEDESTRIAN BRIDGES

Pedestrian bridges shall be designed in accordance with the requirements of AASHTO Standard Specifications for Highways and Bridges, AASHTO Guide Specification for Pedestrian Bridge, and CDOT Standard Specifications for Road and Bridge Construction.

The Design Engineer shall coordinate with RTD for the design of covers on pedestrian walkways over LRT tracks or roadways.

Pedestrian bridges shall provide a minimum width of 12 feet for pedestrian movement. Pedestrian bridges shall be well lit and provided with security cameras in accordance with Section 12 of this Manual.

6.13.0 PARKING STRUCTURES

6.13.1 Objectives

The design criteria for this section were derived from an evaluation and review of design manuals, agency criteria and existing parking structures that service transit agencies, including RTD.

The objective of this section shall provide the basis for design decisions. The objectives shall be used in the design of new and renovated facilities.

In addition to safety and functionality, the design objectives shall consider these four factors:

- Budget
- Architecture
- Intermodal Transfer
- Community Integration

Budget

The established construction budget shall take precedence over all other factors other than safety and functionality.

Architecture

- Create a civic architecture that is permanent, functional and pleasant. The structure should contribute to the RTD context – one that is not entirely derivative of the transit system, but complimentary of the neighborhoods and community within which it is located and within budget constraints. The structure should maintain an overall system or corridor identity.

- All designs must conform to current editions of all applicable codes (e.g., UBC, IBC, ANSI, ADAAG).
- Make transit safe, secure, friendly and accessible to all, including the disabled.
- Design systems that use sustainable, consistent and maintainable materials that minimize life cycle costs.
- Provide an architectural and urban design framework that defines and encourages TOD opportunities.

Intermodal Transfer

- Provide a safe, efficient, and convenient parking structure configuration for intermodal transfer.
- Provide clear and understandable directional signage.
- Develop operational efficiencies that simplify modal transfers and commuter accessibility.
- Provide the best service possible at a reasonable cost.

Community Integration

- Protect, maintain and enhance existing community values.
- Support TOD that fosters neighborhood friendly and desirable facilities.
- Support transit-related uses that are proximate to the transit facilities.
- Initiate and coordinate programs with the community that limit local traffic impacts and minimize disruption during and after the implementation phase.
- Utilize local jurisdictional processes and agencies throughout project design and implementation.

6.13.2 Modal Hierarchy

Parking structures shall be located to minimize the total passenger access time from all modes and, as applicable, enhance TOD potential.

Access modes for and around parking structures shall be located relative to rail platforms and bus bays in the following hierarchy:

- Light Rail Transit/Commuter Rail
- Fixed route feeder bus
- Other fixed route buses
- Taxi and paratransit (private or flexible route bus) drop off
- Auto drop off
- Bicycle parking

- Auto parking
- Motorcycle parking
- Offsite Pedestrian

6.13.3 Parking Structure Context

The "context" is the state of development that surrounds a perspective parking structure site. It can be residential, commercial, industrial, agricultural, suburban, urban, or rural. The character, quality, land use and future of the context shall direct the site planning and design of parking structures.

While all parking structures are to be compatible with existing RTD facilities each parking structure will also be a derivative of the neighborhoods and communities of which it is a part; therefore, parking structures should:

- Contribute to the character and quality of their context.
- Help establish new development patterns where appropriate
- Reinforce and guide desired and established development patterns.
- Recognize development patterns that can be complemented.
- Establish development patterns in rural areas by providing focus and structure for future development.

6.13.4 Design Goals

Design of parking structures and site planning shall include:

Vehicle and Passenger Flow Accommodation:

- Minimize crowding, travel obstructions, conflicts, disorientation, level changes and physical barriers.
- Maximize safety, reliability and the ability to accommodate emergencies.

Passenger Environmental Accommodation:

- Provide adequate lighting, personal comfort, aesthetic quality, weather protection and security.

Design Flexibility

- Allow for future operating changes with minimal reconstruction.
- Coordinate with RTD during concept design phase on needs for future vertical or horizontal expansion of the structure.

Community Enhancement:

- Minimize impacts on local vehicular and pedestrian traffic.
- Promote desired growth.
- Neighborhood context.

6.13.5 Performance Standards

- Durability – Durable and cost-effective materials shall be used that have consistent wear, strength and weathering qualities. Materials shall be capable of good appearance throughout a 50 year useful life.
- Low Maintenance – Life cycle maintenance costs shall be considered in the evaluation of all materials and finishes.
- Quality of Appearance – Materials shall be appealing and harmonious in appearance and texture. They shall reinforce system continuity while relating to local context.
- Drainage – Positive drainage shall be provided for all surfaces within the structure. Grades shall not be less than 0.5% in order to eliminate construction related sump (bird bath, pond) conditions. Ponding water within the parking structure is not acceptable.
- Cleaning – Materials that do not soil nor stain easily shall be used and shall have surfaces that are easily cleaned in a single operation. All porous finishes subject to public contact shall be treated or finished in a manner that allows easy recovery from "casual vandalism."
- Repair of Replacement – Inventory and maintenance costs shall be minimized. Materials shall be standardized as much as possible for easy repair or replacement without undue cost or operational disruption. For example, hose bibs, electrical outlets, lighting fixtures and lamps, glass or plastic lights, information panels, signs, shelter material, etc., shall be standardized using commonly available sizes and finishes for easy inventory stocking and installation.
- Nonslip – Entrances, stairways, and areas around equipment shall have high nonslip properties. Floor finishes shall be nonslip even when wet. This is particularly important at stairs, elevators, and other areas near station entrances as well as platform areas.
- Corrosion Resistance – Because of moisture and the electrical currents associated with transit operation, special consideration must be given to prevent corrosion. Non-corrosive metals shall be utilized. Structures near the LRT guideway shall be grounded. Stairs shall either be precast or cast in place concrete.
- Compatibility – Selected materials shall be compatible with the Denver area climate.
- Availability – Selection of materials shall permit competitive bidding and emphasize regional products and processes over those not available locally.
- Graffiti resistant products shall be used to protect surfaces susceptible to graffiti. The designer shall coordinate with RTD on which surfaces require protection.

- Pavement markings within parking structures shall include glass beads for reflectivity. Glass beads shall meet the requirements of section 713.08 of the CDOT Standard Specifications.

6.13.6 Functional Design

Parking facility design shall consider the following:

- Access
- User type
- Pedestrian needs
- Wayfinding Signage
- Floor-to-floor height
- Dimensions of site
- Parking geometrics
- Peak-hour volumes
- Flow capacity
- Lighting
- Fire Protection

Level of Service

Vehicular Level of Service (LOS) shall be considered for parking structure entry/exits, geometrics, flow capacity, travel distance, turning radii, and floor slopes. For typical parking structures the LOS can range from A to D with D being the lowest.

The level of service at the access to public ROW shall not be less than C. This may require extra drive/access lanes.

Circulation Systems

Circulation systems shall be oriented with drive aisles parallel to pedestrian flows along the shortest routes to station platforms or bus bays, whenever practical, in order to encourage pedestrians to walk along aisles where they can be easily seen by vehicle drivers.

Perpendicular aisles will be considered on a case-by-case basis with RTD approval. The need for pedestrian sidewalks and crosswalks shall be evaluated by the designer during conceptual planning.

Stall Widths and Parking Modules

In general, parking structures shall utilize 90 degree parking depending on site constraints and parking structure grid layout. For two-way drive aisles, with 90 degree parking, stalls shall be 8.5 feet by 18 feet with an aisle width of 24 feet. The parking module (i.e. two parking aisles and drive aisle) shall be 60 feet wide. One-way traffic with angled parking may be considered on a case-by-case basis, with RTD approval.

6.13.7 Access Design

Entry/exit areas for parking structures are critical locations. Care must be taken to determine where entrances and exits will be placed with relation to access roadways, bus lanes, pedestrian movement, TOD and bicycle paths. Primary pedestrian paths through the parking structure shall not be located near entry/exits areas.

Entry/exit areas shall be designed for the parking peak and daily loads. Additionally, entry/exit lane lengths and widths shall be designed to accommodate future revenue control equipment. Depending on peak loads and total parking capacity, more than one access point shall be considered.

Kiss-n-rides (short term parking) shall be incorporated into the parking structure design. Kiss-n-rides located within the parking structures must not interfere with other vehicles trying to move through the facility. When RTD surface parking is located adjacent to a parking structure, kiss-n-rides shall be located within the surface lot.

6.13.8 Security

See Section 12 of this Manual for security requirements at parking structures.

6.13.9 Lighting

Lighting for parking structures shall meet the minimum requirements set forth in Section 9 of this Manual.

These standards recommend minimum illuminance criteria for the safe movement of vehicle traffic and pedestrians within a parking structure. They also recognize the need to deter criminal activity and meet energy constraints. The lighting must also be adequate for CCTV usage within the facility.

Lamp and fixture selections will be governed by RTD. Refer to Section 9 of this Manual for additional information.

Light poles used on the top tier of all facilities shall be hinged near the base to allow easy access to the fixtures and lamps.

6.13.10 Signage and Graphics

Signage provides directions, identification, and warnings, as well as other information to the users of the parking structure. Graphics are the means by which the information is presented on a sign. It is the intention of RTD that the signage in the parking facilities is plain, concise and simple.

Signage shall be in accordance with the requirements of the local jurisdiction, MUTCD, ADA and shall be clear, understandable and provide total coverage.

6.13.11 Structure

Structural systems for parking structures shall be either precast prestressed concrete or cast in place post tensioned concrete and should consider cost, availability, quality, estimated life, function and appearance. The structural elements shall be consistent and replicated from one zone to the next, in order to simplify construction and minimize costs. Unique, aesthetically different and diverse structural elements within an individual structure are discouraged.

6.13.12 Architecture

The standard façade for parking structures shall be precast acid etched colored concrete panels. Maximum glass size for stair towers and elevators shall be 16 square feet (4' x 4').

6.13.13 Fire Protection

New parking structures and renovation projects shall be designed to incorporate efficient, cost-effective passive and automatic fire protection systems. These systems are effective in detecting, containing, and controlling and/or extinguishing a fire incident in the early stages. Fire protection engineers shall be involved in all aspects of the design in order to ensure an acceptable degree of protection of human life from fire and the products of combustion as well as to reduce the potential loss from fire (i.e., real and personal property, operations).

Planning for fire protection in and around a building involves an integrated systems approach that enables the designer to analyze all of the building's components as a total building fire safety system package. The analysis requires more than code compliance or meeting the minimum legal responsibilities for protecting a building. Therefore, it is necessary to creatively and efficiently integrate code requirements with other fire safety measures as well as other design strategies to achieve a balanced design that will provide the desired levels of safety, including and most importantly, coordination with the local fire authority.

Refer to Section 12 and the following for specific requirements:

- NFPA 88A, Standard for Parking Structures
- Uniform Fire Code
- Local jurisdiction fire and building codes

6.13.14 Maintenance Objectives

- Maximize ease of replacement
- Maximize ease of construction
- Maximize the use of available materials and finishes
- Maximize the use of durable materials and finishes
- Maximize the use of similar materials, finished and components.

- Maximize the use of new improved materials and finishes
- Minimize the number of unique and different components
- Minimize the number of shapes
- Minimize life cycle costs

6.13.15 ADAAG

Parking structures shall be designed to conform to all regulations in accordance with ADAAG. This will include accessible paths, number of ADA parking stalls, etc.

6.14.0 GEOTECHNICAL ANALYSIS

The soils in the Denver metropolitan area vary. Soil and geologic data and reports for the preliminary design of structures shall be site specific. Preliminary recommendations shall be provided in the project structural reports prepared during the Preliminary Engineering phase. On Final Design, site-specific soil and geological data shall be obtained to develop the design parameters.

Commonly used foundations for bridges, retaining structures and buildings include: spread footings, driven precast concrete piles and drilled shafts. Foundations recommendations shall be made in a site-specific project geotechnical report. Foundations shall be designed according to AASHTO, CDOT Standards, or local requirements. River scour shall be included in geotechnical reports where appropriate.

6.15.0 LOADS AND FORCES

See RTD Light Rail Design Criteria.