5.1.1 GENERAL REQUIREMENTS FOR ALL WALL TYPES

5.1.1.A GENERAL

Retaining walls shall be designed for a service life based on consideration of potential long-term effects of corrosion, seepage, stray currents and other potentially deleterious environmental factors on each of the material components comprising the wall. For most application, permanent retaining walls should be designed to resist corrosion or deterioration for a minimum service life of 75 to 100 years.

5.1.1.B WALL TYPES AND SELECTION STUDY REPORT

All wall types as classified in Subsection 5.3 and approved proprietary wall systems as listed in the CDOT pre-approval wall list developed through the process as described in Subsection 5.2 shall be fully considered and used for a retaining wall project.

To insure all feasible wall systems are included and generate best decisions, the wall type selection process as shown in the Subsection 5.4 shall be followed. The selection process shall be documented and the work sheets, as shown on Subsection 5.5, shall be used as evidence to support the decision.

The Wall Selection Study Report shall be a stand-alone report with a cover letter and a site plan which clearly indicates the names and locations of the walls.

5.1.1.C WALL DEFAULT DESIGN AND DESIGN ALTERNATIVE(S)

The designer should come up with a default detailed design along with the design alternative(s) if applicable. The requirements for assigning alternate wall are described in Subsection 5.8. The default design is defined to mean the best wall obtained from the selection process. For earth retaining wall project, regardless of the type of wall actually constructed (default or alternate), the measurement and payment are based on the plans of default design as specified in Subsection 5.6. Design alternatives are the products of the selection process described in Subsections 5.4 and 5.5. The design alternatives furnished in the bidding documents shall be at the level of conceptual designs and in the form of typical profiles with dimensions. Using Subsection 5.7 as guides, the designer shall specify the requirements of the Contractor or supplier prepared designs and plans for the design alternative(s).

5.1.1.D OBJECTIVES AND CONSTRAINTS OF RETAINING WALL DESIGN PROJECT

For all earth retaining wall design projects the objective and constraints should be properly defined. These include, but are not limited to, wall geometry, such as: 1. Tolerance on finished product; such as vertical and horizontal position of the wall top line. 2. Allowable long-term wall settlement.

Different allowable long-term wall settlements along the alignment of the wall may be specified to facilitate a smooth transition on top of wall elevation between wall on deep foundation at one end and spread footing at other end.

5.1.1.E GEOLOGY REPORTS AND REQUEST OF ADDITIONAL BORING LOGS

For earth retaining wall projects a request for a preliminary geology report should be done right after the completion of roadway design. Without the exact locations of bridge piers and abutments a default boring log spacing may be

specified to speed up the process and provide valuable information. Wall selection should be based on the preliminary geology report. During the selection process <u>if additional boring log information is needed</u> and requested by the designer an intermediate report should be provided to the designer. The final geology report shall comment on the foundation(s) related to the selected wall type(s) and if applicable give the related design parameters such as properties of on-site fill material for a cut/fill scenario and properties of anchored zone for a tieback case.

5.1.1.F WALL DESIGN BASED ON PLANE STRAIN CONDITION

All walls can be designed with a unit width (except that the plane strain condition is no longer valid, when conditions exist such as wall alignment across a ravine, founded on sloped compressible layer, has a non-uniform seepage force, flood plain erosion is anticipated, etc.). In case of doubt a cross-section of the soil strata along wall alignment plus soil strata section(s) across wall alignment are needed, for serious landsliding potential and a three dimensional study may be needed to determine the pattern of fill movement and the corresponding deformation of the wall. Designer must bear this in mind.

5.1.1.G BRIDGE ABUTMENT WALL

The permissible level of differential settlement at abutment structures must be considered to preclude damage to superstructure units. The following data developed by Molten (FHWA TS-85-228) shall be used as the upper bound of serviceability criteria for abutment wall design.

For span lengths of less than 50, feet differential settlement up to 2 inches between supporting members can be tolerable with maximum negative stress increases in continuous beams on the order of 10 percent.

For span lengths in excess of 100 feet, limiting angular distortions to .005 of span length for simple span bridges and 0.004 of span length for continuous bridges would generally yield increases of maximum negative stress on the order of 5 percent.

For span lengths in the 50 to 100 feet range, differential settlement should be limited to three inches between supporting members to insure that maximum negative stress or stress increases in continuous beams is kept below 10 percent range.

5.1.1.H QUALITY ASSURANCE OF WALL DESIGN AND CONSTRUCTION

A quality assurance plan is the vital center of earth retaining wall project. The plans and specifications shall outline the necessities of quality assurance in design as well as in construction.

5.1.2 CONCRETE CANTILEVER RETAINING WALL

5.1.2.A TOP OF WALL

For a retaining wall without a curb or concrete barrier attached, the top of the wall shall be a minimum of one foot above the ground at the back face.

5.1.2.B FOOTING SLOPED OR STEPPED

Sloped footings are preferred with maximum slope of 10 percent.

Stepped footings may be used with a maximum step of 4 feet.

5.1.2.C FOOTING PRESSURE

For retaining walls under 10 feet in height, or bearing pressures of 1 ton per sq. ft. or less, the designer shall determine if an Engineering Geology Report is needed.

For design height greater than 10 feet, the bearing pressure shall not exceed the allowable pressure as determined by an engineering geology report.

5.1.2.D FOOTING-COVERS

The top of the footing shall have a minimum cover of 1’-6".

The bottom of the footing shall be a minimum of 3 feet below finished grade.

5.1.2.E GUTTER

If the area behind the retaining wall is relatively large and a substantial amount of run-off is anticipated, a concrete gutter is required behind the wall in addition to the drainage required by AASHTO.

5.1.2.F EQUIVALENT FLUID WEIGHT

The requirements and recommendations of applying lateral earth pressure are given in Subsection 5.9.

5.1.3 EARTH WALL (M S E WALLS AND SOIL NAILING WALLS)

5.1.3.A CONSTRUCTION AND ERECTION

Construction and erection shall be as per approved construction drawings and shop drawings. If a proprietary product is used, a company representative shall be present at the project site to assist the Fabricator, Contractor and Engineer until all involved parties are familiar and confident in their functions.

5.1.3.B WALL FACING

For a retaining wall supporting roadways without a curb or concrete barrier attached to the top of wall, there should be a maximum of 4 to 1 slope and 3′ minimum horizontal distance from back of facing to any load carrying member such as rail posts, high mast lights, edge of slab and etc. Run-off shall not be permitted to pass freely over the wall surface; rather, a wall coping, drain system, or a properly designed roadway ditch shall be used to carry run-off water along the wall and to be properly deposited.

For a retaining wall with a curb and concrete barrier attached to the top of facing there should be a minimum 8′ wide (including rail), 20′ long monolithically constructed reinforced concrete barrier and slab system to carry and spread loads.

A minimum 12" wide, properly attached geo-textile fabric either per vertical or horizontal joint at backside is required to protect fines from washing away.

5.1.3.C IMPERVIOUS MEMBRANE

For a retaining wall with reinforcement subject to corrosion (e.g., a metal reinforced MSE wall supporting a roadway which is de-iced with chemicals), an impervious membrane should be placed above the reinforced zone and sloped towards properly designed collector drains. The membrane shall have enough coverage area to intercept all de-icing agents.
The impervious membrane shall be high density polyethylene, 30 mil in thickness, formulated with a minimum of 2% by weight of finely ground carbon black, 20 feet minimum roll width and conforming to the following additional requirements:

Dimensional Stability	-	ASTM D-1024 : + or -2 percent
Tear Resistance	-	ASTM D-1004C: 22 lbs. min.
Resistance Soil Burial	-	ASTM D-3083 : 90 percent Retained Strength

5.1.3.D DRAINAGE BLANKET

For a retaining wall supporting roadways in side hill cuts, geometric involving ground and seepage water, and fills with marginal quality, a drainage blanket should be constructed at the back of reinforced zone to intercept water.

For a retaining wall using cohesive fills a properly designed drainage system with a 2′ minimum thick geo-textile bounded drainage blanket at the back of reinforced zone should be used.

5.1.3.E FILL MATERIAL OF METALLIC REINFORCED ZONE

Fill material shall meet the following requirements when tested with laboratory sieves:

Sieve Size	Percent Passing
3 Inches	100
3/4 Inches	20-100
No. 40	0-60
No. 200	0-5

Metallurgical slag or cinders shall not be used except as specifically allowed by the designer. Furnish material exhibits an angle of internal friction of 34 degrees or more, as determined by AASHTO-T-236, on the portion finer than the number 10 sieve. The backfill material shall be compacted to 95% of AASHTO T-99, method C or D at optimum moisture content.

Provide material meeting the following electrochemical criteria:

Criterion		TEST Method
Resistivity	> 3,000 Ohm-centimeter	Cal. DOT 643
Chlorides	< 50 parts per million	Cal. DOT 422
Sulfates	< 100 parts per million	Cal. DOT 417
PH 6-10		Cal. DOT 643

On-site or local material of marginal quality can only be used on the default wall design with the discretion and assignment of the designer.

5.1.3.F CORROSION PROTECTION OF CARBON STEEL REINFORCEMENTS

Corrosion resulting from the use of de-icing salts in winter time, ph value of ground water, and chemical composition of fill material shall be considered in the design to ensure a design to meet design life. For a design which meets the requirements of this Subsection the following corrosion rates will apply.

For zinc: 15 um/year (first two years).
4 um/year (thereafter).

For carbon steel after zinc loss:
12 um/year

If fusion bounded epoxy coating is used on hardware and/or reinforcements, the minimum thickness shall be 18 mil.

5.1.3.G LIMITATIONS ON SOIL NAILING WALL

This type of wall shall not be used except on an experimental feature subject to prior approval by Staff Bridge.

5.1.3.H DURABILITY OF POLYMERIC REINFORCEMENTS

In the absence of reliable information regarding the quality control of the construction process, the allowable strength of the geo-synthetic should be decreased by 50 percent to account for site damage. Facings shall be used for protection from ultraviolet (UV) effect and possible vandalism. A minimum of 4.5 inches of an articulate precast reinforced concrete facing system or 6" x 6" treated timber structural solid facing is required.

5.1.3.I FILL MATERIAL OF POLYMERIC REINFORCED ZONE

1. Fill material shall meet the following requirements when tested with laboratory sieves:

Sieve Size	Percent Passing
3 Inches	100
No. 40	0-60
No.200	0-15

2. Plasticity Index (PI) shall not exceed 6 or internal friction shall be 25 degrees or more as determined by AASHTO-T-236.

3. Soundness; the material shall be substantially free of shale or other soft poor durability particles. The material shall have a magnesium sulfate soundness loss (or an equivalent sodium sulfate value) of less than 30 percent after four cycles.

4. Pea gravel shall be used to fill between the facing to the 1 to 1 sloped selected fill at each lift unless other provisions are made and approved by the designer to ensure the quality of compaction adjacent to facings.

5. The percent of relative compaction shall be equal to or greater than 95 percent as per T 99, or 90 percent as per T 180 of AASHTO.

On-site cohesive, or local, granular material with sharp edges having marginal quality can only be used on the default wall design with the discretion and assignment of the designer.

5.1.3.J QUALITY ASSURANCE OF CONSTRUCTION

1. The material supplier shall furnish material in compliance with the specifications and with copies of all test results attached.

2. During construction the CDOT shall have a plan for sampling and material testing to ensure that the material meets the specifications in the contract document.

CDOT PROCEDURES OF PROPRIETARY WALL APPROVAL

The recent growth of proprietary earth retaining systems provides many cost effective designs. Prior to being adopted and listed as feasible alternate wall systems in CDOT planning and contract documents, all proprietary products must go through the departmental approval process. The criteria for selection and placement on the approval list are as follows:

A. A supplier or his representative must request in writing that the proprietary wall or wall system be placed on the CDOT pre-approved alternate systems. All new systems shall go through the Department's Product Evaluation Procedure (DPEP) and be approved prior to use on Department projects. The request of application form of product evaluation (Form No. 595) and all correspondences shall address to

Product Evaluation Coordinator,
Department of Transportation,
Staff Material Branch,
4340 East Louisiana,
Denver, CO 80222 Phone No. (303)757-9269

The Product Evaluation Submit Package shall contain the followings:

* A cover letter,
* DOT Form 595,
* Wall Record(s) (Page 5 of 5 of this Subsection)
* Supporting documents (10 items described in this Subsection).

B. The Department will evaluate and approve the system, based on the following considerations.

* The system has a sound theoretical basis so that the Department can evaluate its claimed performance.

* Past experience in construction and performance of proposed system, or the supplier can convince the Department of the soundness of the product by the findings of an experimental study.

* A letter from a P.E. registered in Colorado certifying the product.

For this purpose, the supplier or his representative must submit a package which satisfactorily presents the following items:

1. Complete design procedure and calculations.

2. System theory and the year it was proposed.

3. Laboratory and field experiments, if applicable, including instrumentation and monitoring data which support the theory of product design.

4. Applications with descriptions, including length, height, location and photos, and a list of users including names, location, and phone numbers if available.

5. A sample of the analysis and design of wall elements with different back slope geometries (as in Exhibit 1), if applicable the design of wall attachments (Exhibit 2), all design calculations and assumptions, minimum factors of safety, estimated life, corrosion protection design for soil reinforcement elements that conforms to the latest AASHTO and related ASTM standards.

6. Design aids, design manual, design charts, or computer software may be included if applicable.

7. Sample material and construction control specifications showing material type, quality, certifications, field testing, acceptance and rejection criteria and placement procedures.

8. A well documented field construction manual describing in detail, and with illustrations where necessary, the step by step construction sequence. A copy of this manual should also be provided to the contractor and the project engineer at the beginning of wall construction.

9. Typical unit costs, supported by data from actual projects if applicable.

10. Limitations of the system, data provided must show allowable settlement, maximum toe pressure, equivalent strength parameters of backfills, precautions required during excavation and construction, as well as the possibility of internal and external failure mode.

It is the supplier’s option to submit preliminary design criteria to CDOT before the development of a formal submittal for DPEP. This submittal will be given a thorough review by the Department with regard to the design, constructibility and anticipated performance of the system.

In the submittal package, a cover letter and the record information (format as shown on Exhibit 3) for each wall type submitted are required. The Department’s position on the submission, i.e. acceptance, pending further information, or rejection, with technical comments will be provided by a written notification from CDOT.

Even though a system has been pre-approved, the Department retains the right to decide whether a particular system is appropriate for a given site or location. The list of the pre-approved walls will be revised periodically and the most updated list will supersede the previous one.

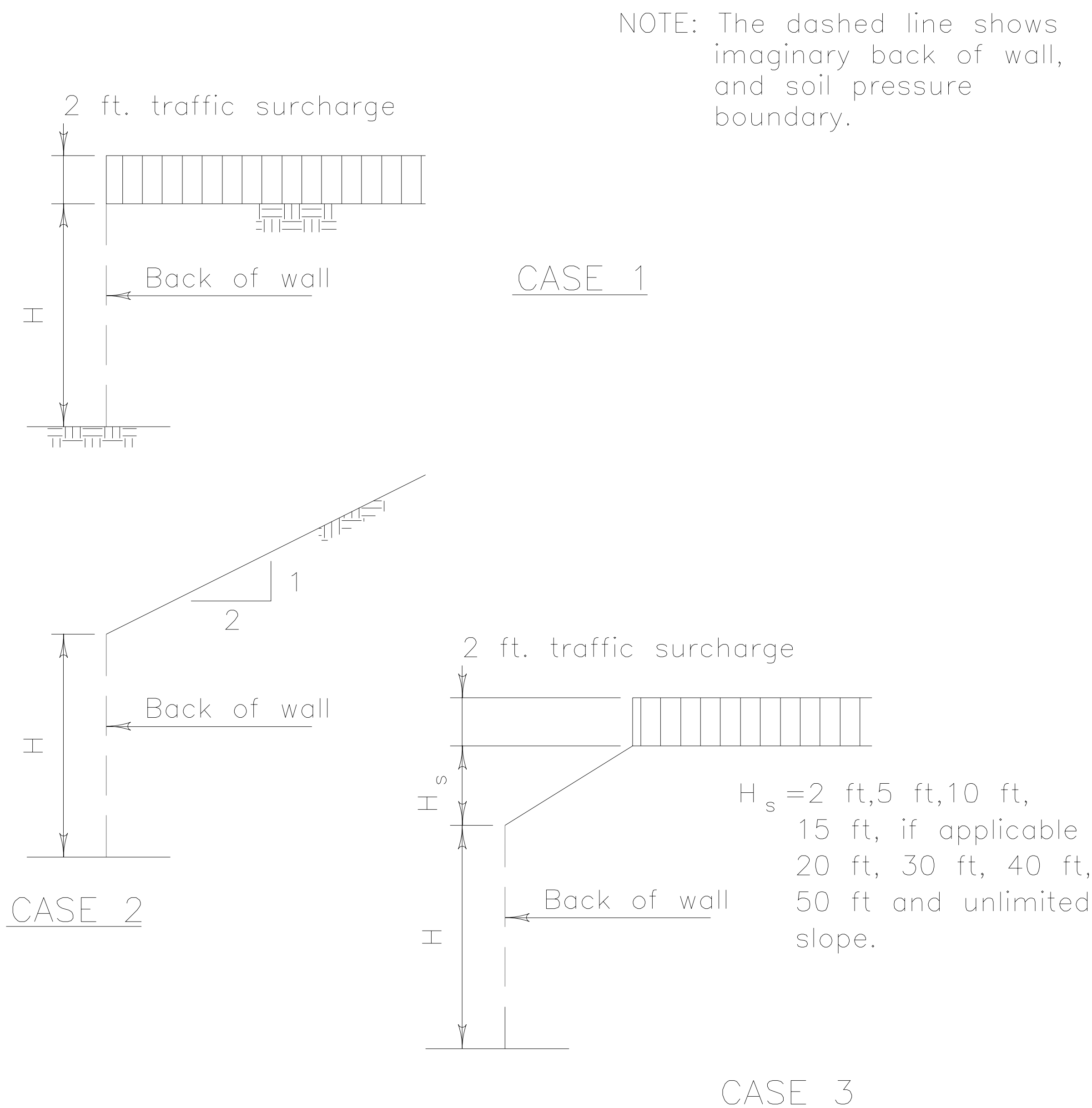


EXHIBIT 1 WALL BACK SLOPE GEOMETRY

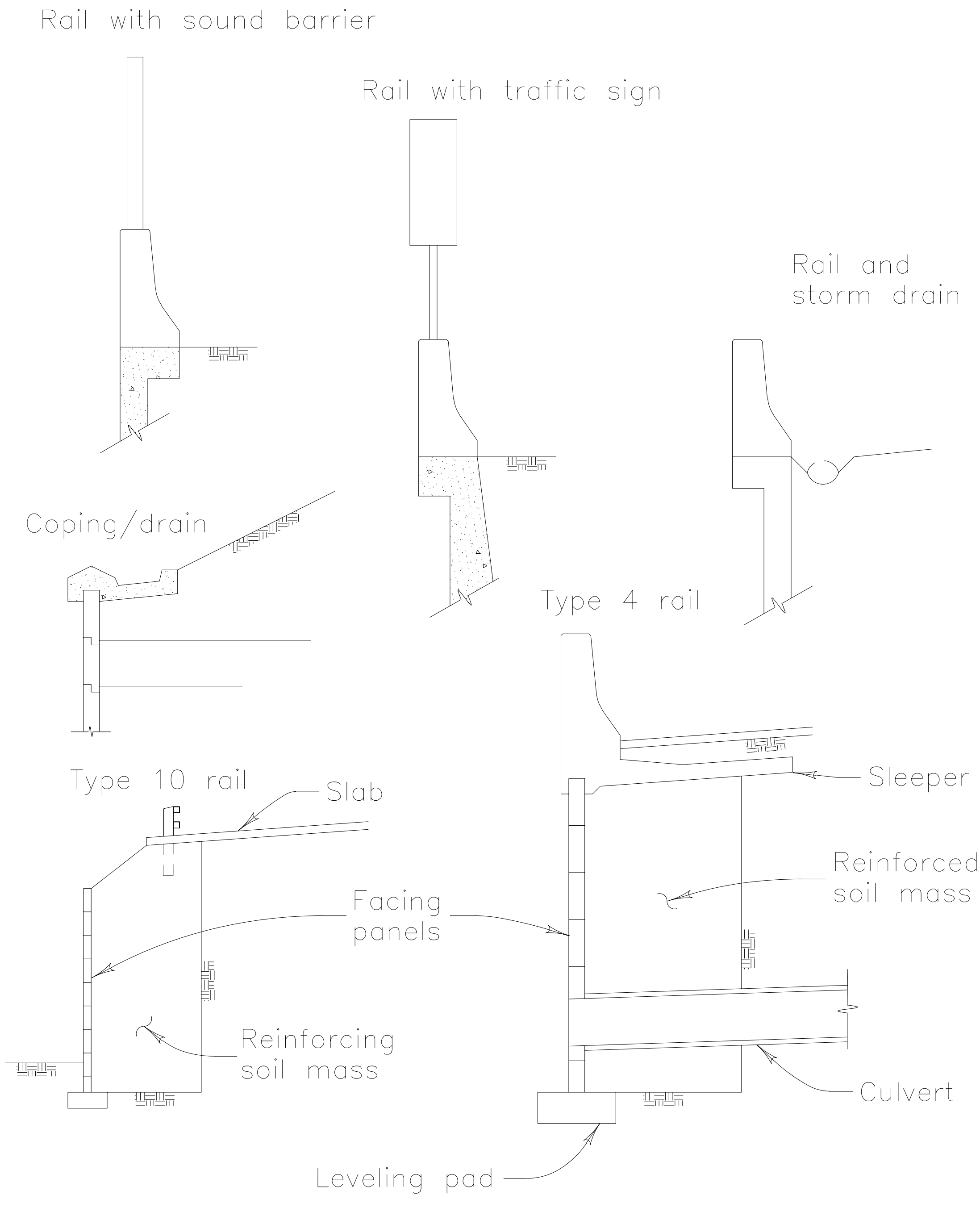


EXHIBIT 2 WALL ATTACHMENTS

WALL NAME(TM):____

____

PATENT INFORMATION (no. and duration of validity):________________________

____

RANGE OF WALL HEIGHT:____

____

WALL SCENARIO (if applicable):

* TYPE AND CONDITION OF STRUCTURAL BACKFILL MATERIAL:__________________

____

* TYPE AND CONDITION OF RETAINED FILL:_________________________________

____

* EQUIVALENT STRENGTH PARAMETERS OF REINFORCED SOIL MASS FOR GLOBAL STABILITY ANALYSIS OF INTERNALLY STABILIZED SYSTEM:___________________

____

* DRAINAGE DESIGN AND/OR ASSUMED WATER PRESSURE:________________________

____

* MINIMUM DEPTH OF TOE COVER:____

____

* MAX. ESTIMATED POST-CONSTRUCTION WALL LATERAL MOVEMENT (ROTATION AND TRANSLATION):____

____

* MAX. ALLOWABLE SETTLEMENT OR DIFFERENTIAL SETTLEMENT:_________________

____

* MAX. TOE PRESSURES (@ 5’ increment to max. height):___________________

____

____

* SURFACE TREATMENT OF BACKFILL:_______________________________________

____

WALL ATTACHMENTS (circle proper applicable items):

* RAIL, * SOUND BARRIER, * TRAFFIC SIGN,
* WALL COPING/DRAIN, * RAIL WITH EMBEDDED POST,
* RAIL WITH SLEEPER SLAB, * POST WITH CHAIN LINK, * FACING PANEL,
* LEVELING PAD.
* OTHER (SPECIFY)____

WALL APPLICATION (circle proper applicable items):

* EARTH RETAINING, * BRIDGE ABUTMENT, * EMBANKMENT,
* FLOOD CONTROL, * UNDERPASS, * LANDSCAPING.
* OTHER (SPECIFY)____

(FORM TO BE FILLED IN WITH COVER LETTER BY APPLICANT)
(ATTACH MORE SHEETS IF NEEDED)

EXHIBIT 3 CDOT PRE-APPROVAL WALL FORMAT

EARTH RETAINING WALL CLASSIFICATION

A classification system is the essential part of the description and selection of different earth retaining wall types.

The earth retaining walls can be logically classified into three categories according to basic mechanisms of retention and source of support.

1. An externally stabilized system uses a physical structure to hold the retained soil. The stabilizing forces of this system are either mobilized through the weight of a morpho-stable structure or through the restraints provided by the embedment of wall into the soil, if needed, plus the tieback forces of anchorages.

2. An internally stabilized system involves reinforced soils to retain fills and sustain loads. Adding reinforcement either to the selected fills as earth walls or to the retained earth directly to form a more coherent stable slope. These reinforcements can either be layered reinforcements installed during the bottom-to-top construction of selected fills, or be driven piles or drilled caissons built into the retained soil. All this reinforcement must be oriented properly and extend beyond the potential failure mass.

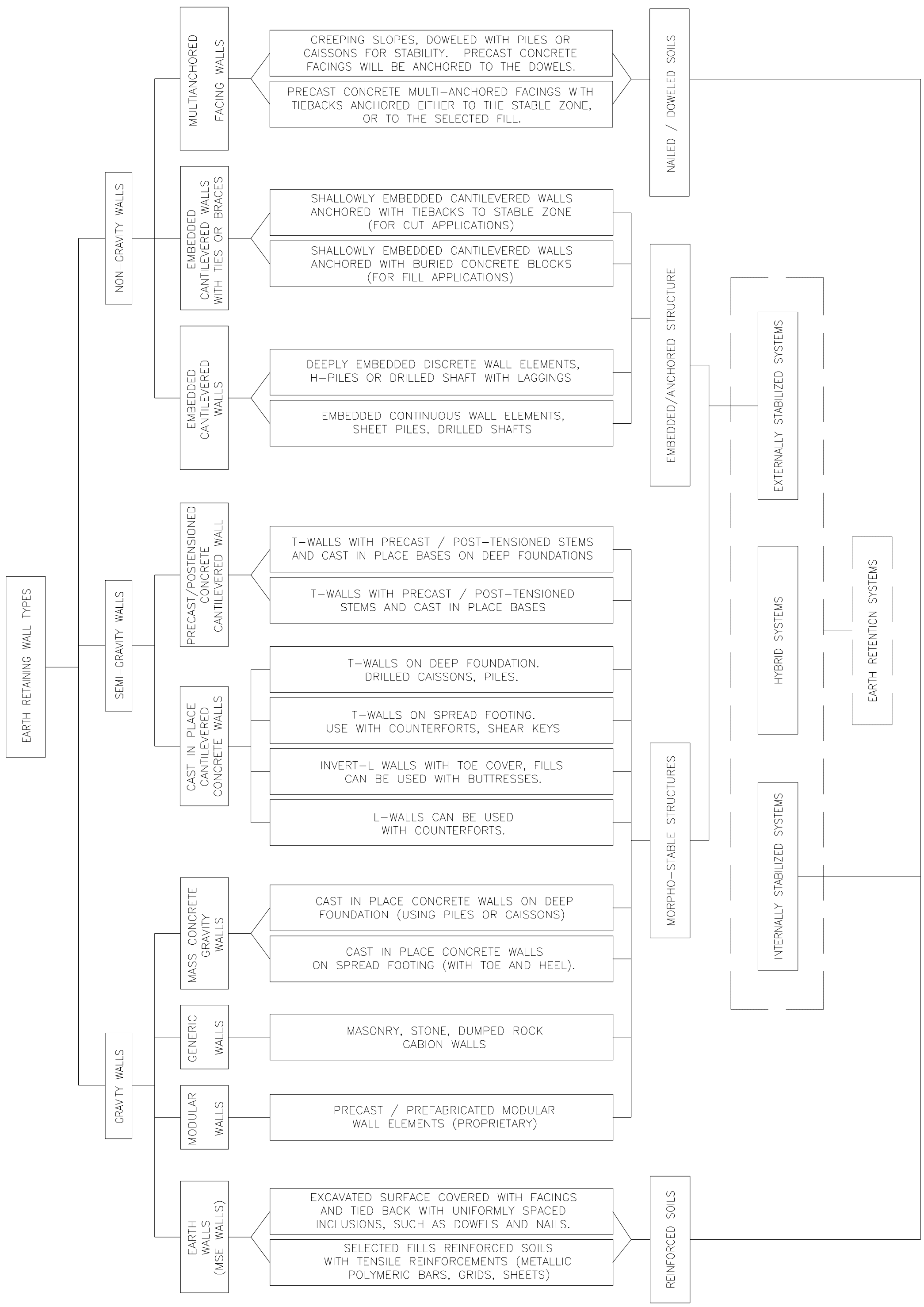
3. A hybrid or mixed system is one which combines elements of both externally and internally stabilized systems.

The conventional earth retaining wall types can be grouped as gravity walls, semi-gravity walls and non-gravity walls as follows:

The gravity walls derive their capacity through the dead weight of integrated mass which can be either externally or internally stabilized systems. They can further be classified into four types; <u>First</u> is an externally stabilized system, generic walls such as masonry, stone, dumped rock and gabion wall; <u>Second</u> is an externally stabilized system; modular walls which can be either precast concrete or prefabricated metal bin wall; <u>Third</u> is an internally stabilized system; earth walls with either facing covered cuts in situly doweled with uniformly spaced top-to-bottom constructed nails or selected fills reinforced with tensile reinforcements which can be either metal (inextensible) reinforcements or geo-textile (extensible) reinforcements, and <u>Fourth</u> is an externally stabilized cast-in-place mass concrete wall or low cost cement treated soil wall with anchored precast concrete facings.

The semi-gravity walls derive their capacity through the combination of dead weight and structural resistance. Concrete cantilever walls designed with different shapes can be further classified into two groups; <u>First</u> is the conventional cast in place wall, and <u>Second</u> is a prefabricated system wall, wall with cast-in-place base and all kinds of innovative precast post-tensioned stems. They are, in general, externally stabilized systems and can be either on spread footings or deep foundations such as caissons or piles.

The non-gravity walls derive lateral resistance either by embedment of vertical wall elements into firm ground or by anchorages provided by tiebacks, dowel actions provided by piles or drilled caissons into stabilized zone. They can be classified into: First, an externally stabilized system with embedded cantilever walls, with or without ties such as sheet pile walls or slurry concrete walls with or without multiple anchorages. Second, an internally stabilized system such as creeping slopes externally covered with multi-anchored facings and internally doweled with pile/caisson inclusions.


EARTH RETAINING WALL TYPES
NON-GRAVITY WALLS
SEMI-GRAVITY WALLS
GRAVITY WALLS
MULTIANCHORED FACING WALLS
EMBEDDED CANTILEVERED WALLS WITH TIES OR BRACES
EMBEDDED CANTILEVERED WALLS
PRECAST/POSTENSIONED CONCRETE CANTILEVERED WALL
CAST IN PLACE CANTILEVERED CONCRETE WALLS
MASS CONCRETE GRAVITY WALLS
GENERIC WALLS
MODULAR WALLS
EARTH WALLS (MSE WALLS)
CREEPING SLOPES, DOWELED WITH PILES OR CAISSONS FOR STABILITY. PRECAST CONCRETE FACINGS WILL BE ANCHORED TO THE DOWELS.
PRECAST CONCRETE MULTI-ANCHORED FACINGS WITH TIEBACKS ANCHORED EITHER TO THE STABLE ZONE, OR TO THE SELECTED FILL.
SHALLOWLY EMBEDDED CANTILEVERED WALLS ANCHORED WITH TIEBACKS TO STABLE ZONE (FOR CUT APPLICATIONS)
SHALLOWLY EMBEDDED CANTILEVERED WALLS ANCHORED WITH BURIED CONCRETE BLOCKS (FOR FILL APPLICATIONS)
DEEPLY EMBEDDED DISCRETE WALL ELEMENTS, H-PILES OR DRILLED SHAFT WITH LAGGINGS
EMBEDDED CONTINUOUS WALL ELEMENTS, SHEET PILES, DRILLED SHAFTS
T-WALLS WITH PRECAST / POST-TENSIONED STEMS AND CAST IN PLACE BASES ON DEEP FOUNDATIONS
T-WALLS WITH PRECAST / POST-TENSIONED STEMS AND CAST IN PLACE BASES
T-WALLS ON DEEP FOUNDATION. DRILLED CAISSONS, PILES.
T-WALLS ON SPREAD FOOTING. USE WITH COUNTERFORTS, SHEAR KEYS
INVERT-L WALLS WITH TOE COVER, FILLS CAN BE USED WITH BUTTRESSES.
L-WALLS CAN BE USED WITH COUNTERFORTS.
CAST IN PLACE CONCRETE WALLS ON DEEP FOUNDATION (USING PILES OR CAISSONS)
CAST IN PLACE CONCRETE WALLS ON SPREAD FOOTING (WITH TOE AND HEEL).
MASONRY, STONE, DUMPED ROCK GABION WALLS
PRECAST / PREFABRICATED MODULAR WALL ELEMENTS (PROPRIETARY)
EXCAVATED SURFACE COVERED WITH FACINGS AND TIED BACK WITH UNIFORMLY SPACED INCLUSIONS, SUCH AS DOWELS AND NAILS.
SELECTED FILLS REINFORCED SOILS WITH TENSILE REINFORCEMENTS (METALLIC POLYMERIC BARS, GRIDS, SHEETS)
NAILED / DOWELED SOILS
EMBEDDED/ANCHORED STRUCTURE
MORPHO-STABLE STRUCTURES
REINFORCED SOILS
EXTERNALLY STABILIZED SYSTEMS
HYBRID SYSTEMS
INTERNALLY STABILIZED SYSTEMS
EARTH RETENTION SYSTEMS

The wall selection process is an iteration process which involves cycles of preliminary design and cost estimation. The first step of this process is to define the optimal design problem properly. This includes design objectives and constraints. The objective of almost all design problems is least cost. Costs, such as material and construction are much easier to quantify than that of aesthetic and environmental costs. It is difficult to verify which one of the feasible solutions is the best (i.e. both feasible and optimal). In order to find solutions which are at least feasible, constraints such as serviceability requirements (wall horizontal movement, vertical differential settlement, etc.) and spatial limitations (right of way, underground easement etc.) should be defined as comprehensively as possible. Designs (wall types) which meet the prescribed constraints are all feasible solutions. A rating on these feasible solutions (wall types) is required. Ideally the wall with the highest rank should be adopted for detailed design, and the rest can be used as design alternatives. At the beginning of the selection process, wall names associated with rough sketches should be adequate to screen out unfeasible wall types. As the selection process proceeds, a conceptual design with preliminary dimensions should be generated. Factors affecting the selection of an earth retaining structure are grouped into three categories. There are spatial constraints, behavior constraints and economic considerations as follows:

5.4.1 SPATIAL CONSTRAINTS

** FUNCTIONS OF WALL**

- ROADWAY AT FRONT OF WALL.
- ROADWAY AT BACK/TOP OF WALL.
- GRADE SEPARATION OR LANDSCAPING OR NOISE CONTROL.
- RAMP OR UNDERPASS WALL.
- TEMPORARY SHORING OF EXCAVATION.
- STABILITY OF STEEP SIDE SLOPE.
- FLOOD CONTROL.
- BRIDGE ABUTMENT.
- OTHER (SPECIFY)____

** SPACE LIMITATIONS AND SITE ACCESSIBILITY **

- RIGHT OF WAY BOUNDARIES.
- GEOLOGICAL BOUNDARIES.
- ACCESS OF MATERIAL AND EQUIPMENT.
- TEMPORARY STORAGE OF MATERIAL AND EQUIPMENTS.
- MAINTAINING EXISTING TRAFFIC LANES OF WIDENING.
- TEMPORARY AND PERMANENT EASEMENT.
- OTHER (SPECIFY)____

** PROPOSED FINISHED PROFILE **

- USING DIFFERENT COMBINATION OF WALL TYPES ALONG THE WALL ALIGNMENT MAY BE THE OPTIMAL SOLUTION.
- LIMIT OF RADIUS OF WALL HORIZONTAL ALIGNMENT.
- CUT/FILL WITH RESPECT TO ORIGINAL SLOPE.
- MINIMAL SITE DISTURBANCE:
  - ANCHORED WALL WITH MINIMAL CUT.
  - STEPPED-BACK WALL ON TERRACE PROFILE WITH BALANCED CUT/FILL.
  - SUPERIMPOSED/STACKED LOW WALLS.
  - MSE WALL WITH TRUNCATED BASE / TRAPEZOIDAL REINFORCED ZONE.

** CHECK AVAILABLE SPACE VERSUS REQUIRED DIMENSIONS **

- WORKING SPACE IN FRONT OF WALL (SHORING, FORMWORK, etc.).
- WALL BASE DIMENSION.
- WALL EMBEDMENT DEPTH.
- EXCAVATION BEHIND WALL.
- UNDERGROUND EASEMENT.
- WALL FRONT FACE BATTERING.
- SUPERIMPOSED WALLS OR TRAPEZOIDAL PROFILE OF WALL BACK.

5.4.2 BEHAVIOR CONSTRAINTS

** EARTH PRESSURE ESTIMATION (MAGNITUDE AND LOCATION) **

- The magnitude of the earth pressure exerted on a wall is dependent on the amount of movement that the wall undergoes.
- Rankine or similar method, pressure increases with depth.
- The vertical component of earth pressure is a function of the coefficient of friction and/or relative displacement (settling) between wall (stem, facing and reinforced earth mass) and retained fill.
- Terzaghi and Peck or similar method, pressure might be as great near the top of the wall as its bottom.
- Compaction of confined soil may result in developing of earth pressure greater than active or at rest condition.
- For complex or compound walls such as bridge abutments, battered faced wall, superimposed walls and walls with trapezoidal backs, a global limit equilibrium analysis is required.
- For embedded cantilever wall profile of lateral pressures acting on both sides of wall are affected by the location of center of wall rotation (pivot point) under the dredge line which is construction dependent.
- For multi-anchored embedded cantilever wall using a minimum penetration depth where there is no static pivot point below dredge line, soil pressure profile is anchorage design dependent and should be developed with the recognition of beam-on-elastic foundation.
- At ultimate limit state the location of the horizontal earth pressure resultant moves up from 0.33 to 0.40 of the wall height.

** GROUND WATER TABLE **

- reduce hydrostatic pressure.
- reduce corrosion.
- prevent soil saturation.

  An appropriate ground water drainage system is required except when water table level prevents settlement of adjacent structure.

** FOUNDATION PRESSURE ESTIMATION **

- uniform average pressure by Meyerhof effective width method.
- maximum toe pressure by flexural formula method.

** ALLOWABLE BEARING CAPACITY ESTIMATION **

- allowable bearing capacity is limited by and related to preset settlement or differential settlement criteria.
- earth walls integrated with wider flexible bases are allowed higher bearing capacity and tolerate more settlement than rigid walls on spread footings.

** ALLOWABLE DIFFERENTIAL SETTLEMENT **

- settlement is a time dependent behavior.
- top of wall settlement is a sum of settlement from wall and from sub-soil strata.

- allowable settlement shall be evaluated by considering tolerable movement of superstructure and wall precast facings.
- simple span bridges tolerate more angular distortion between adjacent footings than continuous span bridges.
- tolerable (vertical and horizontal) movement of wall facing is a function of panel joint width and pattern of connection.

** EARTH PRESSURE ON WALL FACING **

- the rigidity and slope of wall facing affects the development of lateral pressure and displacement at facing.
- the earth pressure is reduced with a decrease in facing stiffness while the facing deformation is only slightly increased for a decrease in stiffness.

** SETTLEMENT AND BEARING CAPACITY IMPROVEMENT TECHNIQUES **

- surcharge (two-phase construction).
- drainage (wick drain).
- compaction.
- reinforced sub-soil.
- compensated foundation.
- light weight fill material.

** METHODS OF REDUCING SETTLEMENT ON REINFORCED MASS **

- increase compaction of fill material.
- using more reinforcements (length, area and spacing of reinforcements).
- cement treated of fills.
- reducing clay content of fill.
- using high density in-situed micro nails.

** EARTH PRESSURE APPLIED AT FACING **

- High: facing with post-tensioned anchors.
- Medium/high: MSE wall with full height panels.
- Medium: rigid concrete facing with inextensible reinforcements.
- Medium/low: concrete panel facing with extensible reinforcements.
- Low: concrete panel facing with nailed soil.

** WALL BASE WIDTH **

- Wall types, foundation types.
- Allowable bearing capacity of spread footing.
- No tension allowed at heel of spread footing.
- Internal and external stability of wall.
- Reinforcement length to control lateral movement of reinforced earth wall.
- Hybrid walls reduce wall base width.

** TOE PENETRATION DEPTH OF EMBEDDED CANTILEVER WALL **

- Water cutoff consideration.
- Heave in front of wall.
- Bearing capacity.
- Stability or passive toe kickout.
- Slope of ground in front of wall.
- Using anchorages.

** WALL SENSITIVITY TO DIFFERENTIAL SETTLEMENT **

- High: cast-in-place concrete retaining walls.
- Medium: earth walls with inextensible reinforcements, geo-grid walls with facings, precast modular walls.

- Medium/low: geo-fabric walls without facing.
- Low: gabion walls, crib walls, embedded cantilever walls, multi-anchored cantilever walls.

** POTENTIAL SETTLEMENT OF RETAINED MASS **

- High: embedded cantilever walls.
- High/medium: some concrete modular walls, geo-fabric walls.
- Medium: cast-in-place concrete retaining wall, concrete modular walls, geo-grid walls.
- Medium/low: earth walls with inextensible reinforcements.
- Low: multi-anchored embedded cantilever walls.

** RELATIVE CONSTRUCTION TIME **

- Long: cast in place concrete walls.
- Medium: earth walls with reinforcements.
- Short: embedded cantilever walls, multi-anchored embedded cantilever walls, precast modular walls.

** WALL DESIGN LIFE **

- Structural integrity.
- Color and appearance.

** LOAD CARRYING CAPACITY AND SETTLEMENT OF DEEP FOUNDATION **

- Maximum frictional resistance along the pile shaft will be fully mobilized when the relative displacement between the soil and the pile is about 1/4" irrespective of pile size and length.
- Maximum point resistance will not be mobilized until the pile tip has gone through a movement of 10 to 25 percent of the pile width (or diameter). The lower limit applies to driven piles, and the upper limit is for bored piles.
- The ultimate load carrying capacity is the sum of pile point and total frictional resistance.
- Pile to cap compatibility should be considered, especially with battered piles and semi-rigid pile cap connection.
- For the estimation of group efficiency in vertical and horizontal displacement, calculation of pile group, pile diameter, spacing, soil type and total number of piles should be considered.

* FILL MATERIAL PROPERTIES *

- The lower the soil friction angle, the higher the internal earth pressure restrained by the wall.
- The lower the soil friction angle, the lower the apparent friction coefficient for frictional reinforcing system.
- The higher the plasticity of the backfill, the greater the possibility of creep deformations, especially when the backfill is wet.
- The greater the percentage of fines in the backfill, the poorer the drainage and more severe the potential problem from high water pressure.
- The more fine grained and plastic the fill, the more potential there is for corrosion of metallic reinforcement.

** FILL RETENTION VERSUS CUT RETENTION **

FILL RETENTION (bottom-to-top construction)	CUT RETENTION (top-to-bottom construction)
1. Earth Walls (extensible and inextensible tensile reinforcements)	1. Earth Walls (soil nails)
2. All semi-gravity walls	2. All non-gravity walls
3. Modular walls, generic walls and mass concrete walls.	

5.4.3 ECONOMIC CONSIDERATIONS

** Environmental constraints **

- ECOLOGICAL IMPACTS ON WET LAND.
- CORROSIVE ENVIRONMENT ON STRUCTURAL DURABILITY.
- WATER POLLUTION, SEDIMENT OR CONTAMINATED MATERIAL.
- NOISE/VIBRATION CONTROL POLICY.
- STREAM ENCROACHMENT.
- FISH/WILDLIFE HABITATION OR MIGRATION ROUTES.
- UNSTABLE SLOPE.
- OTHER (SPECIFY)

** Aesthetic constraints **-URBAN VERSUS RURAL.

- DESIGN POLICY OF SCENIC ROUTES.
- ACOUSTIC/AESTHETIC PROPERTIES OF WALL FACING.
- ANTI-GRAFFITI WALL FACING.
- AVOIDING VALLEY EFFECT OF LONG/HIGH WALL.
- OTHER (SPECIFY)________________________________

** Economic factors **

- CONSTRUCTION SCHEDULE.
- AVAILABILITY OF FILL MATERIAL.
- SUPPLY OF LABORERS.
- HEAVY EQUIPMENT REQUIREMENTS.
- FORMWORK, TEMPORARY SHORING.
- DEWATERING REQUIREMENTS.
- AVAILABLE STANDARD DESIGNS.
- ’BUY COLORADO’ IMPACT.
- TEMPORARY VERSUS PERMANENT WALL AND FUTURE WIDENING
- COST OF DRAINAGE SYSTEM.
- DESIGN AND INSTALLATION OF WALL ATTACHMENTS.
- NEGOTIATED BIDDING AND DESIGN/BUILD ON NON-STANDARD PROJECTS.
- MAINTENANCE COST, READJUSTMENT AND REMODELING.
- UNCERTAINTY OF SITE AND WALL LOADS.
- COMPLEXITY OF PROJECT:
    - HEIGHT DIFFERENCES IN FINISHED OR BASE GRADES.
    - NUMBER OF WALL TURNING POINTS.
    - SCALE OF PROJECT.
    - LENGTH/HEIGHT OF WALL - QUALITY CONTROL OF FILL MATERIAL.
    - POST-TENSIONING, GROUTING, TRENCHING, SLURRY.
    - PILE DRIVING, CAISSON DRILLING.
    - PRE-CASTING, TRANSPORTATION AND INSPECTION.
    - QUANTITY OF EXCAVATION.
    - QUANTITY OF BACKFILL MATERIAL.

- EXPERIENCE AND EQUIPMENT OF LOCAL CONTRACTOR.
- PROPRIETARY PRODUCT AND QUALITY ASSURANCE.
- OTHER (SPECIFY)

small figure

The logical sequence of considering these factors is to reduce the number of the feasible wall types. The first stage of the decision process eliminates the obviously inappropriate walls through spatial and behavior constraints before considering economic factors. The behavior constraints involve the properties of the earth the wall is required to retain and the ground it rests on. A detailed geological investigation and soil property report is needed in the second stage of the decision process. At this stage conceptual designs with dimensioned wall sections and sub-soil strata are required. In the third stage behavior constraints and economic constraints should be repeatedly or simultaneously considered.

After identification of the feasible set of wall types (only a subset of the available walls), the more refined or detailed preliminary designs proceed, then a rating of the these feasible designs should be made.

To work with the factors during the selection process the work sheets attached in Subsection 5.5, along with the properly defined design problem (objectives and constraints), and the requirements of wall cost study as shown in the last page of this Subsection shall be used and form a part of the documentation in support of the final selection(s).

After completing the work sheets, a list of selected wall types with conceptual designs will be generated. A rating matrix shall then be developed for a qualitative evaluation of the selected alternatives. Based on each evaluation factor, a qualitative rating between one and five can be given each alternate. The qualitative ratings are usually multiplied by weight factors reflecting the importance of the factors -- usually, cost and durability related factors are given higher weights than the rest. The alternative(s) with the highest score is (are) then selected for final design and detailed cost estimation.

The intent of this procedure is to identify equally satisfactory alternative wall-types. The plans/specifications will provide the opportunity for the contractor to select from the acceptable alternatives. The designer shall make his decision to assign alternate walls as the case A or B on Page 3 of 3 of Subsection 5.8. The specifications will outline the acceptable alternatives with dimensioned conceptual designs and indicate the requirements for the contractor to submit final site specific details (Subsection 5.8). These submitted (design/build) shop drawings, which clearly establish that the design criteria are satisfied, include but not limited to, aesthetic features, bearing capacity and stability requirements, and design computations for the alternative site specific selection, signed and sealed by a Colorado licensed P.E., and other data as may be necessary to document compliance with project needs (Subsection 5.7).

5.4.4 EVALUATION FACTORS USED ON SELECTED CONCEPTUAL WALL DESIGNS

* CONSTRUCTIBILITY
* MAINTENANCE
* SCHEDULE
* AESTHETICS (APPEARANCE)
* ENVIRONMENT
* DURABILITY OR PROVEN EXPERIENCE
* AVAILABLE STANDARD DESIGNS
* COST (see page 9 of this Subsection)

5.4.5 NOTES ON RATING OF EVALUATION FACTORS

1. The sum of all weight factors shall be a total of 100 points.

2. The sum of weight points of any two major factors shall be less than or equal to 70 points.

3. For simplicity minor factor(s) can be removed from the rating matrix if they are (is) given the same score on all selected wall types.

WALL GEOMETRY AND CONSTRAINS:
WALL HORIZONTAL ALIGNMENT
WALL VERTICAL ALIGNMENT(TOP OF WALL ELEVATION)
FINISHED GRADE ELEVATIONS(FRONT AND BACK)
RIGHT OF WAY LIMITATIONS
TOLERANCES OF FINISHED WALL
WALL FACADE OR ARCHITECTURAL TREATMENT
WALL ATTACHMENTS (BARRIER, RAIL, LIGHT, CULVERT, ETC.)

BORING LOGS(IN BOARD AND OUT BOARD)

▼

WALL CONCEPTUAL DESIGN
(DIMENSIONED PROFILE)

* data base of previous project
* standard design
* generic software/design aid
* vendor’s software

▼

WALL HEIGHTS VS. COSTS TABLE
(detailed itemized costs)

* excavation/shoring
* structural backfill, reinforced conc. soil reinforcements, tieback anchors
* facing/rail/barrier/drainage
* backfill

* previous cost
* data books
* vendors’ information
* quantity index method
* vendors’ site specific price quotes
* old reports

▼

WALL HEIGHTS VS. LENGTHS DISTRIBUTION STUDY

* total wall length
* average height and standard deviation

▼

GROUND IMPROVEMENT COST AND MISC.
(including deep foundation)

▼

WALL TOTAL CONSTRUCTION COST

REQUIREMENTS OF WALL COST STUDY

WALL COST STUDY SPREAD SHEET - TABLE 1 (SAMPLE OF CPI WL)

FT	UNIT COST PER SQUARE FOOT					COST/ST	COST/SF
WL HT	EXCAV	BACKFILL	CONC	STEEL	RAIL	WALL COST	
	$7.00	$14.00	$200	$0.4	$140		
4	1.78	1.19	0.33	17.0	1	$240.0	$61.30
6	1.89	1.62	0.51	22.0	1	$290.0	$48.27
8	2.11	2.38	0.67	27.0	1	$339.0	$42.40
-							
-							
-							

WALL COST STUDY SPREAD SHEET - TABLE 2 (SAMPLE OF MSE WL)

FT	UNIT COST PER SQUARE FOOT					COST/FT	COST/SF
WL HT	EXCAV	BACKFILL	GRIL	FACING	RAIL	WALL COST	
	$6.00	$12.00	$1.25	$7.50	$180.		
4							
6							
8							
-							
-							
-							

WALL HT DISTRIBUTION AND COST SPREAD SHEET - TABLE 3 (SAMPLE)

WL HT	STATION NUMBERS	WALL LENGTH	PERCENTAGE OF TOTAL	CPI WALL $/FT	CPI WALL TOTAL	MSE WALL $/FT	MSE WALL TOTAL
4	64100	145	15%	350.5	50750.	340.0	49300.
6	63955	80	22%	440.0	35200.	480.5	38440.
8	36875	60	25%	520.5	31200.	600.0	36000.
-							
-							
-							
TOTAL		900’	100%	$850,000.		$650,000.	

NOTES ON USING WORKSHEETS

1. Factors that can be evaluated in percentage of wall height:

   - Base dimension of spread footing.
   - Embedded depth of wall element into firm ground.

2. Factors that can be described as ’large (high)’, ’medium (average)’, or ’small (low)’:

   Quantitative Measurement
   - amount of excavation behind wall.
   - required working space during construction.
   - quantity of backfill material.
   - effort of compaction and control.
   - length of construction time.
   - cost of maintenance.
   - cost of increasing durability.
   - labor usage.
   - lateral movement of retained soil.

   Sensitive Measurement:
   - bearing capacity.
   - differential settlement.

3. Factors that can be appraised with ’yes’, ’no’ or ’question (insufficient information)’

   - Front face battering.
   - Trapezoidal wall back.
   - Using marginal backfill material.
   - Unstable slope.
   - High water table/seepage.
   - Facing as load carrying element.
   - Active (minimal) lateral earth pressure condition.
   - Construction dependant loads.
   - Project scale.
   - Noise/water pollution.
   - Available standard designs.
   - Facing cost.
   - Durability.

4. Factors that can be approximated from recorded height:

   - Maximum wall height.
   - Economical wall height

GRAVITY WALL WORK SHEET

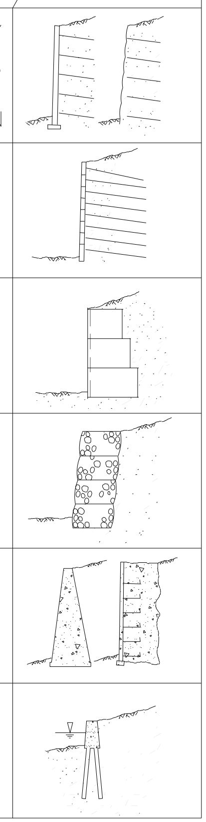
MEASUREMENT INDICATORS:

L LARGE	H HIGH	Y YES
M MEDIUM	M MEDIUM	?
S SMALL	L LOW	N NO

SPATIAL FACTORS — BEHAVIOR FACTORS — ECONOMIC FACTORS

SYSTEM NAMES AND DESCRIPTIONS			FTG. WIDTH (EMB. DEPTH) TO HEIGHTH RATIO	MAXIMUM ECONOMICAL WALL HEIGHTH (FT.)	EXCAVATION BEHIND WALL	WORKING SPACE OF WALL	FRONT FACE BATTERING	TRAPEZOIDAL WALL BACK	SENSITIVITY OF MARGINAL BEARING CAPACITY	SENSITIVITY OF DIFFERENTIAL SETTLEMENT	LATERAL MOVEMENT	MARGINAL BACKFILL MATERIAL	UNSTABLE SLOPE	SCOUR AND FLOOD	HIGH WATER TABLE/SEEPAGE	LOAD CARRYING STRUCTURAL FACING	ACTIVE EARTH PRESSURE CONDITION	CONSTRUCTION DEPENDENT LOADS	NOISE/WATER POLLUTION	QUANTITY OF BACKFILL MATERIAL	FILL COMPACTION AND CONTROL	CONSTRUCTION TIME	PROJECT SCALE AFFECTS COST	COST OF MAINTENANCE	AVAILABILITY OF STANDARD DESIGN	LABOR USAGE	FACING AS AN EXTRA COST	SYSTEM DURABILITY PROBLEM
EARTH WALLS	REINF. SOIL WALLS	SELECTED FILLS REINFORCED WITH TENSILE REINFORCEMENTS (EITHER METAL (INEXTENSIBLE) OR GEO-TEXTILE (EXTENSIBLE) BARS, MATS, GRIDS, ETC.)			L M S	L M S	Y ? N	Y ? N	H M L	H M L	L M S	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	L M S	H M L	L M S	Y ? N	H M L	Y ? N	H M L	Y ? N	Y ? N
	NAILED SOIL WALLS	FACING COVERED CUTS WITH UNIFORMLY SPACED, TOP-TO-BOTTOM CONSTRUCTED NAILS.																											
MODULAR WALLS		PRECAST / PREFABRICATED MODULAR WALLS. MOST ARE PROPRIETARY PRODUCTS. SOME PATENTS HAVE RUN OUT.																											
GENERIC WALLS		PREFABRICATED WALL ELEMENTS SUCH AS MASONRY OR CONCRETE BLOCKS. ROUGH ELEMENTS SUCH AS DUMPED ROCKS, GABIONS.																											
MASS CONCRETE WALLS		CAST-IN-PLACE SOLID CONCRETE WALLS OR PRECAST CONCRETE FACINGS ANCHORED IN CEMENT STABILIZED SOIL ZONES.																											
		C.I.P. REINFORCED CONCRETE WALL ON DEEP FOUNDATION EITHER DRILLED CAISSONS OR PILES.																											

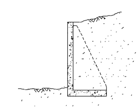
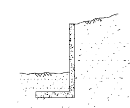
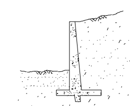
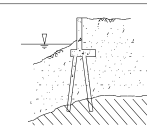
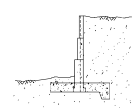
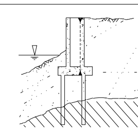
TYPICAL ILLUSTRATIONS



SEMI-GRAVITY WALL WORKSHEET

MEASUREMENT INDICATORS:

L LARGE	H HIGH	Y YES
M MEDIUM	M MEDIUM	?
S SMALL	L LOW	N NO

SYSTEM NAMES AND DESCRIPTIONS		SPATIAL FACTORS								BEHAVIOR FACTORS										ECONOMIC FACTORS								
		FTG. WIDTH (EMB. DEPTH) TO HEIGHTH RATIO	MAXIMUM ECONOMICAL WALL HEIGHTH (FT.)	EXCAVATION BEHIND WALL	WORKING SPACE OF WALL	FRONT FACE BATTERING	TRAPEZOIDAL WALL BACK	SENSITIVITY OF MARGINAL BEARING CAPACITY	SENSITIVITY OF DIFFERENTIAL SETTLEMENT	LATERAL MOVEMENT	MARGINAL BACKFILL MATERIAL	UNSTABLE SLOPE	SCOUR AND FLOOD	HIGH WATER TABLE/SEEPAGE	LOAD CARRYING STRUCTURAL FACING	ACTIVE EARTH PRESSURE CONDITION	CONSTRUCTION DEPENDENT LOADS	NOISE/WATER POLLUTION	QUANTITY OF BACKFILL MATERIAL	FILL COMPACTION AND CONTROL	CONSTRUCTION TIME	PROJECT SCALE AFFECTS COST	COST OF MAINTENANCE	AVAILABILITY OF STANDARD DESIGN	LABOR USAGE	FACING AS AN EXTRA COST	SYSTEM DURABILITY PROBLEM	TYPICAL ILLUSTRATIONS
CAST-IN-PLACE	L-WALLS CAN BE USED WITH COUNTERFORTS			L M S	L M S	Y ? N	Y ? N	H M L	H M L	L M S	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	L M S	H M L	L M S	Y ? N	H M L	Y ? N	H M L	Y ? N	Y ? N	
	INVERT-L-WALLS CAN BE USED WITH BUTTRESSES. USE WITH TOE COVER FILLS.																											
	T-WALLS ON SPREAD FOOTING, USE WITH COUNTERFORTS AND SHEAR KEY IF APPLICABLE.																											
	T-WALLS OR L-WALLS ON DEEP FOUNDATIONS. USE EITHER DRILLED CAISSONS OR PILES.																											
PRECAST POST-TENSION	T-WALLS WITH PRECAST POST-TENSIONED STEM AND C.I.P. BASE ON SPREAD FOOTING.																											
	T-WALLS WITH PRECAST POST-TENSIONED STEM AND C.I.P. BASE ON DEEP FOUNDATION, EITHER DRILLED CAISSONS OR PILES.																											

NON-GRAVITY WALL WORK SHEET

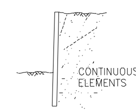
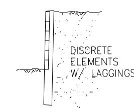
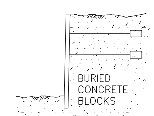
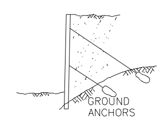
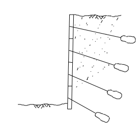
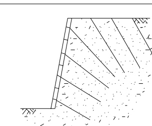
SYSTEM NAMES AND DESCRIPTIONS — SPATIAL FACTORS — BEHAVIOR FACTORS — ECONOMIC FACTORS

MEASUREMENT INDICATORS:

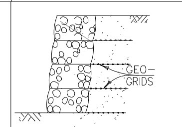
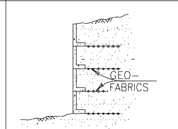
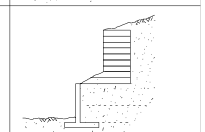
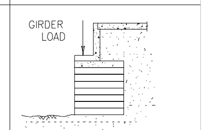
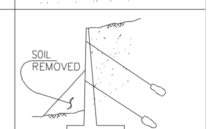
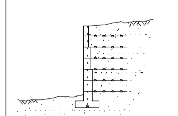
L LARGE — H HIGH — Y YES

M MEDIUM — M MEDIUM — ?

S SMALL — L LOW — N NO

System	Description	FTG. WIDTH (EMB. DEPTH) TO HEIGHTH RATIO	MAXIMUM ECONOMICAL WALL HEIGHTH (FT.)	EXCAVATION BEHIND WALL	WORKING SPACE OF WALL	FRONT FACE BATTERING	TRAPEZOIDAL WALL BACK	SENSITIVITY OF MARGINAL BEARING CAPACITY	SENSITIVITY OF DIFFERENTIAL SETTLEMENT	LATERAL MOVEMENT	MARGINAL BACKFILL MATERIAL	UNSTABLE SLOPE	SCOUR AND FLOOD	HIGH WATER TABLE/SEEPAGE	LOAD CARRYING STRUCTURAL FACING	ACTIVE EARTH PRESSURE CONDITION	CONSTRUCTION DEPENDENT LOADS	NOISE/WATER POLLUTION	QUANTITY OF BACKFILL MATERIAL	FILL COMPACTION AND CONTROL	CONSTRUCTION TIME	PROJECT SCALE AFFECTS COST	COST OF MAINTENANCE	AVAILABILITY OF STANDARD DESIGN	LABOR USAGE	FACING AS AN EXTRA COST	SYSTEM DURABILITY PROBLEM	TYPICAL ILLUSTRATIONS
EMBEDDED CANTILEVER WALLS	SHEET PILES, CONTINUOUS DRILLED CAISSONS, SLURRY TRENCHED CONCRETE DIAPHRAGM WALLS.			L M S	L M S	Y ? N	Y ? N	H M L	H M L	L M S	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	L M S	H M L	L M S	Y ? N	H M L	Y ? N	H M L	Y ? N	Y ? N	
	H-PILES, WOOD PILES, CONCRETE PILES, DRILLED CAISSONS WITH LAGGINGS, TWO ROWS OF CLOSE-PACKED CAISSONS.																											
SHALLOW EMBEDDED CANTILEVERED WALLS WITH TIES OR BRACES	SHALLOW EMBEDDED CONTINUOUS OR DISCRETE CANTILEVERED ELEMENTS ANCHORED WITH BURIED CONCRETE BLOCKS CLOSE TO GROUND.																											
	SHALLOW EMBEDDED CONTINUOUS DISCRETE CANTILEVERED ELEMENTS WITH TIEBACKS ANCHORED TO THE STABILIZED ZONE.																											
MULTI-ANCHORED FACING WALLS	PRECAST CONCRETE MULTI-ANCHORED FACINGS WITH TIEBACKS ANCHORED EITHER TO THE STABILIZED ZONE, OR TO THE SELECTED FILL.																											
	CREEPING SLOPES DOWELED WITH CAISSONS OR PILES FOR STABILITY. PRECAST CONCRETE FACINGS ARE ANCHORED TO THE DOWELS.																											

HYBRID WALL WORKSHEET

SYSTEM NAMES AND DESCRIPTIONS	SPATIAL FACTORS								BEHAVIOR FACTORS											ECONOMIC FACTORS							
MEASUREMENT INDICATORS: L LARGE — H HIGH — Y YES M MEDIUM — M MEDIUM — ? S SMALL — L LOW — N NO	FTG. WIDTH (EMB. DEPTH) TO HEIGHTH RATIO	MAXIMUM ECONOMICAL WALL HEIGHTH (FT.)	EXCAVATION BEHIND WALL	WORKING SPACE OF WALL	FRONT FACE BATTERING	TRAPEZOIDAL WALL BACK	SENSITIVITY OF MARGINAL BEARING CAPACITY	SENSITIVITY OF DIFFERENTIAL SETTLEMENT	LATERAL MOVEMENT	MARGINAL BACKFILL MATERIAL	UNSTABLE SLOPE	SCOUR AND FLOOD	HIGH WATER TABLE/SEEPAGE	LOAD CARRYING STRUCTURAL FACING	ACTIVE EARTH PRESSURE CONDITION	CONSTRUCTION DEPENDENT LOADS	NOISE/WATER POLLUTION	QUANTITY OF BACKFILL MATERIAL	FILL COMPACTION AND CONTROL	CONSTRUCTION TIME	PROJECT SCALE AFFECTS COST	COST OF MAINTENANCE	AVAILABILITY OF STANDARD DESIGN	LABOR USAGE	FACING AS AN EXTRA COST	SYSTEM DURABILITY PROBLEM	TYPICAL ILLUSTRATIONS
GENERIC WALLS ANCHORED WITH GEO-FABRIC GRID REINFORCEMENTS. GABION WALLS ANCHORED WITH GEO-GRIDS.			L M S	L M S	Y ? N	Y ? N	H M L	H M L	L M S	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	Y ? N	L M S	H M L	L M S	Y ? N	H M L	Y ? N	H M L	Y ? N	Y ? N	
MODULAR PRECAST L-WALLS ANCHORED WITH GEO-FABRIC GRID REINFORCEMENTS																											
GEO-FABRIC WALL(S) STACKED ON TOP OF T-WALL																											
EITHER INVERTED-L WALL STACKED ON MSE WALL FOR BRIDGE ABUTMENT APPLICATIONS, OR, L-WALL WITH RAIL STACKED ON TOP OF EARTH WALL FOR ROADWAY APPLICATIONS.																											
T-WALL WITH ANCHORS ADDED TO STABILIZED ZONE. USED FOR WALL REMODELING OR REHABILITATION, AND FOR ROADWAY WIDENING APPLICATIONS.																											
T-WALL WITH PRECAST / POST-TEN-SIONED MODULAR STEM ELEMENTS. ANCHORED WITH GEO-GRID OR WITH REINFORCEMENTS.																											

EARTH RETAINING WALL MEASUREMENT AND PAYMENT

1. Earth retaining structures will be measured and paid for by the square foot. Regardless of the type of earth retaining structure actually constructed (default or alternate wall), and regardless of footing type, the square foot area computed for payment shall be based on vertical heights which are defined by the top of wall elevation and the elevation 18" down from finished grade at the face of wall. In order to accommodate a variable base, the computations shall be made at 20 foot maximum intervals from the beginning to the end station shown on the plans for the default wall design.

2. The unit price bid defined above shall be full compensation for furnishing, handling, and placing of concrete materials; fabricating curing and finishing the wall face; finishing and placing all means of soil reinforcements, joint fillers, waterstops, filter material and incidentals; for all reinforcing steel; for all excavation; for all backfill, including select backfill; for all labor and material required to construct wall facing and concrete leveling pads to the line and grades as shown on the plans; wall erection; sprinkling and rolling for granular backfill material; for finishing and placing all temporary shoring, including soldier shafts or piling; cost of all means of subsoil improvement; deep foundation cost of additional subsoil exploration; and for all labor, tools, equipments and incidentals necessary to complete the work. The unit price bid shall apply for the default wall selection shown on the plans or any allowable alternate which the Contractor elects to construct.

3. An average wall height and standard deviation shall be computed and marked on the default wall design drawing by the designer for record and future cost estimation.

4. Payment of earth retaining wall project shall conform to both Subsection 5.3 (wall classification) and CDOH ITEM BOOK. For retaining wall project allowing alternates payment shall be made under:

Pay Item	Pay Unit
Alternate Retaining Wall (wall descriptions)	Sq Ft

For the purpose of useful record and future selection study, wall descriptions shall contain wall type, wall length, wall average height/standard deviation, type of facing, type of foundation improvement, barrier and rail if applicable.

REQUIREMENTS FOR CONSTRUCTION OF ALTERNATE WALL

1. The successful bidder will be required to indicate the wall type he intends to construct by written notice within three working days after contract award if the wall is not default wall.

2. The Contractor shall submit a detailed design and shop drawings of a proposed alternate wall and have it approved no less than 30 days prior to the beginning of wall construction. The department retains the right to require the construction of the default wall if the Contractor is unable to furnish a satisfactory detailed design or shop drawings to meet the requirement of this Subsection. Any project delay costs resulting from this action by the Department shall be at the expense of the Contractor nor will a project time extension be granted.

3. There will be no allowance of time extension of the contract scheduled completion date for the construction of alternate wall.

4. A plan and elevation sheet or sheets for a proposed alternate wall shall follow the format of the plan drawings for the default wall. They shall contain but not limited by the following:

   A. An elevation view of the wall which shall indicate the elevation at the top of wall, at all horizontal and vertical break points and at least every 50 foot along the wall for case with segmental facing, elevations at the top of leveling pads and footings, the distance along the face of wall to all steps in the footing and leveling pads, the designation as to the type of panel the length, size and number of mesh or strips, and the distance along the face of wall to where changes in length of the mesh or strips occur, and the location of the original and final ground lines.

   B. A plan view of the wall which shall indicate the offset from the construction centerline to the face of wall at all changes in horizontal alignment, the limit on the dimension of the widest mesh or strip and the size and the centerline of any structure or pipe which is behind or passes under or through the wall.

   C. Any general notes required for design and construction of the wall.

   D. A listing of the summary of quantities provided on the elevation sheet of each wall for all items including incidental items.

   E. Cross section showing limits of construction and fill sections, limits and extent of select granular backfill material placed above original ground, and of the location at any structure or pipe together with the treatment strips in the vicinity of each pipe.

   F. Limits and extent of reinforced soil volume.

5. All details including reinforcing bar bending details. Bar details such as rail and barrier shall be in accordance with Department Standards.

6. All details for foundations and leveling pads, including details for steps in the footings or leveling pads, as well as allowable and actual maximum bearing pressures.

7. All facing elements shall be detailed. The details shall show all dimensions necessary to construct the element, all reinforcing steel in the element, and the location of reinforcement element attachment devices embedded in the facing.

8. All details for connections to traffic barriers, coping, parapets, noise wall, and attached lighting shall be shown.

9. Details of the beginning and end of wall including details of connection to the adjacent wall if different wall types are used side by side.

10. Design computations shall include, but are not limited to internal and external, wall stability, bearing capacity and settlement, drainage or waterstop membrane, durability or corrosion protection. The computations shall include a detailed explanation of any symbols and computer programs used in the design of walls.

11. The plans shall be prepared and signed by a professional engineer, licensed in the state of Colorado. Two sets of design drawings and detail design computations shall be submitted to the Bridge Engineer or Branch through the Project Engineer for record purposes. Except in unusual circumstance, such as where insufficient information is submitted for a proper review, it is expected that the Department will issue a notice to proceed within 30 days.

1. When a designer deems an alternate wall or walls to be appropriate in a given location, in addition to default wall design, he shall study a conceptual design of at least one typical section wall of less than 300’ in total length. For walls of 300 feet or longer a conceptual design shall be studied for every 200 feet length of wall. The conceptual design shall include the minimum safety requirements as common to all wall types which is an evaluation of the external stability of the wall against overturning, sliding, bearing/vertical and horizontal movement and global soil shear failure.

2. In those instances where proprietary products are assigned as alternate walls the designer shall provide a matrix or summary of acceptable product names along with the appropriate beginning and ending stations. It is desirable that at least three proprietary product options be named; however, until such time as the Department’s approved product list contains at least three systems, as many as possible systems shall be named. If a cast-in-place wall on a spread footing is selected as the default wall, no less than two proprietary systems shall be identified.

3. Mechanically Stabilized Earth (M.S.E.) walls are considered to be a generic wall system and may be reinforced using wire mesh, metal strap, geo-grid or geofabric systems. If M.S.E. wall type is elected as default, the designer may either design it as generic and allow alternates or she/he may adopt/assign proprietary products in the design as alternate with no default. The requirements of this Subsection for assigning alternate walls with no default shall be applied to modular wall as well.

4. Unless otherwise noted the alternate wall facing type and architecture shall meet the requirements specified for the default wall system.

5. The designer shall indicate that special attention is needed for all walls, including alternate wall systems for the following conditions:

   - Where storm drains, underground utilities, and/or conduits pass through or are continuous and parallel to the wall alignment.
   - Where barrier and/or sign mounting systems are required.
   - Where backfill drainage system is required.
   - Where low bearing capacity exists.
   - Where any other special requirements exist.

6. The designer shall provide LOG OF TEST BORING’S on the final plans which give enough information to support the default wall design and to facilitate the contractor prepared detail design of the identified alternative wall.

7. If the designer selects on-site backfill material for the alternative walls, he shall provide a summary of the site specific material properties from the soils report as well as the minimal

requirement of workmanship and proper drainage system of that backfill material. The wall shall be designed for equivalent fluid weight lateral pressure as described in Subsection 5.9.

8. The CDOT wall design decision matrix is shown on page 3 of this Subsection. The assignment of alternate walls shall be based on a documented wall selection study report using the procedures outlined in Subsection 5.4 and 5.5. For a long wall, the selection of a combination of different wall types may result in the optimum solution.

9. The designer is responsible for preparing a complete set of stand-alone design drawings and specifications for each alternate wall that is to be included in the project's contract documents along with the default wall. This applies to both Case A and Case B alternate walls, as defined by the decision matrix on the following sheet. The contents of this independent set of plans and specifications shall include, but not be limited to, the following:

   A. A site plan showing the locations of all numbered walls and the relative location of the subject wall.

   B. A complete description of the wall's geometry, which shall include wall alignment, the layout line, contour lines, utility lines, drainage lines as well as landscape features and nearby structures.

   C. A plan and elevation view of the wall. The total square facial footage with average wall height and standard deviation (or range of height) per Subsection 5.6 shall be given.

   D. Cross sectional views at appropriate intervals, showing the minimum allowable dimensions of wall components if applicable. These views shall show, but not be limited to, the following:

      - Original and finished grade profile.
      - Type, and compaction requirements, of backfill material.
      - The minimum or range of wall dimensions.
      - The type of reinforcement and its minimum length.
      - Wall front erosion condition and backslope protection.
      - The minimum embedment depth and size of footing.
      - The drainage system along and across the wall.
      - The location of the salt barrier membrane.
      - The facing system and its connection to reinforcement.
      - The rail/sleeper slab, sound barrier, and any high-mast lighting.
      - Any overexcavation or bearing capacity improvement scheme.
      - The architectural requirements of the wall facing.

   E. Boring logs, and a phone number for accessing the geology report. The following information shall also be provided as necessary to implement the designer's intent for the foundation:

      - A summary of applicable information from the geology report.
      - The acceptable foundation types and their corresponding allowables for bearing capacity and settlement.

WALL DESIGN DECISION MATRIX			
CASES	DEFAULT WALL	ALTERNATE WALLS	DESCRIPTIONS
A	N/A	YES	Height less or equalt to 16 feet with class 1 backfill, toe pressure 3 ksf or less, secondary or temporary wall, no bearing capacity and/or settlement problems, mse or modular proprietary walls.
B	YES	YES	Walls on spread footing with correctable settlement and bearing capacity problems, alternate designs tend to be cost effective, or need attention on wall geometry, facade, rail, attachments, site specific detailed design, on-site backfills.
C	YES	YES	Special walls, foundation on difficult soil or site specific marginal backfill material, walls need deep foundation, scour protection, walls inappropriate to design separately.

REMARKS:

- Case A - Designer shall provide wall alignment, grading, wall geometry, architectural specials, etc., asign alternates but no default detail design. Contractor shall provide the signed and sealted detail design/shop drawings for the alternates she/he selects to build
- Case B - Designer shall provide a full design for the default walls and conceptual designs for the alternative walls. Contractor shall provide the signed and sealed detailed design/shop drawings for the alternate wall if he/she elects no to build the default wall.
- Case C - Designer shall provide a full design and not allow an alternate as documented in wall selction report.
- A combination of different cases may be applied along the same alignment for a long wall

Assignment of Alternate Walls

DESIGN PROCEDURES OF A CANTILEVER RETAINING WALL

CDOH Standard Specifications for Road and Bridge Construction will govern the selection and use of backfill materials, including backfill materials behind retaining walls. CDOH Specification Item 703.08 makes reference to Structural Backfill Classes I and II. In most cases these backfill materials shall be assumed in the design of retaining walls as follows.

1. With a proper drainage system and backfilling controlled such that no compaction induced lateral loads are applied to the wall, the Class I or better material may be used. The assumption of a minimal lateral earth pressure of 30 psf/ft (equivalent fluid weight) for level backfills or 40 psf/ft for 2:1 sloped fills shall be acceptable.

2. Class II backfill materials is assumed on site inorganic material; however, depending upon its class designation will need to be designed for varying equivalent fluid weight lateral pressures as contained on page 4 of this Subsection. Therefore, should the designer select a Class II backfill it is incumbent upon him to more clearly specify the backfill material be a supplemental project special provision in order that he use an appropriate equivalent fluid weight lateral pressure for design.

With the design aids provided on pages 4 to 7 of this Subsection, the design of a cantilever cast-in-place retaining wall, based on the Rankine Theory of earth pressure, shall proceed as follows.

1. Obtain soil parameters for both backfill and foundation. Usually the cohesionless backfill as shown by the crosshatched part behind wall on page 5 is slightly larger than Rankine zone. This enables designer to use the properties of backfill material to estimate earth loads, otherwise the properties of retained material shall be used.

2. Determine the design cases and load combinations, such as:

a.	SLOPED OR LEVELED FILL W/O RAIL	D + E
b.	LEVELED FILL W/RAIL	D + E + SC (Surcharge)
c.	LEVELED FILL W/RAIL	D + E + RI (Rail Impact)
d.	LEVELED FILL W/RAIL & FENCE	D + E + SC + W

3. Determine the overall design height including footing thickness (T) and stem height (H), and select trial footing width dimension (B). Usually the toe width (b) is approximately 1/3 to 1/2 of B. The ratio of footing width to overall height shall be in the range from 0.4 to 0.8 for T-shape walls as shown by the design preliminaries on pages 6 and 7 of this Subsection. In these preliminaries, wide base L-shape walls (footing width to height ratios are larger than 0.8) are used for low wall heights (less than 10’), and the factor of safety with respect to overturning is relaxed from a minimum of 2.0 to 1.5 when considering lateral earth pressure that may be relieved by rail impact (Case:D+E+RI).

4. Draw a vertical line from the back face of footing to the top of fill. This line serves as the boundary of the free body to which the earth pressure is applied. The applied active earth pressure shall be estimated by Rankine theory, and direction assumed parallel to the backfill surface. Compute the resultant (P) of the applied earth pressure and associated loads. Resolve P into its horizontal and vertical components (Ph & Pv) and apply it at 1/3 of the total height (TH) of the imaginary boundary from the bottom of footing.

5. Take a free body of the stem and compute the loads applied at the top of stem as well as loads along the stem (height H), and find the moment and shear envelope to meet all the design cases at several points along the height. The WSD method and the concept of shear friction shall be used to calculate the shear strength at the cold joint between footing and stem.

6. Compute the weight (Wt) which is the sum of the weight of concrete and the weight of soil bounded by the back of the concrete wall and the vertical line defined by the step 4 above. Find the distance from the extremity of toe to the line of action of Wt which is the stabilizing moment arm (a).

7. Compute the overturning moment (OM) applied to wall body with respect to the tip of toe as:

   OM = Ph * TH/3,

   compute the resisting moment (RM) with respect to the tip of toe as

   RM = (Wt * a) + (Pv * B),

   and the factor of safety against overturning is

   F.S. (overturning) = RM/OM
   = [Wt * a) + (Pv * B)]/(Ph * TH/3).

   The required F.S. (overturning) shall be equal to or greater than 2.0 unless otherwise accepted and documented by the Engineer (See step 3).

8. Compute the eccentricity (ec) of the applied load with respect to the center of footing through calculating the net moment (NM),

   NM = RM - OM,
   ec = (B/2) - (NM/Wt),

   The resultant shall be within the middle third of the footing width, i.e. |ec| less than or equal to (B/6) to avoid tensile action at heel.

9. For simplicity toe pressure (q) can be evaluated and checked by the following equations:

   q = (Wt/B) * (1 + 6 * ec/B),

   The toe pressure (q) shall be equal to or less than the allowable bearing capacity as noted by the soils report. Toe pressure is most effectively reduced by increasing the toe dimension.

10. The footing, both toe and heel, shall be designed by WSD for soil reaction acting upward and all superimposed loads acting downward. The heel design loads shall include a portion of the vertical component (Pv) of earth pressure which is applied to heel as shown on page 4 of this Subsection. For the toe design loads and stability, the weight of the overburden shall not be used if this soil could potentially be displaced at some time during the life of the wall.

11. Check factor of safety against sliding without using shear key. The coefficient of friction between soil and concrete is approximated to be tan(2/3 * Ø). Neglect the passive soil resistance in front of toe. The sliding resistance (SR) can be evaluated as:

    SR = (Wt + Pv) * tan (2/3 * Ø).

    The required F.S. (sliding) which is (SR/Ph) shall be equal to or greater than 1.5. If F.S. (sliding) < 1.5, then either the width of footing shall be increased or a shear key shall be installed at the bottom of footing.

    If shear key is the choice, the depth of the inert block (c) is computed by the sum of the key depth KD and the assumed effective wedge depth which is approximated to be half the distance between the toe and the front face of shear key (b1/2). Using the inert block concept and knowing the equivalent fluid weight (γ_p) of passive soil pressure, and neglecting the top one foot of the toe overburden (TO), the toe passive resistance (Pp) is

    $$Pp = 0.5 * \gamma_p * [(TO + T + c - 1)^2 - (TO + T - 1)^2].$$

    Total sliding resistance (F) from friction is the sum of the horizontal component of the resistance from toe to shear key (f1) and the resistance from shear key to heel (f2), then

    $$F = [\text{horizontal component of } f1] + [f2] = [(\cos(2/3\ Ø))^2 * R1 * \tan(Ø)] + [R2 * \tan(2/3\ Ø)],$$

    where Ø: internal friction angle of base soil,
    R1: soil upward reaction between toe and key,
    R2: soil upward reaction between key and heel.

    Sliding resistance is

    SR = F + Pp.

    The F.S.(sliding) which is (SR/Ph) shall be equal to or greater than 1.5.

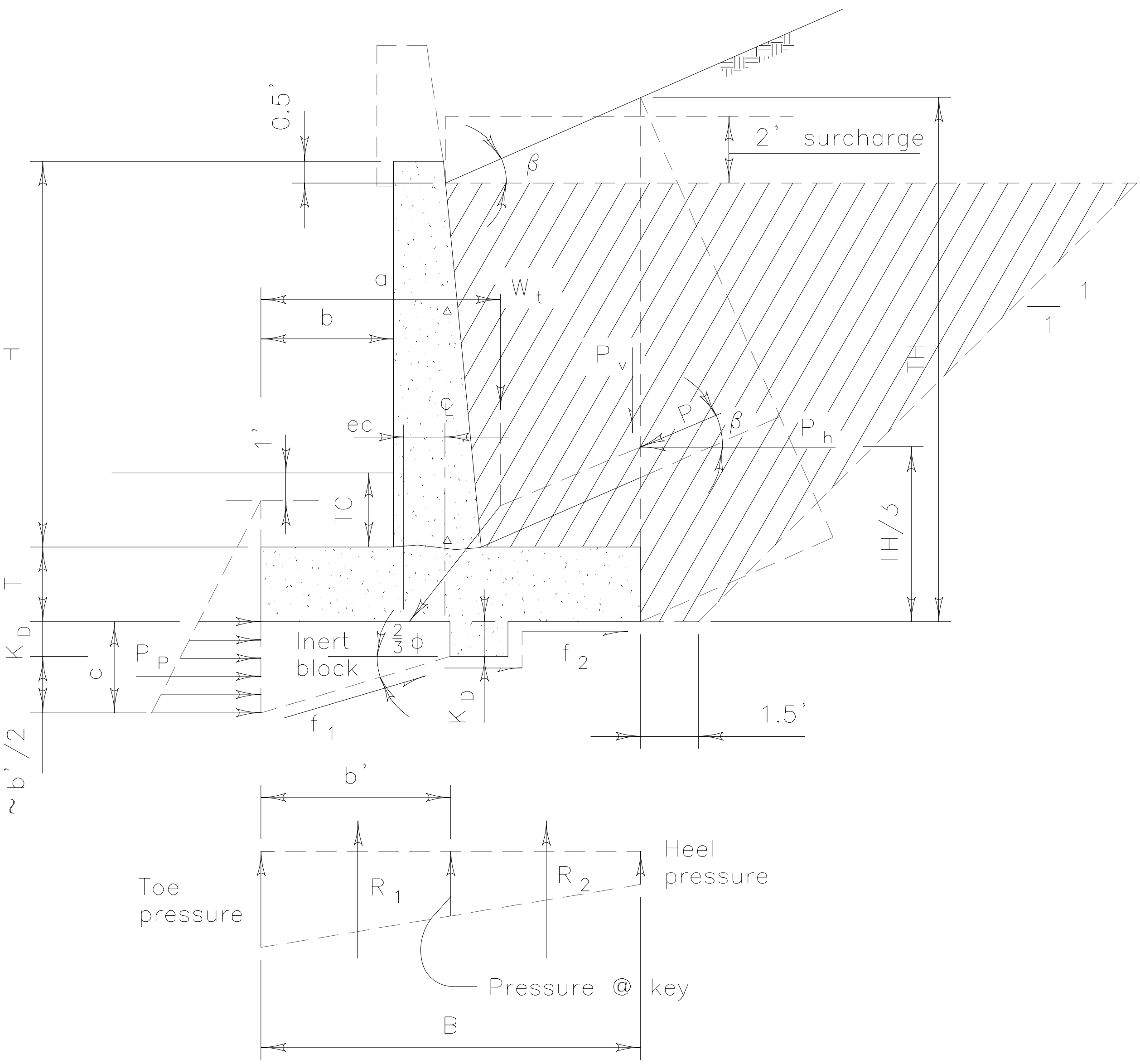
12. Except step 5 which is stem design, repeat steps 3 through 11 as appropriate until all design requirements are satisfied.

CDOT STRUCTURAL BACKFILL CLASS DESIGNATION	TYPE OF SOIL COMPACTION CONFORMS WITH AASHTO 90-95% T180	TYPICAL VALUES FOR EQUIVALENT FLUID UNIT WEIGHT OF SOILS (PCF)	
		LEVEL BACKFILL	2 (H) ON 1 (V) BACKFILL
BORROWED SELECTED COARSE GRAINED SOILS GRADATION PER 703.08 CLASS I[4]	LOOSE SAND OR GRAVEL	40 (ACTIVE) 55 (AT REST)	50 (ACTIVE) 65 (AT REST)
	MEDIUM DENSE SAND OR GRAVEL	35 (ACTIVE) 50 (AT REST)	45 (ACTIVE) 60 (AT REST)
	DENSE[5] SAND AR GRAVEL 95% p T180	30 (ACTIVE) 45 (AT REST)	40 (ACTIVE) 55 (AT REST)
ON-SITE INORGANIC COARSE GRAINED SOILS, LOW % OF FINES CLASS II-A[6]	COMPACTED CLAYEY SANDY GRAVEL	40 (ACTIVE) 60 (AT REST)	50 (ACTIVE) 70 (AT REST)
	COMPACTED CLAYEY SILTY GRAVEL	45 (ACTIVE) 70 (AT REST)	55 (ACTIVE) 80 (AT REST)
ON-SITE INORGANIC LL < 50% CLASS II-B	COMPACTED SILTY/SANDY GRAVELLY LOW/MEDIUM PLASTICITY LEAN CLAY	SITE SPECIFIC MATERIAL, USE WITH SPECIAL ATTENTION, SEE GEOTECHNICAL ENGINEER AND NEED SOILS REPORT ON WORKMANSHIP OF COMPACTION, DRAINAGE DESIGN AND WATERSTOP MEMBRANE.	
ON-SITE INORGANIC LL > 50% CLASS II-C	FAT CLAY, ELASTIC SILT WHICH CAN BECOME SATURATED	NOT RECOMMENDED	

FOOTNOTES:

1. AT REST PRESSURE SHALL BE USED FOR EARTH THAT DOES NOT DEFLECT OR MORE.
2. ACTIVE PRESSURE STATE IS DEFINED BY MOVEMENT AT THE TOP OF WALL OF 1/240 OF THE WALL HEIGHT.
3. THE EFFECT OF ADDITIONAL EARTH PRESSURE THAT MAY BE INDUCED BY COMPACTION OR WATER SHALL BE ADDED TO THAT OF EARTH PRESSURE.
4. CLASS I: 30% OR MORE RETAINED ON NO. 4 SIEVE AND 80% OR MORE RETAINED ON NO. 200 SIEVE.
5. DENSE: NO LESS THAN 95% DENSITY PER AASHTO T180.
6. CLASS II-A: 50% OR MORE RETAINED ON NO. 200 SIEVE.[3]

Typical Values for Equivalent Fluid Pressure of Soils



Typical Section of Retaining Wall

C.I.P Concrete T-Wall Preliminaries (1/2)

(MISSING FIGURE)

C.I.P. Concrete T-Wall Preliminaries (2/2)
(MISSING FIGURE)