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Final Report

FEASIBILITY OF A MANAGEMENT SYSTEM FOR RETAINING WALLS AND SOUND BARRIERS

George Hearn

May 2003

COLORADO DEPARTMENT OF TRANSPORTATION
RESEARCH BRANCH

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16. Abstract

Management systems for retaining walls and sound barriers are feasible, and can be modeled on existing systems for bridge management. A new management system requires the creation of data and procedures specific to walls and barriers, such as: an inventory record, elements and components, condition states, inspection practices, maintenance actions, and asset valuation. In this study, proposals for data and procedures in each of these are examined. No impediment is found to full development of standard data and procedures for walls and sound barriers. Moreover, wall/barrier management can be implemented within existing software for bridge management such as AASHTOWare's Pontis management system.

This final report contains a proposed inventory record for walls and barriers, elements for walls and barriers, the use of components for hidden elements of walls, condition states, and appraisals, together with initial recommendations on inspection practice and intervals.

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Implementation:

Tasks for full development of wall and barrier management are presented. Tasks are sequential, and provide first for collection of basic inventory data, continuing to element-level data, and then to inspections and condition data. After this, procedures for automated evaluation of wall performance, and automated planning of maintenance, repair and replacement actions can be developed.

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FEASIBILITY OF A MANAGEMENT SYSTEM FOR RETAINING WALLS AND SOUND BARRIERS

by

George Hearn
Associate Professor
Univ. of Colorado at Boulder

Report No. 2003-8

Prepared by

George Hearn, PE

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Colorado Department of Transportation
Research Branch
4201 E. Arkansas Ave.
Denver, CO 80222
(303) 757-9506

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EXECUTIVE SUMMARY

A management system for retaining walls and sound barriers is feasible. In many aspects, and importantly in the software required, a system for wall/barrier management can strongly resemble bridge management systems. Wall/barrier management will provide CDOT with information on inventory, conditions, maintenance needs and performance of its walls and sound barriers. Efficient preservation of existing walls and the informed selection of designs in new construction are benefits to be gained through wall management[1].

Wall management will be an essential tool in assessment management. The modified approach to asset valuation (*1*) requires maintenance programs to preserve assets and assessment procedures to demonstrate that preservation has been achieved. The estimate/execute/assess loop required by governmental accountants is, in fact, the evaluate/repair/inspect loop familiar to bridge engineers. A wall management system that addresses the engineering needs will satisfy the accounting requirements.

Wall Management

Wall management includes the functions of inventory, inspection, condition assessment, maintenance, performance evaluation, and asset valuation. Inventory defines the population. Inventory data are, at a minimum, a listing of walls and barriers, their locations and dimensions. Inventory data may also include structure type, year of construction, use (function), load ratings, route carried/route adjacent, ADT, and custodian. Inventory data do not change so long as structures are not modified. Appraisals, often stored together with inventory data, compare existing walls to current design standards and specifications, and indicate sub-standard conditions that are not due to deterioration. Inspections are field observations of current conditions of walls. Inspections occur at regular intervals and follow established practices for observation, and standard protocols for condition rating and recording. Condition assessment is the combined evaluation of condition ratings and appraisals. Maintenance is the application of actions needed to preserve walls and barriers. Performance evaluation is the examination of

[1] In the text, it is often convenient to write ‘wall management’ in place of the longer ‘wall and barrier management’. The term ‘wall management’ is intended to be inclusive of walls and barriers. Exceptions are noted explicitly.

conditions and maintenance costs over time, and comparison of time-histories for various wall types. Asset valuation entails both capital value and annual cost for preservation of walls.

For bridges, all of these functions are established. The NBIS record (*2*) includes inventory data, appraisals and condition ratings. The NBIS record is the basis for computation of the bridge sufficiency index, a combined assessment of conditions, appraisals and importance. Additional standard condition data are available as element-level condition states (*3*). Inspection procedures are codified in the bridge inspectors training manual (*4*). Procedures for condition assessments are established (*5*). Performance evaluation is available through bridge management systems, and a standard basis for comparison is available through procedures for life cycle costing (*6*). Asset valuation is standardized by the Governmental Accounting Standards Board (GASB) (*1*).

Structures inventory is a prerequisite for structures management. This is true historically as well as functionally. Management systems grew out of inventory databases. Simple management systems for bridges use automated decision tools that operate on the Federal NBIS record to identify needs in maintenance and improvement. Widening is needed if inventory deck width is too narrow. Repair is needed if inventory condition is poor. Improvements, generally, are needed where inventory dimensions, capacities, conditions or appraisals are below current standards. Some inventory data, such as deck width, indicate a specific need. Others, such as condition ratings, indicate a general need. For these, an implicit reading of inventory data is used in automated planning for maintenance. The creation of element-level data in the 1990s was directed, in part, at the goal of better correlation of maintenance needs with condition data.

Wall management will be similar to bridge management, and indeed existing data organization and software tools for bridges can be adapted to use for walls. Automated features in management systems such as evaluation of performance of structures, forecasting of budget needs, of future deterioration, and of future programs for maintenance all proceed from data in several basic categories. These include:

Quantities of structures with detailed subdivisions of quantities for particular forms and materials of structural elements.

Deterioration in structural elements, noting type of deterioration, its extent and the relevance of deterioration for structural function or strength.

Deficiencies in structures related to inadequate widths, clearances, or load capacities. Deficiencies related to types of material or design of components. Deficiencies resulting from increased traffic column, or evolution of design standards since the deployment of the structure.

Trends in deterioration over time.

Standard work items for maintenance, repair and replacement of structures. Cost data for these work items.

Impacts and costs of traffic delays, detour lengths or other measures of increased traffic time that may result from reduced or limited function of structures.

These data are the content of management systems. Data exist in all of these categories for bridges. Applications to new classes of structures, such as retaining walls and sound barriers, are achieved if data in all categories can be established, and kept current.

Feasibility of a Management System for Retaining Walls and Barriers

A management system for retaining walls and sound barriers is feasible if data content can be standardized. That feasibility, and the proposal for standard data forms for content are the subject of this study.

Wall management is feasible. Data content can be standardized in all categories. This study proposes:

1. *Inventory data* conveying existence, location, size, type, age of walls and barriers. An inventory record, compatible with the Federal NBIS record and the CDOT Structure Number Coding Guide (*2*) is presented.

2. *Appraisals* for walls and barriers indicating nonconformance of existing structures in geometry, capacity, design details or materials with respect to current standards.

3. *Elements* for walls and barriers that identify the forms, materials, and quantities used in structures. Elements for walls and barriers are modeled on Common Recognized elements for bridges (*3*). A numbering system for elements, consistent with the CDOT Bridge Inspection Coding Guide (*7*), is proposed.

4. *Components* for retaining walls that identify the forms, materials, and quantities of internal features of walls such as fill reinforcement and anchors for facing. A numbering system for components, consistent with the CDOT Bridge Inspection Coding Guide (*7*), is proposed.

5. *Condition states* for elements that are compatible with current practices in element-level bridge inspection. Inspection types, tasks and intervals are also addressed.

In all of these, proposed data are directed at the walls and barriers used by CDOT. Sources employed here include the CDOT Bridge Design Manual (*8*), CDOT Standard Plans and CDOT Structural Worksheets.

CDOT Wall Investment

The CDOT STRNO inventory contains 640 retaining walls and 110 sound barriers. Construction costs for 62 of 110 sound barriers are $19,450,000. This yields a unit cost of $20.10/sq-ft of sound barrier. Total cost of all 110 sound barriers is estimated at $37,075,000. Among the 640 retaining walls, construction costs are recorded for 239. For these, the cost is $104,520,000 or about $41.73/sq-ft of retaining wall. Total cost of all 640 walls is estimated at $224,000,000. There are 110 MSE walls among the 640 retaining walls. There are between 300 and 400 other CDOT retaining walls that are not in the database. CDOT estimates that $278,000,000 has been invested in construction of retaining walls and sound barriers.

If walls have an average service life of 75 years, the $278,000,000 investment translates into a $3,700,000 annual cost. If average service life is extended to 80 years, annual costs are $3,500,000. The difference indicates the savings that may be achieved if a wall management system is used to identify the most durable wall designs and to recommend appropriate maintenance actions. Of course, replacement costs for walls are likely to be higher than initial construction costs. The potential savings, tied to replacement costs, are also higher.

On-going costs for wall management include costs of wall inspection, data entry and operation of the management system software. If wall inspections are conducted every 6 years, and if a two-person crew can inspect 25 walls per week, the annual cost of wall inspections will be about $30,000. Data entry and software operation may cost a similar amount.

Implementation

The inventory, appraisal, elements and components proposed here may be used in development of a management system for walls and barriers. Work is needed to instantiate the electronic records for all CDOT walls and barriers, to assemble element-level models, to inspect walls and barriers and collect condition data, and finally to implement automated functions for management.

Development can be achieved in a sequence of four projects, each producing a functioning part of the final, complete management system. Each project builds on the previous one, and each yields a higher level of management capability.

Level 1 - Inventory system for walls and sound barriers

The existing CDOT activity for STRNO coding for new walls and sound barriers will be expanded with new inventory fields, and the population extended to include older structures.

Level 1 Tasks:

- Database modification for new inventory record. Revised coding guide for walls and barriers.
- Inventory coding for older walls.
- Verification of inventory records.

Level 2 - Element-level data for walls and barriers.

Elements and components for all walls and barriers will be identified, and element-level models will be created.

Level 2 Tasks:

- Assignment of elements, components and quantities for walls and barriers
- Element and component entry (data entry)
- Verification of element-level data.

Level 3 - Wall inspection data.

A manual for standard inspection of walls and barriers will be prepared. Inspections will be completed for all walls and barriers. Condition data, from inspections, will be added to the wall and barrier database.

Level 3 Tasks:

- Creation of inspection manuals, field procedures, reporting format, and database for inspection data.
- Policy on inspection practices, inspectors and intervals.
- Initial inspection of all walls and barriers establishing initial reports of condition.
- Continuing periodic inspections of walls and barriers.

Level 4 - Management of walls and barriers.

Data for walls and barriers will be ported to the Pontis bridge management program, or to other management system software. The software system will help with decisions in preservation and replacement of existing structures as well as design selection for new structures.

Level 4 Tasks:

- Policy on performance measures for walls and barriers.
- Policy on asset valuation of walls and barriers.
- Policy on user costs, and life cycle cost evaluation for walls and barriers.
- Policy on priorities for maintenance, repair and replacement of walls and barriers.
- Software initialization and use.

It is the opinion of the study panel that all the implementation Levels 1, 2 and 4 can be performed by the CDOT Bridge Branch at no additional costs or FTEs to CDOT. The inspection of retaining walls and sound barriers, Level 3, can be performed by contractors as is currently done for the signs structures, and in phases based on allocated budget.

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CHAPTER 1 - REVIEW OF CURRENT CDOT PRACTICES

This chapter includes: justification for management systems for Colorado's retaining walls and sound barriers, study objectives, an outline of basic functions in maintenance management of retaining walls and sound barriers; a review of CDOT inventory and maintenance practices for walls and sound barriers, and; a review of GASB requirements for asset management and the corresponding demands placed on management systems. Based on these, recommendations for CDOT practices are presented.

The study panel for this project has discussed justifications for a management system for walls and barriers. The following statement, drafted by Dr. Naser Abu-Hejleh, presents these justifications.

Statement:

Justifications for New Management Systems for Retaining Walls and Study Objectives

CDOT has databases for management of bridges and pavements. The structure number and time records of periodic inspection for each bridge are stored in the CDOT Bridge Branch database. Recently, the CDOT Bridge Branch started issuing structure numbers to new earth retaining walls and storing this information in the bridge database using the same data format as for bridges (see next section for more details on CDOT practices for management of new retaining walls). For example, fields of maximum span length and total length of bridge are interpreted for retaining walls as maximum wall height and total wall length. The use of the bridge database for new retaining walls is limited because proper descriptions of the data are missing or not adequate. For the existing walls, there are no names (structure numbers) or records for simple bookkeeping or identification. The CDOT Bridge Branch proposes the development of a new and separate management program for new and existing retaining walls. CDOT Bridge engineers propose to document and store relevant information on the design, construction, materials, maintenance and repair, inspection, and performance for each retaining wall. This information, some collected at different times, will be stored in an intelligent database to facilitate the overall

management of retaining wall structures. Additional effort is needed to obtain data for existing walls.

A quick review of the Walls database maintained by the CDOT BMS Unit revealed the following information (from Jim Koucherik, 06/09/2003)

- The database currently has 750 walls identified by an actual location on a state highway.
- Of the 750 walls, 110 are sound barriers.
- Of the 110 sound barriers, 62 had actual costs recorded.
- The 62 sound barriers cost $19,450,158.78, or about $20.10 / sq ft. to build.
- Based on the above information, the other 48 sound barriers are estimated to cost $17,624,926.20.
- The remaining 640 walls are retaining walls.
- Of the 640 retaining walls, 239 had actual costs.
- The 239 retaining walls cost $104,520,956, or about $41.73 / sq ft. to build.
- Based on the above information the other 401 retaining walls are estimated to cost $119,383,854.72.
- The 640 retaining walls include 110 MSE walls.
- The BMS Unit estimates that there are approximately 300 to 400 other retaining walls built, but not identified.
- These un-numbered walls include all the walls on Vail Pass and in Glenwood Canyon.

Based on the above, there are around 1150 walls to 1250 walls in Colorado. A total of 750 walls are identified, and 300 to 400 walls are not identified and documented by CDOT. The estimated costs of 750 walls are approximately 261 million dollars (37 millions for sound walls and 224 for retaining walls). A management system would protect the Department's investment in these walls, and could avert costly failures of walls. Needs for a management system may rely on total investment in these walls, and costs of recent wall failures.

Rare failures with retaining walls are reported that could be averted with management systems for retaining walls. In early 1990, some major distress was noticed on the retaining wall by SH 550 (Red Mountain Pass). In 2000, it was noticed that a retaining wall along SH 9 tipped around 9". Presently, no long-term performance information on sound barriers and MSE walls is available. Sound barriers are a new growing use of walls in Colorado. The construction of MSE (Internally supported not Externally supported by rigid facing) walls is currently the most popular in Colorado. A total of 500 more (mostly MSE walls) walls could be constructed in the next 10 yrs in Colorado. As a part of the construction requirements for the T-REX project along I-25, large numbers of MSE walls with panel facing and metallic reinforcements will be constructed. Will these walls stay in place with acceptable conditions in the next 75 years? This new breed of retaining wall, selected based on economical reasons, lacks records on performance (deterioration) with time and long-term performance records and there is some concern about deterioration of their segmental facing (blocks, panels, and timber) with time. Dr. Trever Wang from the CDOT Bridge Branch believes that these walls could be temporary walls. All these issues could be addressed with a new management system for retaining walls as demonstrated in the example listed below.

It was the personnel of the Salvation Army office who first noticed the significant bulging of the ramp connecting WB I-70 to NB I–25. CDOT's Region 6 Maintenance office requested the review of the distress in this MSE Wall because they could not keep the longitudinal crack in the ramp's concrete roadway pavement sealed. The crack, which is several hundred feet long, varies in width from about 1/16" to about 1". It also has sections that have differential settlement up to ¾". A bulge was also noticed in the facing of the east MSE wall supporting the ramp extending over a 140' with indication. CDOT's Research Branch investigated this bulging through 92 survey targets located at 8 sections. It was concluded that the wall experienced large lateral movements over its entire history (5 inches to 8 inches). The roadway drainage system collectors are located directly behind, and parallel to, the wall. On September 6, 2000, CDOT maintenance employed a video system to inspect the storm drainpipes and to detect breaks/separations. The pipe sections and joints were repaired and the problem of wall movement with time seems to have been controlled. This problem, if inspected properly, could have been detected early (from

information of movement with time) and the drainage system could have been fixed a long time ago to avoid the significant bulging of the wall that occurred over the last few years.

New management system for Colorado's retaining walls will provide:

- Information on the short and long-term performance measures for walls and barriers by documentation and tracking with time condition states (performance!) of walls and their elements from baseline conditions established immediately after construction. This could serve as a knowledge base for avoiding malfunctions related to wall type as well as evidence for better future design/construction practices of elements or walls.
- Policy on asset valuation of walls and barriers to integrate a wall management system with on-going CDOT asset management system.
- Policy on user costs, and life cycle cost evaluation for walls and barriers.
- Policy on priorities for maintenance, repair and replacement of walls and barriers. This is needed for budgeting and cost-effective planning for maintenance and repair of existing retaining walls, and construction of new and better retaining walls.

The Objectives of this study are:

" To review retaining wall management system practices, identify alternatives, and make recommendations for a proposed retaining wall management system for CDOT that can predict the future condition and performance of retaining walls under various budgeting scenarios, and can be integrated with on-going CDOT asset management."

:End of statement

Management of Retaining Walls

Wall management includes the functions of inventory, inspection, condition assessment, maintenance, performance evaluation, and asset valuation. Inventory defines the population. Inventory data are, at a minimum, a listing of walls, locations and dimensions. Inventory data may also include wall type, year of construction, use (function), appraisal ratings, load ratings, route carried/route adjacent, ADT, and custodian. Inventory data do not change so long as structures are not modified. Inspections are field observations of current conditions of walls. Inspections occur at regular intervals and follow established tasks for observation, and standard protocols for condition rating and recording. Condition assessment is the combined evaluation of condition ratings and appraisal ratings. Maintenance is the application of actions needed to preserve walls. Performance evaluation is the examination of conditions and maintenance costs over time, and comparison of time-histories for various wall types. Asset valuation entails both capital value and annual cost for preservation of walls.

For bridges, all of these functions are established. The NBIS record (*2*) includes inventory data, appraisals and condition ratings. The NBIS record is the basis for computation of the bridge sufficiency index, a combined assessment of conditions, appraisals and importance. Additional, standard condition data are available as element-level condition states (*3*). Inspection procedures are codified in the bridge inspectors training manual (*4*). Procedures for condition assessments are established (*5*). Performance evaluation is available through bridge management systems, and a standard basis of comparison is available through procedures for life cycle costing (*6*). Asset valuation is standardized by the Governmental Accounting Standards Board (GASB) (*1*).

Management functions for retaining walls and sound barriers will be similar to management functions for bridges, and it is expected that existing data organization and software tools used for bridges can be adapted to use for walls. Much of the inventory record for bridges will be used, with modifications, for retaining walls and sound barriers. Condition ratings will be developed specifically for walls, and the numerical scales describing conditions will mimic the systems in place for bridges. Performance evaluation, life cycle costing and asset valuation, in terms of procedure, will be identical to bridges. Indeed, management of structures of any type, bridges, retaining walls, sound barriers, sign structures, signals, traffic barriers is similar in

concept. In each application, an inventory of individual structures, of known location, size, type and age, are subject to standardized assessment of condition, and standard maintenance actions with known unit costs.

For walls and barriers, the development of a management system is the development of the details. That is, details of the inventory record, specific definitions of condition ratings, detailed standards for inspections, a basis for condition assessment using data on conditions and appraisals, and specific guidance in life cycle costing and asset valuation.

CDOT Practices for Wall Inventory and Maintenance

CDOT maintains inventory data for newly constructed walls, has a practice for discovery of needs for wall maintenance, and tracks maintenance actions at walls and sound barriers. CDOT does not have inventory data for older walls, does not perform periodic inspections of walls, does not assign condition ratings or appraisal ratings, and does not have a historical record of conditions of walls. CDOT cannot, at present, meet the requirements of asset valuation for walls under the GASB modified/preservation approach.

Walls defined. Wall types.

CDOT defines walls as structures that retain fill and that have width of at least 30m and maximum height of at least 1.5m (*8*). The CDOT definition provides conversions to US customary units as 100 ft width and 5 ft height.

Wall types are identified variously by design types, inventory types, cost items, and maintenance items. Twenty-three wall design types are defined in the CDOT wall selection criteria (*8*). Design types are listed in Table 1. Eight inventory types are defined in the CDOT Structure Number Coding Guide (*9*). Inventory types are listed in Table 2. Walls appear as fifty-two distinct wall types among sixty-eight cost items for walls (*10*). Cost items are defined in Table 3. There are thirty-three types of sound barriers among forty-one cost items for sound barriers (*10*). Cost items for sound barriers are listed in Table 4. Maintenance activity codes recognize all walls and sound barriers as a single type.

CDOT Wall Inventory

CDOT stores inventory data for newly constructed walls by overloading fields in the bridge inventory record. The practice is defined in the Structure Number Coding Guide (*9*). Walls built before 1998 are not included. There is no current program to add older walls to the database.

Inventory data for walls include structure location, age, size and type. Inventory data do not include load ratings, condition ratings, or appraisal ratings. Standards for such ratings for walls are not established at present.

Inventory data include fields that are in common with bridges such as location, and year of construction (Table 5), fields that are overloaded and have different use for walls than for bridges (Table 6) and fields that are used for bridges only (Table 7).

The CDOT inventory record is an extension of the Federal NBI record *2*. The CDOT record expands the entries in some fields such as item 8 where the Federal item for structure number is expanded to CDOT items 8 and 8R, replaced structure. CDOT employs some items, such as 18 and 23, that are not currently used in the Federal record, and adds fields beyond item 116, currently the last item in the Federal record. Since adaptations by CDOT for wall inventory preserve the meaning and numbering of Federal NBI items, the CDOT approach can be useful to other transportation agencies seeking a system for wall inventory.

CDOT does not currently have a set of wall elements that are similar to Commonly Recognized elements for bridges. Elements, once established, will offer more specific descriptions of wall types, quantities and conditions.

Notice that WALL records are flagged by CDOT field 120A. The WALLR and WALLS codes here indicate that the record is for a retaining wall or sound barrier and not for a bridge. For WALL records, entries in 120AA are valid. The codes allowed for 120AA correspond to wall design *groups*, rather than *types*. This level of abstraction is appropriate to NBI-style inventory data. CDOT employs a fuller list of types for bridges. To achieve a similar data content for walls, specific information on wall type could be preserved as element-level data in a wall management

system, or the set of valid codes for 120AA could be expanded. Notice that the codes in 120AA address retaining walls but not sound barriers.

Table 1 - CDOT Wall Design Types (Source: *CDOT Bridge Design Manual* 2002)

Design Class	Design Group	Design Type
Non-Gravity	Multi-anchored facings	Concrete facing anchored to dowels. Dowels are piles or caissons.
		Concrete facing anchored with tiebacks.
	Embedded cantilever walls with ties	Cantilever walls with tiebacks to stable zone.
		Cantilever walls with tiebacks to concrete blocks.
	Embedded cantilever walls	Embedded isolated walls elements with lagging.
		Embedded continuous wall elements.
Semi-Gravity	Precast concrete cantilever walls	T-walls with PT stems and CIP base on deep foundation.
		T-walls with PT stems and CIP base.
	CIP cantilever concrete walls	T-walls on deep foundation.
		T-walls on spread footing with counterforts, shear keys.
		Invert-L walls with toe cover and buttresses.
		L-walls with counterforts.
Gravity	Mass concrete	CIP concrete walls on deep foundation.
		CIP concrete walls on spread footing.
	Generic walls	Masonry, stone, dumped rock or gabion walls.
	Modular walls	Precast modular wall elements (proprietary).
	Earth walls (MSE walls)	Excavated surface covered with facings and tied back with inclusions such as dowels or nails.
		Selected fill reinforced soils with tensile reinforcements.
Hybrid	Hybrid	Modular wall with anchors.
		MSE wall on top of T-wall.
		Invert-L wall on top of MSE wall (for bridge abutment).
		T-wall with anchors into stable zone.
		T-wall precast stem elements anchored with geogrid or mesh reinforcements.

Table 2 - CDOT Wall Inventory Types (Source: *Structure Number Coding Guide* 1998)

Code	Inventory Type
BN	Bin Wall
CIP	Cast-In-Place Concrete Wall
MSE	Mechanically Stabilized Earth
MW	Masonry Wall
PC	Pre-cast Elements Wall
PCP	Pre-cast Elements Wall, Prestressed
TIE	Tie Back Wall
MISC	All Other Walls

Table 3 - CDOT Cost Items for Walls (Source: *Item Book* 2002)

Item	Description	Basis
202-00150	Removal of Wall	EACH
202-00155	Removal of Wall	LF
202-00160	Removal of Wall	SF
202-00165	Removal of Wall	L S
202-06520	Removal of Existing Wall Panels	L S
504-03311 to 504-03351	Retaining Wall (1)(Alternative Systems) to Retaining Wall (41)(Alternative Systems)	L S
504-04410	Block Facing	SF
504-04420	Precast Panel Facing	SF
504-04430	Reinforced Concrete Facing	SF
504-04440	Facing (Special)	SF
504-05000	Wire Mesh Facing	SF
504-05100	Geotextile Wrap of Existing Pier Bents	EACH
504-06100	Ground Nailed Wall	SF
504-06501	Permanent Tieback Anchor System	SF
504-08050	Stone Landscape Wall	SF
504-08100	Timber Retaining Wall	SF
504-08150	Soldier Pile Wall	SF
504-08255	Masonry Landscape Wall (Dry Stack)	SF
601-01050	Concrete Class B (Wall)	CY
601-03050	Concrete Class D (Wall)	CY
601-03052	Concrete Class D (Wall) (Colored)	CY
601-03055	Concrete Class D (Wall) (Special)	CY
601-07000	Concrete Retaining Wall	SF
601-21000	Precast Wall Segment	EACH
601-21003	Precast Wall Segment	SF
601-22010	Place Precast Wall Segment	EACH
601-40010	Masonry Wall	SF
601-40100	Concrete Anchor	EACH
607-11550	Screen Wall	LF

Table 4 - CDOT Cost Items for Sound Barriers (Source: *Item Book* 2002)

Item	Description	Basis
202-01020	Removal of Sound Barrier Fence	LF
606-00456	Guardrail Type 4 (Style CE) (Special) (Sound Barrier)	LF
607-11600	Fence Wood (Sound Barrier)	SF
607-11648	Fence Wood (Sound Barrier) (48 Inch)	LF
607-11672	Fence Wood (Sound Barrier) (72 Inch)	LF
607-11696	Fence Wood (Sound Barrier) (96 Inch)	LF
607-11720	Fence Wood (Sound Barrier) (120 Inch)	LF
607-11744	Fence Wood (Sound Barrier) (144 Inch)	LF
607-11768	Fence Wood (Sound Barrier) (168 Inch)	LF
607-11799	Fence Wood (Sound Barrier) (Special)	LF
607-11924	Fence Metal (Sound Barrier) (24 Inch)	LF
607-11936	Fence Metal (Sound Barrier) (36 Inch)	LF
607-11942	Fence Metal (Sound Barrier) (42 Inch)	LF
607-11948	Fence Metal (Sound Barrier) (48 Inch)	LF
607-11960	Fence Metal (Sound Barrier) (60 Inch)	LF
607-11964	Fence Metal (Sound Barrier) (64 Inch)	LF
607-11972	Fence Metal (Sound Barrier) (72 Inch)	LF
607-11996	Fence Metal (Sound Barrier) (96 Inch)	LF
607-12120	Fence Metal (Sound Barrier) (120 Inch)	LF
607-12144	Fence Metal (Sound Barrier) (144 Inch)	LF
607-13000	Fence Masonry (Sound Barrier)	SF
607-13064	Fence Masonry (Sound Barrier) (64 Inch)	LF
607-13072	Fence Masonry (Sound Barrier) (72 Inch)	LF
607-13096	Fence Masonry (Sound Barrier) (96 Inch)	LF
607-13104	Fence Masonry (Sound Barrier) (104 Inch)	LF
607-13112	Fence Masonry (Sound Barrier) (112 Inch)	LF
607-13120	Fence Masonry (Sound Barrier) (120 Inch)	LF
607-13144	Fence Masonry (Sound Barrier) (144 Inch)	LF
607-13156	Fence Masonry (Sound Barrier) (156 Inch)	LF
607-13168	Fence Masonry (Sound Barrier) (168 Inch)	LF
607-13180	Fence Masonry (Sound Barrier) (180 Inch)	LF
607-13196	Fence Masonry (Sound Barrier) (196 Inch)	LF

607-14000	Fence Composite (Sound Barrier)	SF
607-14090	Fence Composite (Sound Barrier) (90 Inch)	LF
607-14120	Fence Composite (Sound Barrier) (120 Inch)	LF
607-14144	Fence Composite (Sound Barrier) (144 Inch)	LF
607-15000	Fence Concrete (Sound Barrier)	SF
607-15015	Fence Concrete (Sound) (Install Only)	SF
607-15100	Fence (Sound Barrier) Fence (Sound)	SF
607-15144	Fence Concrete (Sound Barrier)(144 Inch)	LF
607-15200	Fence (Sound Barrier) (Alternate) Fence (Sound)	SF

Table 5 - Common Items for CDOT Inventory of Walls and Bridges

CDOT Item	**Description**
3	County Code
5DF	Field Log Route
6	Feature Intersected
8	Structure Number
8R	Structure Number of Replaced Structure
9A	Location
11F	Field Log Reference Point
18A, 18B, 18C	Range, Township and Section
23	Original construction project number
23E	Subaccount number
23EE	Project Indicator
27	Year Built
136F	Field Log, Mileage Log, Section Letter
System	On or Off the state highway system
Notes	Significant Information

Table 6 - Overloaded Items in Wall Inventory

CDOT Item	Description	Note
49	Total Structure Length	Wall Length ≥ 30m Wall data overloads BRIDGE TOTAL STRUCTURE LENGTH
52A	Maximum Wall Height	Wall Height ≥ 1.5m Wall data overloads BRIDGE DECK WIDTH out-to-out
120A	Structural Type	Reinforced Earth (RE) Retaining Wall (WALLR) Sound Barrier Wall (WALLS) Codes for walls overload codes for common bridge types.
120AA	Wall Construction Type	Field supplementing 120A, Codes are: Bin Wall (BN) Cast-In-Place Concrete Wall (CIP) All Other Walls (MISC) Mechanically Stabilized Earth (MSE) Masonry Wall (MW) Pre-cast Elements Wall (PC) Pre-cast Elements Wall, Prestressed (PCP) Tie Back Wall (TIE)

Table 7 - Items Not Used for Wall Inventory

45	Number of Spans in the Main Unit
48	Length of Maximum Span
51	Bridge Roadway Width, Curb-to-Curb
52A	Deck Width, out-to-out

Inspection

CDOT has no program for periodic inspection of walls or sound barriers. Wall problems are discovered during routine surveys by maintenance crews. The procedure has been adequate in practice, although it is better at finding problems for walls that are visible from roadways than for walls that are not. Surveys do not assure early detection of problems.

There are no standards for inspection of walls. There is no format for recording and reporting deterioration of walls, and no set of standard observations for assessment of walls in service. There are no condition ratings for walls, and no historical record of wall conditions. As a result, trends in wall conditions over time, relative performance of different wall types, and evaluation of remaining service life are not possible under current practice.

There are no appraisal ratings for walls. Adequacy of walls with respect to current design standards is not recorded. Clearly, appraisals related to clearances, railings, load capacity, construction type and vulnerabilities could be defined.

Maintenance

Data on maintenance activities for walls are available as cost items for maintenance projects performed by contractors (*11*), and as activity codes in the CDOT maintenance management system.

CDOT's maintenance management system is an SQL database of maintenance needs. The database is used to track needs, activities, achievements, and costs. The system does not set priorities for maintenance activities. Some maintenance activities are completed by CDOT forces. Larger projects, such as re-decking for bridges, are performed by contractors and administered by the CDOT Construction Branch.

The maintenance management system uses codes to identify activities for pavements, bridges, walls, barriers, signs, ancillary structures, etc. These codes are unique to the maintenance management system and are different than cost items for similar work.

Maintenance activities for walls and sound barriers are reported under a single activity code, 217. The most frequent maintenance activity is removal of graffiti. Failures in walls are rare, and most walls serve with no maintenance beyond cleaning.

For bridges, there are a greater number of codes for maintenance activities. A master list of bridge maintenance needs is prepared by CDOT Bridge Staff (*12).* A list of bridge maintenance activity codes is compared to cost items in Table 8. The 351-399 series of bridge maintenance

activities are shown together with activity 217, the activity code for maintenance of walls and barriers.

Table 8 - Maintenance Activity Codes

Maintenance Activity Code	Maintenance Activity Description	CDOT Cost Item(s)
	Walls and Barriers	
217	Wall maintenance. Sound barrier maintenance.	202, 504, 607
	Bridges	
351	Bridge / Structure Visual Inspection / Monitoring	
352	Cleaning or washing	202
353	Bridge Deck Repair, etc.	210, 515, 601, 628
354	Superstructure	210, 508, 509, 601, 602, 618
355	Clean and Paint bridge	508, 509, 601
356	Curbs and Rail	210, 514, 606
357	Bearings	512
358	Substructure	501, 502, 503, 504, 506, 601, 614
360	Approach Slabs and Slope Protection	601, 618
364	Expansion Joints	517, 518, 619
398	Miscellaneous Bridge Work	600
399	Maintenance Requiring Engineering	

Notes on Asset Management

Inventory data are needed for valuation of wall and sound barrier assets. The modified/preservation approach to asset management requires proof that maintenance programs are sufficient to preserve assets indefinitely. Proof demands data on wall conditions, maintenance actions and maintenance costs. Current CDOT practices in inventory, condition assessment and maintenance for walls and barriers are not adequate for the requirements of asset management.

Notes from GASB Primer

Any new system for wall management must be compatible with requirements for asset management. Asset valuation is a central task, and the guidance in the Governmental Accounting Standards Board Primer (*1*) is relevant here. GASB places requirements on inventory data, on condition assessment, and on maintenance programming and reporting. An overview of GASB requirements is presented.

Asset management combines maintenance management with demonstrated execution of maintenance programs. Maintenance management systems, such as Pontis for bridges, indicate conditions, and trends in conditions and needs for maintenance. Asset management requires this information complemented by a record of completed maintenance activities and the demonstration that these activities are sufficient for preservation of assets.

Management of assets entails valuation of assets. Transportation structures, such as walls, can have long service life. Replacement, often, is caused by roadway improvements such as widening and not by poor condition or failed service in walls. For such long-lived facilities, GASB recommends a modified/preservation approach to asset valuation.

Under the modified/preservation approach, the value of a wall is its historical construction cost without inflation or deprecation, plus the construction costs of any additions or improvements. Annual costs are the costs of maintenance activities necessary to preserve the wall, and are not the depreciation costs. The specific requirements from GASB are:

> *"A government using the modified approach will not have to depreciate infrastructure assets as long as: First, reporting entity must establish and make public condition goals for the subject assets. Second, the government must estimate the spending levels necessary to achieve or maintain the condition target. Third, the amount required to maintain the pre-determined condition level must be compared to actual spending. Fourth, the government must document that the assets are being preserved approximately at or above the condition goal it pre-selected."*

GASB requirements include the following:

Inventory data must include construction costs for walls, and costs of additions and improvements.

Condition data must address publicly-stated goals for condition. Measures of condition must be transparent, easily understood, and easily confirmed. Condition ratings must have definitions that are unambiguous. Condition ratings must be responsive to maintenance activities so that steady values of condition ratings truly indicate continued adequate maintenance of walls.

Condition history for walls must be preserved, and it must be evident from this history that preservation of walls is achieved.

Inspections must follow standard procedures and produce standard reports consistent with the requirement for public documentation of condition. Inspections must occur at regular intervals.

Maintenance activities must provide the actions needed for preservation, and must reverse deterioration in condition, if any. Maintenance activities must be reported to demonstrate the preservation of walls. Costs of maintenance must be documented. These are the preservation costs that serve in place of depreciation under the modified/preservation approach to asset valuation.

Practices for condition rating, inspections, maintenance reporting and cost accounting must be standardized. Enhancements to standard practices must provide reports that are consistent with older data.

The GASB modified/preservation approach requirements are shown in Table 9.

Table 9 - GASB & Management of Walls

GASB Requirements	Tasks for Wall Management
Documentation of historical value	Inventory of walls including construction costs and costs of additions and improvements
Documentation of the condition of assets through a reproducible assessment procedure	Standard condition ratings for walls, periodic inspection following standard procedures for observation, assessment and reporting
Demonstration that assets are being preserved at a level predetermined by the government	Report of time-history of condition ratings
Estimate the actual cost to maintain and preserve the assets	Tracking and reporting of maintenance actions and costs

Software for Maintenance Management of Walls

A system for maintenance of retaining walls and sound barriers can be modeled on maintenance management software for bridges. A management system, such as Pontis, can readily be adapted to management of walls and barriers. This will require the definition of wall elements, creation of data records for walls that include inventory data and element-level data, definition of condition states for wall elements, and specification of feasible actions in maintenance, repair and replacement for walls.

Recommendations Related to CDOT Practices

A comparison of CDOT practices with requirements for asset management and with goals in management of walls and barriers yields the following recommendations:

Inventory - CDOT's existing inventory record for walls should be expanded to include data relevant to construction costs, user costs, design type and material type. A proposal for a wall inventory record is presented in Chapter 3 and Appendix A.

Element-Level Data - Elements should be developed for retaining walls and sound barriers. Elements will be similar in concept to CoRe elements for bridges. A proposal for elements for walls and barriers is presented in Chapter 3 and Appendix D.

Condition Data - Standard condition ratings and condition states are needed for walls and sound barriers. Proposals for condition ratings are presented in Chapter 3 and Appendix G.

Condition Assessment - A standard assessment of walls is needed. A sufficiency index, similar to the one for highway bridges, must express the combined assessment of conditions and appraisals. Appraisals are presented in Chapter 3 and Appendix B.

Inspections - Standard inspection intervals, procedures, recording and reporting are needed. Inspections must occur at least once every three years. Recommendations for inspections of walls and barriers are presented in Appendix G.

Maintenance - An expanded set of activity codes for maintenance of walls and barriers is needed. Periodic reports of actions and costs for the expanded set are needed. A common set of codes for cost items and for maintenance activities is recommended in Chapter 3.

Performance - A standard process for evaluation of performance of walls and barriers is needed. The evaluation will combine time-history of wall conditions, appraisals and maintenance costs, and could be expressed as life cycle costs for walls.

CHAPTER 2 – LITERATURE REVIEW

No complete system for management of retaining walls and sound barriers was discovered in the review of literature sources under Task 2. Two US state transportation agencies, Colorado and Wisconsin, have structure numbering records for new retaining walls and sound barriers. Similar inventory data for walls are collected by other national highway agencies including agencies in Switzerland (*13*), France (*14*), Germany, Denmark, Norway, Finland and Sweden.

Wall Management Activities at other DOTs

At least two transportation agencies in the US, Colorado DOT and Wisconsin DOT, collect inventory data on retaining walls. The efforts at the two agencies are similar. Inventory data are collected for new walls only, there is no program for periodic inspection, there are no condition or appraisal ratings in the inventory record, and the inventory is not used to identify maintenance or improvement needs.

Wall Inventory at Wisconsin DOT

Wisconsin DOT maintains an inventory of new retaining walls. Wisconsin began its wall inventory four years ago. There is currently no attempt to include older walls. Wisconsin plans to inspect all ancillary structures, including sound barriers and retaining walls. A new inspection manual for ancillary structures is in final preparation. The data fields in the Wisconsin inventory are shown in Table 10.

Table 10 - Wisconsin Wall Inventory

Inventory Field	Entries (Codes)
Wall Type	Cast-in-Place on Piles (50) Cast-In-Place on Spread Footing (51) Block-Gravity (52, 53, 56) Concrete Bin (54, 55) MSE - Block Facing (58) MSE - Panel Facing (57, 59) SHT Pile - Cantilever (65, 66) Other (60, 61, 62, 63, 64, 67)

Pile Type	Timber Steel Cast-in-Place Concrete
Pile Size	8", 10", 12", 14", Other
Geometric Data	Structure Length, m Maximum Height, m
Feature On Bridge	Retaining Wall
Feature under Bridge	Route number, or railroad Direction, N/E/S/W Roadway Class
Location	Text Field
Bridge Description	Name of wall supplier
Plans Completed	Yr / Mo / Day
Construction ID	ID
Work Performed	New Structure
Designer	WiscDOT Unit Number Consultant
Cost	Cost
Type Service On	Retaining Wall

Codes for Wisconsin wall types are shown in Table 11.

Table 11 - Wisconsin Wall Types

Code	Name	Description
50	CIP CONCRETE-PILES	Standard cast-in-place concrete cantilever retaining wall on piles
51	CIP CONCRETE-SPREAD	Standard cast-in-place cantilever retaining wall on spread footings
52	GABION	Wire-faced gabion wall
53	MOD-BLOCK GRAVITY	Modular concrete block wall placed as a gravity wall
54	MOD-CONCRETE-BIN	Modular concrete bin wall
55	MOD-CONCRETE-BIN-OF	Modular concrete bin wall with open face for plantings
56	MOD-STEEL-BIN	Modular steel bin wall
57	MSE-CIP CONC FACING	Mechanically stabilized earth wall with cast-in-place concrete facing
58	MSE-MOD BLOCK FACING	MSE wall with modular block facing
59	MSE-CON PANEL FACING	MSE wall with precast concrete panel facing

60	MSE-WIRE FACE	MSE wall with wire facing
61	POST & PANEL	Wall with posts and inserted panels
62	POST & PANEL-ANCHORED	Wall with anchored posts and inserted panels
63	SHEET PILE-ANCHORED	Anchored sheet pile wall
64	SHT PILE-FACE-ANCH	Anchored sheet pile wall with facing
65	SHT PILE-CANTILEVER	Cantilevered sheet pile wall
66	SHT PILE-FACE-CANT	Cantilevered sheet pile wall with facing
67	REINFORCED SOIL SLOPE	Mechanically stabilized slope with no facing

Literature Sources

The literature search included the Transportation Research Information System (TRIS), the National Technical Information Service (NTIS), the Scientific Index, Compendex, UnCover (article access), the ASCE Database, and the US Federal Depository at CU Boulder.

Sources reviewed here include:

1. Inspection and Condition assessment of walls:
   Fleckenstein, Rister, and Allen, (1998), Bray and Tatham (1992), Morgan, Kay and Bodapati (2001)

2. Application of management systems to infrastructures other than bridges:
   Fish (2000), Markow, Acharya, McNeil and Kao (1988)

3. Inspection and condition assessment of ancillary structures:
   Collins (1997), Thierrin, Catlett, and Norton (1997)

4. Principles in maintenance management:
   Markow and Alfelor (1997)

Fleckenstein, Rister, and Allen (1998) report the inspection of approximately 200 walls in Kentucky. Conditions of walls were recorded as number and kind of defects together with approximate location of defects. Inspection included a short list of inventory items for walls including County, Route, Milepost, Direction, GPS coordinates, Wall height, and Wall length.

Among the defects noted were cracking, spalling, pop outs, staining, vertical displacement, forward displacement, vegetation in joints, and migration of fines. The types of walls in the Kentucky study are listed in Table 12.

Table 12 - Kentucky Wall Inspection Study

Type	No.	Type	No.
Concrete crib walls	4	Timber lagging tied back	4
Wing walls - double barrel culverts	32	Keystone modular block retaining wall	2
Wing walls - single barrel culverts	20	Reinforced Earth Co. Open bridge abutments	9
Metal bin walls	5	Reinforced Earth Co. Wing walls	18
Gabion walls	5	Reinforced Earth Co. Closed bridge abutment	13
Rigid concrete retaining walls	13	Reinforced Earth Co. Return walls	23
Rigid concrete abutment (breast)	8	Reinforced Earth Co. Retaining walls	3
Rigid concrete abutment (non vertical)	5	VSL retaining walls	2
Rigid concrete wing walls	18	TechWall ramp embankment	2
Rigid concrete approach retaining walls	7	Sound barriers - Brick	1
CIP concrete wall tied back	6	Sound barriers - Metal sheet	1

Bray and Tatham (1992) report maintenance and inspection practices for old waterfront walls. This points up a concern for maintenance management systems: old walls may all be unique, making entry in a standardized database difficult. Similar concerns apply to older bridges, and to any older structures that a transportation agency maintains. Modern structures, and standard designs, fit more easily into automated systems.

Morgan, Kay and Bodapati (2001) report the life cycle costs of sound barriers of various constructions. Life cycle costs consider initial construction costs, maintenance costs during service life, replacement of barriers in part or in whole, and disposal of barriers at the end of service. The paper includes an overview of anticipated service life of sound barriers for different barrier materials, and construction costs of barriers as reported by the US Federal Highway Administration.

Fish (2000) reports that Wisconsin DOT will begin to inspect all ancillary structures. Ancillary structures include: Retaining walls, Sound barriers, Bridges < 20ft, Culverts < 20ft, Overhead sign structures, Cantilever sign structures, Beak-away sign structures, High mast light poles, Standard light poles, and Traffic signal supports.

Markow, Acharya, McNeil and Kao (1988) discuss the development of a management system for inland waterway transportation structures. The application, to a class of structures other than bridges, is informative for its focus on basic requirements in maintenance management systems. Demand for maintenance work arises through both a physical dimension and a policy dimension. These correspond to condition and appraisal.

Requirements of management system include:

1. Definition of condition of facilities.
2. Models to predict deterioration over time as function of original design and causative factors in service.
3. Statements of policy on quality standards.
4. Set of activities or methods to correct or prevent deterioration.
5. Models to predict costs and impacts.

Collins (1997) reports on inventory and inspection of sign structures for Illinois DOT. Fields in the Illinois Basic Data Form for Sign Structures Inventory are listed in Table 13. Inspection forms for sign structures include the items listed in Table 14 and Table 15. Condition ratings are assigned for inspection items listed in Table 15. Types of sign structures in the Illinois inventory include: Cantilever signs, Overhead signs (span type), Bridge parapet signs, Span wire, High mast lighting, Luminaries, Other sign structures. The types of signs include: Standard, Variable message, Combination standard and VMS, Light only, Signal, Signal and signs, Combination light, and Other.

Table 13 - Illinois DOT Sign Inventory Items

State inventory number	Vertical clearance at roadway centerline
Structure number on plans	Vertical clearance at right shoulder

District	Vertical clearance at left shoulder
County	Distance from edge of lane to right support
Route	Distance from edge of lane to left support
Milepost	Main structure material
Station	Type of support
Contract section	Support material
Letting date	Foundation type
Built by	Number of lights on structure
Year built	Type of lights
Type of structure	Walkway present
Standard design	Handrail present
Number of lanes under	Safety chains present
Length of space frame	Date last inspected
Number of panels	Inspectors
Number of spliced sections in the space frame	Date of next inspection
Splices between panel numbers _ & _	Last maintenance performed on structure (date and activity)
Sign descriptions	Cost
Total area of signs	By whom
Is the structure painted	Potential areas of future maintenance
Last painted	Comments
Painted by whom	

Table 14 - Illinois Inspection Reporting - ID and Structure Information

State inventory number	County	Letting date
Inspectors	Route	Type of structure
Structure number on plans	Milepost	Spliced between panel
Inspection date	Station	Space frame span length
District	Contract section	Number of panels

Table 15 - Illinois Inspection Items - Condition Ratings and Notes

All Sign Structures	
Foundations	Handrails
Anchor bolts	Safety chains
Baseplates	Painting
Signs	Simple span structures / end support frames
Lights	Cantilever structures / end post
Walkways	
Space Frames	
Top chord	Diagonals (between trusses)
Bottom chord	Splice flanges and bolts
Verticals	Connection to supports
Diagonals	Camber present
Horizontals (between trusses)	
Bridge-Mounted Signs	
L brackets	T brackets
Upper support	

Thierrin, Catlett, and Norton (1997) report on data collection for outdoor advertising signs along highway corridors for the New Jersey DOT. The project included transfer of data from existing paper records to an electronic database, and verification of data.

The inventory record for advertising signs includes: Sign identification, Sign location, Primary location, Description, Sign characteristics, Sign dimensions, Photos, and Violations and Deficiencies. In field work, each sign was visited, inventory data were verified, and photos were taken for electronic storage. Locations were verified by use, in combination, of GPS units and laser range finders. Range finders were used to adjust GPS coordinates when access was difficult and the sign was observed from a distance.

Location data has a nominal accuracy of <100m. When GPS readings are corrected with fixed base stations, error is <5m.

Markow and Alfelor (1997) review the basis for evaluation of economic benefits of maintenance for transportation facilities. Among these benefits are: 1) Preservation of facilities at minimum

life cycle cost, 2) Maintenance of highway operations, 3) Maintenance of traffic control and safety features, 4) Preservation of convenience features such as sound barriers and structures associated with rest stops, viewpoints, etc., 5) Maintenance of aesthetic qualities of system.

CHAPTER 3 – CONCEPTUAL MANAGEMENT SYSTEM

In this chapter, inventory, appraisals, condition data and maintenance actions for walls and barriers are explored. A wall management system requires the creation of standardized data and practices in all of these areas. To the extent that the proposed data and practices are reasonable, a wall management system is feasible.

Data for Wall Management

A management system may organize data into several categories:

Inventory data are those data items that either do not change, or change infrequently for a structure. Changes to inventory data are external to the structure, as when a route is reclassified or renumbered, or a new value of average daily traffic is obtained.

Appraisal data, or simply appraisals, indicate how well an existing structure conforms to current design standards and material specifications.

Element-Level data are detailed lists of the materials, forms, quantities and conditions of structural members that comprise a structure. Of these, only condition data are updated routinely. Other element-level data are constant unless a structure is modified. For walls, there are *components* in addition to elements. Components are internal, or hidden, features of walls. Components are not accessible for routine inspection, and have no regular updates to condition data.

Inventory Data

Inventory data include data about the structure's age, type, location, dimensions, about its function including routes carried, average daily traffic, and load capacity, and about projects planned for the structure. The US National Bridge Inventory record (*2*) is a model for a standard inventory data record. CDOT has, in addition, its own coding guide (*9*).

Data fields in an inventory record are shown in Table 16. Detailed coding appears in Appendix A. This inventory record for walls and barriers is similar to the NBI bridge inventory record, but data fields and their coding have been adapted to walls and barriers. Inventory data are organized in four groups:

Identification items include structure number, municipality, owner and maintenance responsibility and similar administrative items.

Inventory route includes route, milepost, average daily traffic, detour length and similar items addressing function of the inventory route. These items are important to evaluation of the impact of closure or restriction of traffic due to actions at the structure.

Intersected feature items include identity, average daily traffic, etc., of the second route, if any, at the wall. Intersected features usually do not occur for sound barriers.

Structure data items include structure type, age, materials, material properties, design basis, and strength of structures.

Project data items include scope and costs of planned repair or improvement projects.

Table 16 - Inventory Record

IDENTIFICATION		
Record Type	Location	Owner
County Code	Range, Township and Section	Border Structure
Structure Number	Original Construction Project Number, Subaccount Number, Project Indicator	Border Structure Number
Replaced Structure	Maintenance Responsibility	
INVENTORY ROUTE DATA		
Inventory Route Type	Lanes On	Highway System of Inventory Route
Field Log Inventory Route	Lanes at Front	Federal Lands Highway
Field Log Reference Point	Average Daily Traffic	Average Daily Truck Traffic

Functional Classification of Inventory Route	ADT Year	Designated National Network
Type of Service – Inventory Route	Toll Road	Year of Future ADT
Inventory route R.O.W.	STRAHNET Highway	Field Log Mileage Section Letter
Bypass Detour Length	Direction of Traffic	
INTERSECTED FEATURE DATA		
Feature Intersected	R.O.W. for intersected feature	Navigation Horizontal clearance
Type of Service – Feature Intersected	Navigation Control	Average Daily Traffic
STRUCTURE DATA		
Year Built	Backfill	Wall offset, vertical
Design Load	Backfill unit weight	Curbs & Sidewalk Width – On structure
Slope at Top / Feature at Top	Backfill friction angle	Curbs & Sidewalk Width – At front of Structure
Distance to load Supporting element	Retained Fill (*Undisturbed material behind wall*)	Average wall height
Fill Reinforcement Type	Wall Top Attachment	Maximum wall height
Soil nails, ground anchors, other metal components that support facing but do not reinforce backfill	Wall Attachments / Wall Top	Clearance to travel lane on wall.
Fill Reinforcement Length	Wall Bottom Attachment	Clearance to travel lane at front of wall or barrier
Fill Reinforcement Spacing	Historical Significance	Structure Designer
Fill Reinforcement LTDS	Open/Closed	Structure Load Capacity
Fill Reinforcement MARV	Type of Service - Structure	Posting, Restriction
Connection for fill reinforcement	Inventory slope angle	Parallel Structure Designation
Reinforcement pattern	Wall Type, Barrier Type	Temporary Structure
Geotextile wrap length	Supplier of Pre-Approved Wall	Year Reconstructed
Membrane at Top of Fill	Number of Spans	Facing, Graffiti Treatment
Geotextile filter	Structure Length	Sound: A-Weighted Transmission Loss
Drainage Blanket	Wall Horizontal Curve	Wall Foundation
Drain at bottom	Wall Vertical Batter	Pier Protection (Navigation)

PROJECT DATA		
Type of Work	Wall Costs Total	Future Average Daily Traffic
Length of improvement	Wall Cost Unit	System
Inspection Date	Bridge Improvement cost	Status
Inspection Interval	Roadway Improvement Cost	Notes
Critical feature	Total Project Cost	
Critical feature inspection date	Year of Cost Estimate	

Appraisals

Appraisals are evaluations of structures for their conformance to current design standards and material specifications. Appraisals reveal how *standards* have changed in the time since a structure entered service. Inadequate appraisals indicate modifications and improvements needed at structures. Generally, poor or inadequate appraisals accumulate with continued years of service for any given structure, since standards are updated regularly.

Appraisals are organized into four categories:

Geometric appraisals include lateral clearances from traffic lanes to front of walls or barriers, and lateral clearance to railings for routes on retained fill.

Traffic safety appraisals address transitions at ends of structures and railings at front of walls or barriers and at top of walls.

Material appraisals note non-conforming materials, if any, among facing, fill reinforcements, anchors, posts or other constructed features. Material appraisals also address conditions of structural backfill and retained soils. Inadequate fill materials, or the presence of aggressive conditions due to pH, water movement, stray currents, etc. are all addressed by appraisals for fills.

Design appraisals note non-conforming details, strengths, or other aspects of design.

Appraisal data items are listed in Table 17. Detailed coding for appraisals is listed in Appendix B.

Table 17 – Appraisals for Walls and Barriers

GEOMETRICS	
Lateral clearance at top	Lateral clearance at front
TRAFFIC SAFETY	
Wall Top Attachment Appraisal	Wall /Barrier Transition
Wall Bottom Attachment Appraisal	
DESIGN	
Design adequacy	Proprietary wall system. Design/build wall system
Fill Reinforcement Length	Slope at Top
Fill Reinforcement Spacing	Footing cover
Fill Reinforcement MARV	Footing Pressure
LTDS of fill reinforcement, anchors or soil nails	Distance to load supporting element
Design Life Appraisal	Drainage Design
MATERIALS	
Backfill	Geotextile filter
Natural (undisturbed) soils at wall	Membrane
Embedded components (anchors, soil nails)	Drainage Blanket
Fill Reinforcement	Drainage

Standard Elements for Walls

Wall elements are defined by their form, material and use. This is the same approach used for bridge elements. Elements serve several functions in management systems:

- Elements describe structures. Elements list the parts of structures. Element quantities are recorded, further describing structures. Through elements, a management system recognizes the materials and forms of members in structures.

- Actions in maintenance, repair, rehabilitation and replacement are tied to elements. Unit costs of actions are tied to elements. A structure's elements and quantities form the basis for estimates of costs for a program of actions.

- Elements have conditions reported in periodic inspections. Conditions, by themselves, indicate which elements need maintenance or repair. Time-histories of conditions reveal rates of deterioration, indicate relatively good or poor performance among elements, and allow management systems to forecast future needs for maintenance, future costs, and the probable service life of structures.

New elements for walls and barriers must meet these functions. Elements must identify the parts of a structure, must allow an accounting of quantities, must admit actions for maintenance and repair, and must be accessible for inspections.

For sound barriers, elements can be defined that meet all requirements (Figure 1). Elements for barriers are very similar to elements for highway bridges.

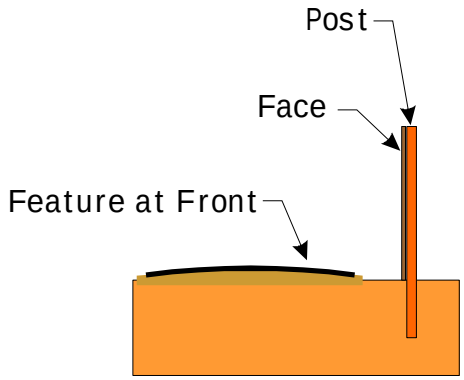


Figure 1 - Elements for Sound Barriers

Retaining walls are not bridges. Walls have hidden parts, such as fill reinforcement, that are not visible and not accessible. Indeed, it is a goal of the design that the internal parts never become visible. Retaining walls require *components* in addition to elements. Elements are the visible parts of walls, such as facing. Components are the hidden parts, such as fill reinforcement.

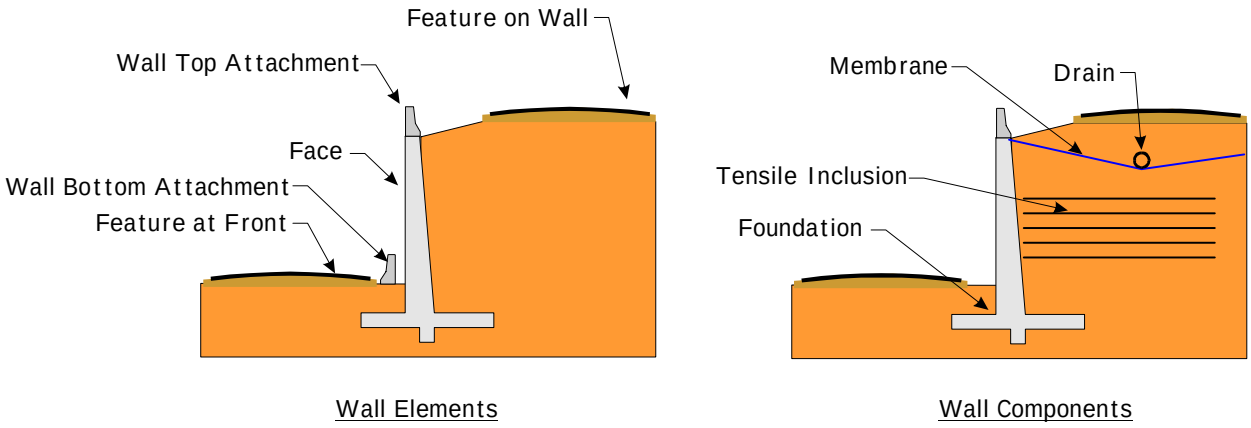


Figure 2 - Elements and Components for Walls

Components can deteriorate and become damaged. But their deterioration cannot be tracked in routine, visual inspection. In the longer term, poor performance in components becomes evident as gross settlement or tilts of walls, or as distress in visible elements or adjacent features. Pavements and railings on walls may exhibit distress that is due to movement in walls or retained fills. Slopes immediately above walls may show disruptions related to walls. Features at the front of walls, such as railings and pavements, may exhibit distress that is related to problems in retaining walls. The conditions of adjacent features are important indicators of conditions of walls. For this reason, adjacent features are included among elements for walls. Being elements, they are inspected and their conditions are recorded in the wall management system. Conditions of adjacent features are a needed part of the condition history of walls.

Table 18 - Properties of Elements and Components

		Quantities	Conditions	Actions
Elements	Feature at Top	Yes	Yes	No (1)
	Top attachment	Yes	Yes	Yes
	Facing	Yes	Yes	Yes
	Bottom attachment	Yes	Yes	Yes
	Feature at front	Yes	Yes	No (1)
Components	Membrane	Yes	No	Yes (2)
	Backfill	Yes	No	Yes (2)
	Fill Reinforcement	Yes	No	Yes (2)
	Anchors/other tensile inclusion	Yes	No	Yes (2)
	Drainage blanket	Yes	No	Yes (2)
	Internal drains	Yes	No	Yes (2)
	Foundation	Yes	No	Yes (2)

(1) – A wall management system is not directly concerned with maintenance of adjacent features, but the system will indicate that actions at walls can affect adjacent features.
(2) – Invasive actions are needed to replace or repair internal components.

Lists of elements and components are presented in Appendices D and E.

Standard Data on Actions and Costs

Maintenance includes actions such as cleaning and clearing that interrupt or eliminate conditions that may lead to damage in walls or barriers. Maintenance actions include removal of graffiti, removal of vegetation at joints in wall facing, removal of trees too near to facing, and clearing of drains and gutters. *Repair* includes actions to restore elements that are damaged. Railings may be repaired after damage by impact. Concrete elements may require crack sealing or minor patching of spalls or popouts. Repairs do not require engineering review. *Rehabilitation* is a substantial reconstruction of walls or barriers that requires engineering review. Rehabilitation is so extensive or intrusive to structures that stability or function may be affected.

A wall management system will track needs, execution and costs for maintenance, repairs and rehabilitation. Standard, numbered actions are needed. Table 19 lists some wall actions.

Table 19 - Maintenance Actions

Action		Walls & Barriers
Maintenance	217.01	Graffiti removal
	217.02	Removal of vegetation
	217.03	Clearing of drains
	217.04	Replacement of riprap or other random slope or channel protections
Repairs	217.11	Repairs to railings and barriers damaged by collision
	217.12	Sealing cracks in facing elements
	217.13	Patching concrete elements
Rehabilitation	217.21	Replacement of facing panels
	217.22	Replacement of drains or membranes
	217.23	Replacement of anchors for facing
	217.24	Replacement of fill reinforcements
	217.25	Shoring

Asset Management

Asset management, in concept, seeks the planning of design, construction, use, maintenance and replacement of facilities to achieve the best service at the least cost. A focus on assets generally, instead of one class of structure specifically, promotes coordinated planning of all actions for all facilities. Systems such as bridge management, pavement management and wall management serve as subroutines to the larger coordinated asset management.

CDOT Wall Investment

The CDOT STRNO inventory contains 640 retaining walls and 110 sound barriers. Construction costs for 62 of 110 sound barriers are $19,450,000. This yields a unit cost of $20.10/sq-ft of sound barrier. Total cost of all 110 sound barriers is estimated at $37,075,000. Among the 640 retaining walls, construction costs are recorded for 239. For these, the cost is $104,520,000 or about $41.73/sq-ft of retaining wall. Total cost of all 640 walls is estimated at $224,000,000. There are 110 MSE walls among the 640 retaining walls. There are between 300 and 400 other CDOT retaining walls that are not in the database. CDOT estimates that $278,000,000 has been invested in construction of retaining walls and sound barriers.

If walls have an average service life of 75 years, the $278,000,000 investment translates into a $3,700,000 annual cost. If average service life is extended to 80 years, annual costs are $3,500,000. The difference indicates the savings that may be achieved if a wall management system is used to identify the most durable wall designs and to recommend appropriate maintenance actions. Of course, replacement costs for walls are likely to be higher than initial construction costs. The potential savings, tied to replacement costs, are also higher.

On-going costs for wall management include costs of wall inspection, data entry and operation of the management system software. If wall inspections are conducted every 6 years, and if a two-person crew can inspect 25 walls per week, the annual cost of wall inspections will be about $30,000. Data entry and software operation may cost a similar amount.

Implementation Plan

The inventory, appraisal, elements and components proposed here may be used in development of a management system for walls and barriers. Work is needed to instantiate the electronic records for all CDOT walls and barriers, to assemble element-level models, to inspect walls and barriers and collect condition data, and finally to implement automated functions for management.

Development can be achieved in a sequence of four projects, each producing a functioning part of the final, complete management system. Each project builds on the previous one, and each yields a higher level of management capability.

Level 1 - Inventory system for walls and sound barriers

The existing CDOT activity for STRNO coding for new walls and sound barriers will be expanded with new inventory fields, and extended to older walls and barriers. The new inventory record is a modification of existing CDOT practice.

Level 1 Tasks:

- Database modification for new inventory record. Revised coding guide for walls and barriers.
- Inventory coding for older walls.
- Verification of inventory records.

Level 2 - Element-level data for walls and barriers.

Elements and components for all walls and barriers will be identified, and element-level models will be created.

Level 2 Tasks:

- Assignment of elements, components and quantities for walls and barriers.
- Element and component entry (data entry).
- Verification of element-level data.

Level 3 - Wall inspection data.

A manual for standard inspection of walls and barriers will be prepared. Inspections will be completed for all walls and barriers. Condition data, from inspections, will be added to the wall and barrier database.

Level 3 Tasks:

- Creation of inspection manuals, field procedures, reporting format, and database for inspection data.
- Policy on inspection practices, inspectors and intervals.
- Initial inspection of all walls and barriers establishing initial reports of condition.
- Continuing periodic inspections of walls and barriers.

Level 4 - Management of walls and barriers.

Data for walls and barriers will be ported to the Pontis bridge management program, or to other management system software. The software system will help with decisions in preservation and replacement of existing structures as well as design selection for new structures.

Level 4 Tasks:

- Policy on performance measures for walls and barriers.
- Policy on asset valuation of walls and barriers.
- Policy on user costs, and life cycle cost evaluation for walls and barriers.
- Policy on priorities for maintenance, repair and replacement of walls and barriers.
- Software initialization and use.

It is the opinion of CDOT staff on the study panel for this project that all the implementation steps (Levels 1, 2, 3, and 4 in the report) (except inspection, Level 3) could be performed by CDOT's Bridge Branch at no additional costs or more FTEs to CDOT. The inspection of

retaining walls will be performed by contractors as is currently done for the signs structures, and in phases based on allocated budget.

Conclusion

A management system for retaining walls and sound barriers is feasible. In many aspects, and importantly in the software required, a system for wall/barrier management can strongly resemble bridge management systems. Wall management will provide CDOT with information on inventory, conditions, maintenance needs and performance of its walls and sound barriers. Efficient preservation of existing walls and the informed selection of designs in new construction are benefits to be gained through wall management.

Wall management will be an essential tool in assessment management. The modified approach to asset valuation (*1*) requires maintenance programs to preserve assets and assessment procedures to demonstrate that preservation has been achieved. The estimate/execute/assess loop required by governmental accountants is, in fact, the evaluate/repair/inspect loop familiar to bridge engineers. A wall management system that addresses the engineering needs will satisfy the accounting requirements.

Longer service life for assets may be achieved if management systems are used to identify durable designs and appropriate maintenance actions. Given CDOT's current investment in retaining walls and sound barriers, the potential costs of a wall management system are more than offset by the potential savings in wall and barrier replacements.

APPENDIX A: CODING FOR INVENTORY FOR WALLS AND BARRIERS

This appendix lists data items and coding in a proposed inventory record for retaining walls and sound barriers. The record is modeled closely after the Federal National Bridge Inventory System (NBIS) (*2*) together with the CDOT Structure Number Coding Guide (STNO).

The table reports data item, coding for the item, and reference to existing data items, if any, in the NBIS or the CDOT STRNO. For some items, coding for walls is defined already by CDOT in STRNO. The use of STRNO coding is noted without further elaboration.

The data items are organized in four groups:

Identification items include structure number, municipality, owner and maintenance responsibility and similar administration items.

Inventory route includes route, milepost, average daily traffic, detour length and similar items addressing function of the inventory route. These items are important to evaluation of the impact of closure or restriction of traffic due to actions at the structure.

Intersected feature items include identity, average daily traffic, etc., of the second route, if any, at the wall. Intersected features usually do not occur for sound barriers.

Structure data items include structure type, age, materials, material properties, design basis, and strength of structures.

Project data items include scope and costs of planned repair or improvement projects.

Table 20 - Inventory for Retaining Walls and Sound Barriers

Data Item	Coding	Ref
IDENTIFICATION		
Record Type	Wall or Barrier	
County Code	per CDOT STRNO	CDOT 3
Structure Number	per CDOT STRNO	CDOT 8
Replaced Structure	per CDOT STRNO	CDOT 8R
Location	per CDOT STRNO	CDOT 9A
Range, Township and Section	per CDOT STRNO	CDOT 18A, 18B, 18C
Original Construction Project Number, Subaccount Number, Project Indicator	per CDOT STRNO	CDOT 23, 23E, 23EE
Maintenance Responsibility	State, County, Municipal, Federal Gov Agency, …	NBIS 21
Owner	State, County, Municipal, Federal Gov Agency, …	NBIS 22
Border Structure	Wall or sound barrier is continuous across state border.	NBIS 98
Border Structure Number	Structure number for border wall or barrier used by neighboring transportation agency.	NBIS 99
INVENTORY ROUTE DATA		
Inventory Route Type *see* Figure 3	1 – Inventory route is carried by the retaining wall 2 – Inventory route is at front of the retaining wall 3 – Sound barrier, route at front A,B,C – Multiple routes at the front of the retaining wall.	NBIS 5A
Field Log Inventory Route	per CDOT STRNO	CDOT 5DF
Field Log Reference Point	per CDOT STRNO	CDOT 11F
Functional Classification of Inventory Route	Interstate, Other Arterial, Collector, Local	NBIS 26

Data Item	Coding	Ref
Type of Service – Inventory Route	Highway, Railroad, Pedestrian/bicycle/trail	NBIS 42
Inventory route R.O.W. *see* Figure 4	R.O.W in feet	
Bypass Detour Length	Bypass mileage for closure of inventory route at wall or barrier	NBIS 19
Lanes On	WALLS: Lanes on the retaining wall. BARRIERS: Not used.	NBIS 28A
Lanes at Front	Lanes at front of structure.	NBIS 28B
Average Daily Traffic	ADT for inventory route.	NBIS 29
ADT Year	Year that ADT was measured.	NBIS 30
Toll Road	(Y/N) for inventory route	NBIS 20
STRAHNET Highway	For inventory route Strategic Highway Network, NBIS coding	NBIS 100
Direction of Traffic	For inventory route: 1-way, 2-way, Single lane for 2-way traffic, No traffic	NBIS 102
Highway System of Inventory Route	ON system, OFF system	NBIS 104
Federal Lands Highway	Bureau Indian Affairs, Bureau Land Management, Forest Service, Defense Dept., …	NBIS 105
Average Daily Truck Traffic	Number of trucks, or percentage of Average Daily Traffic	NBIS 109
Designated National Network	National network for trucks (On/Off network)	NBIS 110
Year of Future ADT	Year of ADT forecast	NBIS 115
Field Log Mileage Section Letter	per CDOT STRNO	CDOT 136F
INTERSECTED FEATURE DATA		
Feature Intersected	per CDOT STRNO WALLS: Record Type 1, code for feature at front of wall, Record Type 2, no entry. BARRIERS: Not used. Feature on wall may be structure, rather than route.	CDOT 6

Data Item	Coding	Ref
Type of Service – Feature Intersected	Highway, Railroad, Pedestrian/bicycle/trail, Building or plaza.	
R.O.W. for intersected feature *see* Figure 5	WALLS: If Record Type is '1', R.O.W. of route at front. If Record Type is '2', R.O.W. of unused corridor on wall. BARRIERS: Not used.	
Navigation Control	N – No waterway, 0 – Structure does not bound/abut navigation channel, 1 – Structure bounds/abuts navigation channel	NBIS 38
Navigation Horizontal Clearance	Clearance where structure bounds/abuts navigation channel	NBIS 40
STRUCTURE DATA		
Year Built	per CDOT STRNO	CDOT 27
Design Load	WALLS: Traffic load, if any, used in design of retaining wall. BARRIERS: Design wind speed or exposure class.	NBIS 31
Slope at Top / Feature at Top	No slope, Constant slope of great length (classes here), Berm for roadway pavement (classes here)	
Distance to Load Supporting Element *see* Figure 7	Distance in feet	
Fill Reinforcement Type	Steel strip, Steel bar mat, Steel deformed bar, Steel mesh, Polymer geogrid, Polymer geofabric, Unknown	
Anchor for Facing (other than Fill Reinforcement)	0 – none, 1 – Soil nail, 2 – Metal anchor, unprotected, 3 – Metal anchor, protected	
Fill Reinforcement Length	Embedment length. Special coding for truncated base.	
Fill Reinforcement Spacing	Spacing in feet.	
Fill Reinforcement LTDS	Value of Long Term Design Strength.	
Fill Reinforcement MARV	Strength: Minimum average roll value (MARV).	

Data Item	Coding	Ref
Connection for Fill Reinforcement	Doweled, Friction, No connection	
Reinforcement Pattern	ID: A, B, C (*see* CDOT B504A2.dwg)	
Geotextile Wrap Length	Value, feet.	
Membrane at Top of Fill	None, Type/Supplier, Unknown	
Geotextile Filter	None, Type/Supplier, Unknown	
Drainage Blanket	Code/ID	
Drain at Bottom	Pipe, Granular layer, none	
Backfill	CDOT Class, Unknown	
Backfill unit weight	Value, PCF	
Backfill friction angle	Value, degrees	
Retained Fill (*Undisturbed material behind wall*)	Unknown, Known/benign, Known/aggressive, Not in contact with metal elements or not relevant	
Wall Top Attachment *see* Figure 6 and APPENDIX F	R3 - Type 3 Railing, R10 - Type 10 Railing, R4D - Type 4 Railing with drain, R4P - Type 4 Railing with rigid pavement, R4S - Type 4 Railing with sleeper, R4B - Type 4 Railing with sound barrier, R7D - Type 7 Railing with drain, R7P - Type 7 Railing with rigid pavement, R7S - Type 7 Railing with sleeper, R7B - Type 7 Railing with sound barrier, C – Coping, CD - Coping with drain, SP - Sidewalk & Post	
Wall Attachments / Wall Top (*simplified*)	No attachment, Railing, Coping/Drain, Fence, Other	

Data Item	Coding	Ref
Wall Bottom Attachment *see* Figure 8 and APPENDIX F	R3 - Type 3 Railing, R10 - Type 10 Railing, R4P - Type 4 Railing with rigid pavement, R7P - Type 7 Railing with rigid pavement, S – Splash Block	
Historical Significance	1 – Structure on National Register of Historic Places, 2 – Structure is eligible for Register, 3 – Structure may be eligible for Register, 4 – Eligibility not known, 5 – Not eligible	NBIS 37
Open/Closed	No restriction, Restricted (load or clearance), Temporary structure, Closed	NBIS 41
Type of Service - Structure	1 - Earth retaining, 2 - Flood control, 3 - Bridge Abutment, 4 – Underpass, 5 – Embankment, 6 – Landscaping, 7 - Roadway at Front, 8 - Roadway at Top/Back, 9 - Grade Separation, 10 - Noise Control, 11 - Stability of Steep Slope	
Inventory Slope Angle	Value	

Data Item	Coding	Ref
Wall Type, Barrier Type see **Error! Not a valid result for table.**	CDOT retaining walls and sound barriers. RSW - Reinforced Soil Wall, NSW - Nailed Soil Wall, MW - Modular Wall, GW - Generic Wall, CWS - Concrete Wall, Shallow foundation, CWD - Concrete Wall, Deep foundation, LW - L Wall, ILW - Invert-L Wall, TWS - T-Wall, Shallow foundation, TWD - T-Wall, Deep foundation, LWD - L-Wall, Deep foundation, TWPTS - P/T T-Wall, Shallow foundation, TWPTD - P/T T-Wall, Deep foundation, CEW - Continuous Embedded Wall, ELW - Embedded Element & Lagging, EWD - Shallow Embedded Wall **w/** Deadmen, EWA - Shallow Embedded Wall **w/** Ground Anchor, MAF - Precast, Multi-Anchor Facing, FASS - Facing Anchored to Stabilized Slope, GAW - Generic, Anchored Wall, LWA - Anchored L-Wall, TWMSE - T-Wall, MSE stack, MSELW - MSE, L-Wall stack, TWA - Anchored T-Wall, TWPTA - Anchored P/T T-Wall, WBS - Wood Barrier **w/** Steel posts, WBT - Wood Barrier **w/** Timber posts, CMB - Concrete Masonry Barrier, MB - Metal Barrier, Alt – Alternate Pre-Approved Wall	NBIS 43 CDOT 120A, 120AA

Data Item	Coding	Ref
Supplier of Pre-Approved Wall	BLOCK WALLS: 11 - Pyramid/RECO Steel Grid, 12 - Diamond/Mirafi, PET Geogrid, 13 - Amastone/Mirafi, PET Geogrid, 14 - Versa-Lok/Mirafi, PET Geogrid, 15 - Venture/Strata, PET Geogrid, 16 - Anchor/Mirafi, PET Geogrid, 17 - Allan/Huesker, PET Geogrid, 18 - Mesa/Tensar, HDPE Geogrid, 19 - Key System, Steel Grid PANEL WALLS: 20 - Reinforced Earth, 21 – VSL, 22 – Hilfiker, 23 – Isogrid, 24 – Transwall, 25 - Strengthened Earth, 26 – ARES, 27 - MSE Plus, 28 - Strengthened Soil	
Number of Spans	Number of discrete units? Esp. for sound barriers	CDOT 45
Structure Length	per CDOT STRNO	CDOT 49
Wall Horizontal Curve	Radius and Arc Length	
Wall Vertical Batter	Value	
Wall Offset, Vertical	Value	
Curbs & Sidewalk Width – On structure	WALLS: Width in feet BARRIERS: Not used.	NBIS 50
Curbs & Sidewalk Width – At front of Structure	Width in feet	NBIS 50
Average Wall Height	feet	
Maximum Wall Height	per CDOT STRNO	CDOT 52A
Clearance to Travel Lane on Wall.	feet	NBIS 55
Clearance to Travel Lane at Front of Wall or Barrier	feet	NBIS 56
Structure Designer	Designer 0 - CDOT staff, 1 – Consultant, 2 – Approved wall supplier	

Data Item	Coding	Ref
Structure Load Capacity	WALLS: Capacity for traffic load, or other transient load. BARRIERS: Wind speed rating or wind exposure rating.	
Posting, Restriction	Appraisal for restriction of use on wall or at front of wall or barrier.	NBIS 70
Parallel Structure Designation	Figure 10 For parallel walls or barriers. Code RIGHT structure, LEFT structure, or NO parallel structure	NBIS 101
Temporary Structure	T – Temporary structure	NBIS 103
Year Reconstructed	year	NBIS 106
Facing, Graffiti Treatment	Type or manufacturer	
Sound: A-Weighted Transmission Loss	BARRIERS: DBA (ASTM E90-75) WALLS: Not used.	
Wall Foundation	Code/ID for type 1 – Footing, 2 - Concrete Pad, 3 – Piles, 4 - Drilled Piers, 5 - Reinforced sub-soil, 6 - Other improved sub-soil	
Pier Protection (Navigation)	For Navigation Control structures, code protection for foundation as good, deteriorated, not present, not required, …	NBIS 111
PROJECT DATA		
Type of Work	Class of project planned for wall or barrier. 31 - Replacement of substandard design, 32 - Replacement due to route relocation, 33 - Replacement due to widening of route, 34 - Replacement due to poor condition	NBIS 75
Length of improvement	Length of wall or barrier to be improved, feet	NBIS 76
Inspection Date	Date of most recent field inspection of wall or barrier	NBIS 90
Inspection Interval	Inspection interval in months	NBIS 91
Critical Feature	Codes for critical item to inspect. 1 – Unstable slope above wall, 2 - Improper drainage, 3 - Settlement or tilt of wall, 4 - Buckling or other misalignment of facing, 5 - Corrosion of metallic reinforcements, 6 - Deterioration of foundation, foundation cover, loss of slope at base of wall	NBIS 92

Data Item	Coding	Ref
Critical Feature Inspection Date	Date of most recent inspection of critical feature.	NBIS 93
Wall Costs Total	Amount	
Wall Cost Unit	Amount / SF	
Bridge Improvement Cost	Engineers estimate of cost for improvement project	NBIS 94
Roadway Improvement Cost	Costs for route(s) at wall or barrier	NBIS 95
Total Project Cost	Total costs	NBIS 96
Year of Cost Estimate	Year	NBIS 97
Future Average Daily Traffic	ADT at 20 years into future	NBIS 114
System	per CDOT STRNO	
Status	per CDOT STRNO	
Notes	per CDOT STRNO	

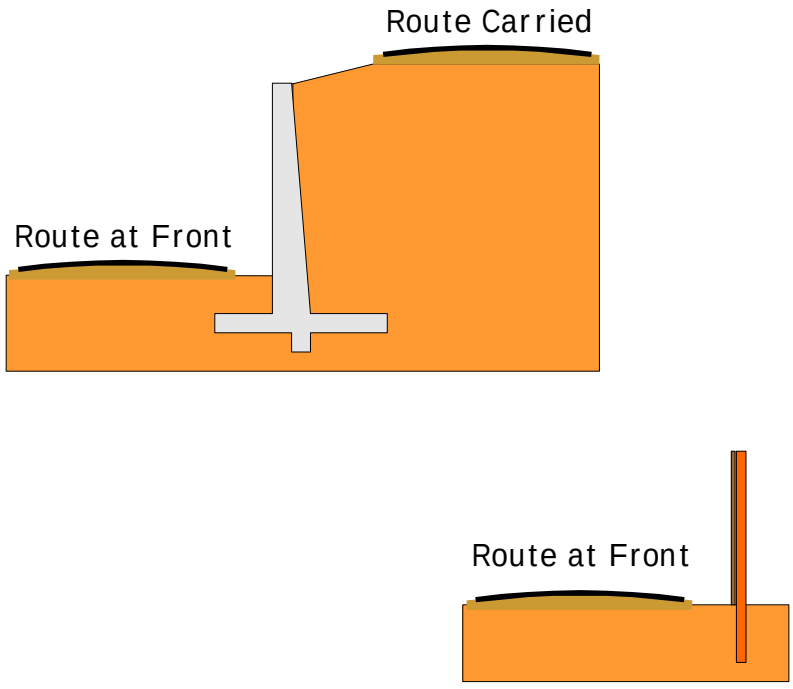


Figure 3 - Record Type

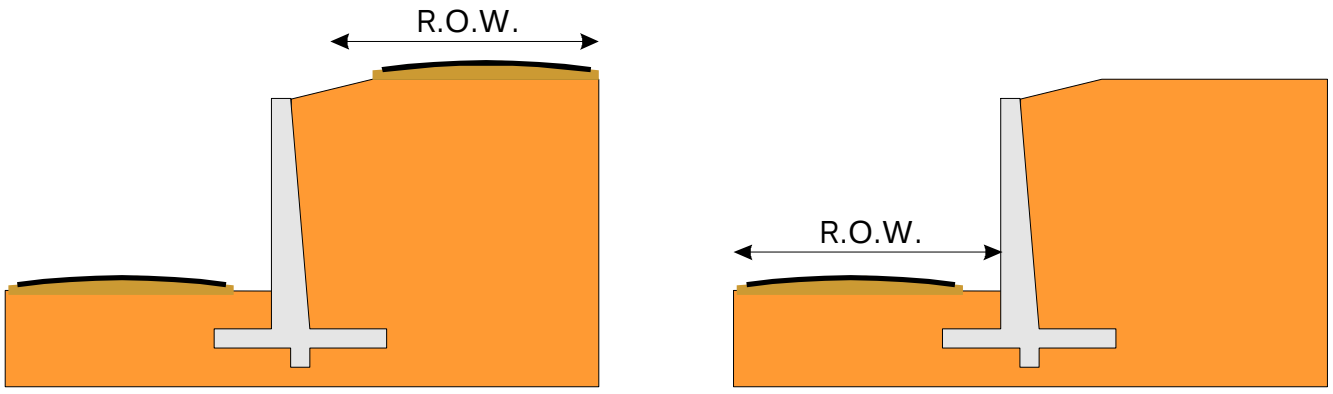


Figure 4 - R.O.W for Inventory Route

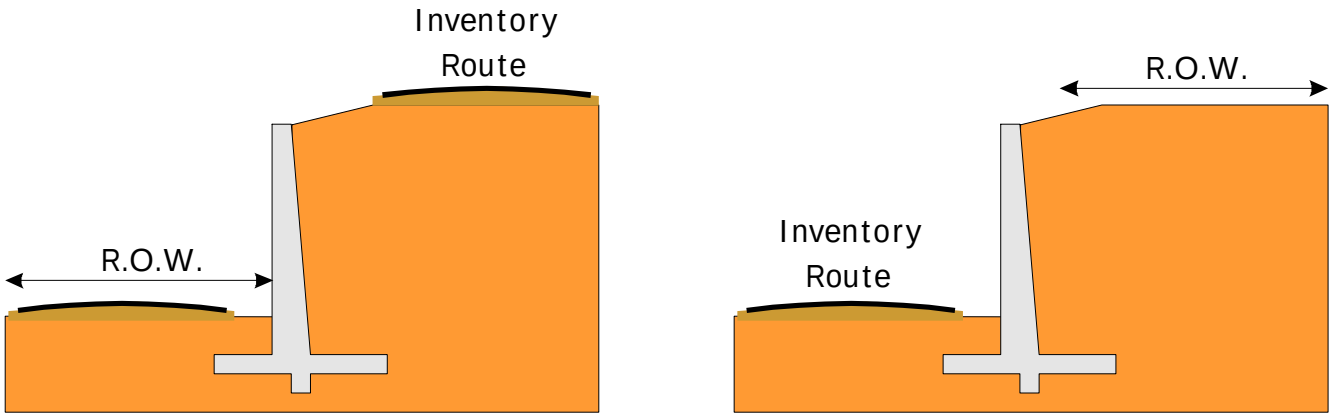


Figure 5 - R.O.W. for Intersected Feature or Unused Corridor

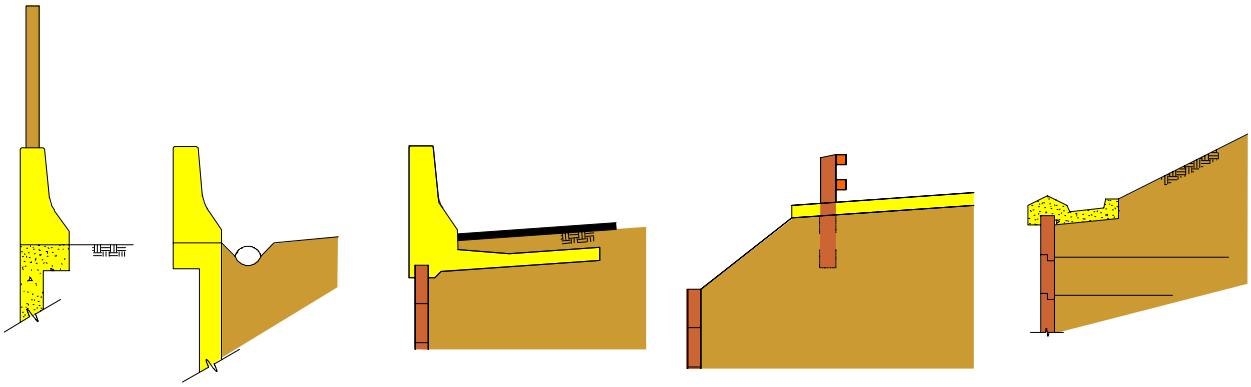


Figure 6 - Wall Top Attachments

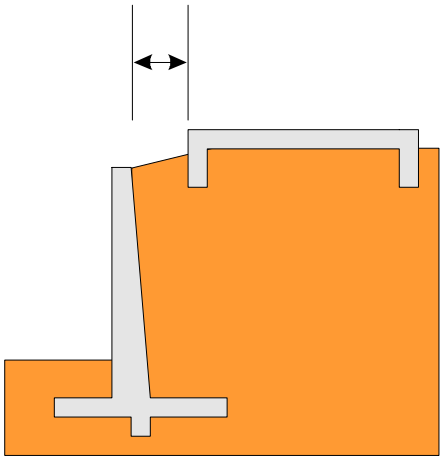


Figure 7 - Distance to Load-Supporting Element

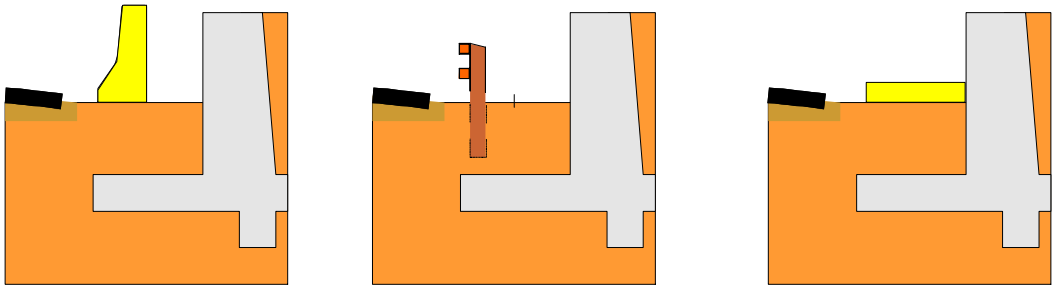


Figure 8 – Wall Bottom Attachments

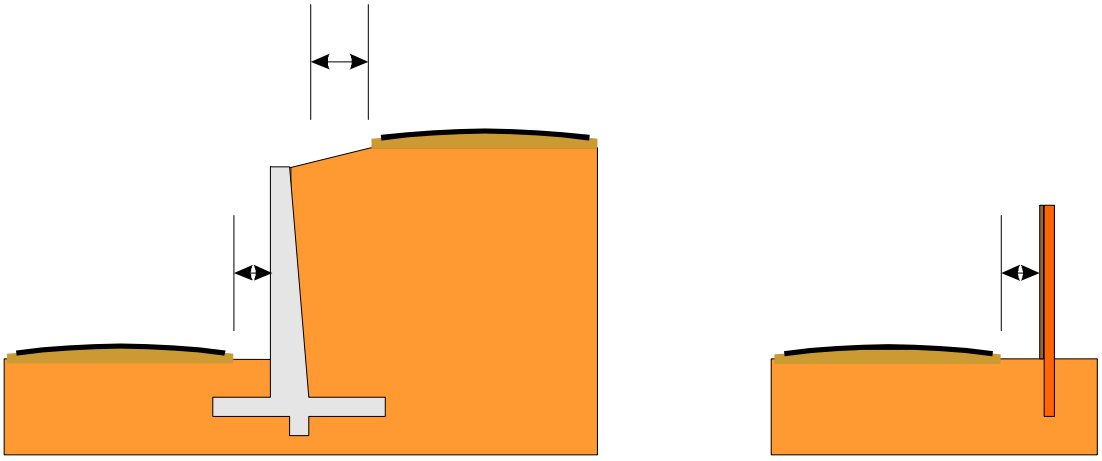


Figure 9 - Horizontal Clearances

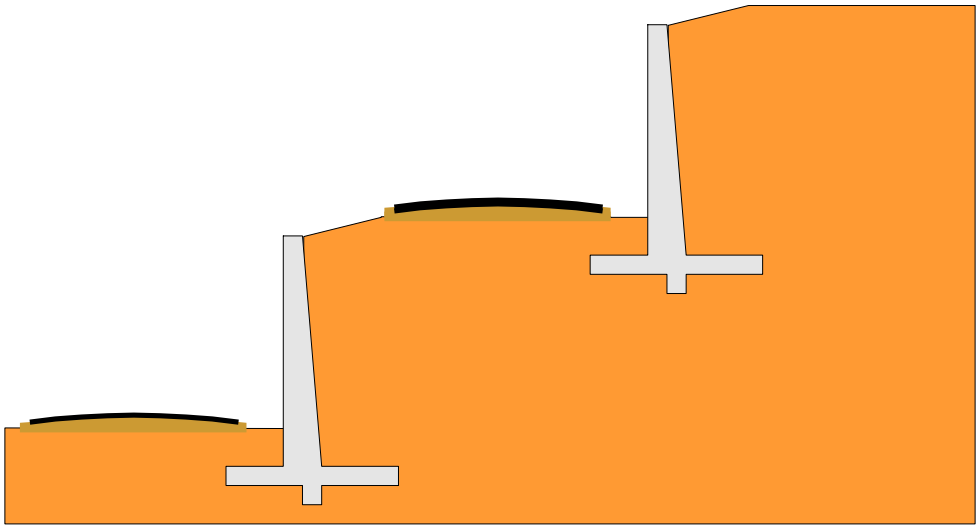


Figure 10 - Parallel Walls

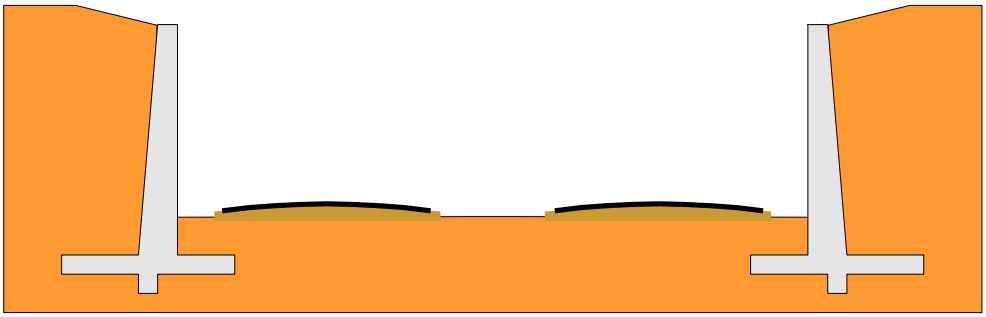


Figure 11 - Parallel Walls

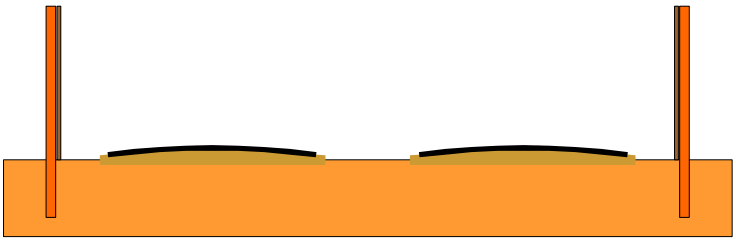


Figure 12 - Parallel Sound Barriers

APPENDIX B – APPRAISALS FOR RETAINING WALLS AND SOUND BARRIERS

Appraisals are evaluations of structures for their conformance to current design standards and material specifications. Appraisals reveal how *standards* have changed in the time since a structure entered service. Inadequate appraisals indicate modifications and improvements needed at structures. Generally, poor or inadequate appraisals accumulate with continued years of service for any given structure, since standards are updated regularly.

Appraisals are organized into four categories:

Geometric appraisals include lateral clearances from traffic lanes to front of walls or barriers, and lateral clearance to railings for routes on retained fill.

Traffic safety appraisals address transitions at ends of structures and railings at front of walls, at front of barriers, and at top of walls.

Material appraisals note non-conforming materials, if any, among facing, fill reinforcements, anchors, posts or other constructed features. Material appraisals also address conditions of structural backfill and retained soils. Inadequate fill materials, or the presence of aggressive condition due to pH, water movement, stray currents, etc. are all addressed by appraisals for fills.

Design appraisals note non-conforming details, strengths, or other aspects of design.

Table 21 - Appraisal Items for Retaining Walls and Sound Barriers

Appraisal	**Coding**
GEOMETRICS	
Lateral Clearance at Top	Adequacy of horizontal clearance from wall attachment to edge of traffic lane.
Lateral Clearance at Front	Adequacy of horizontal clearance from wall or barrier face to

Appraisal	**Coding**
	edge of traffic lane.
TRAFFIC SAFETY	
Wall Top Attachment Appraisal	Adequacy of railing on wall.
Wall Bottom Attachment Appraisal	Adequacy of railing at front of wall or barrier.
Wall / Barrier Transition *see* Figure 13	Traffic safety at structure terminations
DESIGN	
Design Adequacy	Combined appraisal of stability, strength, durability, and function of wall or barrier. Design is not adequate if the design or materials do not meet current standards
Fill Reinforcement Length *see* Table 22	For required reinforcement length relative to height of wall.
Fill Reinforcement Spacing	Maximum vertical spacing is 32" or 2x block depth.
Fill Reinforcement MARV	Fill reinforcement strength is adequate (Y/N).
LTDS of Fill Reinforcement, Anchors or Soil Nails	Long term design strength is adequate (Y/N).
Design Life Appraisal	Required design life is 75 years.
Proprietary Wall System. Design/Build Wall System	Wall system is a CDOT approved system, and design is adequate (Y/N).
Slope at Top	Slope is stable (Y/N)
Footing Cover	Adequate (Y/N)
Footing Pressure	Permissible (Y/N)
Distance to Load Supporting Element *see* Figure 7	Adequate (Y/N)
Drainage Design	Adequate (Y/N)
MATERIALS	
Backfill	Backfill may be unsuitable due to poor gradation, extreme pH, stray currents, water seepage or any other cause that may damage the wall
Natural (undisturbed) Soils at Wall	Natural soils may be unsuitable due to poor gradation, extreme pH, stray currents, water seepage or any other cause that may damage the wall. This appraisal is necessary when natural soils are in contact with wall components, such as in soil nails
Embedded Components (anchors, soil nails)	Combined appraisal of protection for anchors or soil nails and properties of soil.

Appraisal	Coding
Fill Reinforcement	Fill reinforcement meets current material specifications (Y/N).
Geotextile Filter	Approved type (Y/N)
Membrane	Approved type and adequate design (Y/N)
Drainage Blanket	Adequate design (Y/N)
Drainage	Improper passage of water through or over facing (Y/N)

Table 22 – Reinforcement Length Guide

Design Height (DH)	Minimum Reinforcement Length
DH > 11' (3.35 m)	0.7(DH)
11' (3.35 m) ≥ DH ≥ 8' (2.43 m)	8' (2.43 m)
DH ≤ 8' (2.43 m)	Minimum of 1.0(DH) or 6' (1.83 m)
Top Layer	≥ 8' (2.43 m)

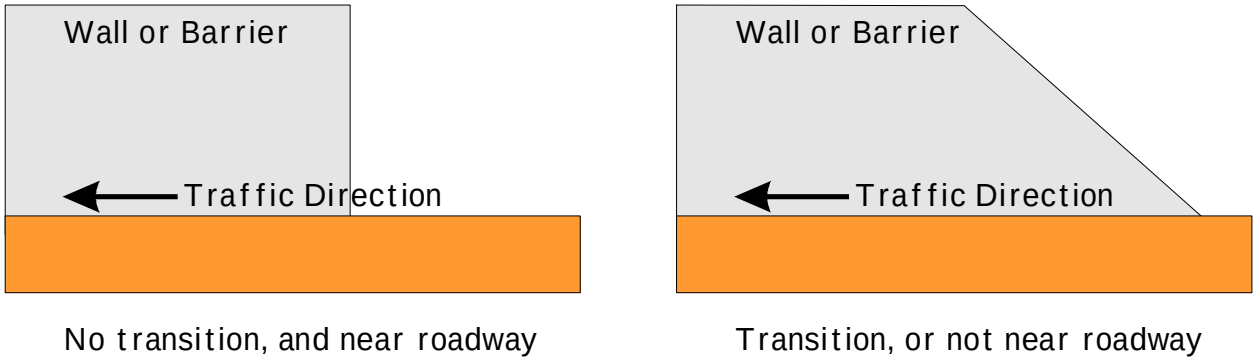


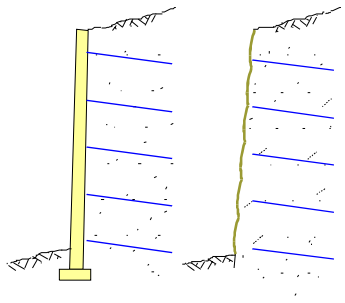
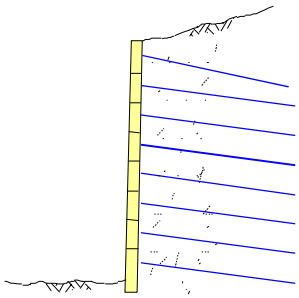
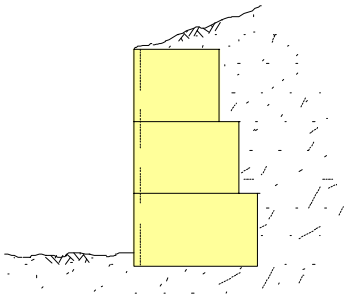
Figure 13 - Appraisal of Wall Transition

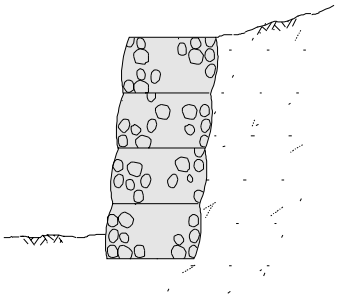
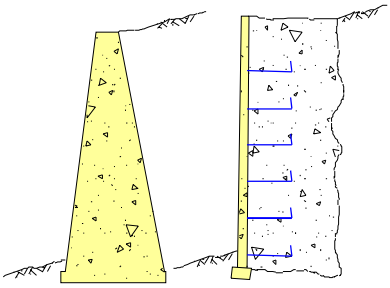
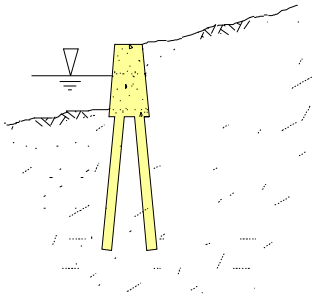
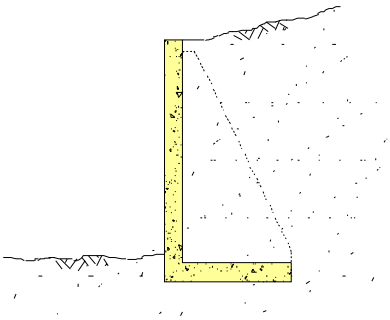
APPENDIX C - RETAINING WALL TYPES. SOUND BARRIER TYPES

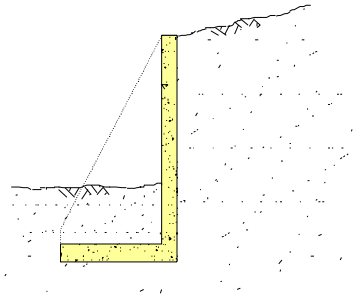
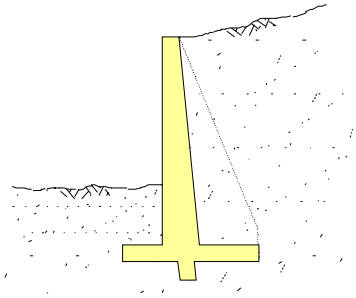
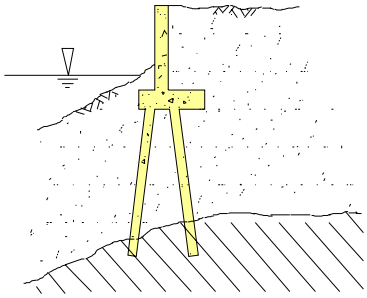
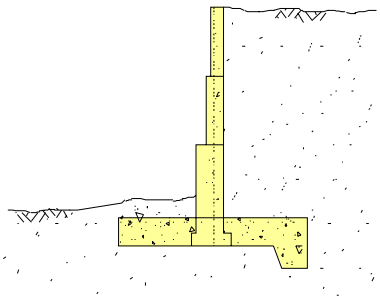
This appendix lists wall types that are identified in the CDOT Bridge Design Manual (*8*). Walls are presented in four groups: Gravity, Semi-gravity, Non-gravity and Hybrid walls. These groups are established in the Bridge Design Manual. Sound barriers are identified in CDOT drawings and specifications.

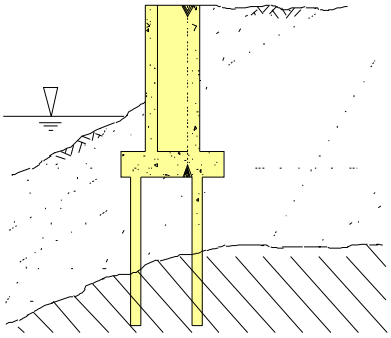
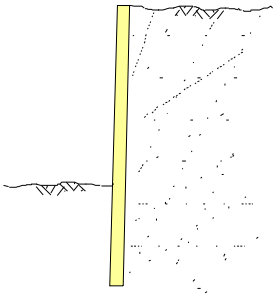
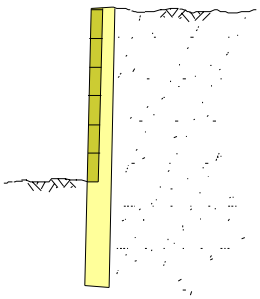
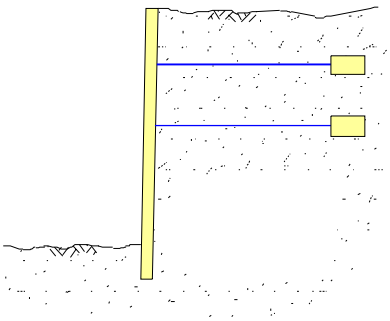
There are two uses for this set. First, coding for a proposed inventory record must include all of these walls. Second, sets of elements and components must include all items necessary for description of these walls.

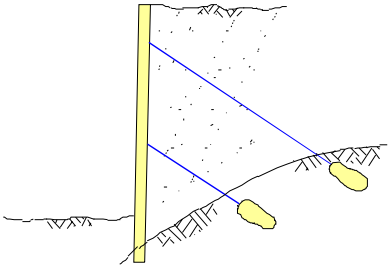
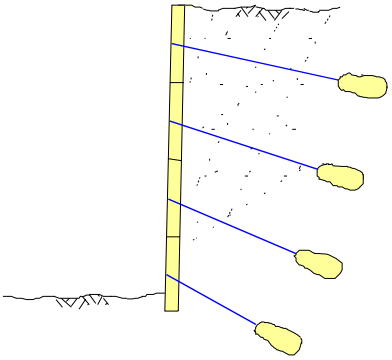
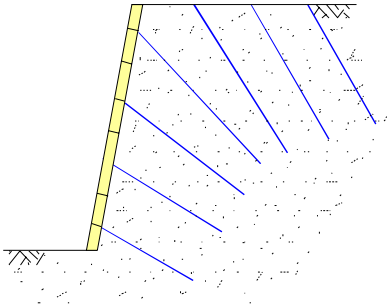
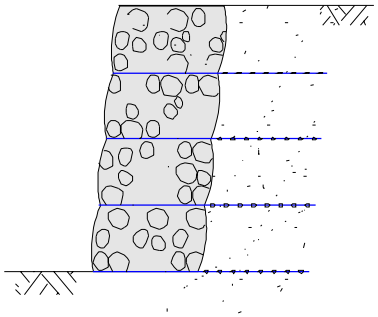
Table 23 - Retaining Wall Types. Sound Barrier Types

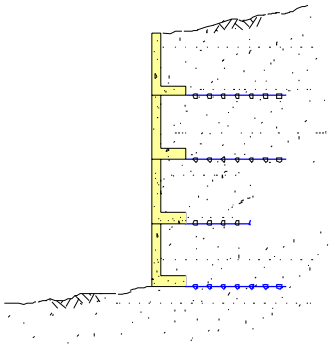
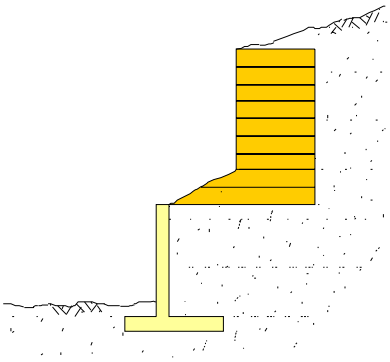
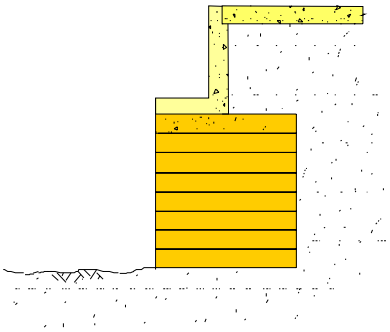
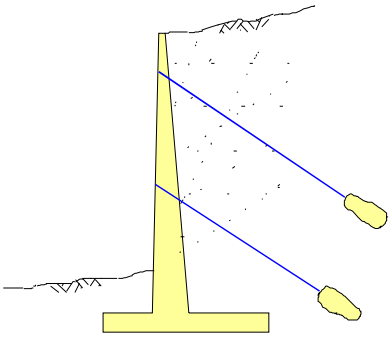
Gravity Walls		
	Reinforced Soil Wall Select fills reinforced with tensile reinforcements either metal or geo-textile bars, mats grids	RSW
	Nailed Soil Wall Facing-covered cuts with uniformly spaced top-to-bottom constructed nails.	NSW
	Modular Wall Precast or prefabricated modular walls.	MW

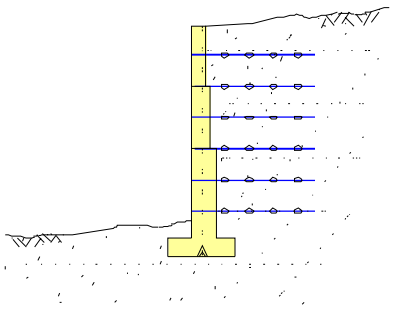
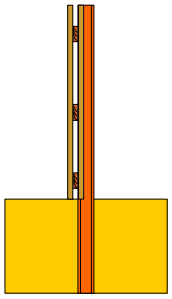
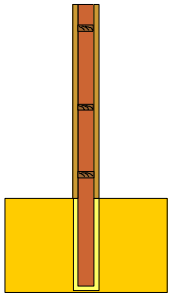
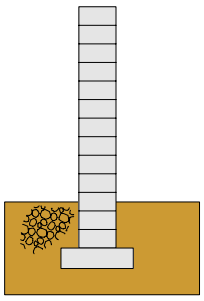
	<u>Generic Wall</u> Prefabricated wall elements such as masonry or concrete blocks, rough elements such as dumped rocks, gabions.	GW
	<u>Concrete Wall, Shallow Foundation</u> Cast-in-place solid concrete walls or precast concrete facings anchored in cement stabilized soil zones.	CWS
	<u>Concrete Wall, Deep Foundation</u> Cast-in-place reinforced concrete wall on deep foundation either drilled caissons or piles	CWD
SemiGravity Walls		
	<u>L Wall</u> Can be used with counterforts.	LW

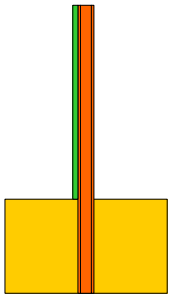
	Invert-L Wall Can be used with buttresses.	ILW
	T-Wall, Shallow Foundation T-walls on spread footing. Use counterforts and shear key if needed.	TWS
	T-Wall or L-Wall, Deep Foundation T-walls or L-walls on deep foundations. Use either drilled caissons or piles.	TWD LWD
	P/T T-Wall, Shallow Foundation T-walls with precast, post-tensioned stem and cast-in-place base on spread footing.	TWPTS

	<u>P/T T-Wall, Deep Foundation</u> T-walls with precast post-tensioned stem and cast-in-place base on deep foundation, either drilled caissons or piles.	TWPTD
NonGravity Walls		
	<u>Continuous Embedded Wall</u> Embedded, continuous drilled caissons, slurry trenched concrete diaphragm walls.	CEW
	<u>Embedded Element & Lagging</u> H-piles, wood piles, concrete piles or drilled caissons with lagging.	ELW
	<u>Shallow Embedded Wall & Deadmen</u> Shallow embedded, continuous or discrete cantilevered elements anchored to buried concrete blocks in stabilized zone.	EWD

	<u>Shallow Embedded Wall & Ground Anchor</u> Shallow embedded continuous discrete cantilevered elements with tiebacks anchored to stable, undisturbed soils.	EWA
	<u>Precast, Multi-Anchor Facing</u> Precast concrete multi-anchored facings with tiebacks anchored to the stabilized zone.	MAF
	<u>Facing Anchored to Stabilized Slope</u> Creeping slopes doweled with caissons or piles for stability. Precast concrete facings are anchored to the dowels.	FASS
Hybrid Walls		
	<u>Generic, Anchored Wall</u> Generic walls anchored with geo-fabric grid reinforcement. Gabion walls anchored with geo-grids.	AW

	Anchored L-Wall Modular precast L-walls anchored with geo-fabric grid reinforcement.	LWA
	T-Wall, MSE Stack Geo-fabric wall stacked on top of T-wall	TWMSE
	MSE, L-Wall Stack L-wall with rail stacked on top of earth wall.	MSELW
	Anchored T-Wall T-wall with anchors added to stabilized zone.	TWA

	Anchored P/T T-Wall T-wall with precast, post-tensioned modular stem elements anchored with geo-grid or with reinforcements	TWPTA
Sound Barriers		
	Wood Barrier & Steel Posts Wood picket and rail fence support on steel posts.	WBS
	Wood Barrier & Timber Posts Wood picket and rail fence support on timber posts.	WBT
	Concrete Masonry Barrier Free-standing concrete masonry on footing or leveling pad.	CMB

	<u>Metal Barrier</u> Metal soundproofing panel supported on metal posts	MB

APPENDIX D – ELEMENTS FOR RETAINING WALLS AND SOUND BARRIERS

This appendix lists proposed elements for retaining walls and sound barriers. Each structure is modeled as a set of elements and quantities of elements. Inspections are organized around elements, and the basic reports from routine inspections are the existence, type and extent (quantity) of defects and deterioration. These reports, in turn, are used in planning programs for maintenance and repair.

Elements are distinct, recognizable parts of walls. Elements are accessible for routine inspection. Figure 14 shows the features included among elements. Table 24 provides a list of elements defined by feature, material and form. The numbering system for elements is set in a range not used for CDOT bridge elements (*7*).

For retaining walls, features on the wall and at front of the wall are included among elements. This is done so that distress in these features may be reported, and the data retained. Distress in nearby features can be an important indicator of problems in retaining walls.

Retaining walls often have hidden features, called components, in addition to their visible elements. Components are not accessible for routine inspection. Components are presented in Appendix E.

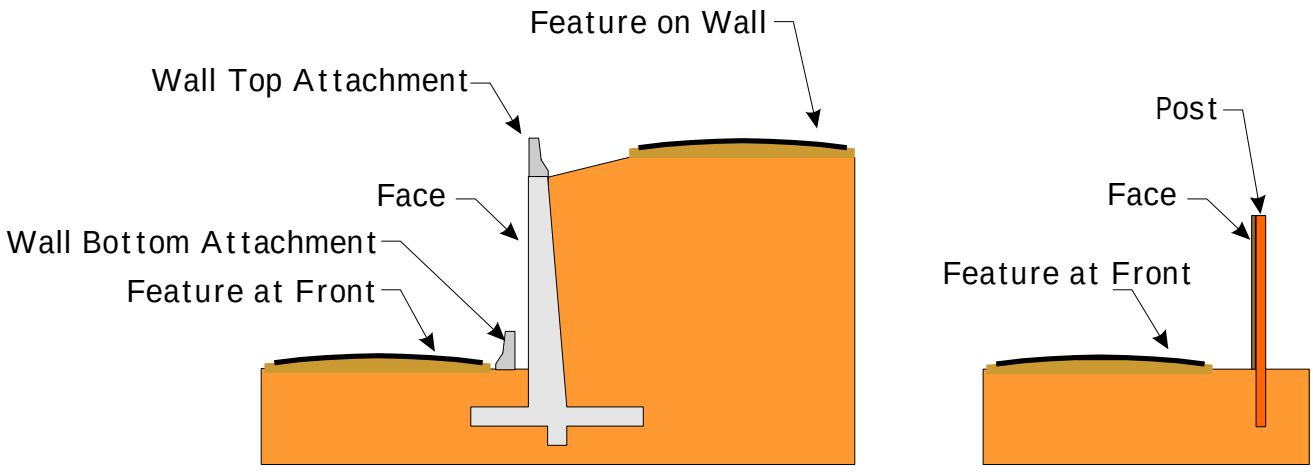


Figure 14 - Elements for Walls and Sound Barriers

Table 24 - Wall Elements

Group	Number	Element	Unit
Feature on Wall	401	Paved road	LF
	402	Unpaved road	LF
	403	Embankment (flat/near-flat surface)	LF
	404	Canal	LF
	405	Vegetated slope	LF
	406	Talus	LF
	407	Other slope	LF
	408	Building	LF
	409	Isolated foundation(s)	LF
Wall Top Attachment	410	Type 3 Railing	LF
	411	Type 10 Railing	LF
	412	Type 4 Railing with Drain	LF
	413	Type 4 Railing with Rigid Pavement	LF
	414	Type 4 Railing with Sleeper	LF
	415	Type 4 Railing with Sound Barrier	LF
	416	Type 7 Railing with Drain	LF
	417	Type 7 Railing with Rigid Pavement	LF
	418	Type 7 Railing with Sleeper	LF
	419	Type 7 Railing with Sound Barrier	LF
	420	Coping	LF

Group	Number	Element	Unit
	421	Coping with drain	LF
	422	Sidewalk & Post	LF
Wall	423	CIP Reinforced Concrete	SF
Facing	424	CIP Concrete – Post-Tensioned	SF
	425	Precast Concrete L, Full Height	SF
	426	Precast Concrete L, Stacked	SF
	427	Precast Concrete T - Prestressed	SF
	428	Precast Concrete T – Post-Tensioned	SF
	429	Precast Full Height Panel - Reinforced Concrete	SF
	430	Precast Full Height Panel - Prestressed Concrete	SF
	431	Precast Full Height Panel – Post-Tensioned Concrete	SF
	432	Precast Modular Panel - Reinforced Concrete	SF
	433	Precast Modular Panel - Prestressed Concrete	SF
	434	Embedded Piers or Caissons – Continuous	SF
	435	Embedded Piers or Caissons w/ Lagging	SF
	436	Concrete trench wall	SF
	437	Concrete bin or crib	SF
	438	Gunnite/Shotcrete	SF
	439	Gabion	SF
	440	Concrete Block Masonry	SF
	441	Concrete Brick Masonry	SF
	442	Clay or Shale Brick Masonry	SF
	443	Stone Masonry	SF
	444	Stone, dumped	SF
	445	Steel Sheet Piling - Type 1	SF
	446	Steel Sheet Piling - Type 2	SF
	447	Steel H Piling - Continuous	SF
	448	Steel H Piling w/lagging	SF
	449	Steel bin or crib	SF
	450	Timber	SF
	451	Timber bin or crib	SF
	452	Wrapped Fabric w/ UV protection	SF
Wall	453	Type 3 Railing	LF
Bottom	454	Type 4 Railing with rigid pavement	LF

Group	Number	Element	Unit
Attachment	455	Type 7 Railing with rigid pavement	LF
	462	Type 10 Railing	LF
	463	Splash Block	LF
Toe Cover	464	Earth Cover	LF
	465	Stone Cover	LF
	456	Leveling Pad, Concrete	LF
	457	Leveling Pad, Other	LF
Sound Barrier Facing	458	Timber Face	SF
	459	Concrete Block Masonry	SF
	460	Metal Panel	SF
	461	Clay or Shale Brick Masonry	SF
Sound Barrier Post	462	Timber Posts	EA
	463	Steel Posts	EA
Sound Barrier Foundation	464	RC Caisson	EA
	465	Flowfill in post hole	EA
	466	Reinforced Concrete Footing	EA
Sound Barrier Pickets	467	1x8 Board	SF
Sound Barrier Rail	468	Timber 4x4 or 2x8	LF

APPENDIX E – COMPONENTS FOR RETAINING WALLS

This appendix lists components for retaining walls. Components are the hidden parts of walls, not accessible for routine inspection, but necessary to complete description of walls and essential to understanding the relative performance of walls.

Table 25 lists generic components. This set may be expanded to indicate specific manufacturers and even specific products from the same manufacturer.

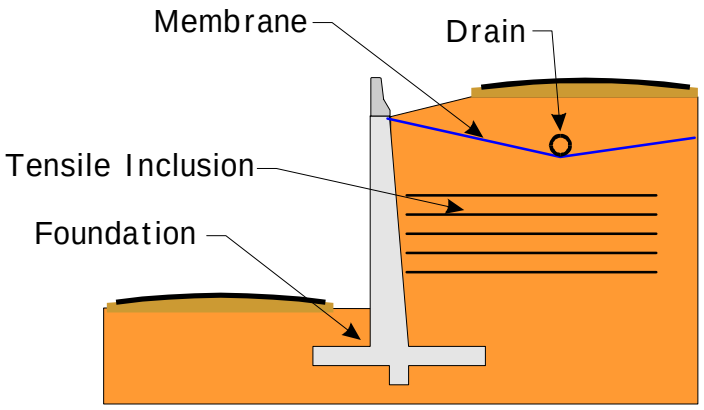


Figure 15 - Components for Retaining Walls

Table 25 - Components of Retaining Walls

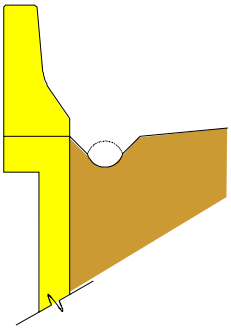
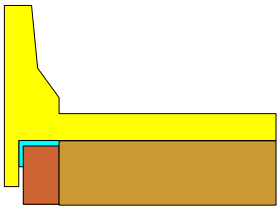
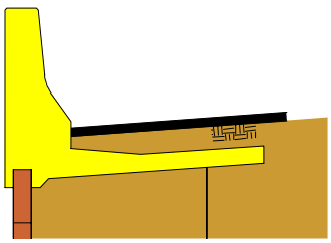
Group	Number	Component	Unit
Membrane	701	Identify manufacturer and product	SF
Drain	702	Identify material and diameter	LF
Backfill	703	CDOT Class I	CF
	704	CDOT Class II-A	CF
	705	CDOT II-B	CF
	706	CDOT II-C	CF
	707	Lightweight Fill	CF
	708	Tire chips	CF
	709	50% Tire chips + Granular backfill	CF
	710	Flowfill	CF
	711	Styrofoam	CF
Fill	712	Polymer Geo-Grid – Manufacturer and product	SF

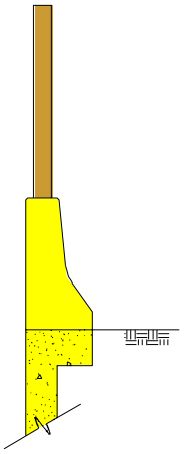
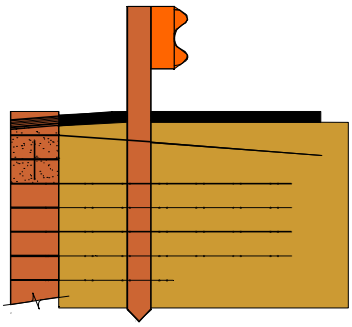
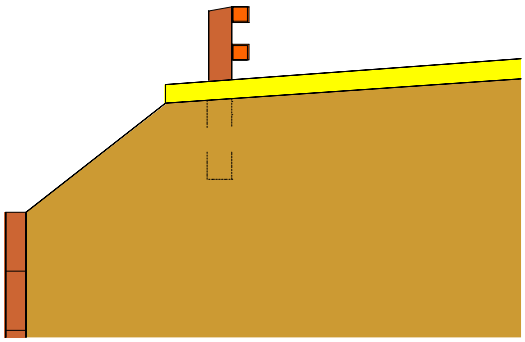
Group	Number	Component	Unit
Reinforcement	713	Geo-Textile – Manufacturer and product	SF
	714	Geo-Textile - nonwoven	SF
	715	Steel Bar Mat - bare	SF
	716	Steel Bar Mat - galvanized	SF
	717	Stainless Steel Bar Mat	SF
	718	Steel Woven Wire Fabric - galvanized	SF
	719	Steel Welded Wire Fabric - galvanized	SF
Tensile	720	Steel deformed bar - bare	LF
Inclusion	721	Steel deformed bar - galvanized	LF
	722	Steel deformed bar - Epoxy coated	LF
	723	Stainless steel bar	LF
	724	Soil Nail	LF
	725	Steel Anchor to Concrete Block	LF
	726	Steel Anchor to Ground	LF
	727	Steel Anchor to Stabilized Zone	LF
Foundation	728	Strip Footing	LF
	729	Leveling Pad	LF
	730	Steel Piles	EA
	731	Prestressed Concrete Piles	EA
	732	Concrete caissons	EA
	733	Cement-stabilized soil	CF
	734	Other stabilized soil	CF

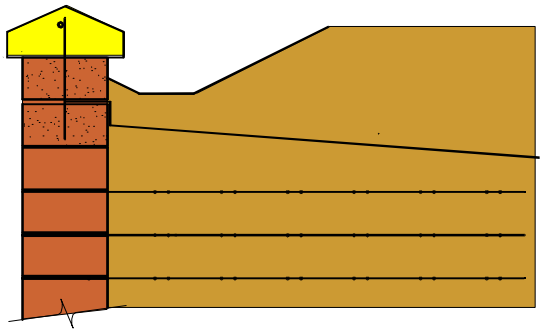
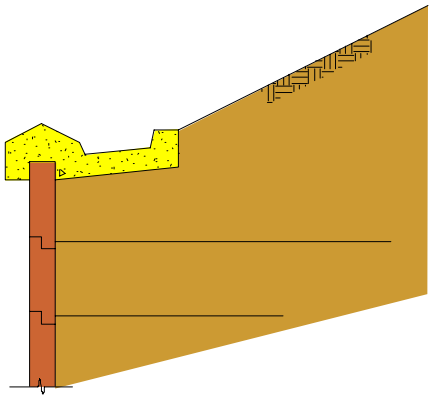
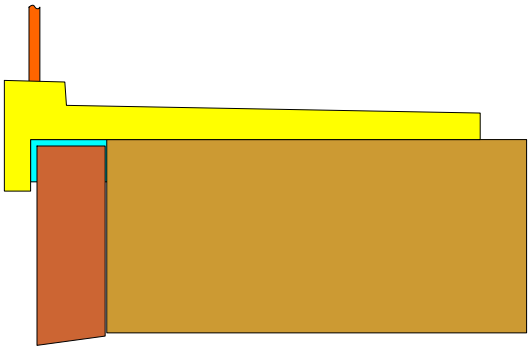
APPENDIX F – ATTACHMENTS FOR WALLS AND BARRIERS

This appendix lists wall attachments. Graphics show wall attachments at top of wall, but many attachments may also be used at the front of walls or at the front of sound barriers. Attachments appear in the proposed inventory record and among the set of elements for walls and barriers. These attachments are taken from the CDOT Bridge Design Manual and from CDOT drawings B504A1, B504B1, and B504C1.

Table 26 – Wall Attachments

Attachment	Name	Code
	Type 4 Railing with Drain Type 7 Railing with Drain Top attachment.	R4D R7D
	Type 4 Railing with Rigid Pavement Type 7 Railing with Rigid Pavement Top or front attachment	R4P R7P
	Type 4 Railing with Sleeper Type 7 Railing with Sleeper Top or front attachment	R4S R7S

Attachment	Name	Code
	Type 4 Railing with Sound Barrier Type 7 Railing with Sound Barrier Top attachment	R4B R7B
	Type 3 Railing Top or front attachment	R3
	Type 10 Railing Top or front attachment	R10

Attachment	Name	Code
	Coping Top attachment	C
	Coping with drain Top attachment	CD
	Sidewalk & Post Top or front attachment	SP

APPENDIX G - NOTES ON INSPECTION OF RETAINING WALLS AND SOUND BARRIERS

Routine inspection of walls and barriers can be similar to routine inspection for bridges. Inspection intervals can be specified, a routine practice of observations can be established, and standard reporting of conditions and deterioration can be established. In all of these, routine inspections address the visible elements of walls and barriers, and not the hidden components. Special inspections, probably invasive, are needed for components.

Inspections should be frequent enough to discover deterioration in walls and barriers before there is significant advance of distress and certainly before there is any loss of safety for highway users. For older walls that are performing well, there may be little change and perhaps no visible deterioration over several years. Often, an older wall that has performed well can be expected to continue to perform well. The performance of new walls is less certain. Intervals might be selected to ensure more frequent inspection for new walls and less frequent inspection for older walls that are performing well.

Inspection type is coupled with inspection interval. Cursory inspections, essentially a drive-by view of structures, may be done more frequently so that important, emerging distress may be found. Routine inspections, similar to current bridge inspections, may be done at longer intervals. Special inspections, entailing soil sampling, testing for aggressive conditions, and partial excavation of walls, are performed at long intervals, or when the condition of a wall is suspect. A possible arrangement of inspection intervals and types is shown in Table 27.

For sound barriers, there may be little need for in-depth inspection. Apart from the embedded portion of posts, sound barriers are completely accessible for inspection. Cursory inspections will reveal any significant damage (often due to vehicle impact). Cursory inspections are already performed by CDOT maintenance crews, though graffiti removal is the motivation.

Table 27 - Inspection Types and Intervals

Structure	Inspection Type	Inspection Interval
New walls (less than 10 years service)	Cursory	every year
	Routine	every 2 years
Older walls with no distress	Cursory	every year
	Routine	every 5 years
Problem walls (all ages)	Routine	interval as directed by the inspector, usually 2 years or shorter.
	Special	Intervals and methods as directed by the Engineer
Sound Barriers	Cursory	every year
	Routine	every 5 years

Routine Inspection

Observations to make in the course of a routine inspection of retaining walls.

Table 28 - Routine Inspection Tasks

Area	Element	Observations
Feature at top	Slope	Note any evidence of movement. May be evident as disruption of vegetation, as depressions or heaves, as scars as slumps or settlements. Note evidence of water movement causing erosion or otherwise disturbing the slope.
	Pavement	Note cracks, depressions, heaves, and any other evidence of movement, especially note movement along the edge of pavement nearest to the retaining wall.
Wall Top Attachment	Railing, Sidewalk	Note deterioration wall attachments such as surface rust, minor cracking, rot in timber, etc. that may require maintenance. Note rooting of vegetation that may disrupt wall attachments. Note cracking, misalignment, tilting or other evidence of movement. Note loss of fill or exposure of foundations for wall attachments
Wall Facing Barrier Facing		Note graffiti on facing. Note deterioration in wall/barrier facing such as surface rust, cracking, rot in timber that may require repair of facing elements. Note evidence of water drainage over the wall, or emerging

		from the facing in joints or cracks. Note vegetation rooted in joints or cracks. Note settlement, tilt, or cracking related to movement of wall. Observations of water infiltration or movement. Loss of fines Other settlement, tilt movement of the walls or barrier.
Wall Bottom Attachment	Railing, Sidewalk, Splash Block	Note evidence of movement at cover for toe of wall. May be evident as depressions, heaves, scars, damage to pavements, railings or barriers at toe.
Sound Barrier	Posts	Note deterioration in posts such as rust and rot. Note any collision damage to posts Note evidence of movement of posts such as settlement or tilt. Note any exposure of foundations for posts, or other distress in foundations.

Condition Reporting

Condition reporting for bridges in the US exists in two widely-used systems. Condition ratings in the Federal NBIS indicate general conditions, reflecting both the severity and extent of deterioration, but without identifying specific types of deterioration. The NBIS reports the condition of an entire structure in exactly three condition ratings reported on a 0 to 9 qualitative rating scale. Bridge conditions may be reported using the set of Commonly Recognized elements and condition states, developed together with the Pontis bridge management system. Element-level reporting using CoRe can produce condition ratings for all elements of a bridge (often between six to twelve elements) and reports the extent, in element length or element area, of deterioration. Condition states for CoRe elements do not identify types of deterioration. Potential condition states are shown in Table 29.

Table 29 - Condition States for Elements

	State	Description
1	Good	No deterioration of elements. No movement, settlement, or misalignment.
2	Fair	Minor, repairable deterioration of elements. Minor movement settlement or misalignment
3	Poor	Deterioration that may require replacement of elements. Significant movement, settlement or misalignment that is not (yet) a threat to safety or stability of the wall.
4	Serious	Deterioration that impairs function of elements. Movement, settlement or misalignment that may threaten to safety or stability of the wall.
5	Critical	Deterioration or movement, etc., that requires emergency shoring, anchoring or closure of lanes adjacent to the wall

In practices abroad, conditions are reported under three-part systems variously terms DER (Defect, Extent, Relevance) or TSE (Type, Severity, Extent) systems. In these approaches, for each incidence of deterioration, the type is identified, the extent is measured, and the effect on structural strength or function is evaluated.

APPENDIX H – INFORMATION FROM CDOT WALL DATABASE

Prepared by Jim Koucherik
06/09/03

BMS Walls Database Facts

A quick review of the Walls database maintained by the BMS Unit revealed the following information:

- The database currently has 750 walls identified by an actual location on a SH.
- Of the 750 walls, 110 are Sound Walls.
- Of the 110 Sound Walls, 62 sound walls had actual costs recorded.
- The 62 sound barrier walls cost $19,450,158.78, or about $20.10 / sq ft. to build.
- Based on the above information, the other 48 sound barrier walls are estimated to cost $17,624,926.20.
- The remaining 640 walls are retaining type walls.
- Of the 640 retaining walls, 239 retaining walls had actual cost.
- The 239 retaining walls cost $104,520,956.50, or about $41.73 / sq ft. to build.
- Based on the above information the other 401 retaining walls are estimated to cost $119,383,854.72.
- The 640 retaining walls include 110 MSE walls.
- The BMS Unit estimates that there are approximately 300 to 400 actual retaining walls built, but not identified.
- These un-numbered walls include all the walls on Vail Pass and Glenwood Canyon.
- The walls on Vail Pass include many of the first MSE Walls in the state and they have been functioning well since about 1975.

CDOT Wall Investment

- CDOT has built or is currently building 604 inventoried retaining type walls.
- CDOT has a $223,904,811 investment in these inventoried retaining walls.
- CDOT has built or is currently building 110 inventoried sound walls.
- CDOT has a $37,075,085 investment in these inventoried sound walls.
- CDOT has up to 400 undocumented retaining walls.
- CDOT has an estimated $16,692,000 investment in these undocumented retaining walls.

Inventory

The hardest part of finding the 400 or so un-inventoried walls is finding them. A lot of them will be near overpass structures, but when you are on the roadway and the wall is below you, that would mean a stop at every overpass…. A very time consuming process. I would suggest that the bridge inspectors note the walls while they are at a structure inspection, the details could be pulled from the plans. The Vail Pass area and the Glenwood Canyon might require a more concerted effort. The Glenwood Canyon will have to be the subject of meetings and some conclusions defined on what to call walls, where to change types, and other considerations as we look at those structures.

The inventory data needs to initially use just a few items and as the system is used, other items can be added as needed. There may be additional items necessary for PONTIS to actually function. These additional items will turn up as the system is used.

Inspections

Only two or three elements would be needed to get a handle on the condition of walls. These elements would relate to the visible condition of the wall. The elements needed would be one for cast-in-place walls, MSE walls, and sound barriers.

For cast-in-place walls there would be five condition states ranging from new condition, minor cracking, measurable cracking with minor vertical alignment problems, major cracking with major vertical alignment problems, and failure.

For MSE walls, there would be five condition states ranging from new condition, minor cracking/separation, measurable cracking/separation with minor bulging problems (unzipping), major cracking/separation with major bulging problems (unzipping), and failure.

For sound barrier walls, there would be five condition states ranging from new condition, minor cracking, measurable cracking with minor vertical alignment problems, major cracking with major vertical alignment problems, and failure.

A quick initial inspection of walls would create a general state of condition of the various types of walls, and create a baseline from which to judge future inspections on.

REFERENCES

1. *Primer: GASB 34.* (2000). US Federal Highway Admin., FHWA-IF-00-010, Washington, 48p.
2. *Recording and coding guide for the structure inventory and appraisal of the nation's bridges*. (1995). FHWA-PD-96-001, Washington DC, 124p.
3. *AASHTO guide for commonly recognized (CoRe) structural elements*. (1997). AASHTO, Washington DC, 60p.
4. Hartle, R.A., Armhein, W.J., Wilson, K.E. III, Baughman, D.R., and Tkacs, J.J. (1991). "Bridge inspector's training manual 90. Final manual." FHWA, McLean, VA., 586p.
5. *Manual for condition evaluation of bridges.* (2000). 2nd Ed., AASHTO, Washington DC.
6. *Bridge life-cycle cost analysis guidance manual*. (2001). NCHRP 12-43, 72p.
7. *Pontis Bridge Inspection Coding Guide* (1998). Staff Bridge Branch, Colorado DOT, Denver, 187p.
8. *CDOT bridge design manual.* (2002). Colorado DOT, Staff Bridge, Denver, 211p.
9. *Structure number (STRNO) coding guide*. (1998). Colorado DOT, Denver, 31p.
10. *Item book. Spec year 2002*. (2002). Colorado DOT, Contracts and Market Analysis Branch, Engineering Estimate and Market Analysis (EEMA) Unit, Denver, 113p.
11. *2001 Cost data. Maintenance projects*. (2002). Colorado DOT, Engineering Estimates and Market Analysis Unit, Agreements and Market Analysis Branch, Denver, 27p.
12. *Master list of year 2002 bridge maintenance needs*. (2002). CDOT Bridge Management Unit. Denver, 522p.
13. *KUBA – DB 3.0* (2000). Swiss Federal Roads Authority, Infrastructure Div., Engineering Structures Unit, Berne Switzerland
14. Mahut, B. (2003). *IQOA Bridges, Retaining Walls, Tunnels*. Laboratoire Central des Ponts et Chausees, Paris.
15. Bray,R.N. and Tatham, P.F.B. (1992). "Old waterfront walls. Management, maintenance and rehabilitation." E&FN Spon, London, 267p.
16. Collins,T.J. (1997). "Maintenance and management of sign structures." 8th AASHTO/TRB Maintenance Management Conf., Saratoga Springs, NY, pD1-D10.
17. Fish,P. (2000). "Inspection of ancillary structures, a public safety responsibility." SMT IV, S. Alampalli, ed., Technomic, Lancaster, PA.

18. Fleckenstein,L.J., Rister,B., and Allen,D.L. (1998). "Evaluation of wall structures in Kentucky." Kentucky Transportation Center, KTC-97-10. Frankfort, KY, 207p.
19. Markow,M.J., Acharya,D.R., McNeil,S. and Kao,A. (1988). "Management system for repair, evaluation, maintenance and rehabilitation of inland water transportation facilities." Trans Res Rec.1156, Washington, p47-55.
20. Markow,M.J, and Alfelor,R.M. (1997). "Estimating the benefits of highway maintenance." 8th AASHTO/TRB Maintenance Management Conf., Saratoga Springs, NY.
21. Morgan,S.M., Kay,D.H., and Bodapati,S.N. (2001). "Study of noise barrier life-cycle costing." ASCE Jou of Transportation Engrg, V127, N3, p230-236.
22. *Standard specifications for road and bridge construction*. (1999). Colorado DOT, Denver, 1003p.
23. Thierrin,R.D., Catlett,S., Norton,W. (1997). "Outdoor advertising sign data collection and management." 8th AASHTO/TRB Maintenance Management Conf., Saratoga Springs, NY.