Asset management of earth retaining structures

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ABSTRACT: Thousands of earth retaining structures (ERS) are along North American highways. There is no reliable tally of these structures, their value or their condition. As part of a study sponsored by the NCHRP (National Cooperative Highway Research Program), questionnaires were sent to all U.S. state highway departments, and ten additional highway agencies in the U.S. and Canada about ERS management practices. Eight of 40 responses had an inventory and regular condition inspections, often based on bridge inspection programs and conducted by bridge engineers. Three others had inventories but no regular inspections.

Recent failures have underscored the need for ERS asset management. Newer systems utilize materials whose properties can be altered by harsh underground conditions. ERS often have assumed design lives of 100 years, but knowledge of actual design life is minimal, and failures often occurred without warning. Lack of information has implications for both public safety and highway operations.

This paper summarizes an approach to an ERS asset management program.

1 INTRODUCTION

Gandhi Engineering, Inc. (Gandhi) was selected in 1999 by the New York City Department of Transportation (NYCDOT) to create a database of all types of retaining walls that were more than 2 meters high under the jurisdiction of the City of New York, and to visually rate them on a scale of 1 to 7 (7 being brand new and 1 being on the verge of collapse). Since the NYCDOT maintains the bridges and highways under the jurisdiction of the New York State Department of Transportation (NYSDOT), State-owned retaining walls were also included in this program. Private retaining walls along the railroads' right-of-way were excluded from this assignment. Gandhi inventoried more than 2,000 retaining walls. Gandhi also developed and assigned each structure a Wall Identification Number (WIN), similar to the Bridge Identification Number (BIN) used by the NYSDOT and NYCDOT.

In 2005, a 75 foot high massive private retaining wall failed along Riverside Drive in Manhattan. The collapse closed the northbound Henry Hudson Parkway under the jurisdiction of NYSDOT for a week. Gandhi was subsequently retained by the NYSDOT to develop a retaining wall management system, using commercially available software and hardware, that could be adopted on a state-wide basis. The software was to be used to identify retaining walls, irrespective of ownership, whose failures could impair the operations of NYSDOT highways within New York City. The system was completed and is currently in use by NYSDOT with Gandhi providing technical support services.

In 2008, Gandhi was selected by the National Academies of Science and Engineering in Washington, D.C. under the National Cooperative Highway Research Program (NCHRP) to develop a "Guide to Asset Management of Earth Retaining Structures" (ERS). This paper summarizes the results of the study conducted under NCHRP Project 20-07, Task 259. The guide was posted on the NCHRP website in October 2009.

"An earth retaining structure is any structure intended to stabilize an otherwise unstable soil mass by means of lateral support or reinforcement" (FHWA 1997). This definition doesn't restrict the angle that the face of the wall makes with the horizontal. The generally accepted definition by the National Highway Institute limits this angle to 70 degrees. However, some groups have reduced this angle to 45 degrees (slope 1:1) to include special ERS such as rock buttresses, gabion walls, rockeries, etc.

Catastrophic failures of ERS are relatively rare, but some serious incidents in recent years have called to attention the need for better management of ERS. Some of these wall failures occurred in Davis County, TN (TN DOT 2003), in New York City (NYCDOB 2007), and on Blue Ridge Parkway (Virtual Blue Ridge 2008) at Mile Post 364.6. A large number of ERS along the nation's highways date from the major Interstate Highway construction program from the 1950s through the 1970s. In the case of the National Park Service (NPS), most of the walls were built during the 1930s and 1940s. In New York City, some of the walls inventoried (both public and private) were more than 100 years old. The older walls are approaching the end of their anticipated service lives. Additional catastrophic failures are likely to occur in the future if preventive measures are not taken in a timely manner.

As part of the NCHRP study, Gandhi was asked to survey the current state of practice of highway agencies in managing ERS assets. The emphasis was on ERS other than those typically covered by bridge inspection programs, including all retaining wall types such as gravity walls, soldier pile with lagging, mechanically stabilized earth (MSE), and soil nail walls. Gandhi contacted all 50 State DOTs and 10 additional agencies in the United States and Canada. Forty agencies responded. Of those, only13 had implemented to some degree an Inventory and Inspection (I&I) program for ERS. The I&I programs implemented are listed below:

1. Federal Highway Administration (FHWA) / US National Park Service (NPS),
2. California Department of Transportation,
3. Colorado Department of Transportation,
4. Kansas Department of Transportation,
5. Maryland Department of Transportation,
6. Minnesota Department of Transportation,
7. Missouri Department of Transportation,
8. New York State Department of Transportation,
9. Oregon Department of Transportation,
10. Pennsylvania Department of Transportation,
11. The City of Cincinnati,
12. New York City Department of Transportation, and
13. British Columbia Ministry of Transportation.

Most of the other respondents had very little information on the number, location or condition of their ERS assets (again, other than those related to bridges). Based on an analysis of the information provided by the 13 agencies listed above, putting together an Asset Management platform for Earth Retaining Structures requires the development of an I&I program to provide the following basic types of information:

1. The Map showing where the ERS are located,
2. The Data Base, giving the characteristics of each structure,
3. The Condition Assessments, documenting the current condition of each structure, and
4. The Performance Assessments, observing the rate of change of these conditions.

1.1 *Getting to the Map*

The initial objective of an I&I program is to have a map showing all of the agency's Earth Retaining Structures. This sounds simple enough, but many transportation agencies don't know where all their ERS are--much less how big they are, what condition they are in, or what they would cost to replace. This is especially true of older retaining walls that support highway embankments or have been overgrown by vegetation. Since they are not readily visible from vehicles traveling on the highway, they are often literally out of sight and out of mind.

The map can start on paper; for example, on USGS quad sheets. But these days it makes sense to utilize GIS mapping, which enables a user to associate descriptive data and images with any location on the map.

The job of putting together a map will depend to some extent on geographical factors, such as the size of the agency's jurisdiction and the nature of its terrain, but a lot will depend on the quality of the agency's record keeping. America has been building roads in earnest for over a century and most agencies have accumulated a lot of as-built drawings. Many as-builts have been scanned; many more have been microfilmed; but many exist only on paper and not a few have been lost altogether.

If the as-builts are in good shape and well indexed, most of an agency's mapping can be done right in in the office. If the as-builts are not adequate, the agency can make use of aerial photos and other remote-sensing media. But there are bound to be places where the only solution is to ask people to go out and look.

A number of agencies have mounted systematic field survey programs to map their ERSs. Others, who have seasoned field personnel familiar with specific areas, have relied on them to identify ERS locations within those areas.

Within the last two or three years, cell phone technology has made it feasible to enlist volunteers - perhaps from civic groups or outdoors clubs - to look for ERS in their areas, and to transmit GPS locations and other basic data that can be incorporated directly into a GIS map.

Clearly, an important issue in planning an I&I program is deciding how the mapping is to be done. Another important issue is deciding what structures should be mapped. It may be more useful to describe this as deciding what doesn't have to be mapped.

- As we are all aware, bridge abutments and wingwalls are common types of Earth Retaining Structures. But there is no need to include them in an ERS management program, since they are already covered by existing bridge inspection programs. Thus, the inventory, and hence the map, can be limited to ERS that are unrelated to bridges.
- It is not cost effective to collect data and conduct inspections of very low retaining walls, since a failure would not result in significant damage or safety issues. Thus, nearly every transportation agency with an ERS management program has a minimum height criterion. The criteria reported in our survey ranged from 2 feet to 10 feet, but most agencies use either 6 feet or 2 meters. A few allow some flexibility for structures that are slightly lower but exceed a certain length. Thus, an agency can decide to limit its inventory, and hence its mapping, to ERS meeting one or more dimension criteria.
- Retaining walls are by far the most common type of earth retaining structures. Some ERS programs are limited to retaining walls; others include additional types of ERS such as culvert headwalls, rockeries, and slope protection structures. These decisions will depend on local circumstances.
- Another important question is ownership of ERS. Some agencies limit inventories to ERS that they actually own or that they are responsible for maintaining. But an ERS owned by others could severely affect a highway facility. This was the case with the 2005 failure of the Castle Village retaining wall in upper Manhattan, which was part of a privately owned apartment complex. Rebuilding the wall cost the owners $26 million, but the collapse also cost the City and State millions of dollars for emergency personnel and repair costs. Thus, there is a strong case to be made for an agency to inventory all ERS whose failure could affect its facilities.

1.2. *The Data Base*

The second type of information needed is a uniform set of data on each ERS shown on the map. This begins with working out a list, or standard form, showing all the data fields that it would be useful to record for each structure.

Because of the enormous storage capacity of electronic media, it is tempting to make the form very detailed. But every so-called required data field takes the time of an actual person to perform some form of observation, measurement, identification, or recording, all of which ultimately translate into personnel time and money. Therefore, it is important to resist the temptation to make a database overly complicated.

Your fields should probably include, at a minimum:

- An ERS identification number, analogous to a bridge BIN number.
- Location data, such as GPS coordinates, highway number and milepoint, and town or other political subdivision.
- Dimension data, such as height, length and approximate face area.
- Structural type, such as gravity wall or sheet pile wall.
- Functional type, which is most often either supporting a roadway embankment or protecting a roadway by retaining a slope above it. Also, retaining walls can be identified by whether or not they support Live Load in addition to Dead Load or Earth Load.
- Data on ownership and maintenance responsibility
- Data on condition, and
- A record of inspections and actions taken
- Dimension and wall-type data can also be used to generate an estimate of replacement cost that will be useful in establishing program priorities.

If the agency has a good file of as-built drawings, a great deal of this data can be compiled in the office. Otherwise, people are going to have to collect it in the field. If people are going to go out looking for ERS, there is certain information they can collect without too much additional effort. Fortunately, modern measuring instruments have greatly reduced the need for waders and rock climbing gear. Fortunately again, it is relatively easy to link digital photographs and drawing files to an individual ERS data file, reducing the need for lengthy descriptions.

Table 1 is a Data Options Table. It is essentially a consolidated list of the data fields used in existing ERS inventories.

Table 1. ERS data options

Minimum	Recommended Additional fields	Additional desirable fields	F	O
Survey log data				
1. ID number			X	X
2. Date of survey			X	
3. Times of arrival and departure			X	
4. Surveyed by			X	
5. Weather			X	
	6. Soil moisture		X	
		7. Work zone safety devices or measures	X	
		8. Special access equipment	X	
Location data				
9. GPS location coordinates			X	
10. Location			X	
11. Offset			X	
12. Location photos			X	
	13. District/political subdivision			X
	14. End coordinationes		X	
	15. Bridge/culvert association		X	
	16. Other related feature		X	
		17. Block and lot number		X
	18. Access constraints		X	
	19. Did constraints affect accuracy?		X X	
		20. Photo(s) of access Constraints	X	

Table 1. ERS data options (cont.)

Minimum	Recommended Additional fields	Additional desirable fields	F	O
Function data				
21. Functional type			X	
	22. Supported feature		X	
	23. Protected feature		X	
		24. Photo(s) of supported and/or protected features	X	
Dimension data, general				
25. Exposed height			X	
26. Total length			X	
27. Wall face slope			X	
	28. Exposed height at beginning point		X	
	29. Exposed height at end point		X	
	30. Height above retained soil		X	
31. Total height				X
32. Estimated area of exposed face			X	
		33. Criterion length	X	
		34. Offset of criterion portion	X	
		35. Photo(s) of top profile	X	
	36. Upslope angle		X	
	37. Downslope angle		X	
		38. Roadside features above	X	
		39. Roadside features below	X	
		40. Photos of roadside features	X	
Structural, data, preliminary				
41. Wall face material			X	
	42. Apparent wall type		X	
		43. Wall surface treatment	X	
		44. Wall top feature	X	
		45. Top of wall attachments	X	
		46. Wall face attachments	X	
Structural, data, verified				
47. Structural type				X
48. Total wall face area				X
49. Estimate replacement cost per square foot				X
50. Cost estimate reference				X
51. Estimated total replacement cost				X
	52. Foundation type			X
53. Wall face angle as built				X
	54. Proprietary type			X
		55. Fill material		X
History and ownership				
56. Year built				X
57. New or retrofit				X
58. Design service life				X
59. Current owner				X
60. Owner contact information				X

Table 1. ERS data options (cont.)

Minimum	Recommended Additional fields	Additional desirable fields	F	O
History and ownership (cont.)				
	61. Original owner			X
	62. Original contract number			X
	63. Original cost			X
		64. Original designer		X
		65. Original contractor		X
	66. Maintenance/repair/ modification record			X
Condition data, preliminary				
67. Checklist conditions			X	
	68. Condition photos & sketches		X	
69. Inspection priority				X
Condition data from inspection				
70. Inspection report				X
71. Inspection date			X	
72. Name of inspector			X	
73. Prior documentation reviewed			X	
74. Potential failure type			X	
75. Condition rating			X	
76. Performance rating			X	
77. Projected replacement date			X	X
78. Recommended action type			X	
	79. Recommended action summary		X	
Consequences of failure factors				
80. Critical wall height			X	
81. Critical distance			X	
82. Roadway type and lanes			X	
83. Sensitive facility supported			X	
84. Sensitive facility protected			X	
85. COF rating			X	X
	86. Traffic volumes			X
	87. Interchange distances			X
		88. Detour length		X
		89. Affected locations		X
	90. Utilities near top of wall		X	X
	91. Utilities near base of wall		X	X
	92. Utilities on wall face		X	X
Action priority				
93. Action approved				X
94. Action priority				X
95. Action date scheduled				X
96. Action completed				X

One important type of data that cannot always be identified in the field is Structural Type. This is best obtained from as-built drawings, especially when dealing with some of the various types of internally stabilized walls that have become increasingly common since the 1970s. Fortunately, these are walls for which as-built drawings are generally available. Table 2 is a suggested classification of wall structural types.

Table 2. Suggested classification of wall structural types.

Fill-constructed walls (built from the bottom up)	
Externally stabilized	Internally stabilized
Rigid gravity walls - Masonry gravity walls ((stone, concrete, brick) - Cast-in-place (CIP) concrete gravity walls	Mechanically stabilized earth (MSE) walls - Segmental, pre-cast facing MSE wall - Prefabricated modular block facing - Flexible facing (geotextile, geogrid, or welded- wire facing)
Rigid semi-gravity walls - CIP concrete cantiliever T-wall or L-wall (including counterforted walls and buttressed walls)	Reinforced soil slopes (RSS)
Prefabricated modular gravity walls - Crib wall - Bin wall - Gabion wall	
Rockeries	

Cut-constructed walls (built from the top down)	
Externally stabilized	Internally stabilized
Non-Gravity Cantilevered (Embedded) Walls - Sheet-pile wall (steel, concrete, timber) - Soldier pile and lagging wall - Slurry (diaphragm) wall - Tangent/secant pile walls - Soil-mixed wall (SMW)	In-situ Reinforced Walls - Soil-nailed wall - Root-pile wall - Insert pile wall
Anchored Walls* - Ground anchor (tieback) - Deadman achor	

(Adapted from FHWA Geotechnical Engineering Circular No. 2, 1997)

*Anchors are often used in combination with embedded walls of various types and may also be used in combination with semi-gravity cantilever walls.

1.3 *The Condition Assessment*

The one category of information that must be obtained in the field – up close and personal, so to speak – is the Condition Assessment. This presents some logistical issues. An ERS inventory for a state highway agency is likely to include thousands of walls spread over a large geographical area. For most agencies, it is not cost effective to send out bridge inspectors –or people with equivalent structural expertise—as part of ERS inventory teams. Rather, most agencies utilize junior engineers and technicians to perform inventories and collect basic data in the field. As part of the field data collection process, these people are provided with a checklist of conditions that may indicate a structural problem. A sample condition checklist is shown in Table 3.

Table 3: ERS condition checklist.

1. Wall or parts of it, out of plumb, tilting or deflected
2. Bulges or distortion in wall facing
3. Some elements not fully bearing against load
4. Joints between facing units (panels, bricks, etc.) are misaligned
5. Joints between panels are too wide or too narrow
6. Cracks or spalls in concrete, brick, or stone masonry
7. Missing blocks, bricks, or other facing units
8. Settlement of wall or visible wall elements
9. Settlement behind wall
10. Settlement or heaving in front of wall
11. Displacement of coping or parapet
12. Rust stains or other evidence of corrosion of rebars
13. Damage from vehicle impact
14. Material from upslope rockfall or landslide adding to load on wall
15. Presence of graffiti (slight, moderate, heavy)
16. Drainage channels along top of wall not operating properly
17. Drainage outlets (pipes/weepholes) not operating properly
18. Any excessive ponding of water over backfill
19. Any irrigation or watering of landscape plantings above wall
20. Root penetration of wall facing
21. Trees growing near top of wall
22. Any other observations not listed above

If any of these conditions exist, the field team records them and takes photographs. These are reviewed in the office and a decision is then be made as to the need for an in-depth inspection. Agencies that have conducted inventories using this system report that the proportion of walls requiring urgent attention is relatively small, perhaps one or two percent.

Another type of information that requires field observation is the recording of what can be described as Consequences of Failure (COF) Factors. This refers to conditions in the vicinity of a wall that might increase the damage or safety risk in the event of a wall failure. For example:

- Ancillary facilities within the R.O.W., such as a service area or a scenic overlook, and
- Non-Highway facilities, such as a school, shopping center, or a recreational area.

Where available, the COF information should include data on traffic volumes and potential length of detour in the event of failure.

FHWA has identified the three COF levels as given below:

1. Low or Minor. No loss of roadway, no to low public risk, no impact to traffic during wall repair / replacement.
2. Moderate or Significant. Hourly to short-term closure of roadway, low-to-moderate public risk, multiple alternate routes available.
3. High or Severe. Season to long-term loss of roadway, substantial loss-of-life risk, no alternate routes available.

A high COF rating is useful in establishing inspection priorities.

Table 4 is another example of a condition checklist, reproduced from the Federal Highway Administration (FHWA) and the National Park Service (NPR) Retaining Wall Inventory Program Field Guide (WIFG). This checklist is broken down by primary and secondary exterior wall elements, reflecting the great variety of retaining walls, many of them quite old, along roads in the National Parks:

Table 4. Primary and Secondary Wall Elements as defined in the FHWA NPS WIFG.

Primary Element Condition Ratings	
Piles and Shafts	Soldier piles, sheet piles, micropiles or drilled shafts, as well as supplemental structures such as walers, comprising part or all of the visible wall.
Lagging	Structural lagging between piles and walers.
Anchor Heads	All visible parts of tieback anchor, including pad (generally observed without removing cap).
Wire/Geosyn. Facing Elements	Visible facing/basket wire, soil reinforcing elements, hardware cloth, geotextile/geogrids and facing stone.
Bin or Crib	Visible portion of cellular gravity wall.
Concrete	Visible precast or cast-in-place concrete wall and footing elements (does not include piles, lagging, crib blocks, manufactured block/brick, and architectural facing).
Shotcrete	Visible shotcrete (does not include piles, lagging, architectural facing or other specific elements).
Mortar	Visible mortar used between uncut or masoned rock, manufactured blocks or brick, or used for wall repairs.
Manufactured Block/Brick	Manufactured blocks and bricks, including CMU's segmental blocks, large gravity blocks, etc. (does not include concrete lagging or crib wall components).
Placed Stone	Dry-laid or mortar-set *uncut* rock.
Stone Masonry	Dry-laid or mortar-set cut rock.
Wall Foundation Material	Soil or rock immediately adjacent to and supporting the wall.
Other Primary Wall Element	Any primary wall element not listed (provide detailed narrative definition).

Secondary Element Condition Ratings	
Wall Drains	Function and capacity of visible drain holes, pipes, slot drains, etc., that provide wall subsurface drainage.
Architectural Facing	Facing that is not relied on for structural capacity, including concrete, shotcrete, stone, timber, vegetation, etc.
Traffic Barrier/ Fence	Traffic barrier or fence above or below wall, and within the influence of the wall.
Road/ Sidewalk/ Shoulder	Road and/or sidewalk surface above or below a wall, and within the influence of the wall.
Upslope	Groundslope area above a wall affecting wall condition and/or performance.
Downslope	Groundslope area below the wall, distinct from the Wall Foundation Material element, affecting wall condition and/or performance.
Lateral Slope	Groundslope laterally adjacent to a wall affecting wall condition and/or performance.
Vegetation	Vegetation near wall or on wall face affecting wall condition and/or performance.
Culvert	Culverts and inlets/outlets through, below, or adjacent to walls.
Curb/ Berm/ Ditch	Lined or unlined surface drainage feature above or below wall.
Other Secondary Wall Element	Any secondary wall element not listed (provide detailed narrative definition).

Table 5 presents a matrix showing, for each structural type, the wall elements that should be given condition ratings. The structural types are essentially those shown previously in Table 2.

Table 5: Matrix showing the Wall Elements that should be rated based on the Wall Structural Type (as shown on the FHWA NPS WIFG).

WALL TYPE	PRIMARY ELEMENTS	Piles and Shafts	Lagging	Anchor Heads	Wire/Geosyn. Facing Elements	Bin or Crib	Concrete	Shotcrete	Mortar	Manufactured Block/Brick	Placed Stone	Stone Masonry	Wall Foundation Material	Other Primary Element	SECONDARY ELEMENTS	Wall Drains	Architectural Facing	Traffic Barrier/Fence	Road/Sidewalk/Shoulder	Upslope	Downslope	Lateral Slope	Vegetation	Culvert	Curb/Berm/Ditch	Other Secondary Element	WALL PERFORMANCE	Performance
[AH] Anchor, Tieback H-Pile		●	●	●									●			●			○	○	○	●						●
[AM] Anchor Micropile		●		●									●			●			○	○	○	●						●
[AS] Anchor, Tieback Sheet Pile		●		●									●			●			○	○	○	●						●
[BC] Bin, Concrete						●							●			●			○	○	○	●						●
[BM] Bin, Metal						●							●			●			○	○	○	●						●
[CL] Cantilever, Concrete							●						●			●			○	○	○	●						●
[CP] Cantilever, Soldier Pile		●	●										●			●			○	○	○	●						●
[CS] Cantilever, Sheet Pile		●											●			●			○	○	○	●						●
[CC] Crib, Concrete						●							●			●			○	○	○	●						●
[CM] Crib, Metal						●							●			●			○	○	○	●						●
[CT] Crib, Timber						●							●			●			○	○	○	●						●
[GB] Gravity, Concrete Block/Brick									●	●			●			●			○	○	○	●						●
[GC] Gravity, Mass Concrete							●						●			●			○	○	○	●						●
[GD] Gravity, Dry Stone											○	○	●			●			○	○	○	●						●
[GG] Gravity, Gabion					●								●			●			○	○	○	●						●
[GM] Gravity, Mortared Stone									●		○	○	●			●			○	○	○	●						●
[MG] MSE, Geosyn. Wrapped Face					●								●			●			○	○	○	●						●
[MP] MSE, Precast Panel							●						●			●			○	○	○	●						●
[MS] MSE, Segmental Block										●			●			●			○	○	○	●						●
[MW] MSE, Welded Wire Face					●								●			●			○	○	○	●						●
[SN] Soil Nail								●					●			●			○	○	○	●						●
[TP] Tangent/Secant Pile		●											●			●			○	○	○	●						●
[OT] Other, User Defined													●			●			○	○	○	●						●

● Wall elements that should always be rated for the given wall type (others may also apply).

○ 1 of 2 primary wall elements required depending on material observed.
2 of 3 secondary wall elements required depending on wall location relative to roadway.

Road/Sidewalk/Shoulder: Rate only when these elements lie within the influence of the wall. The shoulder is generally defined as extending no greater than 5 ft horizontally from the roadway/sidewalk, and less than -5 ft vertical offset.

Upslope: Rate the upslope condition for all walls above roadway grade, regardless of slope ratio. Rate the upslope condition for all walls below roadway grade, regardless of slope ratio, when the vertical offset to the wall from the roadway/shoulder is greater than 5 ft (otherwise evaluate the condition of the upslope under the "Road/Sidewalk/Shoulder" element).

Downslope: Rate the downslope condition for all walls below roadway grade, regardless of slope ratio. Rate the downslope condition for all walls above roadway grade, regardless of slope ratio, when the vertical offset to the wall from the roadway/shoulder is greater than 5 ft (otherwise evaluate the condition of the downslope under the "Road/Sidewalk/Shoulder" element).

1.4. *The Performance Assessment*

The retaining walls built more than 50 years ago were designed very conservatively using the allowable stress method with big factors of safety against sliding and overturning. Most of them were reinforced with concrete or gravity retaining walls. This conservatism in design has prevented the failures of these walls until recently. However, there is much less data available for recently built walls, which often use techniques and materials that are too new to verify their projected service life based on their actual performance.

Some of the factors affecting performance are:

- Errors or shortcuts during construction
- Exposure to corrosive effects of chemicals or electrical activity in retained soil
- Adjacent land development that can increase runoff
- Excavation for new utility lines, which can damage drainage channels and protective membranes resulting in saturation of retained soil and buildup of lateral pressure behind the ERS

The majority of these problems are hidden behind the wall face and become evident only with the appearance of external signs of distress such as bulging, deflection, cracking, or staining. A reliable estimate of remaining service life can only be obtained by identifying these conditions and by observing their rate of change. This implies: systematic inventories of ERS and their characteristics; regular inspections; and good record keeping.

2. CONCLUSIONS

The Inventory and Inspection program outlined above is valuable in itself because it can head off potentially disastrous retaining wall failures. However, the I&I program has a further value in laying the foundation for Asset Management of an agency's Earth Retaining Structures. Asset Management is a systematic way of optimizing the allocation of resources—budget and personnel--among inspection, maintenance, repair and replacement.

Over the long term, the I&I program will enable highway agencies to build up a nationwide body of knowledge about earth retaining structures, about what materials and techniques perform best under what conditions, similar to the body of knowledge about bridges that we have built up over more than four decades since the passage of the 1968 Federal Aid Highway Act.

3 ACKNOWLEDGMENTS

Gandhi's work in developing a data base, an inventory of retaining walls, and Asset Management program, was carried out over a 10-year period for NYCDOT, NYSDOT, and the NCHRP and its Advisory Panel.

Assistance and guidance from members of these Agencies, the Advisory Committee, and our Geotechnical Consultant are gratefully acknowledged.

The authors also would like to thank our staff for assisting in the preparation of this paper.

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