Retaining Structure Selection at Project Level

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With recent advances in retaining structure technology, the retaining structure selection process has become increasingly complicated. Because of the potential for cost savings, the benefits of optimizing the selection process are significant. Eight state departments of transportation (DOTs) are characterized in terms of how they select and analyze designs of, and obtain subject-matter expertise on, retaining structures. Results indicate most retaining structure types are specified by DOT engineers, including those designed by engineering consultants. However, 90 percent of the DOTs select only retaining structures for which they have in-house design expertise. The rational is presented for DOTs to have design expertise within their agencies for the full range of retaining structure technologies available if they are to select optimal structure types.

Recent advances in retaining structure technology complicate the selection of retaining structures at the project level. In the past, retaining structure options consisted of a limited number of externally stabilized structures with few other choices available. Today, the decision maker has numerous options encompassing internally and externally stabilized structures. As a result, retaining structure selection has become an optimization problem covering not only new technologies but also new engineering concepts. To select the optimum structure for a given project, the decision maker must have expertise in a wide variety of retaining structure technologies or access to subject-matter expertise.

The benefits of optimizing the retaining structure selection process are tremendous. State departments of transportation (DOTs) collectively overspend approximately $700 million per year by not optimizing decisions to take advantage of new retaining structure technologies and materials (*1*).

As part of an effort to characterize the retaining structure selection process, questionnaires were sent to subject-matter experts at eight state DOTs: California, Colorado, Florida, Kentucky, New York, Ohio, Texas, and Washington. Six of the experts are geotechnical engineers and two are structural engineers. These DOTs are considered national leaders in the application of diverse retaining structure systems (J. DiMaggio, FHWA, personal communication with T. M. Adams, July 1993). The data collected are representative across the United States. All the questionnaires were completed. Subsequently, six of the experts explained their responses during telephone interviews.

Varying design and construction practices influence the selection process. Each expert estimated the percentage of retaining structures designed by DOT engineers and consultants. Table 1 summarizes the results. Three of the eight states use DOT engineers to complete the design and construction plans for less than 25 percent of their retaining structure projects. All three of these states are east of the Mississippi River. In the other five states, DOT engineers complete the design and construction plans for 50 to 100 percent of the projects. All but one of these states are west of the Mississippi River.

The responses to the questionnaire and telephone surveys were analyzed. The results indicate that it is essential for state DOTs to develop and maintain subject-matter experts for the full range of retaining structure solutions and to build communication channels between subject-matter experts and project engineers.

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OBJECTIVE

This paper characterizes the selection of earth-retaining structures associated with highway projects. In particular, the paper focuses on characteristics of the decision maker, the decision process, the information available at the time of the decision, the importance of project parameters, and the impact of available expertise at the time of the decision. The objective is to answer the following questions about retaining wall selection at the project level.

- Who selects the type of earth-retaining structure to construct?
- Are selection decisions made in house (within the DOT) or by consultants?
- Does the decision maker's lack of expertise restrict the outcome of the decision?
- At what stages of highway construction are retaining walls selected?
- Is a formal decision process used to select retaining walls?
- Who designs the wall and prepares the construction plans?
- Who prepares preliminary and detailed cost estimates for retaining structures?
- Who determines the construction methods and specifies the construction materials?
- Are retaining structure decisions optimized by value engineering?
- Do decision makers receive comments on constructability from the field?
- What project parameters influence the type of wall selected?
- What information is available at the time of retaining structure selection?

The availability of new economical retaining structure systems stimulates the desire to optimize the choice of retaining structure. Obviously, the decision maker has control. Some questions gathered information on whether a geotechnical engineer, structural engineer, or project manager is the decision maker. Other questions determined whether professional consultants are included in the decision process and under what circumstances.

TABLE 1 Design Practices by State

States	Percent of Retaining Structures Designed by DOT Engineers
FL, KY, OH	0-25%
	26-50%
CO, NY TX	51-75%
CA, WA	76-100%

For simplicity, a consistent terminology was adopted. In this paper, *project manager* refers to engineers who are project managers or project engineers. *Design* includes both engineering design and engineering analysis. The scope of retaining structures is earth-retaining walls; thus in this paper, *structure* and *wall* are synonyms.

SCOPE OF RETAINING STRUCTURES

In spring 1993, a survey for collecting knowledge about selecting earth-retaining structures for highway projects was developed. The survey covered 24 conceptual retaining structures included in a formalized retaining wall selection procedure described in the Colorado DOT bridge design manual (*2*). Twelve retaining structure experts, including owners, consultants, contractors, and educators, completed the survey. Considering their suggestions, six wall designs were deleted and five wall designs were added. The revised scope of retaining structures was presented to 12 additional experts in January 1994. Considering their responses, the scope of walls was edited again. Five more walls were deleted from the list. Table 2 contains the final set of 18 retaining structures.

Eight state DOTs ranked the 18 walls in Table 2 according to frequency of use, with 1 being most frequent. A ranking of 18 indicates most infrequently or never used. Table 2 lists the 18 retaining

TABLE 2 Ranking of Retaining Structures From Most Frequently Used to Least Frequently Used

Description	Stabilization Method	Average Ranking
Mechanically stabilized earth wall. Select fill reinforced earth with strips, mats, or grids of metal or geosynthetic tensile reinforcements	I	1.9
Shallow embedded cantilever wall with tiebacks anchored to the stabilized zone	E	6.6
Cast-in-place cantilever T-wall	E	7.4
Soldier piles. Cantilevered H-piles (driven or placed in drilled caissons) with wood or precast concrete lagging	E	8.5
Shallow embedded cantilever wall with deadman anchors	E	9.6
Gabions. Welded wire baskets filed with course aggregate stone	E	10.3
Cast-in-place L-wall or invert L-wall	E	10.6
Crib wall. Single or double, step-front or step-back crib wall constructed of precast concrete or lumber stringers and tie members	E	11.5
Metallic bin walls. Corrugated aluminum or steel bins and in-filled soil form composite material	E	11.6
Mass cast-in-place concrete gravity wall	E	11.9
Modular wall. Precast/prefabricated. Most are proprietary. Modular units and in-filled soil form composite material	I	11.9
Sheet pile. Embedded sheet pile cantilever wall	E	13.5
Soil nailed wall. Facing covered cuts with uniformly spaced top-to-bottom drilled or driven nails	I	13.8
Cantilever T-wall with precast post-tensioned stem	E	14.4
Drilled caissons. Embedded cantilever wall constructed of contiguous, secant or tangent drilled caissons back-filled with concrete. With or without lagging	E	15.0
Multi-anchored facing wall. Precast concrete multi-anchored facings with tiebacks anchored to the stabilized zone or fill	E	15.3
Multi-anchored facing wall. Creeping slopes doweled with caissons or piles for stability. Precast concrete facings are anchored to the dowels	E	15.5
Diaphragm wall. Embedded cantilever wall constructed of a trenched slurry concrete diaphragm wall	E	16.8

E=externally stabilized structure, I=internally stabilized structure

structure types ordered from most to least frequently used based on average ranking.

The wall types in Table 2 are internally or externally stabilized. Internally stabilized walls rely on the soil itself for stability and are often considered geotechnical solutions. Externally stabilized walls use structural mechanisms for stability and are usually regarded as structural solutions.

The most frequently used retaining structure is the mechanically stabilized earth wall. Various externally stabilized cantilever structures comprise the remaining four most frequently used wall types. Three infrequently used wall types are diaphragm walls and doweled or tieback multianchored facing walls.

CHARACTERISTICS OF DECISION MAKER

Each DOT identified the project participants (DOT engineer, consultant, or contractor) who select the wall type, complete the design, determine construction methods, specify materials, and prepare cost estimates for retaining structures associated with highway projects. The results characterize the overall responsibility of each participant for retaining structure selection and design.

Table 3 shows the percentage of responses indicating the responsible project participant for various activities. At some DOTs, more than one participant performs an activity. For example, the type of retaining structure selected by a DOT engineer or consultant may depend on whether the wall is also designed by the DOT engineer or the consultant. In these cases, the responses were distributed so that the results are evenly weighted among the eight DOTs. Three-fourths of the responses indicate that a DOT engineer selects the type of retaining structure. Only half the responses indicate that design, analysis, and construction plans are completed by a DOT engineer. This means many retaining structures are selected by DOT engineers, then designed by consultants or contractors. Data collected during the interviews explain this. Six experts say their DOT never seeks the services of a consultant solely for selecting the type of retaining structure. Consultants select and design or design only. The data presented in Table 3 include all retaining structure projects, regardless of whether DOT engineers or consultants prepare the design and construction plans.

Table 4 shows a breakdown of who selects the wall type for projects sent to a consultant for design. Half the responses indicate a DOT engineer decides the type of retaining structure for these projects. The most frequent decision maker within the DOT is the project manager. Project managers are responsible for the project schedule and project coordination. Project managers, usually in the DOT roadway design division at the regional level, often have backgrounds in geometric design. Otherwise a project manager's background may be in a variety of other engineering disciplines. This suggests a need for direct communication between project managers and subject-matter experts for selecting wall types.

According to Tables 3 and 4, 12 percent of the responses indicate the construction contractor selects the retaining structure. This percentage is probably not representative of all state DOTs, but because of the unique contracting practices of one of the DOTs interviewed. This particular DOT requires the construction contractor to select and design all retaining structures associated with the project. The contractor must select a retaining structure from a preapproved list and hires a consultant to complete the design.

Each DOT indicated by discipline who within the DOT performs planning and design activities when these activities are done by DOT engineers. Table 5 shows the results. At some DOTs, various participants perform the activities depending on the scope of the project. Thus, some DOTs indicated more than one discipline. In these cases, responses were adjusted accordingly. As shown in Table 5, half the responses indicate that the project manager selects the type of retaining structure. If the schedule permits, the project manager usually makes the decision on the basis of advice from a geotechnical or structural team member and sometimes from both. About 40 percent of the responses indicate that the structural engineer selects the type of retaining structure, and less than 10 percent indicate the geotechnical engineer is directly responsible for selecting the type of retaining structure. Typically at a DOT, most project managers are within the roadway design division and most structural engineers are within the bridge division. Because these engineers are selecting the type of retaining structure, it is imperative that they have knowledge in the full range of retaining structure technologies available or involve subject-matter experts from other divisions.

When asked who completes the design and prepares construction plans for retaining walls, a third of the responses indicate a geotechnical engineer, and twice as many indicate a structural engineer. When this information is considered along with the frequency of wall type in Table 2, it appears structural engineers within the bridge divisions are not strictly selecting and designing traditional externally stabilized retaining structures. At several DOTs studied,

TABLE 3 Planning and Design Activities by Project Participant

	Percent of Responses*		
Project Activity	DOT Engineer	Consultant	Contractor
Select Type of Retaining Structure	76	12	12
Complete Design and Prepare Construction Plans	54	46	0
Determine Major Construction Methods	43	7	50
Specify Construction Materials	92	8	0
Prepare Preliminary Cost Estimate	72	28	0
Prepare Detailed Cost Estimate	88	12	0

*multiple responses are uniformly distributed so that results are evenly weighed among DOTs

TABLE 4 Retaining Structure Selection by Discipline When Design is Contracted Out

Discipline	Percent of Responses*
DOT Geotechnical Engineer	12
DOT Structural Engineer	12
DOT Project Manager/Engineer	26
Consultant	38
Contractor	12

*multiple responses are uniformly distributed so that results are evenly weighed among DOTs

structural engineers in the bridge divisions design all retaining structures, externally and internally stabilized. At other DOTs, however, internally stabilized structures are designed solely by geotechnical engineers in the geotechnical divisions, with the bridge division having responsibility for external solutions involving steel and concrete. Less than 10 percent of the responses indicate the project manager completes the design and plans. A project manager completes the design and construction plans for sites conducive to standard plans.

The division of the organization is not particularly important as long as optimal solutions are designed. It is important for retaining structure types to be selected and designed by an engineer or team of engineers with knowledge of the full range of retaining structure technologies available. Otherwise a DOT cannot be sure it is specifying optimal retaining structure solutions.

CHARACTERISTICS OF DECISION PROCESS

Characteristics of the decision process include the project phase during which the retaining structure type is selected, the selection procedure, and the impacts of value engineering and constructability comments on the decision process. Each DOT surveyed provided information about these characteristics.

Each DOT indicated the phase of the project during which the type of retaining structure is selected. Responses indicating multiple phases were uniformly distributed so that results are evenly weighed among the DOTs. As shown in Table 6, almost three-fourths of the responses indicate that the wall type is selected during preliminary or final design. Few responses indicate that the structure type is selected during the planning phase. About one-fourth of the responses indicate that the retaining structure type is selected during the construction phase.

There are three scenarios for selecting a retaining structure during the construction phase. The first involves the use of a proprietary retaining wall. The use of a proprietary wall is usually determined during the design phase. The DOT specifies on the contract drawings that the contractor will choose a wall system from a list of previously approved proprietary walls. Typically, the list includes at least three different retaining wall systems. The second scenario involves value engineering. For six of the eight states surveyed, value engineering studies may change the type of retaining structure constructed. For 50 percent of the states, a value engineering study team applies value engineering during design. For the other 50 percent, value engineering studies are conducted during construction by the construction contractor. If a contractor proposes a significantly less expensive structure that is equal to the specified structure, the proposal is usually accepted and the type of retaining structure is changed. The third scenario was described earlier. One of the DOTs requires the construction contractor to select the type of retaining structure from a preapproved list.

The states indicated whether the types of retaining structures selected are never, rarely, frequently, or always on the basis of a formal or informal decision process. A formal decision process includes a formal design report describing several retaining structure alternatives and recommendations based upon some decision analysis. An informal analysis is not documented in a formal report. As shown in Table 7, the responses were distributed. Two states frequently prepare a formal report, and an informal analysis is always or frequently done. One state rarely completes a formal report or informal analysis because the contractor selects the structure type. The remaining five states prepare a formal design report or an informal analysis, but not both. As a result, half the states frequently or always prepare a formal design report and half do not.

The states were asked how often the engineer, who selects the type of retaining structure, receives comments on the constructability of different retaining structures. Table 8 summarizes the results. Only about one-third of the DOTs have programs that facilitate con-

TABLE 5 Planning and Design Activities at DOTs by Engineering Discipline

Project Activity	Percent of Responses*			
	Geotechnical	Structural	Project	Cost
Select Type of Retaining Structure	8	42	50	0
Complete Design and Prepare Construction Plans	29	63	8	0
Determine Major Construction Methods	24	66	10	0
Specify Construction Materials	50	50	0	0
Prepare Preliminary Cost Estimate	12	39	49	0
Prepare Detailed Cost Estimate	0	14	43	43

*multiple responses are uniformly distributed so that results are evenly weighed among DOTs

TABLE 6 Phase of Project When Retaining Structures are Selected

Phase	Percent of Responses*
Planning	4
Preliminary Design	58
Final Design	15
Construction	23

*multiple responses are uniformly distributed so that results are evenly weighed among DOTs

structability comments from the field. Some of the respondents indicate they receive constructability comments only when there are problems; otherwise constructability comments are rare.

AVAILABILITY OF INFORMATION AT TIME OF RETAINING STRUCTURE SELECTION

Performance of internally stabilized wall systems depends on the in situ soil conditions or properties of available fill. Wall selection decisions for externally stabilized retaining structures depend as well on local site and soil conditions.

Each state indicated whether certain information is always, usually, or never available at the time of retaining structure selection. Table 9 summarizes the responses. The experts who indicate that soil and water table data are never available noted that during selection these parameters may be available for nearby sites.

IMPORTANCE OF PROJECT PARAMETERS

Each expert ranked by priority six project decision parameters on a scale of 1 to 6, where 1 is most important and 6 is least important. Table 10 contains the priority ranking and average rankings. On average, estimated cost and cut versus fill application are the most important decision parameters. All eight DOTs priority ranked one of these parameters as first or second. However, four DOTs also priority ranked one of these parameters very low. On average, expected deflection and aesthetics are least important of the six parameters. For several states, aesthetics is not a limiting factor because it is possible to add an architectural facia to many retaining structures.

IMPACT OF DESIGN EXPERTISE ON RETAINING STRUCTURE SELECTION

The DOTs characterized the impact of design expertise of DOT and consulting engineers on the type of retaining structure selected. The states estimated the impact of designer expertise on the selection process, then the frequency a DOT engineer or consultant has design expertise for the type of retaining structure selected. The results indicate the effect of design expertise on the selection process.

Each DOT was asked whether personal expertise of DOT engineers affects the type of retaining structure selected. The compiled results in Table 11 show almost two-thirds responded that in-house design expertise rarely or never affects the selection of retaining structure type. Ninety percent of responses indicate DOT engineers frequently or always have design expertise for the structure selected. This includes all projects designed in house or by a consultant. Only about 10 percent of responses indicate the DOT rarely has in-house design expertise for the structure type. Thus, most retaining structures being selected for highway projects are those for which DOTs have design expertise.

The DOTs described the role of engineering consultants. Table 12 contains the results. Fifty percent of the respondents are uncertain whether design expertise of their consultants influences the type of wall selected. The other 50 percent believes design expertise of consultants rarely or frequently affects the structure type. Each DOT estimated the frequency that prime consultants have design expertise for structures the consultant selects and designs. Much like the results in Table 11, almost 90 percent of the responses indicate consultants frequently or always have design expertise for the type of retaining structure selected. The states estimated the frequency a prime consultant selects the structure type and then, because of lack of expertise, obtains the services of a subconsultant to complete the design. Prime consultants more frequently subcontract the all-geotechnical or structural work, including selection of the structure types.

OPTIMIZATION OF SELECTION PROCESS

The last two decades brought the introduction and growing use of internally stabilized retaining structures, such as mechanically stabilized earth walls, modular walls, and a variety of ground improvement techniques. From the results presented, DOT engineers select most retaining structures from the types for which they have expertise. For the current paradigm to produce optimal solutions, it is essential for DOTs to have expertise in the full range of retaining structure technologies available. Consequently, highway agencies are challenged to develop and maintain in-house design

TABLE 7 Frequency of Different Retaining Structure Selection Methods

	Percent of Responses			
Retaining Wall Selection Method	Never	Rarely	Frequently	Always
Wall type is selected based on formal report comparing several wall types.	12	38	38	12
Wall type is selected by informal analysis using designer's expertise.	12	25	38	25

TABLE 8 Frequency DOT Engineers Receive Constructability Feedback from Field

Frequency	Percent of Responses
don't know	0
never	0
rarely	38
sometimes	24
frequently	38
always	0

expertise for all feasible retaining structure solutions (*3*). Because of the tremendous cost savings, the state DOT must develop and rigorously maintain its knowledge base.

Alternatively, DOTs could move the retaining structure selection decision out of the DOT. Increasing reliance on design consultants and proprietary retaining wall vendors accomplishes this. However, there are two problems with this approach. The first occurs because consultants rarely or never select retaining structures for which they have no design expertise. To optimize the selection process, it would be necessary for state DOTs to require engineering consultants to have design expertise in most or all of the feasible retaining structure solutions. Although this might not be a problem for some larger consultants, many otherwise technically capable consultants would be restricted from state DOT design contracts. This would severely restrict the state's choices in selecting consultants for retaining structure design and would not be in the best interest of the highway agency. Second, proprietary retaining wall vendors promote and build one or a limited selection of retaining wall systems. Now, many DOTs have excellent success using proprietary wall systems after DOT engineers identify the appropriate proprietary system. Most proprietary wall systems are based on specific technology not applicable to the entire range of grade separation problems. A proprietor should not be expected to understand all alternative technologies.

An alternative to acquiring and maintaining in-house expertise is for state DOTs to rely on competitive bidding. At one of the DOTs interviewed, most retaining structures are selected by construction contractors. The DOT engineers indicate the lines, grades, and location of a retaining structure on the construction plans without indicating the type of structure. As part of the bid proposal, the contractor selects the most cost-effective retaining structure from a group of preapproved wall systems. This particular DOT has a large number of preapproved retaining structures, so the competitive bidding process usually results in a good choice. The competitive bidding process does not guarantee the best solution. To be competitive, the construction contractor no doubt picks the most cost-effective structure. However, the contractor has no incentive to pick the optimum structure based on other parameters such as durability, maintenance, and least life-cycle cost, unless specifically required by the DOT. To analyze and specify parameters other than cost, DOTs need in-house expertise.

The best solution for optimizing retaining structure selection is for a state DOT to select the type of retaining structure with in-house DOT engineers. Once the type of structure is selected, the state can design the structure and prepare construction plans with DOT engineers or consultants as appropriate. One exception is a highway project entirely planned and designed by a consultant. In this case, the retaining structure can be selected by the consultant if the consultant has the necessary expertise.

CONCLUSION

As part of an effort to characterize the selection process for earth-retaining structures on highway projects, information was collected from subject-matter experts at eight state DOTs. This information focused on the characteristics of the decision maker, the decision process, the availability of information at the time of decision, the importance of project parameters, and the impact of design expertise. The results reveal some interesting patterns. First, consultant services are never used exclusively to select the type of retaining structure. Half the responses indicate consultants or design-build contractors design and prepare construction plans for retaining structure types specified by DOT engineers. DOTs and their consultants always or frequently have the design expertise for the type of retaining structure selected.

Recent advances in retaining structure technology bring the introduction and use of numerous new retaining structure systems. These advances require state highway agencies to develop and maintain in-house knowledge of new technologies if they are to continue to specify the best retaining structure solutions. State DOTs should assess their knowledge level and ensure they possess up-to-date expertise for current retaining structure technologies. A DOT should develop and maintain expertise within its organization for the full range of retaining structure solutions available today, especially those listed in Table 2.

TABLE 9 Availability of Information at Time of Wall Selection

	States Surveyed							
Project Data	1	2	3	4	5	6	7	8
Soil borings with strata identified	A	N	U	U	U	A	A	A
Water table location	A	N	U	U	U	A	A	A
Soil lab test report	A	N	U	U	U	A	A	A
Horizontal and vertical alignments	A	U	A	A	U	A	A	A

A=always, U=usually, N=never

TABLE 10 Importance of Project Parameters for Selecting Retaining Structures

	States Surveyed								
Project Parameter	A	B	C	D	E	F	G	H	Average
Cut/Fill Application	1	2	6	4	1	2	1	2	2.4
Estimated Cost	5	1	1	2	2	5	5	1	2.8
Tolerance to Settlement	4	3	2	3	5	4	2	4	3.4
Wall Height	2	5	4	5	3	1	4	3	3.5
Expected Deflection	3	6	3	6	6	3	3	5	4.4
Aesthetics	6	4	5	1	4	6	6	6	4.6

TABLE 11 Percentage of Responses Indicating How Design Expertise of DOT Engineers Influences Type of Retaining Structure Selected

Design Expertise	Never	Rarely	Frequently	Always
Expertise of DOT engineers influences type of structure selected	24	38	38	0
DOT engineers have expertise for the type of retaining structure selected	0	12	38	50
DOT engineers do not have expertise for type of retaining structure selected	38	50	12	0

TABLE 12 Percentage of Responses Indicating How Design Expertise of Consultants Influences Type of Retaining Structure Selected

Design Expertise	Don't Know	Never	Rarely	Frequently	Always
Prime consultant's expertise influences type of retaining structure selected	50	0	25	25	0
Prime consultant has expertise for the type of retaining structure selected	0	0	12	63	25
Prime consultant does not have expertise for the type of retaining structure selected and subcontracts design to specialty consultant	12	12	76	0	0

ACKNOWLEDGMENTS

This work was supported by the Colorado DOT Division of Information Services Contract #94437; the NSF Award No. MSS-9301284, Mehmet Tumay, cognizant program director; the U.S. Army Engineers and Scientists Professional Development Program; and the U.S. Army Corps of Engineers, Rock Island District. The authors gratefully acknowledge this support and the assistance of the following: T. Dickson, New York State DOT; J. Dimaggio, FHWA; G. Garofalo, California DOT; D. Greer, Kentucky Transportation Cabinet; D. Jenkins, Washington State DOT; G. Odem, Texas DOT; P. Passe, Florida DOT; M. Riaz, Ohio DOT; J. Siccardi and T. Wang, Colorado DOT; and J. Withiam, D'Appolonia Consultants.

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Publication of this paper sponsored by Committee on Geosynthetics.