ARCHITECTURAL RESEARCH, Vol. 4, No. 1 (2002), pp. 45-52

Knowledge Extraction of Highway Retaining Structure Selection:
Characteristics of Knowledge Database

Chang Young Song, Boong Yeol Ryoo and Soo Gon Lee
Graduate Student, Dept. of Architecture, Chonnam National University, song4624@hanmail.net
CEO & R&D Director, Intellix Technologies Co., bryoo@intellixtech.com
Professor, Dept. of Architecture, Chonnam National University, sgl@chonnam.chonnam.ac.kr

Abstract

Selection procedures of earth retention systems are increasingly complex and directly related to the serviceability of the retaining structure selection systems since significant changes in earth retention technology motivates the review of design, and selection processes of earth retaining structures. Collection and classification of retaining structure selection knowledge are key issues because two expert groups, geotechnical and structural engineers, are mainly involved in the retaining structure selection. The course of natural tendency of expert knowledge are investigated considering the decision factors. The decision factors for selecting retaining structures are divided into four categories: application of the structure, and spatial, behavior, and economic constraints.

Keywords : Knowledge bases, Retaining Selection, Probability, Structural Knowledge, Geotechnical Knowledg

1. INTRODUCTION

The purpose of earth retaining structures is to reinforce a substantial elevation change in earthwork construction and a space constraint is a main issue. In the 1970s, geotechnical engineering practice focused on understanding earth pressure and selection of appropriate design methods (Cheney 1990a; 1990b). Between 1970s and 1990s, there are significant changes in retaining structure construction technologies such as incremental burial or systematic in-site installation for increasing soil strength (O'Rouke and Jones 1990).

Selection of a retaining structure system is complex in the 1990s due to participation of several expert groups in selection process. The diversity of retaining structures affects the type of consideration factors. New construction technologies and more stratified perspectives of owners, project managers and designers increase the number of consideration factors in selection depending on design and construction methods. In addition to the classical advantages, low costs and maintenance, and well-studied constructability affect selection of retaining structures (Cheney 1990b).

A decisionmaker selects a retaining structure depending on engineer's expertise. Different levels of expertise may create inconsistent decision inputs as well. Thus, different fields of expertise, when considered in retaining structure selection knowledge at the same time, may cause problems for convergence of system solution for all causes under all conditions. A new model containing various attributes a form of multi-attribute decision making(MADM) must be modeled and adjusted to satisfy expectations among participants

2. PROBLEM STATEMENT

There are two groups of experts representing different fields of expertise: structural and geotechnical engineers. They are key personnel in retaining structure selection at state DOTs (Hess and Adams 1995). They make decisions concerning on site evaluation, material selection, and cost estimation, depending on the engineer's expertise. But, the engineer's expertise shows a disagreement in final selection.

In retaining structure selection, geotechnical and structural engineers have measures of the various attributes and structure types with respect to their own perspectives. These are (1) general considerations such as aesthetic, cost, durability, and risk by owners, (2) technical considerations such as constructability, cost estimates of alternatives by project managers and (3) constructability of physical elements of a retaining structure depending on site conditions by contractors.

There are many actual decisionmaking cases where the decisionmakers are not constrained to accept only the best alternative, cannot accept all the good ones, or do not even know how many of the alternatives will be accepted in advance. When a set of alternatives is classified in such a way that these alternatives are arranged systematically, decisionmakers can select the desired or preferred alternatives with respect to their preference priorities. When all alternatives are compared at the same time, the alternatives can be classified into an order of desirability or preference.

The main objective is to investigate expert knowledge in order to define expert knowledge for retaining structure selection procedure.

3. METHODOLOGY AND APPROACH

The opinions and decisions of decisionmakers are often not clear but sometimes contain valuable information. Since a membership function must be clearly defined, vagueness or ambiguity of information must be eliminated as much as possible during the knowledge acquisition phase.

Prerequisites of the certainty factor method are crisp memberships between structure types and consideration factors, and a mathematical framework to capture qualitative information. Thus conditional probability and prior probability of preference are used to measure preference of application of retaining structures.

The suggested steps to accomplish the research are as follows:

- Analyze the knowledge of retaining structure selection for checking consistency and conflict between geotechnical and structural engineering perspective;
- Measure the conditional probabilities, prior probabilities, project level preference data, and validation cases for retaining structures selection,
- Validate the experts knowledge base.

In order to complete acquisition and analysis of Knowledge Bases, four types of knowledge acquisition surveys have been performed through in state DOTs. First, Certainty Factor (CF) Acquisition Survey was distributed and collected in order to analyze the behavioral relations between twenty-four retaining structures and thirty-four attributes from twelve experts. Second, the prior probabilities of retaining structures from twelve experts are collected to measure the preference of retaining structures for highway projects. Third, the frequency of use of retaining structures from ten experts are collected. Forth, the conditional probability of twenty-two retaining structures given twenty-six attributes are collected.

For retaining structure selection, qualitative measurement of attributes is difficult because of an ill-defined membership between an alternative and criterion. Inequality of attributes adds to the complexity of computation and the number of comparisons required. Subjective inputs also cause vagueness and ambiguity in a membership function. Due to measurement in different scales, a selection problem becomes a Multiple Attribute Decision Making (MADM) method. MADM deals with identifying courses of actions in the presence of multiple attributes given a set of alternatives.

(1) TYPES OF RETAINING STRUCTURES

The types of retaining structures are listed in Table 1 (CDOT 1991a: CDOT 1991b). In order to identify feasible retaining structures, constraints such as spatial limitations, serviceability requirements, and economic considerations must be defined. The scope of structure such as applications, constraints and project level factors are listed in Table 2 (CDOT 1991a: CDOT 1991b)

4. ANALYSIS OF EXPERT KNOWLEDGE

The spatial constraints include factors about space limitations and site accessibility. The factors in evaluating site limitations and accessibility are: (1) available space for underground utility works, (2) accessibility of construction workers and equipment, (3) a space for material storage, (4) maintaining existing traffic lanes or widening, and (5) a workspace for construction workers and equipment.

The behavioral constraints include factors about and serviceability requirements and behavior of retaining structures. The factors in evaluating serviceability requirements and behavior of retaining structures are: (1) potential settlement of retained backfill, (2) allowable bearing capacity, (3) load carrying capacity during construction, (4) wall sensitivity to differential settlement, (5) ground water table, and (6) fill material properties.

The economic constraints includes factors about cost and environmental effects. The factors in evaluating economic and environmental effects are: (1) construction schedule, (2) labor experience, (3) noise, and (4) vibration control policy.

The CDOT procedure focuses on the selection of earth retaining structures for highway construction projects. Decision factors are grouped as functional applications, behavioral constraints, and spatial, and economic constraints. The structures are grouped into four categories: (1) gravity, (2) semi-gravity, (3) non-gravity, and (4) hybrid retaining structures. The knowledge does not include hybrid retaining structures, length of retaining structures, and earthquake factors because a mixture use of the retaining structures may vary according to circumstances(Adams 1993a; Adams 1993b, Adams 1993c).

Table 1 Classification of the Retaining Structures

Gravity	Semi-Gravity	Non-Gravity
MSE	CIP-L	Embed-cant-Spile
Soil-nailed	CIP-invert-L	Embed-cant-Hpile
Modular	CIP-T-spread	Embed-cant-dman
Gabions	CIP-T-deep	Embed-cant-tbk
Mass-concrete-spread	PPT-T-spread	Multi-anch-dwl
Mass-concrete-deep	PPT-T-deep	Multi-anch-tbk
Crib		Diaphragm
Metallic-bin		Drilled-caissons

(2) STRENGTH OF LINGUISITC VALUES

In order to express the probability of each retaining structure, the strength of linguistic values confirmed by the numerical intervals are adopted (Terano et. al. 1992). Five linguistic values in Table 3, always, usually, sometimes, unlikely, and never, are used as description intervals in the retaining structure probability survey because those are the most basic description that can be rationally made.

The analysis is performed by One-way Analysis (ANOVA) and Principal Component Analysis (PCA) in order to identify the interrelations between and among the variables or experts involved and the principal component variables. ANOVA is also used to find the equality of the raw data by testing the equality of two or more means using variances from the sample data (Monks and Newton 1988).

The mean of rating by each expert and the 95% confidence intervals are calculated to look closely at the equality of the raw data. PCA is used to identify a set of variables that represent correlation and covariance to the variables in the original data.

(1) ANALYSIS OF VARIANCE AND PRINCIPAL COMPONENT ANALYSIS

The purpose of these analyses is to identify the agreement among the experts and the dominant given attributes. When clustering patterns are found, the experts are grouped by the degree of variance. Correlation and covariance of a group of attributes are examined to identify how much each attribute contributes to the results and the total amount of variance. ANOVA and PCA do not guarantee the completeness of involved variables, but show uniqueness among variables.

ANOVA is used to test the hypothesis is that the means of populations (from k different groups) are equal.

$$H_0:\ \mu_1 = \mu_2 = \mu_3 = \ldots = \mu_k \quad (1)$$

H_1: Means are not all equal (2)

Table 2 Scope of Design and Project Level Factors

Application	Design Level			Project Level
	Spatial	Behavioral	Economic	
Abutment	Backspace	Backfill settlement	Time	Aesthetics
Flood control	Equipment access	Bearing capacity	Labor	Constructability
Grade-separation	Material storage	Construction loads	Noise	Cost
Landscape	Traffic maintenance	Differential	Vibration	Durability
Noise control	Workspace	settlement		Environment
Ramp		Ground Water Table		Maintenance
Road-back		Fill quality		Schedule
Road-front				Standard Design
Shoring				
Steep-slope				
Underpass				

Table 3 Linguistic, Strength, and Sizable Values(Terano et. al. 1992)

Degree of Certainty	Linguistic Value	Strength Value	Sizable Value	Probability Interval	Representative Value
certainly	Always	always		[1 ,1]	1
	Almost always	almost always		[0.98, 0.99]	0.99
very likely	very often	very strong	very large or very high	[0.83, 0.97]	0.90
Likely	Often(usually)	strong	large or high	[0.68, 0.82]	0.75
not sure but considered	sometimes	medium	medium	[0.33, 0.67]	0.50
Unlikely	Seldom (unlikely)	weak	small or low	[0.18, 0.32]	0.25
very unlikely	very seldom	very weak	very small or very low	[0.03, 0.17]	0.10
	Almost never	almost never	ignoble	[0.01, 0.02]	0.01
certainly not	Never	never	never	[0, 0]	0
no information	no information	no information	no information	ϕ	ϕ

In order to compare two expert groups, F *-table* is used because the distribution is appropriate for comparing two variances. For ANOVA, group comparison is made by dividing the variance *between-group* by the variance *within-group*. The within-group variance represents a measure based on the inherent or average variance and the between-group variance reflects the difference in groups. When some of the individual groups may not closely cluster together, F *-ratio* will generate larger variance in order to reject the null hypothesis of equal means.

PCA is a data reduction analysis in order to identify a smaller set of variables that account for a large proportion of the total variance in the original variables (Minitab 1991). Evaluation of the four attribute groups such functional, behavioral, spatial, and economic, are performed by PCA in order to identify the principal component variables which affect to the total amount of covariance. Correlation of each attribute with a group is also examined to identify principal components.

When a clustering pattern occurs, which is an agreement among experts, the experts are grouped by the degree of variance in order to represent the general acceptable behavior of each discipline. If there is any significant disagreement between or among the experts, the experts are excluded in order to maintain consistency. In order to eliminate dominated attributes, the results of PCA is used since PCA can measure a variance of individual attributes to the total variance of total variables.

Thus PCA identifies relevancy among the attributes. The contribution of the individual attribute to the total variance of all attributes is observed because five categories, functional, spatial, behavioral, economic, and project level, are involved.

5. CLASSIFICATION OF EXPERT KNOWLEDGE

Table 4 shows the frequency of use of retaining structures in state DOTs and probability values of the frequency.

Frequency of Use in Table 4 is rated 1 is the most and 18 is the least commonly used by the description in Table 3 (Ryoo 1995). Probability of frequency in Table is re-scaled by (20-Frequency of Use)/20 to convert the frequency of use into probability format

Table 4 Summary of frequency of Use of Retaining Structures for Highway Projects

Types of Structures	Frequency of Use	Probability of Frequency
MSE	2.67	0.87
Soil-nailed	12.50	0.38
Modular	9.67	0.52
Gabions	9.00	0.55
Mass-conc-spread	8.50	0.58
Mass-conc-deep	10.67	0.47
CIP-L	10.17	0.49
CIP-invert-L	10.17	0.49
CIP-T-spread	5.83	0.71
CIP-T-deep	5.50	0.73
PPT-T-spread	12.80	0.36
PPT-T-deep	12.80	0.36
Embed-cant-Spile	10.00	0.50
Embed-cant-Hpile	7.67	0.62
Embed-cant-dman	9.17	0.54
Embed-cant-tbk	9.33	0.53
Multi-anch-dwl	14.00	0.30
Multi-anch-tbk	13.67	0.32
Crib	10.00	0.50
Metallic-bin	10.20	0.49
Diaphragm	15.80	0.21
Drilled-caissons	12.80	0.36

(1) DISTRIBUTION OF FREQUENCY PROBABILITY

Twelve experts from five state DOTs, two consultants and five universities are asked to provide the probability of application of retaining structures for highway projects. The states involved are Arizona, California, Colorado, Kentucky, New York, Montana, Pennsylvania, Texas, and Washington. The universities involved are Texas A & M, Florida Technical University, University of Arizona, and University of Houston. The objective of the survey is to identify the preference of retaining structures of highway application at state DOTs.

Mass-conc-spread has been selected and constructed by state DOT engineers, but is not recommended any more due to economical reason. Seven retaining structures within the state DOTs have been used in state highway projects. They are MSE, Multi-anch-tbk, Mass-conc-spread, PPT-T-spread, Modular, CIP-T-spread, and Soil-nailed. Most of the retaining structures are gravity and semi-gravity. Deep foundation retaining structures have been rejected as the final selections. Some constraints are expected such as noise, material storage requirement, accessibility, and additional construction costs.

Ten retaining structures which can be recommended by experts for highway construction are MSE, Soil-nailed, Modular, Gabions, CIP-T-spread, Embed-cant-Spile, Embed-cant-Hpile, Multi-anch-dwl, Crib, and Drilled-caissons. Drilled-caissons has been used by both expert disciplines within limited conditions.

The knowledge bases of retaining structures, the control knowledge (elimination and ranking methods), and the problem specific knowledge (restrictions and limitations at sites) must be organized. Control knowledge comprises two steps: elimination and ranking because decisionmakers should provide information about the particular applications and site specific constraints priori.

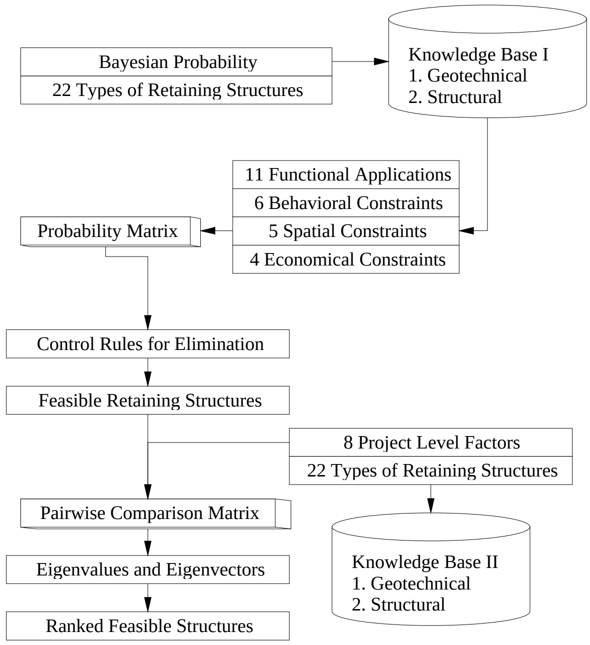
Table 5 lists applicability and economical retaining structure height. Generally speaking, retaining structures can be used for cut and fill conditions. However, some retaining structures require cutting such as soil-nailed, Embed-cant-Hpile, Embed-cant-tbk, Diaphragm, Drilled-caissons, and Multi-anchor retaining structures. Table 4 shows the frequency of use of retaining structures in state DOTs and probability values of the frequency.

Table 5 Applicability of Retaining Structures

Types of Structures	% of Fill	% of Cut	Economical Height (ft)
MSE	100	50	37.50
Soil-nailed		100	26.67
Modular	100	57	31.67
Gabions	100	86	18.75
Mass-conc-spread	100	67	7.33
Mass-conc-deep	100	67	15.33
CIP-L	71	100	28.75
CIP-invert-L	71	100	28.75
CIP-T-spread	100	100	28.67
CIP-T-deep	100	100	30.33
PPT-T-spread	100	75	25.00
PPT-T-deep	100	75	27.50
Embed-cant-Spile	17	100	16.25
Embed-cant-Hpile		100	18.33
Embed-cant-dman	33	83	26.67
Embed-cant-tbk		100	27.50
Multi-anch-dwl		100	35.00
Multi-anch-tbk		100	30.00
Crib	83	100	22.50
Metallic-bin	100	100	26.88
Diaphragm		100	30.00
Drilled-caissons		100	28.33

(2) FRAMEWORK OF KNOWLEDGE BASES AND SELECTION PROCESS

Figure 1 shows control components of retaining structure selection process. Figure 2 shows structure of knowledge bases for retaining structure selection. The preliminary screening factors in Figure 2 are recommended by CDOT engineers(Ryoo 1995).



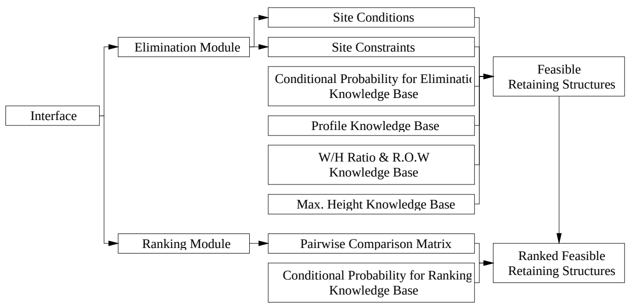


Figure 1 Control Components of Retaining Structure Selection Process

Figure 2 Structure of Knowledge Bases for Retaining Structure Selection

6. INFESIBLE STRUCTURES CLASSIFIED FROM KNOWLEDGE BASES

Based on observation of the knowledge bases, infeasible retaining structures concerning attributes are identified. Observation tells us Crib, Metallic-bin, Diaphragm, and Drilled-caisson retaining structures have been used within limited conditions. Moreover PPT-T-spread and PPT-T-deep retaining structures are not used often by structural experts. Table 6 through Table 13 show limitations imposed on retaining structures by both experts. There is no infeasible retaining structures given the spatial constraints by using the geotechnical knowledge base.

Table 6 Infeasible Retaining Structures Given Project Level Factors by Geotechnical and Structural Knowledge Bases

Structure	Diaphragm	Drilled-caissons
Aesthetics	√	√
Construc-tability		
Cost	√	√
Dura-bility		
Environ-ment		
Main-tenance		
Schedule		
Standard	√	

Table 7 Infeasible Retaining Structures Given Functional Applications(Geotechnical Knowledge Base)

Strucutre	Metallic-bin
Abut-ment	
Grade-sep	
Land-scape	
Noise	
Ramp	
Road-back	
Road-front	
Steep slope	
Temporary	√
Under-pass	√

Table 8 Infeasible Retaining Structures Given Behavioral Constraints (Geotechnical Knowledge Base)

Structures	Crib	Mettalic-bin
Bearing Capacity		
Fill Quality	√	√
GWT		√
Diff. Settlement	√	√
Backfill Settle		
Construction Loads		

Table 9 Infeasible Retaining Structures Given Economic Constraints(Geotechnical Knowledge Base)

Structure	Crib	Mettalic-bin
Noise	√	√
Time		
Vibration	√	√
Labor		

Table 10-1 Infeasible Retaining Structures Given Functional Applications Constraints (Structural Knowledge Base)

Types of Structures	Soil-nailed	Mass-conc-spread	Mass-conc-deep	CIP-L	CIP-invert-L	PPT-T-spread	PPT-T-deep	Embed-can Spile
Abutment						√	√	
Flood	√	√		√	√	√	√	
Grade-sep		√	√			√	√	√
Landscape	√	√	√	√	√	√	√	
Noise	√	√	√	√	√	√	√	
Ramp		√	√			√	√	√
Road-back		√	√			√	√	√
Road-front		√	√			√	√	√
Steep slope		√	√	√	√	√	√	√
Temporary		√	√			√	√	
Under-pass		√	√			√	√	√

Table 10-2 Infeasible Retaining Structures Given Functional Applications Constraints (Structural Knowledge Base)

Types of Structures	Embed-cant-Hpile	Embed-cant-dman	Embed-cant-tbk	Multi-anch-dwl	Multi-anch-tbk	Crib	Metallic-bin	Diaphragn
Abutment	√	√	√	√	√			
Flood				√	√			√
Grade-sep								
Landscape				√	√			√
Noise			√	√	√			√
Ramp								
Road-back								
Road-front								
Steep slope					√			
Temporary						√	√	
Under-pass				√				

Table 11 Infeasible Retaining Structures Given Behavioral Constraints (Structural Knowledge Base)

Structures	PPT-T-spre	PPT-T-deep
Bearing Capacity	√	√
Fill Quality	√	√
GWT	√	√
Diff. Settlement	√	√
Backfill Settle	√	√
Construction Loads	√	√

Table 12 Infeasible Retaining Structures Given Spatial Constraints(Structural Knowledge Base)

Structure	Mass-conc-spread	Mass-conc-deep	PPT-T-deep	PPT-T-deep
Equipment Access	√	√	√	√
Backspace	√	√	√	√
Material Storage	√	√	√	√
Traffic	√	√	√	√
Workspace				

Table 13 Infeasible Retaining Structures Given Economic Constraints(Structural Knowledge Base)

Structure	Mass-conc-spread	Mass-conc-deep	PPT-T-deep	PPT-T-deep
Noise	√	√	√	√
Time	√	√	√	√
Vibration	√	√	√	√
Labor	√	√	√	√

7. CONCLUSION AND SUGGESTION

The knowledge bases can be used to formulate a set of Multi-attribute Decision Making (MADM) for retaining structure selection. Without the knowledge bases, selection procedure a multiple objective problem to a single objective problem. The single objective is to maximize score. Thus the outcome is highly influenced by subjective decisions. The knowledge bases can eliminate this problem.

ANOVA and PCA, show a difference between the geotechnical experts and the structural experts. Both groups of experts show a disagreement in selecting feasible retaining structures. Thus, experts are grouped as geotechnical and structural based on the results of analysis of variance. The data are also grouped and analyzed separately in order to identify behavior of each group. The correlation of the attributes used to collect the conditional probabilities of retaining structures are closely related to each other. The contribution of each attribute to the total variance, covariance, is high. Thus, it is better to include all the attributes used.

Diaphragm, Drilled-caissons, Crib, and Metallic-bin have been used by the group of geotechnical experts within limited conditions. Diaphragm, Drilled-caissons, CIP-T-deep, PPT-T spread, PPT-T-deep, Mass- conc-spread, and Mass-conc-deep have been used by the group of structural experts within limited conditions

REFERNECES

Adams, T. M. (1993a). "*Expert System for Retaining Wall Selection, PHASE I*," Technical Report CDOT-DTD-R-93-5, University of Wisconsin-Madison in cooperation with the U.S. Department of Transportation Federal Highway Administration and Colorado Department of Transportation, March.

Adams, T. M. (1993b). "*Expert System for Retaining Wall Selection, PHASE II*," Progress Report CDOT-DTD-R-93-5, University of Wisconsin-Madison in cooperation with the U.S. Department of Transportation Federal Highway Administration and Colorado Department of Transportation, March.

Adams, T. M. (1993c). "*Decision methods for selecting earth-retaining structures*," Computing in Civil and Building Engineering, Proceeding from Fifth International Conference on Computing in Civil and Building Engineering, ASCE, New York, June 1993,

CDOT (1991a). "*Wall selection factors and procedures, memo no. 5-4*.". Colorado Department of Highways Staff Bridge Design Policy Memo, June 3, Colorado Department of Transportation.

CDOT (1991b). "*Work sheets for earth retaining wall type selection, memo no. 5-5*.". Colorado Department of Highways Staff Bridge Design Policy Memo, June 3, Colorado Department of Transportation.

CDOT (1991c). "*Bridge Design Manual*," Colorado Department of Transportation, Stuff Bridge Branch, Denver, CO, Oct. 1. Subsection 5.4 Wall Selection Factors and Procedures, Subsection 5.5 Work Sheets for Earth Retaining Wall Type Selection.

Cheney (1990a). Cheney, R. S., "*Permanent Ground Anchors Demonstration Project 68 Final Report*", FHWA-HHO-42, Washington, D.C., February 1990.

Cheney (1990b). Cheney, R. S., "Selection of retaining structures: The owner's perspective", In Lambe, Philip C. and Hansen, Lawrence A., editors, *Design and Performance of Earth Retaining Structures*, pages 52-66, June, American Society of Civil Engineers, ASCE. Geotechnical Engineering Special Publication No. 25.

Hess, T. G. and Adams, T. M. (1995). "*Retaining Structure Selection at the Project Level*", Paper # 950956, 74th annual Transportation Research Board Meeting, Jan, 1995, Washington, D.C..

Minitab Inc. (1991). "*Minitab Reference* Manual, Release 8, PC Version, November.

Monks, J. G. and Newton, B. L. (1988). "*Statistics for Business,*" Science Research Associates, Inc., 2nd Edition .

O-Rouke, T. D. and Jones, C. J. F. P. (1990). "Overview of earth retention systems: 1970-1990," In Lambe, P.C. and Hansen, L. A., editors, *Design and Performance of Earth Retaining Structures*, pp. 22-51, Ithaca, New York, June, American Society of Civil Engineers, ASCE, Geotechnical Special Publication No. 25.

Ryoo, B. Y. (1995). "Selection of Highway Retaining Structures: Implementation and Evaluation Using Bayesian Fuzzy Logic", Ph.D Thesis, University of Wisconsin-Madison.

Terano, T., Asai, K., and Sugeno, M. (1992). "*Fuzzy Systems Theory and Its Applications,*" Academic Press.