

Computer-Aided Planning in Construction Evaluations of Alternatives in Construction Planning

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In this paper, the author developed five evaluation models for selecting among alternate construction methods based on past construction records and studied the reliability of the models by applying each to excavation retaining wall construction. The author also proposed the Majority Evaluation Method to improve the reliability of these evaluation models and employed computers to select an appropriate alternate construction method.

Keywords: Construction Planning, Computer-Aided Planning, Construction Methods, Excavation Retaining Wall, Majority Evaluation Methods

1. Introduction

Many areas of construction planning require the knowledgeable judgment of experienced engineers, particularly in the initial stages of planning when sufficient data needed to make a decision is less likely to be available. During these stages, it is common practice to rely on the decisions of experienced engineers.

When using a computer to select one of several construction methods based on ambiguous data, we would develop a method for assessing construction plans retrogressively by analyzing data on past construction projects. While there are many evaluation models ^{1) 2)} and a few applications ^{3) 4)} have been implemented, such a method has yet to be employed in the wide range of applications in construction planning.

In this paper, the author developed five evaluation models for selecting among alternate

construction methods based on past construction projects and studied the reliability of the models by applying each to excavation retaining wall construction. The author also proposed the Majority Evaluation Method to improve the reliability of these evaluation models and employed computers to select an appropriate alternate construction method.

2. Needs Computer-Aided Planning with Company's Experience

2.1 Engineer's Experience in Construction Planning

Even without receiving detailed information or performing involved calculations, experienced engineers can generally select an appropriate construction method for specific problems with a degree of reliability. Their ability to do this has been widely recognized from past performances in construction planning. Engineers that have learned construction projects through experience can

unconsciously form analogous connections between past construction projects and a current situation based on the knowledge they accumulated.

2.2 Limitations of an Engineer's Experience

The scope of an engineer's experience is primarily defined by the construction projects he or she has directed. Since an engineer does not generally work on a large number of projects in a year, one engineer must work for a considerably long time in order to accumulate enough experience to make informed decisions. Hence, even if a company has a long track record of construction achievements, the company will eventually lose its ability to apply that experience as the senior engineers with the most knowledge eventually quit or retire from the company. The company must then wait for other engineers to accumulate enough experience in order to regain this knowledge.

Consequently, engineers without sufficient experience are often responsible for making planning decisions, resulting in companies making the same poor planning decisions time and again.

3. Models for Selection

3.1 Models for Selecting Construction Methods

When forming plans during the bidding stage and the initial stages of construction planning, it is necessary to develop a rough course of action based on an outline to determine the appropriate construction methods to employ. During these stages it is more important to develop a general idea of possible construction methods based on sketchy construction data than to compare the detailed cost factors of each construction method.

In this paper, the author used the following five models to determine an appropriate construction

method.

- 1) Discriminant Analysis Model
- 2) Preference Analysis Model
- 3) Neural Network Model
- 4) Case-Based Model
- 5) Rule-Based Model

3.2 Discriminant Analysis Model

This model assumes that the attributes of construction projects can be represented by parameters X_i ($X_1, X_2, X_3, \dots, X_n$) that will reveal the construction method G_i employed in each project. Discriminant analysis is employed to find a discriminant function for classifying each construction project according to each group of methods employed.

3.3 Preference Analysis Model

Preference analysis employs a hypothetical linear function for evaluating the selections and finds a coefficient for this function such that the value of the function for an employed method is larger than that for other methods. Equation (1) below was defined for all construction methods k when employing a method j in a construction project i , where $k \neq j$.

$$S_{ij} > S_{ik} \text{ ----- (1)}$$

Here, the preference function S_{ij} is expressed as a linear function. Solutions of half-space problems, such as the least-squares or relaxation procedures, are used to find a linear function to express the preference based on past construction projects.

3.4 Neural Network Model

A neural network is a computer network model based on a nervous system in which neurons connected in a series are stimulated and in turn stimulate other neurons in the series. The attributes X_i are the stimuli applied to the neurons, which in turn stimulate other neurons in the series. The result is the construction of

a neural network, in which specific neurons display numbers representing a construction method to be employed in the construction project.

3.5 Case-Based Model

In this method, past construction records is referenced to find parameters that indicate attributes of the construction project. After normalizing the parameters, a case-based model is constructed to express the attributes of construction projects. Attributes of a target construction project are matched with those of projects stored in the case-based model. The construction method for the project that most closely resembles the target project is assumed to be employed. The squared Euclidian distance is used to evaluate similarity.

3.6 Rule-Based Model

Criteria that engineers use to select a method are modeled as if-then rules. Usually, engineers themselves do not understand the process they use to determine a method based on their experience. In this study, the author interviewed an expert of construction planning. The thought process he used to reach a solution was recorded and converted into if-then rules.

4. Evaluation for Excavation Retaining Wall Construction Methods

4.1 Excavation Retaining Wall Construction

When excavating an area for constructing underground floors, retaining walls are set in place to prevent soil around the excavated area from collapsing inward. There are three principal methods for constructing these retaining walls.

(1) H-Pile Wall (Soldier Piles)

In the H-Pile Wall method, Steel H-Piles are set into the ground from above. As the area is excavated,

timber is attached crosswise to the H-Pile to prevent soil from collapsing inward. This method is not optimal when groundwater is present, because the water tends to seep through gaps in the retaining wall (see Figure 1).

(2) Steel Sheet Pile Wall

A Steel Sheet Pile Wall is installed by interlocking the pile walls together. Because the pile walls are linked together, groundwater cannot seep through the wall into the excavated side. This method is not suitable for deep excavation since the wall has little rigidity to withstand pressure from the soil (see Figure 2).

(3) Cast-in-Place Wall

The wall section area is excavated using an earth drill positioned above ground on the edge of the excavation area. Soil is mixed with a cement paste, replacing the soil with soil cement to create a cast-in-place retaining wall (see Figure 3.a). It is also possible to build a reinforced concrete wall under the ground. This is done by excavating the retaining wall area with an excavator while the hole is kept filled with bentonite slurry, and installing reinforcing bars in the wall area and placing concrete (see Figure 3.b). Both of these types of Cast-in-Place Walls are suitable for groundwater and deep excavation. However, they are expensive to construct.

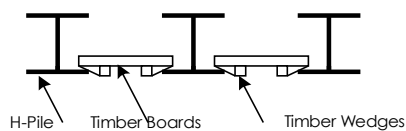


Figure.1 H-Pile Wall

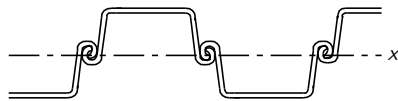
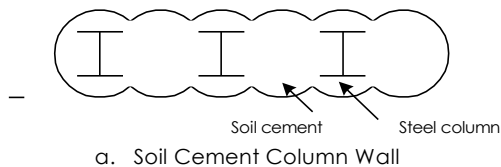
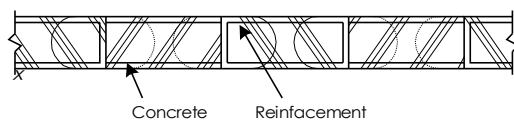


Figure.2 Steel Sheet Pile Wall



a. Soil Cement Column Wall



b. Reinforced Concrete Wall

Figure.3 Cast-in-Place Wall

4.2 Collecting Data on Previous Projects

In order to determine the precision of deductions using the five evaluation models described in the

influence on the selection of a method for excavation retaining wall construction, the author defined nine variables to represent these factors in the following lists..

- Excavation depth (m)
- Excavation area (m²)
- Depth of groundwater level from excavation bottom (m)
- Thickness of gravel soil, fine-sand soil, rock soil, and surface soil layers between the groundwater level and excavation bottom (m)
- Thickness of fine-grained soil and organic soil layers between the groundwater level and excavation bottom (m)
- Average N-value (SPT blow count) for soil between the ground surface and the excavation bottom
- Ratio of fine-sand soil between the ground surface and excavation bottom
- Ratio of fine-grained soil and organic soil between the ground surface and excavation bottom
- Thickness of firm soil layer (N-value of 50 or greater) between the ground surface and the excavation bottom (m)

Methods	Construction	H-Pile Wall	Steel
Attributes			
Excavation Depth (m)		7.44	
Excavation Area (m ²)		916.21	
Depth of groundwater level from excavation bottom (m)		2.05	
soil layers between the groundwater level and excavation bottom (m)		1.78	
Thickness of fine-grained soil and organic soil layers between the groundwater level and excavation bottom (m)		0.70	
Average N-value (SPT blow count) for soil between the ground surface and the excavation bottom		18.37	
Ratio of fine-sand soil between the ground surface and excavation bottom		0.26	
Ratio of fine-grained soil and organic soil between the ground surface and excavation bottom		0.32	
Thickness of firm soil layer (N-value of 50 or greater) from the ground surface to the excavation bottom (m)		1.07	
Cases		100	

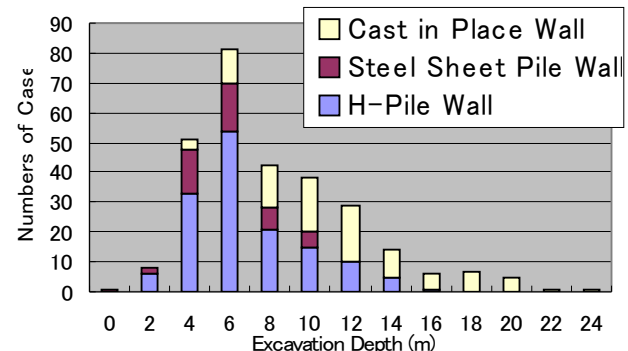


Figure.4 Excavation Retaining Walls

previous section, the author collected and analyzed data on underground construction projects performed throughout Japan. All of the construction projects were started between 1965 and 1986 and had excavation depths of 2–25 meters and excavation areas of 50–15,000 m². All projects using the Open Cut method were excluded.

After analyzing factors that would have

By studying the records for previous construction projects, as described above, the author obtained valid data for 324 cases. Table 1 shows the mean values of attributes of construction projects for each of the construction methods. Figure 4 shows the number of construction projects according to excavation depth

and excavation retaining wall method.

To develop evaluation models, cases for each construction method was randomly divided into two groups with one group having approximately twice as much data as the other. The larger of the groups were used for analyzing models (analysis data) and the smaller was used for verifying the models (verification data).

4.3 Construction Method Evaluation Models

4.3.1 Discriminant Analysis Model

Using the nine descriptive variables described above, the author attempted to find a linear discriminant function for distinguishing between the three construction methods, H-Pile Wall, Steel Sheet Pile Wall, and Cast-in-Place Wall. The following discriminant functions (2) and (3) were obtained after performing discriminant analysis on the analysis data.

$$X = 1.65 \times 10^{-1}a + 8.09 \times 10^{-5}b + 4.97 \times 10^{-2}c + 2.59 \times 10^{-1}d - 9.54 \times 10^{-2}e - 2.34 \times 10^{-2}f - 1.10 \times 10^{-1}g - 5.53 \times 10^{-1}h - 2.29 \times 10^{-1}i - 1.95 \quad (2)$$

$$Y = 2.94 \times 10^{-1}a + 1.03 \times 10^{-4}b - 2.56 \times 10^{-1}c + 5.22 \times 10^{-2}d - 6.78 \times 10^{-2}e + 7.21 \times 10^{-2}f - 4.43 \times 10^{-1}g + 3.28 \times 10^{-1}h - 2.79 \times 10^{-1}i - 2.52 \quad (3)$$

Here, variable 'a' to 'i' are correspond to the lists of attributes of construction projects. In the analysis data, 75.0% of the methods determined matched the methods that were actually used.

Table 2 shows the results of the accuracy of selecting appropriate construction methods for specific projects using the above discriminant functions on the verification data. As shown in Table 2, the accuracy of cases that matched is 72.2%, indicating a slight drop from the accuracy in the analysis data. Although relatively high accuracy was

achieved with the verification data in deducing projects employing H-Pile Walls (71.1%) and projects employing Cast-in-Place Walls (80.0%), the accuracy rate for deducing projects using Steel Sheet Pile Wall was only 60.0%.

4.3.2 Preference Function Model

A preference function S_{ij} was created using equation (4) below for a construction method j employed in a construction project i .

$$S_{ij} = \sum A_{kl} * V_{ik} * M_{jl} \quad (k=1 \text{ to } 9, l=1 \text{ to } 3) \quad (4)$$

Here, A_{kl} is predictor variables of preference function. V_{ik} is the k th attribute of construction project i . M_{jl} is the l th attribute of construction method j . The attributes of construction methods represent the resistance degree for groundwater, the rigidity to withstand pressure and the index of construction cost.

Using the analysis data, the author analyzed predictor variables A_{kl} for the preference function that would yield satisfactory preference results in terms of numerical value when analyzing past projects with the function. With the analysis data, the author compared the construction method determined by the function to the actual construction method and found an accuracy of 73.3%.

The results shown in Table 3 were obtained by

Table.2 Results by Discriminant Analysis Model					
Excavation Retaining Wall		Original Membership			Total
		H-Pile Wall	Steel Sheet Pile Wall	Cast in Place Wall	
Predicted Group Membership	H-Pile Wall	32	1	0	33
	Steel Sheet Pile Wall	71.1%	6.7%	0.0%	36.7%
	Cast in Place Wall	11	9	6	26
	Steel Sheet Pile Wall	24.4%	60.0%	20.0%	28.9%
Predicted Group Membership	Cast in Place Wall	2	5	24	31
	Steel Sheet Pile Wall	4.4%	33.3%	80.0%	34.4%
	Cast in Place Wall	45	15	30	90
	Steel Sheet Pile Wall	100.0%	100.0%	100.0%	100.0%
Percentage of Accuracy:					72.2%

Table.3 Results by Preference Analysis Model					
Excavation Retaining Wall		Original Membership			Total
		H-Pile Wall	Steel Sheet Pile Wall	Cast in Place Wall	
Predicted Group Membership	H-Pile Wall	41	6	7	54
	Steel Sheet Pile Wall	91.1%	40.0%	23.3%	60.0%
	Cast in Place Wall	2	3	1	6
	Steel Sheet Pile Wall	4.4%	20.0%	3.3%	6.7%
Predicted Group Membership	Cast in Place Wall	2	6	22	30
	Steel Sheet Pile Wall	4.4%	40.0%	73.3%	33.3%
	Cast in Place Wall	45	15	30	90
	Steel Sheet Pile Wall	100.0%	100.0%	100.0%	100.0%
Percentage of Accuracy:					73.3%

Table.4 Results by Neural Network Model					
Excavation Retaining Wall		Original Membership			Total
		H-Pile Wall	Steel Sheet Pile Wall	Cast in Place Wall	
Predicted Group Membership	H-Pile Wall	34	2	0	36
	Steel Sheet Pile Wall	75.6%	13.3%	0.0%	40.0%
	Cast in Place Wall	6	5	6	17
	Steel Sheet Pile Wall	13.3%	33.3%	20.0%	18.9%
Predicted Group Membership	Cast in Place Wall	5	8	24	37
	Steel Sheet Pile Wall	11.1%	53.3%	80.0%	41.1%
	Cast in Place Wall	45	15	30	90
	Steel Sheet Pile Wall	100.0%	100.0%	100.0%	100.0%
Percentage of Accuracy:					70.0%

Table.5 Results by Case-Based Model					
Excavation Retaining Wall		Original Membership			Total
		H-Pile Wall	Steel Sheet Pile Wall	Cast in Place Wall	
Predicted Group Membership	H-Pile Wall	34	3	3	40
	Steel Sheet Pile Wall	75.6%	20.0%	10.0%	44.4%
	Cast in Place Wall	7	7	3	17
	Steel Sheet Pile Wall	15.6%	46.7%	10.0%	18.9%
Predicted Group Membership	Cast in Place Wall	4	5	24	33
	Steel Sheet Pile Wall	8.9%	33.3%	80.0%	36.7%
	Cast in Place Wall	45	15	30	90
	Steel Sheet Pile Wall	100.0%	100.0%	100.0%	100.0%
Percentage of Accuracy:					72.2%

Table.6 Results by Rule-Based Model					
Excavation Retaining Wall		Original Membership			Total
		H-Pile Wall	Steel Sheet Pile Wall	Cast in Place Wall	
Predicted Group Membership	H-Pile Wall	36	2	3	41
	Steel Sheet Pile Wall	80.0%	13.3%	10.0%	45.6%
	Cast in Place Wall	4	11	5	20
	Steel Sheet Pile Wall	8.9%	73.3%	16.7%	22.2%
Predicted Group Membership	Cast in Place Wall	5	2	22	29
	Steel Sheet Pile Wall	11.1%	13.3%	73.3%	32.2%
	Cast in Place Wall	45	15	30	90
	Steel Sheet Pile Wall	100.0%	100.0%	100.0%	100.0%
Percentage of Accuracy:					76.7%

applying the preference function found above on the verification data. The accuracy of the preference function was 69.0% overall. The percentage of accurately deducing H-Pile Wall was high at 75.6%. Cast-in-Place walls were accurately determined at 80.0%. However, the accuracy rate of determining the Steel Sheet Pile Wall was only 46.7%.

4.3.3 Neural Network Model

The network architecture was determined by selecting a number of intermediate layers and neurons through trial and error. In the current model, we selected one intermediate layer having eight neurons. The Sigmoid Function, which is the most commonly used function in neural networks, was employed to represent the synapses.

Network training was performed 20,000 times using the analysis data. The best result for the analysis data was obtained on the 7,729th trial.

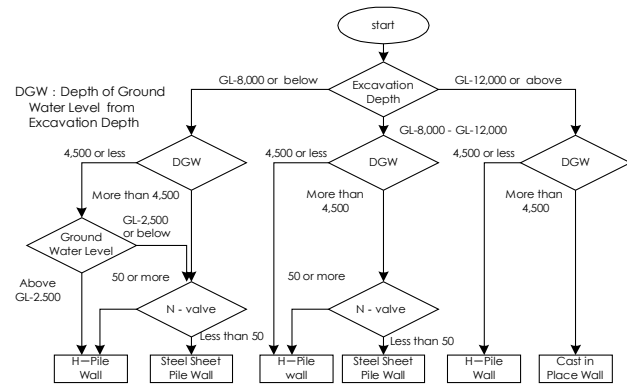


Figure.5 Flowchart of IF-THEN Rules

Therefore, the network for this trial was adopted. The accuracy in guessing the construction method for analysis data at this time was 84.0%.

Table 4 shows the results of applying the neural network to the verification data. This table shows that an accuracy of 70.0% overall was obtained for the verification data. The highest accuracy of 80.0% was obtained when deducing Cast-in-Place wall. Next was the estimation of H-Pile Wall at an accuracy of 75.6%. However, the percentage for accurately selecting Steel Sheet Pile Wall was only 33.3%.

4.3.4 Case-Based Model

A database of construction cases was created using the analysis data. This database employed 194

construction projects, where each case represented a project using nine attributes. In order to find an overall similarity between these past projects and the target construction project, each of the nine attributes has been normalized to achieve a mean value of 0.0 and a standard deviation of 1.0.

After normalizing the attributes of each target project in verification data by using the mean and standard deviation of the attribute in the database, the author extracted from the database a construction case which is most similar to the target project. The method that had been employed in the extracted construction project was assumed as the method for the target construction project.

Table 5 shows the results of deducing methods of construction projects in the verification data using the above method. The overall percentage of accuracy in our deductions was 77.0%. The highest accuracy of 91.1% was achieved for projects employing H-Pile Wall. An accuracy of 73.3% was achieved for projects employing Cast-in-Place Wall. Deductions for Steel Sheet Pile Wall were extremely low at 20.0% accuracy.

4.3.5 Rule-Based Model

An interview was conducted with an engineer having more than thirty years of experience. The process in which the engineer used to determine construction methods based on experience was modeled in if-then rules. Since the engineer himself was not conscious of his/her procedure for determining methods based on experience, these rules were created through trial and error in the meetings which were conducted over four times lasting roughly two hours each..

The flowchart shown in Figure 5 was created based on the above expert rules for selecting construction methods.

Table 6 shows the accuracy when using the Rule-Based Model of Figure 5 on the verification data to determine an appropriate construction method. The overall accuracy was 76.0% with an 80.0% accuracy for construction projects employing H-Pile Wall, 73.0% accuracy for construction projects employing Steel Sheet Pile Wall, and 73.3% accuracy for construction projects employing Cast-in-Place Wall. Hence, the Rule-Based Model achieved relatively high accuracy even when determining Steel Sheet Pile wall projects, which yielded comparatively low accuracy when using other deduction methods.

5. Majority Evaluation Method

Each of the five models introduced in Section 4 were able to achieve an accuracy of 70% or greater in selecting an appropriate construction method. When considering that a random classification of three construction methods would generate an accuracy ratio of 1/3, the deductions using these models achieved a comparatively high accuracy. The above results indicate that any of the above models can determine a construction method for use in construction planning based on data that expresses attributes of the construction project, provided all attributes are available.

However, the greatest problem in selecting a construction method using these evaluation models is the existence of predicting error in the models. As described above, none of the models have an accuracy of 100%. In order to minimize the amount of error in these models, it must be known in advance whether the model produces a correct solution or not. The author used the majority principle in the present study, wherein a solution obtained from each model was compared to the solutions from other models in order

Table.7 Results by Majority 5/5				
		Original Membership		
		H-Pile Wall	Steel Sheet Pile Wall	Cast in Place Wall
Excavation Retaining Wall		28	1	0
Predicted Group	H-Pile Wall	100.0%	33.3%	0.0%
Memberships	Steel Sheet Pile Wall	0	1	0
	Cast in Place Wall	0.0%	33.3%	0.0%
		0	1	18
		0.0%	33.3%	100.0%
Total		28	3	18
		100.0%	100.0%	100.0%
Percentage of Accuracy:				95.9%
Table.8 Results by Majority 4/5				
		Original Membership		
		H-Pile Wall	Steel Sheet Pile Wall	Cast in Place Wall
Excavation Retaining Wall		29	2	0
Predicted Group	H-Pile Wall	90.6%	18.2%	0.0%
Memberships	Steel Sheet Pile Wall	3	5	2
	Cast in Place Wall	9.4%	45.5%	8.3%
		0	4	22
		0.0%	36.4%	91.7%
Total		32	11	24
		100.0%	100.0%	100.0%
Percentage of Accuracy:				83.6%

to eliminate errors. This process is called the majority evaluation method.

With the Majority Evaluation Method, multiple evaluation models are used to evaluate construction methods. The selection is assumed to be correct only if a majority of the models point to the same method.

When applying the five evaluation models to the verification data, cases in which all models selected the same construction method is 49 out of 90 cases. In these 49 cases the overall accuracy in selecting an appropriate method is 95.9%, as shown in Table 7. This is a very high rate of accuracy. In other words, if all five models produced the same result, we can consider this conclusion to be very reliable.

In the case that four out of five models produced the same result, there are 67 cases out of 90 cases. Then we still obtain only a slightly less accuracy of 83.6%, as shown in Table 8.

6. Conclusion

When creating a construction plan with a computer, it is not possible to completely eliminate the errors inherent in the planning logic and the inferring mechanism in the models. The author's study shows that we can increase the accuracy of the evaluation using the computer to apply multiple evaluation models which have different inferring principles. An engineer can tell in advance whether

the selection is reliable by comparing the results from each model in the Majority Evaluation Method.

Nowadays, various data related to construction projects is being stored in computers. Attribute data for past construction sites are recorded on digital media, simplifying the creation of an immense database of construction records. Such a database enables us to accumulate more detailed and diverse data on attributes of each construction project. In addition to this, by employing the majority evaluation method on multiple evaluation models presented in this paper, we can more quickly and more accurately predict an appropriate construction method in the initial stages of construction planning.

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