An Expert System for FRP Composite Repair

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ABSTRACT: This paper describes an expert system to estimate the cost to install fiber reinforced polymer (FRP) repairs on bridges at the pre-design levels by using a cost-engineering model that integrates current design specifications, a knowledge-based inference engine, decision trees, algorithms, the USA Pontis bridge management database, and other cost databases. Key elements of this model development include breaking down the FRP repair process in tasks, defining task duration and sequence, identifying factors that affect the duration of each task, creating rules to simulate the repair process as well as algorithms to calculate material, labor, and equipment costs. Using this procedure, it is possible to incorporate site conditions that are specific to each repair. Site conditions have a considerable effect in the final cost of the repair, yet they are not considered when using traditional historical data to make estimates at the pre-design stage. Use of site condition and sequencing as cost driving parameters is a critical breakthrough and make this modeling approach unique. The model uses inspection data and other bridge data in the USA Pontis system as input data. The model results from interdisciplinary research that combines the knowledge from FRP composites, construction, design, and corrosion specialists from academia and industry. The integrated cost engineering system is composed of a full set of models, which deal with over 100 repair options for different bridge elements.

1 INTRODUCTION

The methodology in this paper provides a means to estimate the cost of FRP repair without having complete design drawings, and without visiting each job site. Implementing the methodology described facilitates the process of estimating costs of FRP repair alternatives and making critical decisions in prioritizing and allocating limited budgets. See Figure 1 for sample repair in progress. Currently, the cost of installing FRP repairs on bridges at the pre-design stage is estimated using historical data in the form of lump sum estimates. Contractors later develop detailed estimates before bidding a specific project. The detailed estimating process requires both a critical inspection of the site conditions and complete design drawings, which are not available at the pre-design stage. Using the design drawings, the contractor estimates the material quantities, but the contractor uses the specific conditions of the site to determine both the equipment and the labor required. Finally, the contractor converts this estimate into his proprietary bid/tender according to his interest in getting the job, experience of the firm performing the same type of construction, available labor, and site specific conditions, among other factors. All these cost adjustments are buried within the proprietary bid and are not transparent. Furthermore, to adjust the final cost of the bid, contractors may increase the cost of different pay items to account for adverse site conditions. For example, if the location of the bridge provides limited access to the piles, the FRP repair installation cost increases. To account
for this increase in cost due to an adverse site condition, one contractor may increase the cost of repair while another contractor may increase the cost of traffic control. Therefore, when comparing historical data there are unarticulated proprietary adjustments and cost inconsistencies among similar repair.

The concepts in this paper include the components of the methodology and uses components bridge FRP pile jackets with cathodic protection as the subject FRP repair examples. Next, it provides the analysis of the specially designed work breakdown structure for pile repair. After full explanation of the pile FRP repair is given, this paper then ties the methodology components together of the unique expert system model designed for the bridge repair applications.

![Figure 1. Sample Repair In Progress](image1)

![Figure 2. Site Conditions Floating Platform](image2)

![Figure 3. Bridge FRP Repair Model](image3)
2 METHODOLOGY

Developing a model to accurately estimate the cost to FRP repairs includes the following steps:
1. Break down the construction process in tasks.
2. Define the task duration.
3. Define the task sequence.
4. Define construction milestones.
5. Define factors that affect the duration of each task.
6. Create rules to simulate the construction process.
7. Create algorithms to calculate material and labor quantities.
8. Create rules to select appropriate equipment.
9. Define the criteria used by the knowledge–based system.
10. Define required parameters and secondary parameters.
11. Design a relational database.
12. Integrate the relational database with the existing Pontis™ database. Steps (1) through (6) are related to the design and construction of the project, and they do not include any cost analysis. To complete these steps, the research team needed to understand both the process used by an engineer to design a specific bridge repair and the process used by the contractor to install it. This information is in the form of specifications, design drawings, design guidelines, expert knowledge, and actual field data. Contractors, engineers and researchers who are active in FRP and concrete repair provided the research team with valuable expert knowledge, the product of years of experience, and heuristics or “rules of thumb.”

The knowledge acquisition techniques used to collect information from the experts were informal reporting and protocol analysis. Informal reporting consisted of meetings with the experts in which the expert explained the design and installation procedures. During these meetings, the experts also provided cost information, such as cost factors that affect the final cost of the project. Later, the experts provided sample design and sample cost estimates for specific examples. The process of providing expert knowledge through specific examples is known as protocol analysis (Baker 1999). Finally, the researchers collected actual field data during several weeks of observation of construction sites. These data included task duration, task sequence, construction milestones and factors that affected the duration of each task. Combining these data with the data obtained from specifications, design guidelines and expert knowledge, it was possible to simulate the construction process. After defining the construction process and completing steps (1) through (6) described in the methodology, the researchers calculated material and labor quantities and selected the appropriate equipment, which are steps (7) and (8). The material quantities could be calculated using algorithms, rules, decision trees and knowledge tables. The algorithms may be functions of several parameters, such as the dimensions of the columns, the length of a pile jacket, the clearance between the jacket and the pile. In addition, according to the specific conditions of the job site, the same task may require different pieces of equipment. For example, if the water depth is higher than 1.5 ft., the crew may need a floating platform. Therefore, rules, decision trees and knowledge tables may be used to select the appropriate equipment for each task. Step (9) described in the methodology, which consists of defining the criteria used by the knowledge base system, integrates all rules, algorithms, decision trees and tables. There are multiple variables, factors, and parameters that are incorporated to calculate material, labor and equipment cost. Some of these parameters must be known and are called required parameters. Others parameters can be assumed and are called secondary parameters. For example, the side dimension of a rectangular column must be known, but the clearance between the jacket and the pile could be assumed as 3 inches because this is a typical value in most projects. After defining the required and secondary parameters, which constitutes step (10), the cost analysis is completed. The remaining steps deal with organization and use of new and existing data. Some of this data may be used as input data, other, as output data, so that it should be accessible to the system as knowledge-bases or databases. Properly designed databases assure the integrity of the data. The design involves defining the domain model of the data and the relational database. This design allows new databases of new designs or new
technologies to be integrated with the existing databases. Design of the knowledge database and the integration with other databases constitutes steps (11) and (12) described in the methodology.

Table 1. Heuristics for Cathodic Protection Repairs

- Remaining service life of the structure should be > 10 years.
- Delaminations and spalls should be < 50% of structure area.
- Chloride content should be > 0.026% by weight of concrete (1.0 lb./yd3).
- Half cell potentials should be > -200 mV.
- The structure should be sound.
- The majority of reinforcing steel bars should be electrically continuous.
- AC power supply should be available for impressed current systems only.

Figure 8. Inference Engine
3 CONCLUSION

1. The methodology described in this paper can be implemented to create a model to estimate the cost of a bridge FRP repair.
2. The cost model is an expert system since it combines knowledge at the level of “human experts” and contains all elements of an expert system as described in the paper.
3. The knowledge used by the expert system is not separated from the inference engine to follow a pre-defined work-breakdown structure.
4. Sequence and specific site conditions can be incorporated into an expert system to estimate cost at the pre-design level.
5. Use of site condition and cost sequencing is a critical breakthrough and makes this modeling approach unique.
6. It is possible to use inspection data from Pontis™ and other databases as input data for the system.

4 REFERENCES

Baker, N. 1999. Personal communication, Professor, Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA