Multiobjective Lifecycle Management of Steel Bridge Coating System

Nagoya University, Member, ○ Chunlu Liu
Nagoya University, Fellow, Yoshito Itoh

1. INTRODUCTION

According to the statistical annual report on the highway in Japan, the number of bridges over 15 m in their length reached 125,000 on April 1, 1995. The total length of these bridges is about 7200 km. Among these bridges, steel bridges are 40.8% and 49.8% in the number and length, respectively. Furthermore, the length of 254 steel bridges in Nagoya is about 81.6% of the whole length of 435 bridges located in this city. Therefore, the steel bridge management occupies an important place in maintaining the national or regional bridges open for constant use, and bridge engineers and researchers have paid great attention to the performance of steel bridges.

The service life of a steel bridge is limited by several factors such as structural deterioration and functional insufficiency. Corrosion of steel bridges is one major deterioration cause of steel bridges. It is an endless and costly bridge maintenance problem. Numerous failures of steel bridges due to corrosion and related phenomena have been reported in the literature. For most bridges, a paint coating system is required to provide corrosion protection and to enhance the aesthetic appearance. Painting costs of steel bridges over the design life are very high. Furthermore, environmental and health concerns about the removal and disposal of lead-based paints increase costs related to the painting of steel bridges. On the other hand, the repair cost and structural safety of the steel bridges should also be considered simultaneously while a decision is made for the coating systems. This issue can be formulated as a multiobjective optimization problem. This report aims to describe the optimization methodology to search the ideal cost and safety tradeoff by modifying the genetic algorithm (GA). The numerical example illustrating the steel bridges located in Nagoya City will be presented.

2. MODIFICATIONS OF GNETIC ALGORITHMS

In most books or papers on GA, only the advantages of GA were discussed. As a computing method, GA is also of its disadvantages. In the remaining of this section, some disadvantages will be discussed and the potential solutions will be proposed. Fig.1 shows the proposed GA optimization procedure with several modifications including local search, elitist strategy and adaptation of basic operators.

(1) It is well known that GA is a robust method in finding the global near-optimum solution. However, once the optimum solution region is identified using GA, finding the true optimum becomes inefficient or impossible. Therefore, GA is always called a near-optimum search method. This problem comes from the discrete coding representation and the random nature in the GA procedure. Integrating GA and the local search may be an efficient approach to find the exactly optimal solution. Goldberg (1989) suggested a method in which a single bit value is simply changed such as from 0 to 1. If the fitness of the modified string is better, the original string is replaced by a modified string. Otherwise the original string remains unchanged. This test is executed repeatedly from the first bit to the last bit of a string.

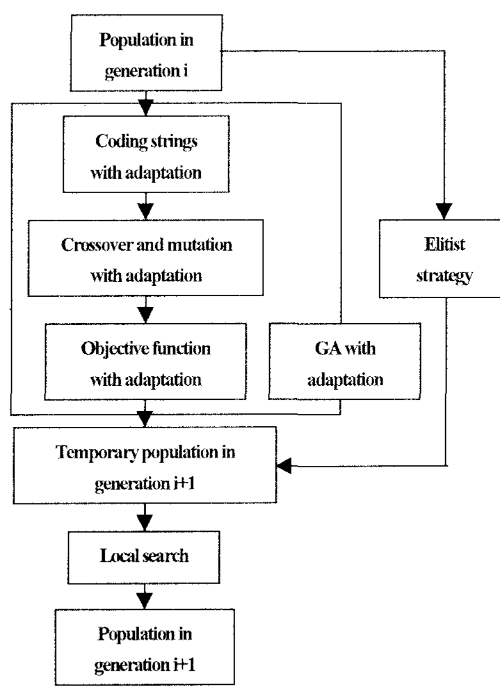

Fig. 1 Modified GA Procedure in One Generation

(2) In the GA optimization procedure, there exist same duplicated strings in one generation and between two generations. For example, some eliminated strings in the previous generations may be generated after crossover and mutation, and some near-optimal solutions may survive in several subsequent generations. The elitist strategy guarantees

the survival of the best individual in a generation. This strategy ensures the continuous increase of best fitness value generation after generation. This strategy can be implemented by replacing the worst individual in the next generation by the best individual from the previous generation for the purpose of the stable increase of the best and average fitness values. A parameter named *generation gap* G ($0<G\leq 1$) was defined to permit overlapping populations in Goldberg (1989). Giving the population size is represented as n, nG individuals of each generation will be generated by reproducing the selected individuals in the previous generation, and $n(1-G)$ will be copied directly from the best solutions in the previous generation.

(3) GA is relatively weak in dealing with the constraint conditions within the optimization process. The popular way is to transform the constraints into a penalty function that is a part of the objective function or to eliminate the solutions that do not satisfy the constraints after decoding all strings. Either way wastes a lot of calculation time due to handling the inefficient solutions. It may be better to increase the penalty parameters gradually generation after generation. This idea stems from the fact that with the increase of the generation number more individuals should satisfy the constraints or the distance between the constraint and the solution should be reduced. Furthermore, the fixed GA parameter such as fixed population sizes, crossover probability and mutation probability, are usually defined at the beginning of each run and adopted until the final generation. This causes the calculation speed to be same from the first generation to the final generation. It may be better that the optimization process is accelerated with the increase of generation number by changing some parameters. All these approaches are related to the adaptation of GA operators with generation.

3. FORMULATION OF COATING SYSTEM

The usual coating maintenance methods can be summarized as spot repair, overcoating, and complete recoating. In spot repair, only rusted or delaminated areas are removed from the surface and a new coating is applied. Areas with minor defects will not be removed until they deteriorate to a specific condition. In overcoating, all defective areas are removed and the entire steel structure is finished with a new coating that is compatible with existing system. The third strategy, complete recoating, was the method used in the past to maintain bridges. In this method, the coating system is allowed to deteriorate until the structural damage due to corrosion is so imminent that a new coating system has to be applied. No painting is considered as the forth maintenance method for the coating system of a steel bridge in this research. Each of them requires a different operation procedure and provides different effect on the recovery of deteriorated coating system and protection to the steel bridge structures.

The long-term maintenance cost of the coating systems is conflicting with the structural safety of steel structures. To determine the appropriate optimal time to apply a coating maintenance method for each steel bridge, both the painting maintenance cost and the possible structural deterioration are minimized using a multiobjective optimization technology based on the above-mentioned modified GA. According to previous research such as Fujiwara and Sugano (1996), Tam and Stiemer (1996), the basic parameters are formulated and adopted in the optimization procedure, including (1) the unit area cost of each coating method, (2) the corrosive procedure of steel members, (3) the correlation between condition upgrades and coating methods, (4) the constraints for the selection of each coating method, and (5) the optimization objective functions. Finally, a numerical example is studied to examine the proposed optimization procedure and these formulations.

4. CONCLUSIONS

In this research, the deterioration rate of coating systems and the corrosion degree of the steel bridge structures under them are first studied. Then, the cost for maintaining the coating systems and the deterioration assessment of steel members are formulated for a long period. A multiobjective optimization strategy is proposed to deal with the cost and safety tradeoff for the bridge lifecycle using a modified genetic algorithm. Finally, a numerical example is illustrated for the steel bridges located in Nagoya City.

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