I − 24 OPTIMIZATION OF A PC BRIDGE SYSTEM CONSIDERING MULTIPLE OBJECTIVES AND FUZZINESS

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1. Introduction

This paper proposes a rational, systematic and efficient intelligent optimum design method for a prestressed concrete bridge system that is developed by combining classification of design variables and design parameters, suboptimization concept, introduction of measure membership functions for relative evaluation of all objective functions and fuzzy decision-making techniques.

2. Primary optimum design problem of a PC bridge system

The bridge system considered in this paper consists of a three-span parabolic shape prestressed concrete box girder (superstructure) and four RC piers and RC pile foundations (substructure) as shown in Fig. 1. The bridge has a total length of 200m and a width of 14m. The superstructure is elevated 30m from the top of the RC foundations. In this multicriteria fuzzy optimum design problem of the prestressed concrete bridge system, the total construction cost of the bridge system f_t to be minimized, the aesthetics f_a to be maximized and the seismic safety of the bridge system f_l to be maximized are dealt with as the objective functions. As it has been experienced at the huge earthquake, the collapse of piers and foundations of the bridge system at urban area causes huge damages not only the direct collapse of the bridge system itself but also the tremendous secondary damages caused by the blockages of traffic flows. For this reason, the magnitude of the safety parameter to be used for the design of the substructure is very significant design parameter from the viewpoint of maximization of the seismic safety of the bridge system. Therefore, the value of the safety parameter f_s for the design of the substructures is dealt with as a design parameter objective instead of the direct use of f_l.

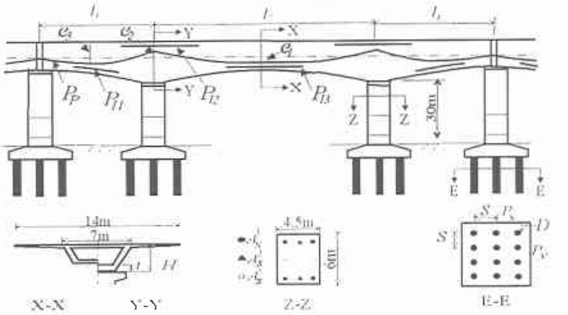

Fig. 1. Design variables of a three-span continuous prestressed concrete bridge system

In the prestressed concrete bridge system shown in Fig. 1, the span ratio Sr $(=l_1/l_2)$ and girder height H affect significantly two objectives of the total construction cost and the aesthetics, therefore, Sr and H are dealt with as the common design variables X_c of the bridge system. However, the parabolic prestressing force P_p, linear partial prestressing forces P_{l1}, P_{l2} and P_{l3}, thickness of the bottom slab of box section t and tendon eccentricities of parabolic prestressing e_1, e_2 and e_3 as shown in Fig. 1 affect only the cost of the superstructure, therefore these design variables are dealt with as the objective oriented design variables X_o. In the pier optimization, only the reinforcement areas $A_{sjk}=[A_{sjk}^1, A_{sjk}^2, A_{sjk}^3]^T$ in each pier segment shown in Fig. 1 are dealt with as the objective oriented design variables. In the optimization problem of rectangular RC pile foundation, number of RC piles P_xxP_y, diameter and spaces of piles, D and S, are dealt with as the objective oriented design variables.

3. Suboptimization of the total construction cost and the aesthetics of the bridge system

As described in the preceding section, we deal with f_s as a design parameter objective and it specifies discrete design conditions. Then the suboptimization problems on the total construction cost f_t and the aesthetics f_a are solved for the combinations of the following discrete values of H, Sr and f_s. H = 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5 (m), Sr = 0.5, 0.61, 0.75, 0.93 and f_s= 1.0, 1.2, 1.4, 1.6, 1.8. In the suboptimization of the superstructure, stress and cracking constraints in serviceability limit state and flexural-strength and ductility constraints in ultimate limit state specified by the ACI code are taken into account. In the suboptimization problem of the kth segment of the RC pier the ultimate limit state constraints g_{kj} under vertical force and bending moments due to horizontal forces caused by the earthquake are considered. In the suboptimization problem of the RC pile foundation, the constraints on bearing or tensile capacities of piles are taken into account as design constraints. For the suboptimization of the aesthetics of the bridge system, preparation of the perspective views of the bridge system for all discrete combinations of common design variables Sr and H are conducted for the relative evaluation of the aesthetics of the bridge system.

4. Relative evaluation of all objective functions f_t, f_a and f_s

In this optimum design problem, three different characteristic objectives f_t, f_a and f_s are considered and relative evaluation of these objectives has some tolerance or fuzziness. Considering these characteristics of design problem the fuzzy decision-making techniques are adopted for the determination of the global optimum solution. At the first step of mutual evaluation of the objectives, we introduce the measure membership functions for all objectives. The measure membership function of the total construction cost β_{tm} is introduced as shown in Fig.2 by inspecting the budget limitation for the total construction cost and the range of variation of the suboptimized minimum total construction costs of the bridge system for all discrete sets of Sr, H and f_s. The measure membership function of the aesthetics objective β_{am} is introduced as shown in Fig.3 by evaluating relatively aesthetics of perspective views of the bridge system for all discrete combinations of Sr and H. The measure membership function of the seismic safety is to be determined by evaluating the total social loss caused by the failure of the bridge system designed with safety parameter f_s In this study, it is assumed that the bridge system designed with f_s=1.0 might cause twice much of social loss compare with that of the bridge system designed with f_s=1.8. Then, the membership value of the bridge system designed with f_s=1.0 is assumed to be 1/2 of that of the bridge system designed with f_s=1.8. The social losses caused by the failures of the bridge systems designed with f_s=1.2, 1.4, 1.6 are assumed to be linearly proportional to f_s. On the basis of this assumption, the measure membership function of seismic safety of this bridge system β_{fm} is introduced as that shown in Fig. 4. From the viewpoint of the minimization of total damages due to an earthquake the measure membership function of the total construction cost of the bridge system $\beta_{tm}(f_t)$ has to be modified with respect to the seismic safety of structural system. In this study, the modified measure membership functions of the total construction cost for discrete $\tilde{f}_s$, $\lambda_{tm}(f_t,\tilde{f}_s)$ is assumed to be obtained by multiplying $\beta_{fm}(\tilde{f}_s)$ to $\beta_{tm}(f_t)$. In these introduction processes of measure membership functions, the designer's preferences, design emphases, client and/or general consent are also to be satisfied.

The membership function of the minimum total construction cost with respect to girder height H for the kth discrete span ratio Sr_k and the jth discrete safety parameter f_{sj}, $\mu_t(H,Sr_k,f_{sj})$, can be introduced using the modified measure membership function of the total construction cost corresponding to the jth discrete safety parameter f_{sj} and suboptimized minimum total construction costs for all discrete combinations of H_i (i=1,..,9), Sr_k and f_{sj}. The membership functions stated above are introduced for every combination of discrete Sr_k and f_{sj} where k=1,..,4 and j=1,..,5.

The membership function of the aesthetics with respect to girder height H for the kth discrete span ratio Sr_k, $\mu_a(H,Sr_k)$, is introduced by evaluating relative aesthetics of perspective views of the bridge system with girder height H_i (i=1,..,9) for Sr_k referring to the measure membership function of the aesthetics β_{am} as datum.

5. Determination of the global fuzzy optimum solution

In the previous sections, we introduced the membership functions of the minimum total construction cost with respect to H for all discrete span ratios Sr and the safety parameter f_s and the aesthetics with respect to H for discrete Sr. Then, using these membership functions, we can determine the fuzzy optimum girder heights H_{opt} for each combination of discrete span rations Sr and discrete safety parameters f_s by the weighted operator method with assumed weight ratio. Fig. 5 shows the determination process of maximum membership value for Sr_2=0.61 and fs_2=1.2. Then we can introduce the relationship between maximum value of membership at the optimum girder height H_{opt} and span ratio for every discrete f_{sj} (j=1,..,5). The optimum span ratios for every discrete f_s can be obtained by searching the maximum values of the relationships. The maximum membership values for every discrete f_{sj} (j=1,..,5) are summarized with respect to the safety parameter f_s, as Fig. 6 and the global optimum safety parameter $f^g_{s\,opt}$ can be obtained as 1.57 by searching maximum membership value in the relationship. The global optimum Sr and H can be determined as Sr^g_{opt} =0.65 and H^g_{opt}=7.28m by backward interpolation process. The final global optimum values of the objective oriented design variables $X^g_{o,opt}$ can be determined by suboptimizing f_o for the set of the global optimum values of $X^g_{c,opt}$ and $f^g_{s,opt}$.

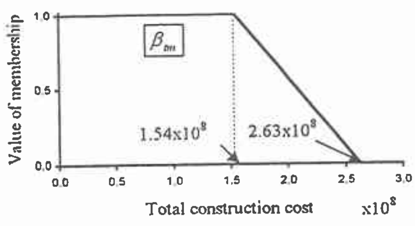

Fig.2 The measure membership function of the total construction cost

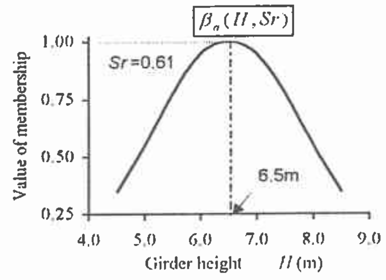

Fig.3 The measure membership function of the aesthetics of the bridge system

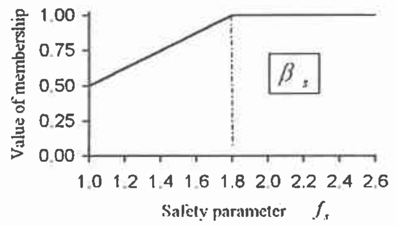

Fig.4 The measure membership function of the seismic safety of the bridge system

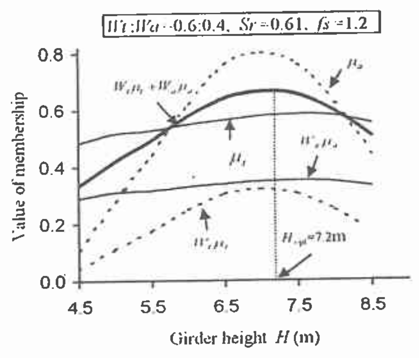

Fig.5 Determination of max. membership value and optimum H by the weighted operator method

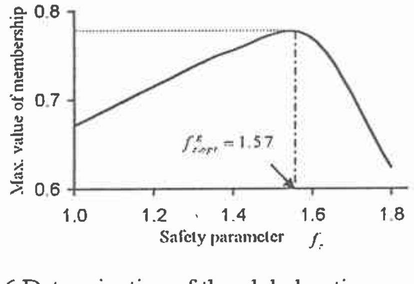

Fig. 6 Determination of the global optimum f^g_s