OPTIMUM SPAN RATIO OF PRESTRESSED CONCRETE BRIDGE CONSIDERING SUPER AND SUBSTRUCTURES

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1. Introduction

In this paper, an optimum design process is studied to find optimum span ratio of 3-span continuous prestressed concrete box girder bridge considering minimum cost of super and substructures. The superstructure is optimized subject to the stress and cracking constraints in serviceability limit state, the flexural-strength design constraints and ductility constraints in ultimate limit state, while the substructures are subjected to ultimate limit state specified in ACI code. A numerical example of 3-span continuous girder bridge, total bridge length is 200m, is illustrated.

2. Optimal design of superstructure[1)]

The superstructure with a parabolic shape girder and box cross section is depicted in Fig.1. In the optimum design of the superstructure, parabolic prestressing force P_p, linear partial prestressing force P_l and tendon eccentricities at the middle of center spans e_1 and interior supports e_2, heights of cross section at the middle support H_1 and rises at both center span H_2 and side span H_3, width of a box girder B are dealt with as the design variables. The cross-sectional area of tendons A_{ps} are determined by P/f_{pe} where f_{pe} is the permissible tensile stress of prestressing tendon. The primary optimal design problem for superstructure with specific span ratio is formulated so as to find the P_p, P_l, $\mathbf{e}=[e_1,e_2]^T$ $H=[H_1,H_2,H_3]^T$ and B which minimize the total cost of superstructure W subject to the stress constraints and cracking constraints in serviceability limit state, the flexural-strength design criterion and sufficient ductility criterion in ultimate limit state.

In the analysis of continuous prestressed concrete box girder bridge, the maximum and minimum bending moments due to live loads are calculated by applying a uniformly distributed live load to each span and summing up all positive or negative bending moment separately. The secondary bending moments due to prestressing forces are calculated by considering the primary prestressing bending moment as the equivalent loads at each element. The sectional properties for the analysis of structure, such as cross-sectional area and moment of inertia, are calculated by taking the mean values of the properties at both-end nodes of each member element.

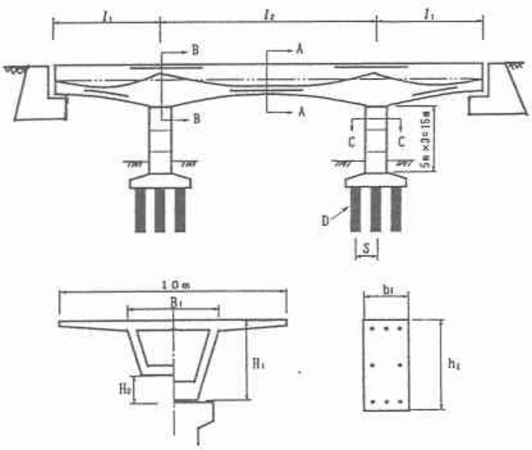

Fig.1 3-span continuous prestressed concrete box girder beam

The above primary optimum design problem of superstructure is solved by utilizing the convex and linear approximation concept and a dual method.

3. Optimal design of substructures[2)]

The intermediate substructure shown in Fig. 2 consists of a rectangular shape RC pier and a RC pile foundation. The RC pier is assumed to be consisted of three segments, and the reinforcement areas A, length h and width b of each segments are dealt with as the design variables. The optimum A, h, b and minimum cost of each pier segment for specific span ratio bridge are determined by the dual algorithm subject to the ultimate limit state constraint for vertical forces and bending moments caused by the optimum superstructure's weight and maximum reactions due to live loads including impact and dead load of pier segments.

In the design problem of rectangular RC pile foundation, numbers of piles in the direction of bridge axis P_x, and perpendicular direction to bridge axis P_y, diameter of pile D and space of piles S are dealt with as the design variables. The optimum P_x, P_y, D, S which satisfy the constraints on bearing or tensile capacities of piles and give the minimum cost for the specified loading condition are determined by applying iterative and comparing process for discrete sets of P_x, P_y, D, S. The vertical and horizontal loads acting to each pile are calculated by the elastic ground reaction method, a kind of displacement method. The optimum design process is quite simple and the optimum set of P_x, P_y, D, S for each span ratio can be determined usually about 2000–3000 analysis iterations and within 1.5 sec. cpu time by DEC 3000/300 computer.

4. Determination of optimum span ratio

Usually the cost of the abutments is not so much affected by the span ratio, therefore we assumed it constant with span ratio in this paper. Then the relative amount of total minimum cost of the whole bridge structure at various ratio can be compared with each other by adding the minimum costs of superstructure, two intermediate piers and their pile foundations obtained by the optimum design processes described in 2 and 3. The optimum span ratio which gives the minimum total cost can be determined by comparing total costs at various span ratios.

5. Numerical design examples and discussions

The above method has been applied to 3–span continuous prestressed concrete bridges with various bridge lengths. In this paper, the numerical results of a three–span continuous prestressed concrete box girder bridge with $l_1+l_2+l_1$ = 200m are illustrated.

In the numerical design example, relative unit costs of prestressing tendon, reinforcement and concrete are assumed, respectively, as 6916800 /m^3, 110000/m^3 and 24000 /m^3. In the analysis problem the superstructure is divided into 36 member elements in order to obtain the accurate result. Fig.2 shows the relation between total cost and span ratio from span ratio 0.33 to 0.93. As clearly seen from this relationship, total cost of the bridge system is affected so much by span ratio. The optimum span ratio for this design example is 0.75 (l_1/l_2). This minimum total cost at optimal span ratio is 35% less than that at the span ratio 0.33. On the optimum web height H_1, higher H_1 are obtained, such as 8.0 m – 7.5 m at the smaller span ratios, however, near the optimum span ratios, optimum H_1, is not so sensitive with span ratio and it is about 7.0 m.

In this paper, relative unit costs of 3 materials are assumed as above mentioned. However the optimum span ratio would be affected by these relative unit costs. Therefore more detailed investigation will be necessary for the determination of optimum span ratio from more wider range factors.

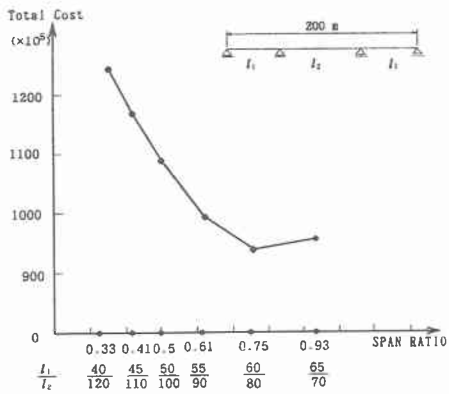

Fig.2 Relation between total cost and span ratio(l_1/l_2)

6. References

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