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SPSA Algorithm based Optimum Design of Longitudinal Section of Bridges

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Abstract

The purpose of this study is to determine the optimum design of arch longitudinal no prismatic single-cell section. The FE model of the Cetina open spandrel arch bridge was constructed using the ANSYS. In this present work the optimum design is carried out by taking total material volume of substructure of bridge as objective function. Substructure includes of column and reinforced concrete arch. Finally, the optimization technique is performed by Simultaneous Perturbation Stochastic Approximation (SPSA) algorithm. It is concluded that SPSA can be effectively used in the shape optimization of the bridges.

Keywords: Long Span, Longitudinal Section Optimization, Open Spandrel Bridge, SPSA Algorithm, Substructure

1. Introduction

Arch bridges have several positive features which make them a very useful design. These features include[1]: Material choice, rather unrestricted, as structure suitable for distinct material; span length can vary up to 500m, theoretically even more. Currently the longest span of an arch bridge is 552m in China; suitable for large relief in surrounding and aesthetically beautiful structures. Features hindering the use of arch bridges are: in cases where long span are required, other type of bridges are economically better options; risk of buckling is higher in arch bridge as in other bridge types and for large spanned arches cost of framework are high. Thus, in this study, longitudinal section optimization of bridge is considered. Most part of reinforced concrete volume is used in bridge substructure. Component of substructure is column and arch with single-cell section. References[2,3] carried out the optimization of the cable stayed bridges for cross sectional area of members. Reference[4] studied the application of genetic algorithms on optimum design of bridge decks. None of the studies above used SPSA.

Case study of this research is Cetina Bridge, which is a long span open reinforced concrete arch bridge spanning Cetina river canyon near the town of Trilj. The arch is of span 140m with a rise of 21.5 m, giving rise-to-span ratio of 1/6.5. Figure 1 shows Arial view of Cetina Bridge. The material consumption for the Cetina river bridge, without abutments and foundations, is shows in Table 1. Total reinforced concrete volume used in superstructure and substructure is 35% and 65% respectively and Total reinforced concrete used in superstructure and substructure is 32% and 68% respectively[5]. Longitudinal layout of Cetina River Bridge is shown in Figure 2. The 10-span continuous bridge superstructure consists of precast prestressed concrete girders, cast-in-site deck plate and cross-girders at supports only. Nine pairs of columns support to deck structure, of which six pairs are connected to the arch (Figure 2). All dimension are in meters. 8.3-m long cap-beam connects the column in transverse direction. Columns are of box cross-section 1.5m x 1.8m with 30 cm thick walls, except the highest columns which are located at the arch springing. Cross sections of particular columns were determined on the basis of stability calculations (Figure 3). The arch is fixed of single-cell cross-section with constant outer dimensions: 5.5m x 8.0m. (Figure 4). The designed concrete class for the arch was C45/55[5].

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Figure 1. Arial view of bridge.

Table 1. Material consumption of Cetina River bridge

Concrete	Class	quantity	consumption
Arch	C45/55	1411 m^3	0.69 m^3/m^2
Columns	C30/37	615 m^3	0.30 m^3/m^2
Prestressed T-girder	C45/55	693 m^3	0.34 m^3/m^2
Deck plate	C45/55	445 m^3	0.22 m^3/m^2
Reinforcement			
Arch		545.2 t	265.4 kg/m^2
Piers	BSt 500 S	196.1 t	96 kg/m^2
Prestressed T-girder		151.8 t	73.9 kg/m^2
Deck plate		193.7 t	94.3 kg/m^2
Tendons			
Prestressed T-girder	St 1570/1770	33.8 t	16.5 kg/m^2

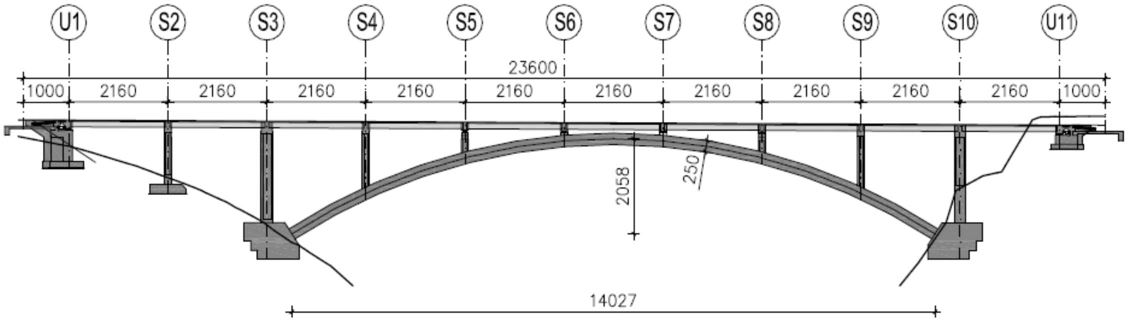

Figure 2. Longitudinal layout of Cetina River Bridge[5].

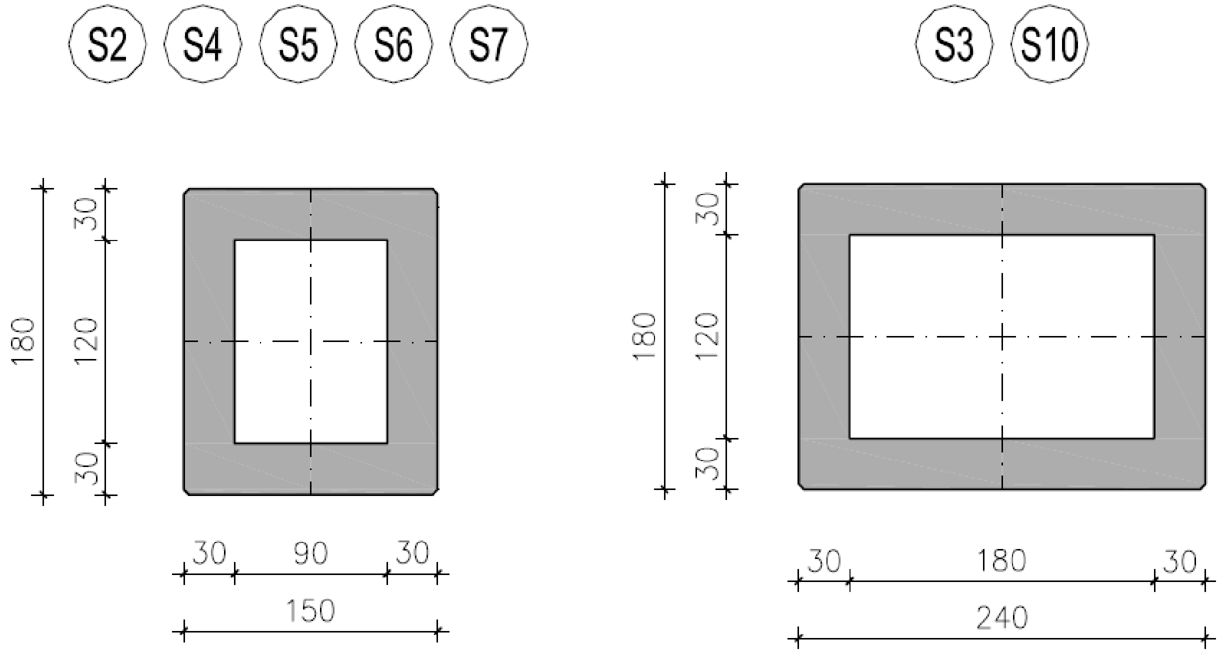

Figure 3. Substructure cross section of bridge columns.

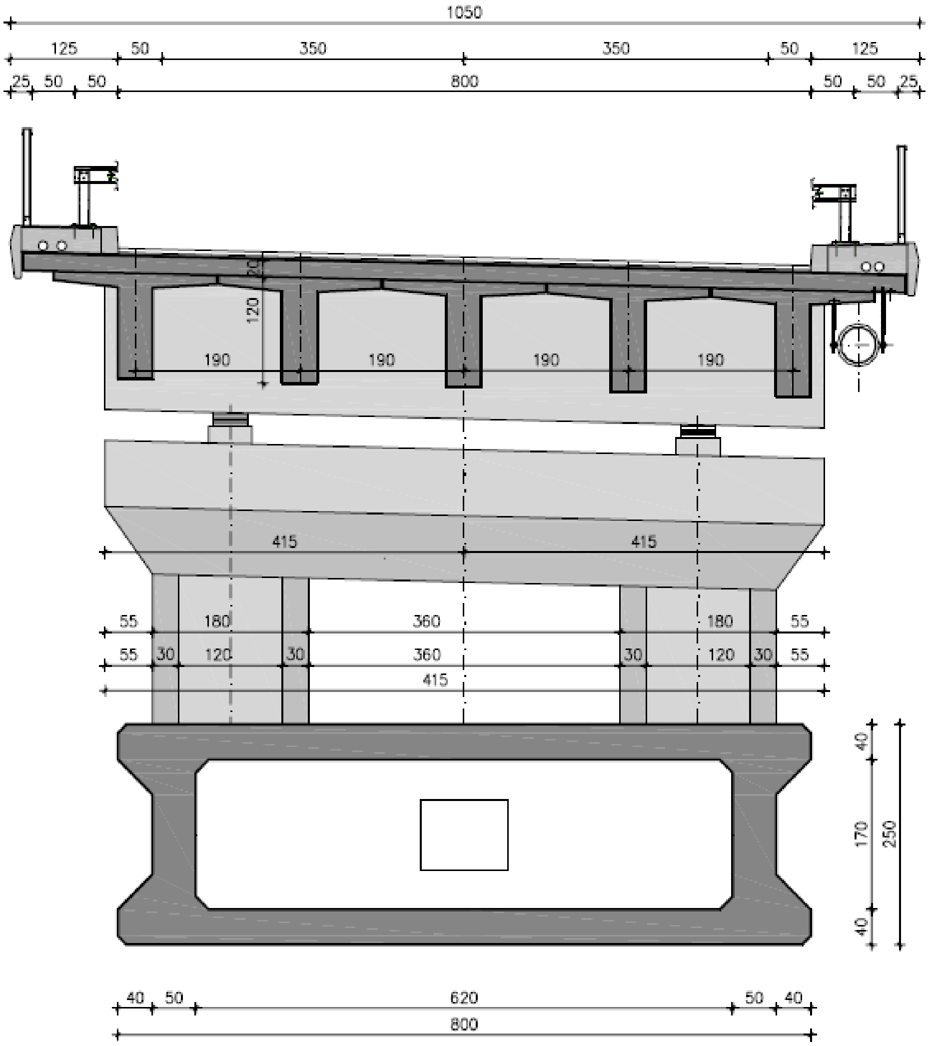

Figure 4. Arch and superstructure cross section of Cetina River Bridge[5].

2. Optimization Algorithm

The SPSA has recently attracted considerable attention in areas such as statistical parameter estimation, feedback control, simulation-based optimization, signal and image processing and experimental design. However, the SPSA has not been tested yet for structural optimization and it is the first study that is employed for this aim. The promising feature of the SPSA optimization algorithm is that requires only two structural analyses in each cycle of optimization process, regardless of the optimization problem dimensions. This attribute can drastically reduce the computational cost of the optimization, particularly in problems with a great number of variables to be optimized. The process of SPSA in arch dam optimization is shown in Figure 5 [6]:

The shape optimization problem is to find the design variables X while minimizing the objective function F(x) under the constraint functions $h_j(X)$ and $g_j(X)$ that can be stated mathematically as:

$$\text{Find } X=[X_1\ X_2 \ldots X_n]^T,\ a_i \le X \le b_i\ (i=1, 2, \ldots, n)$$
$$\text{To minimize } F(x)$$
$$h_j(X) = 0 \qquad (j = 1, 2, \ldots, p)$$
$$g_k(X) = 0 \qquad (k=1, 2, \ldots, m)$$

The subscripts j, k and i denote the number of equality constraints, behavioral constraints and design variables respectively, where, ai and bi are allowable lower and upper limits of the design variables which are introduced to deal with various requirements.

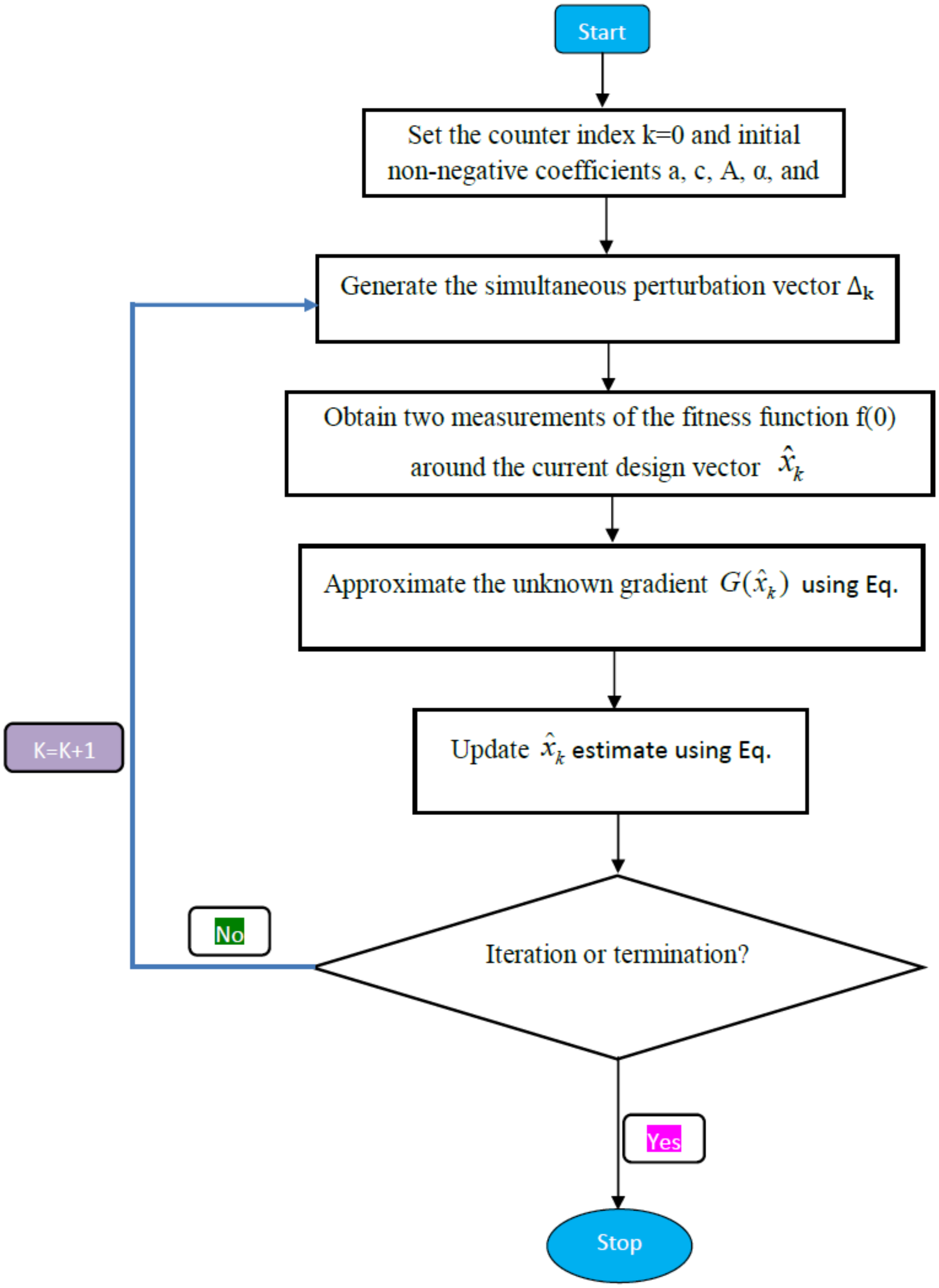

Figure 5. SPSA Flowchart.

3. Finite Element Analysis

A three-dimensional finite element model was developed was carried out in ANSYS. The main span and columns was simulated with elements (Beam4) having three translational degrees of freedom (DOFs) and three rotational DOFs at each node, and element solid45 was used for reinforced concrete non prismatic single cell arch. Hence, the full FE model consisted of 94 beam elements, 286 solid elements and 380 nodes. Figure 6 shows the full 3-D view of the FE model of the arch bridge. For simplification, a total uniform load of 5500 kg/m for live loads considered on the deck according to AASHTO[7,8].

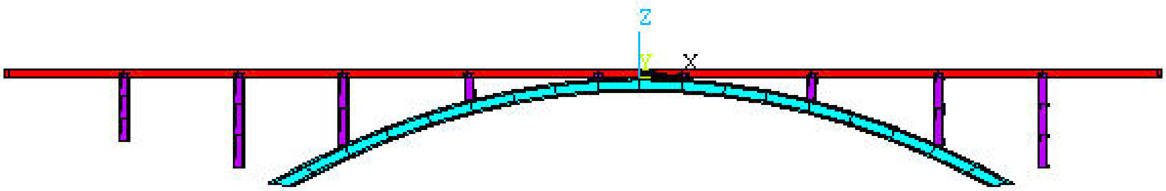

Figure 6. The 3-D FE model of the bridge.

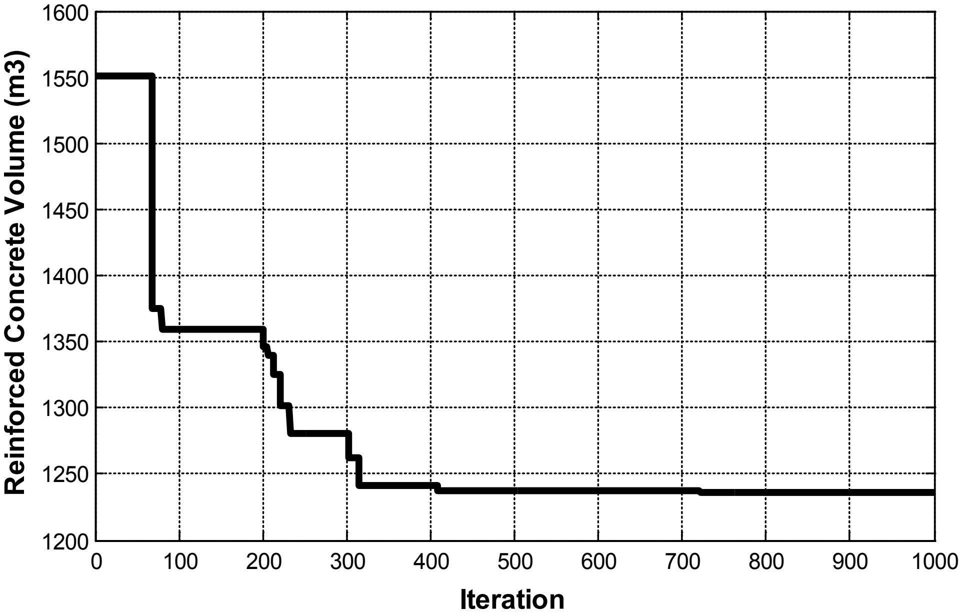

Figure 7. Convergence rate of the dam body volume.

4. Program Description

Initially, a program was developed in MATLAB in order to generate coordinate of nodes and then used finite element software ANSYS for modeling the geometry of an arch dam. Finally, the optimization technique was performed by Simultaneous Perturbation Stochastic Approximation (SPSA) algorithm. Shape optimization for application project of the arch web thickness to be examined. For definition of arch geometry in longitudinal sections, parabolic conic functions are employed.

Height of skewback abutment, Height of crown of arch, back and soffit radii of arch and position of crown respect to global axes are considered as design variables. The distance between the columns is assumed constant and equal to 21.6 m in optimization process. Also the cross sections of column are not taken as design variables. Instead of this, cross section of piers is selected proportionally with these of application project. During problem formulation most of practical design variables and constraints are considered. Three type of design constraints were taken into account: stress constraints of arch, transversal displacement constraints of arch crown and geometric constraint. The appropriate values of the displacement limit are used for each type of bridges. These values are determined based on the recommendation of the Australian Bridge Design Code where the deflection allowance under the service load should not exceed 1/800 of the main span of the bridge[9].

Convergence rate of the objective function in the optimization process is shown in Figure 7. After performing the optimization process, the dam volume has decreased by 18% in comparison with the initial design.

5. Conclusion

The computer code created allows change on the finite element model (geometry, physical properties of material, boundary condition, flange thickness of arch section and longitudinal section of bridge) in a simple way. Beside it permits to include new load combinations within the optimization process. SPSA can be effectively used in the shape optimization of the bridges. The total reinforced concrete volume obtained in this study is 18% less than the application project. Minimum volume of substructure achieved 1219 m^3. This research can be enhanced from many points of view such as: Considering sequence of construction and geometric nonlinearity in structural analysis. Including other structural elements such as the column and Prestressed T-girder as design variables and including optimum number of columns as design variables.

6. Acknowledgement

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