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Parallel Search Engines for Topology Optimization of an Arch Truss using Evolutionary Algorithms

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Abstract
The use of parallel search engines to solve NP-Hard problems is increasingly in use with the computational power becoming more economical. The objective of this paper is to effectively explore and exploit the search domain to identify the optimal point using two search engines in parallel. This paper proves that intensification and diversification can be performed effectively using two search engines in parallel. The use of two search engines in parallel not only greatly reduces the overall computational effort but also identify a better optimal point to minimize the weight of the structure. Aqua search metaheuristic algorithm is used here to perform optimization of arch truss grid structures. A simple ESO approach is used here. An arch truss grid structure numerical is solved and the results are compared with those available in the literature.

Keywords: *Arch Truss, structural optimization, aqua search, parallel search engines, topology*

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INTRODUCTION
Arch trusses are used for truss bridges. In a through type truss bridge the load is carried by the bottom chord members. These bottom chord members are subjected to tensile stresses. The top chord members are subjected to compressive stresses. An arch truss is provided to carry the compressive loads over larger spans. These trusses combine the characteristics of both arches and trusses. The arch truss can be used over longer spans.

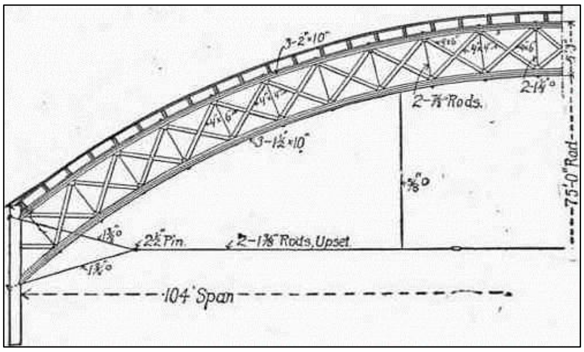

Fig. 1a: *Showing the Arch Truss Grid [1].*

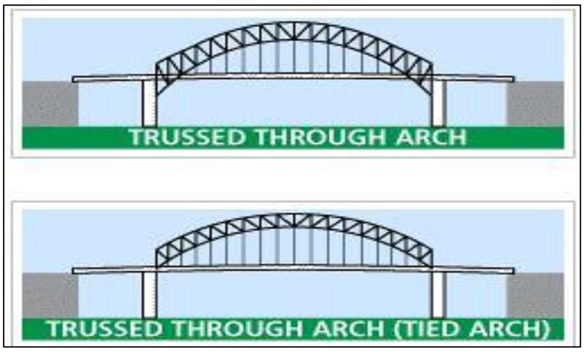

Fig. 1b: *Showing a Trussed through Arch [2].*

Fig. 1c: *Showing an Arch Truss over a Track [3].*

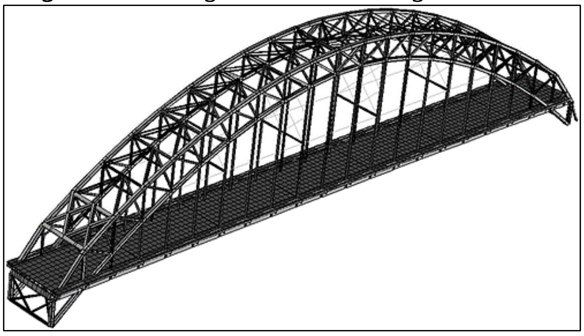

Fig. 1d: *Showing an Arch Truss over a through Type Truss Bridge [4].*

The arch truss members carry only axial forces and can be treated as truss or 1-d bar elements during the analysis. As shown in the Figure 1a-d, a few examples of the arch truss grid.

Objectives

To minimize the weight of an arch truss grid with two search engines in parallel using Aqua Search Algorithm.

Scope of the Study

1. The study is limited to linear static analysis only.
2. The study does not include buckling analysis.

LITERATURE REVIEW

There are a few journal papers optimizing an arch truss grid. An arch truss is used in a through type bridge as discussed above. Ohsaki et al. [5] applied semi-definite programming to optimize the arch truss under multiple eigen value constraints. The eigen frequency is taken as constant at 1000 rad^2/s^2 and the plane arch truss is optimized. Adeli [6] in his paper designed a super high rise multi-storey building on a massively parallel machine using an AI model. Yihua [7] in his doctoral dissertation on high performance parallel eigen value solvers for real symmetric matrices; by using a parallel orthogonal block tridiagonal reduction algorithm to reduce a dense real symmetric matrix to a tridiagonal matrix. Adeli [8] in his paper on neural networks in civil engineering presents a review of the application of neural networks in various disciplines of civil engineering namely water resources engineering, environmental engineering, and highway engineering, and geotechnical engineering.

Parallel Search Engines

The optimization of large structures [9] requires several thousands of members subjected to several constraints usually takes several hundreds of hours to several thousands of hours when a workstation having one processor is used. These long hours can be considerably reduced when a workstation having multi-processors is used. With the increase in the ease of availability of computational power and storage becoming more economical, structures can be further analysed under various conditions with larger number of constraints. Adeli [6] in his paper presents a parallel approach for optimization of structures (Figure 2).

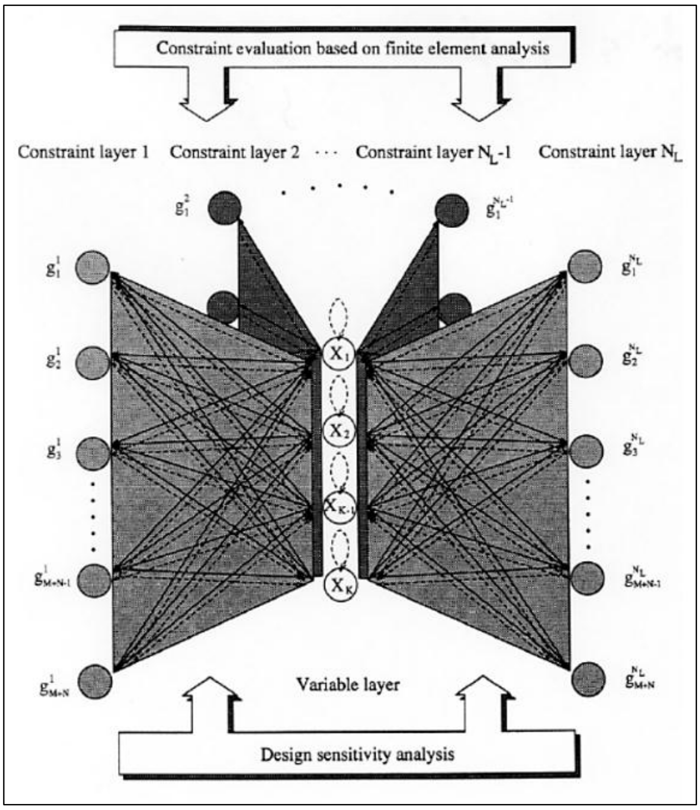

***Fig. 2:** Showing the New Model for Optimization of Structures, Adeli (1999) [6].*

Aqua Search

Aqua Search, a metaheuristic algorithm proposed by the Chandrasekhar [10] is used here to perform topology optimization of continuum structures. This algorithm is based on a group of divers searching in the deep sea. Inside the deep sea, it is completely dark and the diver has to search based on a set of criteria namely the interaction of the diver with the base above using a GPS device, his instinct and visibility as well. Alike other metaheuristic algorithms, this algorithm has quite a few parameters. A group of divers are performing the search operation. The divers can interact with each other using an electronic device and can exchange information between them. The base station above co-ordinates with every one of them and keeps a track of the search operation. Similar to FFA, the cartesian distance can be calculated. The waterbody here is compared to the design domain. Every waterbody is weighted using a factor which will distinguish it from other waterbodies, it accounts for the relative safety, difficulty to search and so on.

Mathematical Formulation

The diver while training should account for the base factor which reflects in factor1.

$$term1 = (1 - factor1) * (1 + RR)^{-t} \quad (1)$$

where, Factor1 is the base factor and will vary from zero to one. A value close to zero is recommended.

RR is the Cartesian distance, calculated in a similar way as in FFA, t is the iteration number.

$$Cartesian\ distance\ RR = \sqrt{\sum_{k=1}^{d}(x_{i,k} - x_{j,k})^2} \quad (2)$$

The diver while performing search operation has to account more for the instructions from the base. The underlying assumption is that the base above is well familiar with the territory. In other words, lower the value more weightage to the base. Normally, this factor will vary in the range of [0 1]. A value close to zero means that there is low safety and domain is difficult to search assuming that the base above will safeguard the best interests of the diver. A value close to one implies that the diver prefers to give less weightage to the base. This factor can also be used to include the experience of the diver as well, in which case the value can be kept high. If the diver goes by his experience and his instinct, then the second criteria which is based on his instinct carries more weightage. A gamma distribution can be used to account for the instinct in the second term. If not, a random distribution can be used instead as well.

$$term2 = factor1 * rand(0,1) \quad (3)$$

where, rand is the random value generated between 0 and 1.

The third criterion is visibility. A human eye can see things clearly at a distance of 25 cm, and anything above and below is usually not clear. To account for this visibility, we can use an F-Distribution. Existing literature in physics can be referred to check the viability of an F-distribution.

$$term3 = Fd(t) * sign \quad (4)$$

where, Fd(t,m,n) is the F-Distribution with ‘t’ the iteration number, degree of freedom in the numerator 'm’ may be taken as 12 and the degree of freedom in the denominator ‘n’ may be taken as 20. Sign is randomly generated, it takes one of the two values either positive unity or negative unity.

The divers are distributed with the domain at several locations. Each diver is identified by the vector x. Each vector defines a new distribution of material, in other words a new design. The elements in the vector denote the relative densities of the Isoparametric elements used. For each diver, the relative densities are different. The total weight of the structure is the objective function which should be minimized. The total weight of the structure is calculated based on the material used. In other words, the volume of each element is multiplied by the relative density of the element to calculate the total volume of the material used. The total volume is then multiplied by the density of the material used to calculate the total weight of the structure.

The objective function, weight of the structure is compared between two divers i and j. The diver j having higher weight will move towards the diver i having the lower weight of the structure. The new position of the diver j is given by,

$$x_j = x_i + (term1 + term2) * (x_j - x_i) + term3 \quad (5)$$

Truss element

Truss elements are one dimensional elements carrying axial force only. The degree of freedom for on-dimensional elements is equal to one at each node as shown in the Figure 3 below.

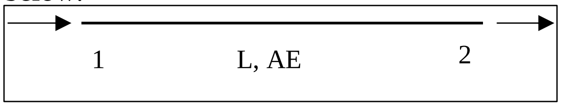

Fig. 3: *One Dimensional Truss Element.*

The stiffness matrix for an element '*e*' is given by [11]

$$k^e = \begin{bmatrix} \frac{AE}{L} & \frac{-AE}{L} \\ \frac{-AE}{L} & \frac{AE}{L} \end{bmatrix} \qquad (6)$$

METHODOLOGY

The arch truss is modelled with the given input parameters namely,

- Material properties such as Young's Modulus of Elasticity.
- Geometry – grid dimensions, the initial cross sectional area at the beginning of the optimization process.
- Kinematic Boundary conditions such as support conditions.
- Natural Boundary conditions such as applied external loads.

Aqua Search metaheuristic algorithm [12] is used to re-assign the relative densities of each element in each iteration. A simple ESO approach is adopted here. The relative density of each element is calculated as the ratio of the stress carried by each element at the centroid to the maximum stress in the entire structure. In case of one dimensional elements the axial stress is equal to the principal stress. The elements carrying the relative density below a minimum value of 1e-3 are excluded in the subsequent iteration. A sample program in C++ is used to perform the entire optimization process. The analysis has been performed on an Intel i7-6700 processor, 4 core, 4GB RAM.

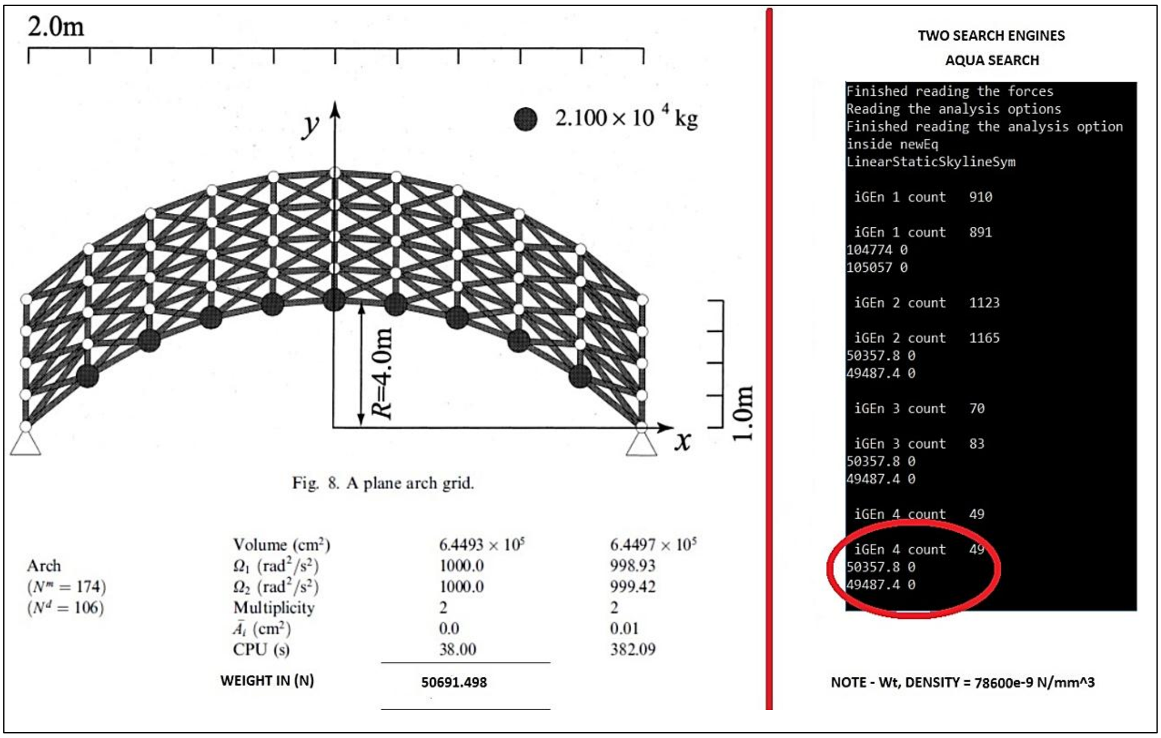

Fig. 4: *Showing the Arch Grid Truss and the Minimum Weight using Aqua Search Algorithm.*

Table 1: *Showing the Results of Truss Topology Optimization using Aqua Search Algorithm.*

	Minimise Weight Using Aqua Search Algorithm proposed by Chandrasekhar, 2016 [10]	**Minimise Volume using Frequencies (Ohsaki, 1998) [5]**
Minimum Weight (N)	49487.438 (Using Two Engines)	$6.4493 \times 10^8 * 78600 \times 10^{-9} = 50691.498$
Number of FE Computations	4429	

Note – For the sake of simplicity the following relation is used. Take 1Kg = 10 N

ANALYSIS

Numerical Problem 1: Consider the plane arch truss as shown in the Figure 4. The numbers of nodes are 55 and the numbers of elements are 174. The structure carries non-structural masses at nodes on the lower arch except the end support nodes. The magnitude of each load is 2.1 x 10^4 Kg each acting in the vertically downward direction. For the sake of ease and simplicity, take 1 Kg = 10 N. The distance between two end supports is 20 m and the central rise of lower arc is 4 m. The length of each vertical member is 1 m. The modulus of elasticity is taken as 2e5 MPa.

The Weight Density is taken as 7860 kg/m^3. The initial area of each member is taken as 5000 mm^2. The optimization is performed using Aqua Search algorithm (AS) proposed by Chandrasekhar [10]. The total number of finite element computations is 4429. The final weight at convergence is 49487.4 kg which is lower than the final weight obtained by Ohsak [5] is 50691.49 kg by using frequencies. The final weight is obtained by multiplying the final volume with the weight density of the material as shown in the Table 1.

CONCLUSIONS

Arch truss grid structures are used in through type truss bridges. Arch trusses have the characteristics of both an arch spanning over long distances and a truss carrying only axial forces. These arch trusses can withstand large value of forces than a linear truss bridge. The objective of this paper is to use effectively the computational resources by using two search engines in parallel to identify the optimal weight of the structure. A simple ESO approach is used here. The newer value relative density is calculated as the ratio of the stress carried by the member to the maximum stress carried by the entire structure.

Aqua search, a meta-heuristic algorithm is used to calculate the newer value of relative density for each element. The analysis has been performed on an Intel i7-6700 processor with 4GB RAM and it took 4429 iterations to arrive at a minimum weight of 49487.438 N which is lower than the existing minimum value of 50691.498 N.

Future Study

Three dimensional arch truss structures can be analysed which may require higher computational effort. The study can also include buckling analysis as well.

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