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TRUSS DESIGN OPTIMIZATION USING FUZZY GEOMETRIC PROGRAMMING IN PARAMETRIC FORM

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Abstract: The main goal of the structural optimization is to minimize the weight of structures while satisfying all design requirements imposed by design codes. A truss design model in fuzzy environment has been developed. The present paper proposes a fuzzy geometric programming approach in parametric form .We have considered a single objective structural optimization problem with weight as an objective function. The structural related load and other parameters are taken as fuzzy in nature. This structural model is formulated as a fuzzy geometric programming problem in parametric form. Fuzzy geometric programming in parametric approach is used to solve this single objective structural optimization model. Numerical example is given to illustrate the model through this approximation method. This approach provides an alternative solution technique to this problem. This method is more reliable and acceptable.

Keywords: fuzzy set,fuzzy geometric programming technique in parametric form, structural weight optimization, sensitivity analysis.

2000 AMS Subject Classification: 90C70, 03E72, 90C31, 74P05.

1. Introduction

The structural optimization is an important research topic in structural engineering and civil engineering. Traditionally, the design of a certain structure has depended on the experience of an engineer. But engineer's main objective is to reduce complex real-world systems into precise mathematical model on the basis some related data. In real life, the data cannot be

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recorded or collected precisely due to human errors or some unexpected situations. So one may consider ambiguous situations like vague parameters, non-exact objective and constraint functions in the problem and it may be classified as non-stochastic imprecise model. In the earlier stage of structural design the decision is usually made on precise data but in real life problem, available data is incomplete and imprecise in nature. Here fuzzy set theory may provide a method to described or formulate this imprecise model. In 1965, Professor Zadeh founded the basis of new dimension of mathematics which is now known as fuzzy set theory [23]. It opposes the crisp set, but adapts the idea of fuzzy boundaries to science. This theory has been used to represent uncertain or noisy information in mathematical form. Later on Bellman and Zadeh [2] used the fuzzy set theory to the decision making problem. In the real-world structural engineering design problems, the input and parameters are often fuzzy. In practical, the problem of structure may be formed as a typical non-linear programming problem with non-linear weight function in fuzzy environment .Some researchers applied the fuzzy set theory to structural analysis [8, 13, and 15]. Structural optimization with fuzzy parameters was developed by Yeh et.al [22]. In 1989, Xu [21] used two-phase method for fuzzy optimization of structures. In 2004, Shih et.al [16] used level-cut approach of the first and second kind for structural design optimization problems with fuzzy resources .Shih et.al [17] used an alternative α -level-cuts methods for optimum structural design with fuzzy resources in 2003.

Many researchers have presented different situations and solutions techniques on structural optimization model [7, 9-11] in different environments. The non-linear optimization problems have been solved by various non-linear optimization techniques. Geometric Programming (GP) [6, 14] is an effective method among those to solve a particular type of non-linear programming problem. Duffin, Peterson and Zener [14] laid the foundation stone to solve wide range of engineering problems by developing basic theories of geometric programming and its application in their text book. Chiang [12] used geometric programming in Communication Systems. One of the remarkable properties of Geometric programming is that a problem with highly nonlinear constraints can be stated equivalently with a dual program. If a primal problem is in posynomial form then a global minimizing solution of the problem can be obtained by solving its corresponding dual maximization problem because the dual constraints are linear, and linearly constrained programs are generally easier to solve than ones with nonlinear constraints. Cao [5] discussed fuzzy geometric programming (FGP) with zero degree of difficult. In 1987, Cao [4] first introduced FGP. There is a good book dealing with FGP by Cao [3]. Islam and Roy [18] used FGP to solve a fuzzy EOQ model with flexibility and reliability consideration and demand dependent unit production cost a space constraint. FGP method is rarely used to solve the structural optimization problem. But still there are enormous scopes to develop a fuzzy structural optimization model through fuzzy geometric programming (FGP). The parameter used in the GP problem may not be fixed. It is more fruitful to use fuzzy parameter instead of crisp parameter. In that case we introduced the concept of fuzzy GP technique in parametric form.

The present paper proposes the concept of fuzzy geometric programming technique in parametric form. Here we have considered the coefficients of the problem are fuzzy and taken these in parametric form and solve it by fuzzy geometric programming technique in parametric form.

The rest of this paper is organized in the following way. In section 2, we discuss about structural optimization model of a two-bar truss in crisp form as well as fuzzy form. In section 3, we discuss about mathematics Prerequisites. In section 4, we discuss about formation of fuzzy geometric programming problem in parametric form and solution technique of fuzzy geometric programming in parametric form. In section 5, we discuss about parametric geometric programming technique on two bar truss structural model. In section 6, we discuss about an illustrative example and in section 7, we discuss about sensitivity analysis. Finally we draw conclusions from the results in section 8.

2. Structural Model

Two bar truss model is developed and work out under the following notations.

2.1. Notation

We define the following variables and parameters;

2P = applied load;

t = thickness of the bar;

d = mean diameter of the bar (decision variable);

2b= the distance between base point.

WT= weight of the structure;

h = the perpendicular distance from loaded joint to the base line (decision variable);

y = depends on b and h (decision variable);

2.2. Crisp Model

The symmetric two-bar truss shown in Figure 1 has been studied by several researchers in optimization [19, 20] and approximation modeling [1]. Here we consider same model. The objective is to minimize the weight of truss system subject to the maximum permissible stress in each member is σ_0. There are two design variables- mean tube diameter (d) and height (h) of the truss.

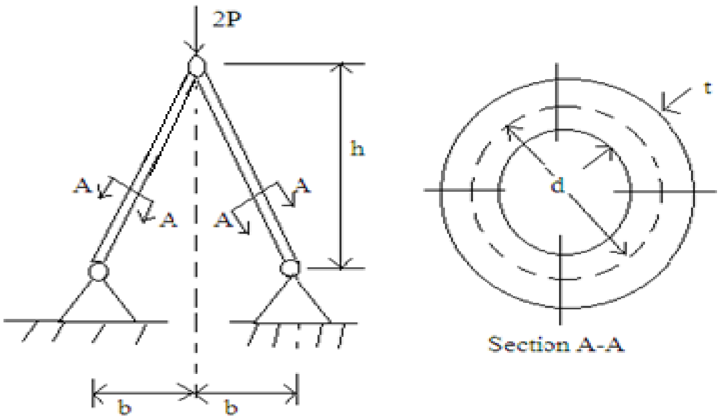

Figure 1: Two bar truss under load

The weight of the structure is $\rho\left(2d\pi t\sqrt{b^2+h^2}\right)$ and stress is $\left(P\sqrt{b^2+h^2}\right)/(d\pi th)\le\sigma_0$.

The structural model can be written as

$$\begin{aligned}
&Minimize\ WT(d,h)=\rho\left(2d\pi t\sqrt{b^2+h^2}\right)\\
&Subject\ to\ \sigma(d,h)\equiv\frac{P\sqrt{b^2+h^2}}{d\pi th}\le\sigma_0;\\
&\qquad d,h>0;
\end{aligned}\tag{2.2.1}$$

Let $\sqrt{b^2+h^2}=y\Rightarrow b^2+h^2=y^2$. Hence the new constraint is

$b^2+h^2\le y^2\Rightarrow b^2y^{-2}+h^2y^{-2}\le 1.$

Hence the structural model is

$$\begin{aligned}
&Minimize\ \ WT(d,h,y)=2\rho td\pi y\\
&Subject\ \ to\ \sigma(d,h,y)\equiv\frac{Pyh^{-1}}{d\pi t}\le\sigma_0;\\
&\qquad b^2y^{-2}+h^2y^{-2}\le 1;\\
&\qquad d,h,y>0;
\end{aligned}\tag{2.2.2}$$

The above problem (2.2.2) can be treated as a Posynomial Geometric Programming problem with zero Degree of Difficulty.

2.3. Fuzzy Model

The objective as well as constraint goal can involve many uncertain factors in a structural optimization problem. Therefore the structural optimization model can be represented in fuzzy environment to make the model more flexible and adoptable to the human decision process. If the coefficient of objective function and constraint goal of (2.2.2) are fuzzy [23] in nature .Then the crisp model (2.2.2) is transformed into fuzzy model as follows

$$\begin{aligned} &Minimize\ \ WT\left(d,h,y\right)=2\rho\tilde{t}\ d\ \pi y \\ &Subject\ \ to\ \ \frac{\tilde{P}\ y\ h^{-1}}{d\ \pi\ \tilde{t}} \le \tilde{\sigma}_0; \\ &\qquad b^2y^{-2}+h^2y^{-2}\le 1; \\ &\qquad d,h,y>0; \end{aligned} \tag{2.3.1}$$

where $\tilde{P}, \tilde{t}$ and $\tilde{\sigma}_0$ are fuzzy in nature.

3. Mathematics Prerequisites

Fuzzy set theory was introduced by Professor Zadeh [20] as a new way of representing impreciseness or vagueness.

Definition 3.1. Fuzzy Set: a fuzzy set $\tilde{A}$ in a universe of discourse X is defined as the set of ordered pair

$$\tilde{A}=\left\{\left(x,\mu_{\tilde{A}}(x)/x\in X\right)\right\}$$

Where $\mu_{\tilde{A}}:X\rightarrow[0,1]$ is a mapping called the membership function of the fuzzy set $\tilde{A}$ and $\mu_{\tilde{A}}$ is called the membership value or degree of membership of $x\in X$ in the fuzzy set $\tilde{A}$.

Definition 3.2 Normal Fuzzy Set: A fuzzy set $\tilde{A}$ of the universe of discourse X is called a normal fuzzy set implying that there exists at least one $x\in X$ such that $\mu_{\tilde{A}}(x)=1$.Otherwise the fuzzy set is subnormal.

Definition 3.3. α **-Level Set or** α **-cut of a Fuzzy Set:** The α -level set (or interval of confidence at level α or α -cut) of the fuzzy set $\tilde{A}$ of X is a crisp set A_α that contains all the elements of X that have membership values in $\tilde{A}$ greater than or equal to α i.e.

$$\tilde{A} = \left\{ x, \mu_{\tilde{A}}(x) \geq \alpha, x \in X, \alpha \in [0,1] \right\}$$

Definition 3.4. Triangular Fuzzy Number (TFN): A triangular fuzzy number $\tilde{A} = (a,b,c)$ is a fuzzy set of real line R whose membership function is of the form

$$\mu_{\tilde{A}}(A) = \begin{cases} \dfrac{x-a}{b-a} & for\ a \leq x \leq b \\ \dfrac{c-x}{c-b} & for\ b \leq x \leq c \\ 0 & for\ otherwise \end{cases} \tag{3.4.1}$$

Where a and c denote the lower and upper limits of support of a fuzzy $\tilde{A}$ respectively.

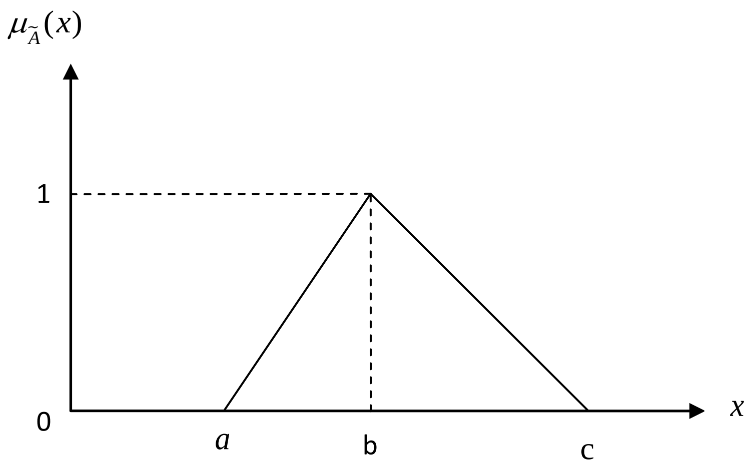

Figure 2 Triangular fuzzy number

4. Mathematical Analysis

4.1. Fuzzy geometric programming problem in parametric

Consider a geometric programming problem

$$Minimize\ \psi_0(s) = \sum_{k=1}^{T_0} c_{ok} \prod_{j=1}^{m} s_j^{a_{okj}}$$

$$subject\ to\ \ \psi_i(s) \equiv \sum_{k=1}^{T_i} c_{ik} \prod_{j=1}^{m} s_j^{a_{ikj}} \le 1; \quad i = 1, 2, 3, ..., n \tag{4.1.1}$$

$$x_j > 0,\ \ j = 1, 2, ..., m$$

where c_{ik}, a_{ikj} are real numbers.

Here we are considering the problem of fuzzy objective and constraint with fuzzy coefficients, therefore the problem (4.1.1) transforms into a fuzzy geometric programming as follows

$$Mini\widetilde{m}ize\ \psi_0(s) = \sum_{k=1}^{T_0} c_{ok} \prod_{j=1}^{m} s_j^{a_{okj}}$$

$$subject\ to\ \ \psi_i(s) \equiv \sum_{k=1}^{T_i} c_{ik} \prod_{j=1}^{m} s_j^{a_{ikj}} \tilde{\le} 1; \quad i = 1, 2, 3, ..., n \tag{4.1.2}$$

$$x_j > 0,\ j = 1, 2, ...m$$

where coefficients c_{ik} are fuzzy numbers.

Here we consider coefficient $\tilde{c}_{ik}$ as a triangular fuzzy number i.e. $\tilde{c}_{ik} = \left(c_{1ik}, c_{2ik}, c_{3ik}\right)$ with membership function as follows

$$\mu_{\tilde{c}_{ik}}(x) = \begin{cases} \dfrac{x - c_{1ik}}{c_{2ik} - c_{1ik}} & for\ c_{1ik} \le x \le c_{2ik} \\ 1 & for\ x = c_{2ik} \\ \dfrac{c_{3ik} - x}{c_{3ik} - c_{2ik}} & for\ c_{2ik} \le x \le c_{3ik} \\ 0 & otherwise \end{cases} \tag{4.1.3}$$

Here α -cut of $\tilde{c}_{ik}$ is given by

$$c_{ik}(\alpha) = \left[c_{ikl}(\alpha), c_{ikr}(\alpha)\right] = \left[c_{1ik} + \alpha\left(c_{2ik} - c_{1ik}\right), c_{3ik} - \alpha\left(c_{3ik} - c_{2ik}\right)\right], 0 \le i \le n, 1 \le k \le T_i.$$

If the coefficients are taken as triangular fuzzy number then the fuzzy geometric programming problem (4.1.2) can be written in the form

$$\widetilde{Minimize}\ \psi_0(s) = \sum_{k=1}^{T_0} \tilde{c}_{ok} \prod_{j=1}^{m} s_j^{a_{okj}}$$

$$subject\,to\ \ \psi_i(s) \equiv \sum_{k=1}^{T_i} \tilde{c}_{ik} \prod_{j=1}^{m} s_j^{a_{ikj}} \le 1; \quad i = 1, 2, 3, ..., n \tag{4.1.4}$$

$$x_j > 0,\ j = 1, 2, ...m$$

Using α -cut of the fuzzy numbers coefficients, the above problem is reduces to

$$Minimize\ \psi_0(s) = \sum_{k=1}^{T_0} \left[c_{0kl}(\alpha), c_{0kr}(\alpha)\right] \prod_{j=1}^{m} s_j^{a_{okj}}$$

$$subject\,to\ \ \psi_i(s) \equiv \sum_{k=1}^{T_i} \left[c_{ikl}(\alpha), c_{ikr}(\alpha)\right] \prod_{j=1}^{m} s_j^{a_{ikj}} \le 1; \quad i = 1, 2, 3, ..., n \tag{4.1.5}$$

$$x_j > 0,\ j = 1, 2, ...m$$

Which is equivalent to

$$Minimize\ \psi_0(s) = \sum_{k=1}^{T_0} c_{0kl}(\alpha) \prod_{j=1}^{m} s_j^{a_{okj}} \tag{4.1.6}$$

$$subject\,to\ \ \psi_i(s) \equiv \sum_{k=1}^{T_i} c_{ikl}(\alpha) \prod_{j=1}^{m} s_j^{a_{ikj}} \le 1; \quad i = 1, 2, 3, ..., n$$

$$x_j > 0,\ j = 1, 2, ...m$$

This is known as fuzzy geometric programming problem in parametric form.

4.2. Solution of fuzzy geometric programming in parametric form

Now we discuss the solution procedure to solve the problem (4.1.6) by using fuzzy parametric geometric programming technique. Here problem (4.1.6) is a constrained posynomial geometric programming problem with degree of difficulty = T-(m+1), where $T = T_0 + T_1 + ... + T_p$ be the total number of terms in the primal problem and m is the number of variables.

The dual problem of the primal problem (4.1.6) can be written as

$$Maximize\ \ g(w) = \prod_{r=0}^{p} \prod_{k=1}^{T_r} \left(\frac{c_{rkl}}{w_{rk}}\right)^{w_{rk}} \left(\sum_{s=1+T_{r-1}}^{T_r} w_{rs}\right)^{w_{rs}} \tag{4.1.7}$$

$$\textit{subject to } \sum_{k=1}^{T_0} w_{0k} = 1 \qquad \text{(Normality condition)}$$

$$\sum_{r=0}^{p}\sum_{k=1}^{T_r} a_{rkj} w_{rk} = 0,\ j = 1,2,..,m \qquad \text{(Orthogonality conditions)}$$

$$w_{rk} > 0,\ r = 0,1,2,...p;\ k = 1,2,...T_r \qquad \text{(Positivity conditions)}$$

Case 1: For $T \geq m+1$, a solution exists for the dual variables w_{rk} .

Case 2: For $T < m+1$, no solution exists for the dual variables w_{rk} .

The solution of the geometric programming problem is obtained by solving the system of linear equations of dual problem (4.1.7). Once optimal dual variable w^* is known, the corresponding values of the primal variable s is found from the following relations:

$$c_{ikl}(\alpha)\prod_{j=1}^{m} s_j^{a_{ikj}} = w_i^* g^*\left(w^*\right) \qquad i = 0,1,2,...,T_0 \tag{4.1.8}$$

Taking logarithms on both side of (4.1.8), then above simultaneous equations are transformed as

$$\sum_{j=1}^{m} a_{ikj}\left(\log s_j\right) = \log\left(\frac{w_i^* g^*(w^*)}{c_{ikl}(\alpha)}\right)\ i = 0,1,2,...,T_0 \tag{4.1.9}$$

It is a system of linear equations in $\log s_j$ for $j = 1,2,....,n$ .For different value of $\alpha \in [0,1]$, equation (4.1.9) will provide different solution set of dual variable w_i^* .Using dual- primal variable relation ,we will obtained different set of solution of primal variable s_j^* . Now decision maker take best from these solutions sets.

5. Parametric Geometric Programming Technique on Two bar Truss Structural Model

According to section 4, the fuzzy two bar truss structural model (2.3.1) reduces to a fuzzy parametric programming by replacing $\tilde{t} = t_0 + (1-\alpha)t_1$, $\tilde{P} = P_0 + (1-\alpha)P_1$ and $\tilde{\sigma} = \sigma_0 + (1-\alpha)\sigma_1$ where $\alpha \in [0,1]$

The model (2.3.1) takes the reduces form as follows

$$\begin{aligned}
&\textit{Minimize } WT(d,h,y) = 2\rho d\pi y(t_0+(1-\alpha)t_1)\\
&\textit{Subject to } \frac{(P_0+(1-\alpha)P_1)yh^{-1}}{d\pi(t_0+(1-\alpha)t_1)(\sigma_0+(1-\alpha)\sigma_1)} \le 1;\\
&\qquad b^2y^{-2}+h^2y^{-2}\le 1;\\
&\qquad d,h,y>0;
\end{aligned} \tag{5.1.1}$$

Applying Geometric Programming Technique, the dual programming of the problem (5.1.1) is

$$\begin{aligned}
\max g(w) = &\left(2\pi\rho(t_0+(1-\alpha)t_1\right)^{w_{01}}\left(\frac{(P_0+(1-\alpha)P_1)}{\pi(t_0+(1-\alpha)t_1)(\sigma_0+(1-\alpha)\sigma_1)}\right)^{w_{11}}\left(\frac{b^2}{w_{21}}\right)^{w_{21}}\\
&\times\left(\frac{1}{w_{22}}\right)^{w_{22}}\left(w_{21}+w_{22}\right)^{(w_{21}+w_{22})}
\end{aligned} \tag{5.1.2}$$

subject to $w_{01}=1$ (Normality condition)

For primal variable y: $1.w_{01}+w_{11}+(-2).w_{21}+(-2).w_{22}=0$ (orthogonal condition)

For primal variable h: $0.w_{01}+(-1).w_{11}+0.w_{21}+2.w_{22}=0$ (orthogonal condition)

For primal variable d: $1.w_{01}+(-1).w_{11}+0.w_{21}+0.w_{22}=0$ (orthogonal condition)

$w_{01},w_{11},w_{21},w_{22}>0$

This is a system of four linear equation with four unknowns. Solving we get the optimal values as follows

$w^*_{01}=1, w^*_{11}=1, w^*_{21}=0.5$ *and* $w^*_{22}=0.5$

From primal dual relation we get

$$2\rho d\pi y(t_0+(1-\alpha)t_1)=w_{01}g^*(w)$$

$$\frac{(P_0+(1-\alpha)P_1)}{\pi(t_0+(1-\alpha)t_1)(\sigma_0+(1-\alpha)\sigma_1)}yd^{-1}h^{-1}=\frac{w_{11}}{w_{11}}$$

$$b^2y^{-2}=\frac{w_{21}}{w_{21}+w_{22}} \text{ and } h^2y^{-2}=\frac{w_{22}}{w_{21}+w_{22}}$$

The optimal solution of the model (5.1.1) through parametric approach is given by

$$g^*(w)=\left(2\pi\rho(t_0+(1-\alpha)t_1\right)^{w_{01}}\left(\frac{(P_0+(1-\alpha)P_1)}{\pi(t_0+(1-\alpha)t_1)(\sigma_0+(1-\alpha)\sigma_1)}\right)^{w_{11}}\left(\frac{b^2}{w_{21}}\right)^{w_{21}}\left(\frac{1}{w_{22}}\right)^{w_{22}}$$
$$\times\left(w_{21}+w_{22}\right)^{(w_{21}+w_{22})}$$

$$y^*=\sqrt{\frac{b^2(w_{21}+w_{22})}{w_{21}}}\quad,\quad h^*=\sqrt{\frac{b^2w_{22}}{w_{21}}}$$

$$d^*=\frac{(P_0+(1-\alpha)P_1)}{\pi(t_0+(1-\alpha)t_1)(\sigma_0+(1-\alpha)\sigma_1)}\times\sqrt{\frac{b^2(w_{21}+w_{22})}{w_{21}}}\times\sqrt{\frac{b^2w_{22}}{w_{21}}}$$

Note that the optimal solution of GP technique in parametric approach is depends on α .

6. An illustrative example

The input data for the structural optimization problem (2.2.2) is given as follows: single load 2P=66,000 lbs. The two bars are identical, having a cross section with wall thickness t= 0.1 in. The distance between the supports is 2b= 60 in. The material properties are: density $\rho=0.3\,\text{lbs}/\text{in}^3$ and permissible stress $\sigma_0=60,000\,\text{psi}$ .Now determine the mean diameter d and height h of the said two bar truss model.

Formulation of the said model is presented as follows

$$\begin{aligned}&\textit{Minimize}\;\; WT\left(d,h,y\right)=0.188yd\\&\textit{Subject to}\;\; 1.75\,yd^{-1}h^{-1}\le 1;\\&\qquad 900y^{-2}+h^2y^{-2}\le 1;\\&\qquad d,h,y>0;\end{aligned}\tag{6.1.1}$$

This is a Posynomial Geometric Programming Problem with degree of difficulty (DD) $=4-(3+1)=0$.

Applying Geometric Programming Technique, the dual programming of the problem (6.1.1).is

$$\max g(w)=\left(0.188\right)^{w_{01}}\left(1.75\right)^{w_{11}}\left(\frac{900}{w_{21}}\right)^{w_{21}}\left(\frac{1}{w_{22}}\right)^{w_{22}}\left(w_{21}+w_{22}\right)^{(w_{21}+w_{22})}$$

subject to $w_{01} = 1$ (Normality condition)

For primal variable y : $1.w_{01} + w_{11} + (-2).w_{21} + (-2).w_{22} = 0$ (orthogonal condition)

For primal variable h : $0.w_{01} + (-1).w_{11} + 0.w_{21} + 2.w_{22} = 0$ (orthogonal condition)

For primal variable d : $1.w_{01} + (-1).w_{11} + 0.w_{21} + 0.w_{22} = 0$ (orthogonal condition)

$w_{01}, w_{11}, w_{21}, w_{22} > 0$

This is a system of four linear equation with four unknowns. Solving we get the optimal values as follows

$w_{01}^* = 1, w_{11}^* = 1, w_{21}^* = 0.5 \; and \; w_{22}^* = 0.5$

From primal dual relation we get

$$0.188yd = w_{01} g^*(w) \;, 1.75yd^{-1}h^{-1} = \frac{w_{11}}{w_{11}}, 900y^{-2} = \frac{w_{21}}{w_{21} + w_{22}} \text{ and } h^2 y^{-2} = \frac{w_{22}}{w_{21} + w_{22}}$$

Solving this we get the optimum solution of the problem (6.1.1) by Geometric Programming (GP) Technique is presented in Table 1

Table 1 Optimal solution of Two Bar Truss Structural Model (6.1.1)

Method	Weight WT^*(lbs)	Diameter d^*(in)	Height h^*(in)	y^*(in)
GP	19.74	2.474874	30	42.426402
NLP	19.74	2.474874	30	42.42641
Schmit [19]	19.8	2.47	30	--------

When the input data is taken as triangular fuzzy number i.e.

$\tilde{P} = 3\tilde{3}000 = 30000 + (1-\alpha) \times 3000$

$\tilde{t} = 0\tilde{.}1 = 0.07 + (1-\alpha) \times 0.03$, and $\tilde{\sigma} = 6\tilde{0}000 = 57000 + (1-\alpha) \times 3000$ where $\alpha \in [0,1]$

The optimal solution of the fuzzy model by fuzzy parametric geometric programming is presented in table 2.

Table 2 Optimal solution of Two Bar Truss Structural Model (6.1.1)

α	Weight WT^*(lbs)	Diameter d^*(in)	Height h^*(in)	y^*(in)
0.1	19.71859	2.540926	30	42.42641
0.2	19.63636	2.611085	30	42.42641
0.3	19.55330	2.685756	30	42.42641
0.4	1946939	2.765397	30	42.42641
0.5	19.38462	2.850533	30	42.42641
0.6	19.29897	2.941766	30	42.42641
0.7	19.21244	3.039787	30	42.42641
0.8	19.125	3.145399	30	42.42641
0.9	19.03665	3.259534	30	42.42641
1	18.94737	3.383286	30	42.42641

7. Sensitivity analysis

The change of optimal solutions of the problem for fuzzy model with small change of tolerance of constraint goal when α change, is given in Table 3.

Table 3 shows that as stress σ_0 changes increasingly the total weight of the given problem slightly increase, which is expected. It is also noted that the mean diameter of the bar is increasing with increasing tolerance of constraint goal stress. So it is clear from the sensitivity analysis that the mean diameter of the rod is increasing as well as total weight of truss is also increasing on account of stress σ_0 changes increasingly.

Table 3 Change of value of objective function and decision variable for change of α

α	Tolerance of σ_0	Weight WT^*(lbs)	Diameter d^*(in)
0.1	0.25	19.86835	2.560224
	0.5	20.12308	2.593048
	0.75	20.38442	2.626724
0.3	0.25	19.50380	2.678956
	0.5	19.75385	2.713302
	0.75	20.01039	2.748540
0.5	0.25	19.13924	2.814451
	0.5	19.38462	2.850533
	0.75	19.63636	2.887553
0.7	0.25	18.77468	2.970526
	0.5	19.01538	3.008610
	0.75	19.26234	3.047683
0.9	0.25	18.41013	3.152258
	0.5	18.64615	3.192672
	0.75	18.88831	3.234135

8. Conclusion

This method provides an alternative solution technique to this problem. This method is more reliable and acceptable. Here decision maker (engineer) may obtain the optimum results as per his/her requirement .The methodology presented in this paper can be applied in other fields of engineering optimization.

Conflict of Interests

The author declares that there is no conflict of interests.

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