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Optimization of Rcc Dome using Genetic Algorithm

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Abstract:
Optimization is the selection of a best element (with regard to some criteria) from some set of available alternatives. More generally, optimization includes finding "best available" values of some objective function given a defined domain, including a variety of different types of objective functions and different types of domains. The best design of a structure means the most economic structure without impairing the functional purposes the structure is supposed to serve.
Genetic Algorithms (GA) belongs to the family of evolutionary algorithms. GA is an iterative procedure that is motivated by the "survival of the fittest" principle of Darwinian theory of natural solutions.
In the present work, optimum design of reinforced concrete spherical dome is studied according to IS 456-2000. The objective function is the total cost of the concrete dome which includes the costs of concrete and steel excluding formwork. In the proposed optimization, the cross sectional dimensions of dome along with the number of bars and diameter of the reinforcement bars are considered as design variables. The design constraints are sizing, allowable compressive strength of concrete and buckling. The MATLAB Programming code has been developed for the analysis of 2D Reinforced Concrete dome and for Genetic Algorithm process. The concept and working of GA methodology has been studied and appropriate codes have been formulated. The GA program has been developed to deal with continuous as well as discrete variables. The results are studied for the optimum cost of dome for number of generations and number of population sizes. It shows that the number of iterations of 250 and the population size of 30 give the best solution. Thus, it is concluded that as the number of generations and population size increases, the obtained solution enhances up to a certain limit, beyond which the solution will no longer enhance.

Keywords*: Optimization of rcc dome, optimum Cost of rcc dome Genetic Algorithm*

1. Introduction

Domes are space structures which provide large column free net precious area for utilization. Domes enclose the maximum amount of space with minimum surface. This feature provides economy in terms of consumption of constructional material. The availability of high speed computational tools and numerical software for analysis in recent years has facilitated structural engineers to develop many economical designs of space structures.

Optimization is the act of obtaining the best results under given circumstances. Optimization is being used in those design activities in which the goal is not merely to achieve a feasible design, but also a specified design objective. In the design of an engineering structure, engineer has to take many technical decisions at several stages. The ultimate goal of all such decisions is to either minimize the effort required or maximize the desired benefit. Now a day, a number of optimization techniques are available. Most of them use mathematical programming techniques to arrive at optimum solutions. Among the stochastic direct search methods, the most popular method for use in optimization process is the "Genetic Algorithm" (GA) which is based on the principles of natural selection and survival of the fittest. Recently, it has been significant applications in structural design optimization. In the present work, genetic algorithm has been used to get the optimum sectional configuration of the Reinforced concrete Dome by minimizing the cost. Even though Genetic Algorithm is a powerful tool in getting the optimum design solution for a given type of reinforced concrete dome, analysis of the reinforced concrete dome needs to be carried out for evaluation of the constraints and fitness function at each stage of generation of population in the Genetic Algorithm

Since economy can be easily assessed by total weight of structure, an attempt is hereby made to reduce the total weight of the structure.

The shape of the dome depends upon the type of the curve and the direction of the axis of revolution. When the segment of a circular curve revolves about its vertical diameter, a spherical dome is obtained. Similarly, conical dome is obtained by the revolution of a right angled triangle about its vertical axis, while an elliptical dome is obtained by the revolution of an elliptical

curve about one of its axes. However, out of these, spherical domes are more commonly used. In the case of a spherical dome the vertical section through the axis of revolution in any direction is an arc of a circle.
Domes are used in variety of structures, such as (i) roof of circular areas (ii) circular tanks (iii) hangers, (iv) exhibition halls, auditoriums and planetariums' and (v) bottoms of tanks, bins and bunkers. Domes may be constructed of masonry, steel, timber and reinforced cement concrete. Stone and brick domes are one of the oldest architectural forms. However, reinforced concrete domes are more common now-a-days, since they can be constructed over large spans.

2. Theory of Shells of Revolution

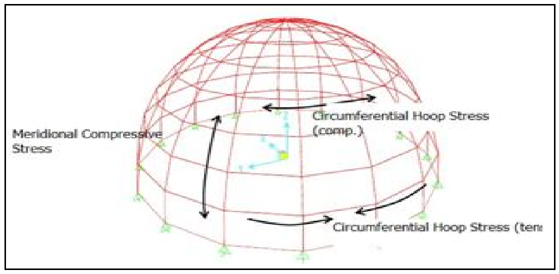

Figure 1: Stresses in dome

The Fig shows a typical shell of revolution, on which equilibrium of an element, obtained by intersection of meridian and latitude, is indicated. Forces along the circumference are denoted by $N\varphi$ and are called meridian stresses and forces at right angles to the meridian plane and along the latitude are horizontal and called the hoop stresses, denoted by $N\theta$. These two forces and the external force normal to the surface must be in equilibrium.
To summarize, therefore, two types of stresses are induced in a dome
(i) Meridional thrust (T) along the direction of meridian.
(ii) Hoop stress (H) along the latitudes.
Dome structure subject to various kinds of loads like dead load, imposed loads, wind loads, snow loads etc. But in this study work has been carried out for only dead load and imposed loads.
Summary of formulae:

$$\text{Meridional thrust } T = \frac{w\,R}{1+\cos(\theta)}$$

$$H = \frac{W*R}{t}\left\{\cos\theta - \frac{1}{(1+\cos\theta)}\right\}$$

Dead load on the dome structure includes the self weight of the structure and weight of the roof covering if any. For calculation dead load recommendations of IS:875 (Part 1)-1987 is referred. For calculation and estimation of imposed loads IS: 875 (Part 2)-1987 is referred.
The aim of the present work is to develop a suite of computer programs in MATLAB programming language that will generate geometry and loading data, analyze and design spherical domes and to optimize steel weight and volume of concrete of the rcc dome to carry given loads for given topology using constrained optimization method.

2.1. Scopeof the Study

- To minimize the material and construction cost of reinforced concrete structural elements subjected to serviceability and strength requirements described by the IS Code.
- To develop genetic algorithm (GA) optimization models using MATLAB software. To develop a suite of computer programs in MATLAB programming language that will generate geometry and loading data, analyze and design spherical domes and optimize the steel weight and volume of concrete of the rcc dome to carry given loads for given topology. Only gravity loads are considered in the present study.

3. Optimization Methods

Optimization is the selection of a best element (with regard to some criteria) from some set of available alternatives. In the simplest case, an optimization problem consists of maximizing or minimizing a real function by systematically choosing input values from within an allowed set and computing the value of the function.
As the construction materials are getting extinct day by day it is important for the structural engineers to concentrate on optimum designing of the structures. With a special reference to structural problem it is always one of the minimizing or maximizing a certain specific characteristic of structural system like cost, weight, performance capability of the system depends on the problem. This to be achieved without sacrificing any of the functional requirements like stresses deformation and load capabilities. Thus, the optimization procedure must only be used to those problems where there is a definite need of achieving a quality product or competitive product.

3.1. Definition of Optimization Problem

An optimization or a mathematical programming problem can be stated as follows.
Find X = { X1,X2….Xn} …………..which minimizes f(x)
Subject to the constraints
$gj(x) \le 0$, j=1,2,…m ………….. inequality constraint
$hj(x) = 0$ j=1,2,…p …………… equality constraint
Where, X is an n-dimensional vector called the designed vector, f(x) is termed the objective function. The number of variables n and the number of constraints m and/or p need not be related in any way.
There are three classes of optimization methods:

- Simultaneous Mode of Failure
- Optimality Criteria
- Mathematical Programming

Types of search techniques:

- Linear Programming
- Nonlinear Programming

Various methods used in Nonlinear Programming are:

- Feasible Direction Method
- Sequential Unconstrained Minimization Method
- Dynamic Programming
- Geometric Programming
- Sequential Linear Programming

Non traditional search techniques:

- Genetic Algorithms
- Simulated Annealing
- Neural Networks Method Based Optimization

In the present study Dynamic Programming method has been used for optimization.

3.2. Dynamic Programming

It is a very powerful optimization technique applicable to multistage decision problems. If the optimization problem can be conveniently decomposed into several stages of decision making by taking advantages of the serial relationship which may exist, dynamic programming method is useful. This method suggests decomposing a system into N-single stage problems; get a set of solution for each stage and finally pickup optimal solution of the system.

4. Methodology

To develop the software, MATLAB version 9.0 has been used. The analysis of the dome structure is carried out by empirical formulas of Shell theory. Design is done by Working stress method and optimization is done by dynamic Search technique. All IS code provisions are incorporated in design process.

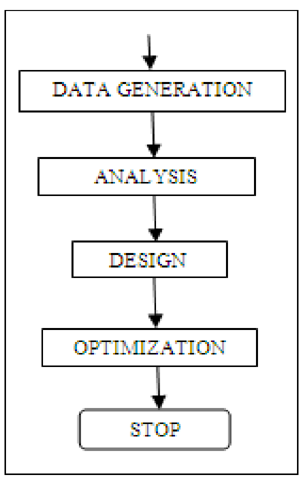

Figure 3: Master Flow chart

4.1. Data Generation

Data generation includes the generation of information pertaining to Radius of curvature of dome, angle θ, for a given base diameter, height and load. This reduces the error prone task of entering the information manually
The steps involved in the data generation of the dome structure are as follows.

- Calculating Radius of Curvature & angle θ: The program requires the base diameter and height/Rise of dome. Based on these input parameters, Radius of Dome and angle θ is generated.

- Boundary conditions: The analysis of the dome is performed assuming the dome to be simply supported at the the bottom circular segment.
- Load application: The dome is analyzed for two independent load cases, namely, load and live load. Dead load consists of self weight of Dome for given thickness. Self weight of the dome is calculated using density of concrete, surface area of dome and thickness of the Dome. Initially the assumed cross section areas are used and subsequently during the optimization process, the designed area for the current optimization cycle is used. For design of dome structure, live load is calculated as per IS 456 4. Formulae used in data generation

Some of the formulae used in data generation process are listed below:

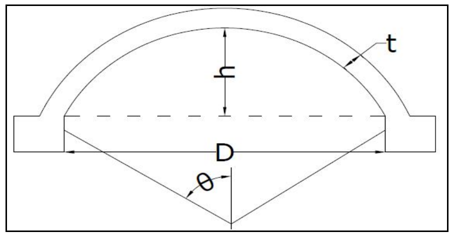

Figure 1: RC dome

Radius of the dome curvature

$$R = \frac{(D/2)^2 + h^2}{2h}$$

$$\theta = \sin^{-1}(D/(2*R))$$

4.2. Analysis

Analysis includes the calculation of forces in the Dome due to the applied loads. The analysis program is based on the empirical formulas derived from shell theory. It takes the output of the data generation program as its input.

Calculation of Meridional stress,

$$T = \frac{w\,R}{t*(1+\cos\theta)}$$

Hoop stress, $$H = \frac{W*R}{t}\left\{\cos\theta - \frac{1}{(1+\cos\theta)}\right\}$$

4.3. Design

The output of the analysis program serves as the input for the design program.

Area of Steel is calculated based on the stresses calculated in both Meridional direction and Hoop direction as below

$$Ast\_T = \frac{T_{Max} * t}{\sigma_{st}}$$

$$Ast\_H = \frac{H_{Max} * t}{\sigma_{st}}$$

Spacing of Rebar is calculated as below:

$$Spacing\_T = \frac{(\Pi/4)*d^2}{(Ast\_T)}$$

$$Spacing\_H = \frac{(\Pi/4)*d^2}{(Ast\_H)}$$

Number of bars in both calculated as below:

$$N1 = \frac{(2 * \prod * (D/2))/2}{Spacing\_T}$$

$$N2 = \frac{h}{Spacing\_H}$$

Length of bars in Meridional Direction:
LT = Π * (D/2)
Length of bars in Hoop Direction:
Bottom most bar LH1 = 2* Π * (D/2)
Radius @ second level, r1 = $\sqrt{(R^2-(R-h+ Spacing\_H))}$
Length of successive bars toward crown:
$LH_n = 2 * \Pi * (r_n)$

Weight of Steel in Kg (Ws) :

$$Ws = 7850 * \Pi/4 * d^{2*} \left\{ N1*LT) + \sum_{1}^{n} LH \right\}$$

Volume of Concrete in m³ (Vc):

$$Vc = \Pi * \{h^2 + (D/2)\} * t$$

4.4. Optimization of Dome

4.4.1. Objective Function
In the present study, the total cost of a RC dome is considered as the objective function F(x) which is given as follows,
(i) Weight of reinforcement
F(x) = {Ast*ρs*l }
Where Ast=Area of steel in mm^2
ρs = density of steel =7850 kg/m^3 for Mild steel
l = length of bars in mm
Three variables are defined namely, area of reinforcement, length of bars and density of steel which is kept constant throughout the member, so two variables alone are sufficient to represent weight of reinforcing steel.
(ii) Volume of concrete
F(x) = {Ac*t }
Where, Ac= Surface Area of Dome in m^2
$= \prod * (h^2 + (D/2)^2)$
t = Thickness of the Dome in m

4.4.2. Design Constraints
This section describes constraints imposed on optimization of Domes as below
1) The first one specifies that the compressive stress of any point in the shell should not exceed the permissible value. Then,

$$g(1) = \frac{\sigma}{\sigma_{cb}} - 1 \leq 0$$

2) IS 2210 specifies the following two constraints to avoid buckling,

$$g(2.A) = \frac{\sigma_L}{\sigma_{ac}} - 1 \leq 0$$

$$g(2.B) = \frac{\sigma_T}{\Sigma ac} - 1 \leq 0$$

Where,
σ_L-Maximum Compressive stress in longitudinal direction
σ_T - Maximum Transverse compressive stress
σ_{ac} = Allowable buckling stress

$$= \frac{Ec*t}{R\sqrt{3}}$$

3) Following side constraint also to be provided for minimum thickness of Dome to be adopted

$$g(3) = \frac{40}{t} - 1 \leq 0$$

4.5. Working of Genetic Algorithm

Genetic algorithms, initially introduced by Holland from the University of Michigan, and are based on the principles of natural genetic and natural selection from Darwin's evolution theory, indicating that in the process of biological evolution, through several generations and genetic variation. Fig.5-2 shows the flowchart for GA optimization of Reinforced concrete Dome. The program for Genetic algorithms is written in the MATLAB, and the process starts with generating the initial population of the design variables. The binary coding system has been used to represent the design variables which are coded by string. Total seven variables for column and six variables for beams have been used and each design variable is represented by a four bit string. The design process from the Matrix Analysis of dome used to evaluate the constraint violations and the objective function. Fitness function based on the objective function and constraint violations of each design strings are evaluated.

The constraint violation factor is computed for each candidate solution and also the modified objective function (ObjV) is computed. On the basis of the modified fitness, each design is assigned a Probability of being selected as a mating parent. In this study, the selection of mating pairs is carried out using roulette wheel selection method. This method Optimum was proved to provide good selective pressure by selecting a given number of individuals, N from a population.

The process of randomized selection of individuals can be simulated using a roulette wheel in which the width of each slot corresponds to the fitness of a specific individual of the population. The wheel is then spun and the individual that come under the marker of the wheel is selected. Then the fitter individuals have a greater chance to be selected to enter the matting pool. All individuals in a current population may initially be considered to enter the matting pool. However, a criterion may be determined for the acceptance or rejection of certain individuals for reproduction. The average fitness of the current population can be considered as an acceptance limit for individuals to enter the mating pool.

The roulette wheel selection is repeated until the desired number of individuals has been selected. The mating pool comprising the roulette wheel best has a single average fitness. Once a mating pool is selected, the crossover operation is performed.

In Genetic algorithms, it is the process of crossover which insures that design information is transferred from one generation to the next, essentially by a simple swapping of one (single point) or two point of bit string representation of two parent-designs to obtain two off-spring design solutions. The positioning and extent of crossover is chosen at random and may be different for each mating couple in each generation. In the present study, multi point crossover has been adopted. The population finally subjected to the mutation operation with a mutation probability of 1/L (L is the length of string). This action is important since it guards against premature convergence of the design towards an optimal solution.

The probability of crossover and mutation is selected based on several trials. The procedure is repeated until the new generation ceases to improve according to the objective function. When this convergence occurs, the fittest individuals of the youngest generation represent optimal design solution. The convergence criteria has been specified by allowing the predetermined number of generations to continue to process without further improvement before concluding that the appropriate solution has been attained.

5. Steps for the Program

The computer program for the project is done using MATLAB version 9.0. The program is written for the manual design and later to optimize the area of steel using Genetic Algorithm Technique. The versatility of MATLAB's high level language, problems can be coded in M-files. The Genetic Algorithm toolbox uses MATLAB matrix functions to build a set versatile tool for implementing a wide range of Genetic Algorithm methods. The input for Genetic Algorithm are programmed as,

- Number of variables of objective function,
- Number of generations
- Number of individuals per subpopulation

Name of selection function: In selection function we have adopted Roulette wheel selection. Roulette wheel probabilistically selects individuals based on their fitness values.

Name of crossover function: For crossover we have adopted general multi-point crossover. An advantage of having more crossover points is that the problem space may be searched more thoroughly. In two point crossover, two cross over points are chosen and the contents between these points are exchanged between two mated parents.

- We have considered four variables in which two is continuous and two are discrete design variables and each have been coded.
- The program is coupled with analysis program and Genetic Algorithm program to calculate the objective fitness in MATLAB.
- The operators of Genetic Algorithm are selection of fit individuals; crossover and mutations are formulated in the program.

- The generations are continued until all the constraints and objective functions are satisfied.

6. Example of Optimization

The dimensions of the dome are: D = 45 m. A factored uniformly distributed vertical load of w = 3 kN/m^2 is applied on. The unit weight of concrete and steel are taken as 25 kN/m3 and 7850 kg/mm2 respectively. The strength of concrete, fck = 20 N/mm2 and the yield strength of steel, fy = 415 N/mm2.

The design conforms to the Indian Standard Code of Practice for Reinforced Concrete (IS 456-2000) design code and does not consider the shear capacity of the ring beam sections

The estimated cost of the dome is,

F(x) = {Cc *VC + Cs*WS}

The following values are assumed for unit cost parameters:

Unit cost of concrete (Cc) = 4200 Rs /m3

Unit cost of steel (Cs) = 47000 Rs/ton, or 47 Rs/kg

7. Results and Discussion

In the subsequent sections the results obtained for the optimization of RC dome for number of generations and for number of populations are presented. Following are the variables considered:

- Thickness of the dome
- Rise of the dome
- Number of bars
- Diameter of bars

7.1. Effect Of Number Of Iterations (Generations) On Optimization Results

I. The number of iterations was studied by keeping the values of other parameters fixed as follows:

Characteristic compressive strength of concrete, fck = 20 N/mm2, population size = 30, discrete mutation function, roulette wheel selection function, multi point crossover and simple penalty method.

The results obtained from GA optimization of RC dome for number of generations is listed in below table 1 and result shows in fig 2.

No.of Generations	Optimum cost of Dome is Rs.
20	1,564,814
50	1,547,972
100	1,271,012
150	1,249,943
200	1,249,943
250	1,249,943
300	1,249,943

Table 1: Optimum Cost of dome for Number Of Generations

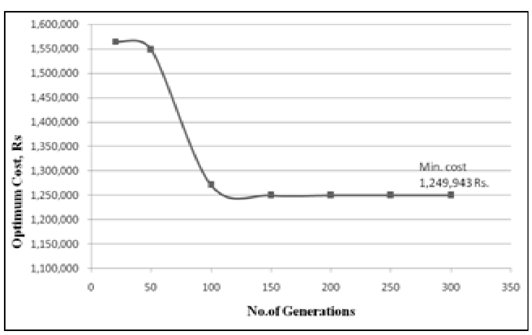

Figure 2: No. of generations Vs Min cost for the RC dome

Discussions about figure 2:

- From the above figure it is clear that by using a very little number of iterations (<50), the optimizer kept the value of the cost away from the optimum (minimum). It may allow little application of the basic operators of the GA on the population. Therefore, the model will not be able to explore wide range of developed populations (solutions) and the model may get stuck to a suboptimal or infeasible solution.
- From the above figure it can be found that the number of iterations of 250 is a moderate value that could result in the optimum solution. Below Table 3 gives the optimum design variables for 250 generations.

- By increasing the number of generations there is decrease in the cost of the dome.
- Sudden drop in fitness occurs usually when the algorithm finds a better alternative size of the dome elements, meaning that many variables can change drastically.

thickness, t (m)	0.104
rise, h (m)	8.775
no.of variables,n(m)	340
diameter of bars,d(m)	8

Table 3: Optimum Design Variables for 250 Generations

II. Fig. 3 ,4,5, 6, 7 and 8 shows a convergence history of the GA procedure for the example dome design. The computation is carried out for 300 generations with a population size of 30.

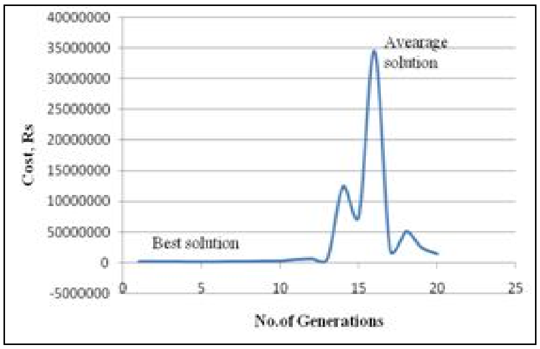

Fig.3 GA Convergence History for generations 20

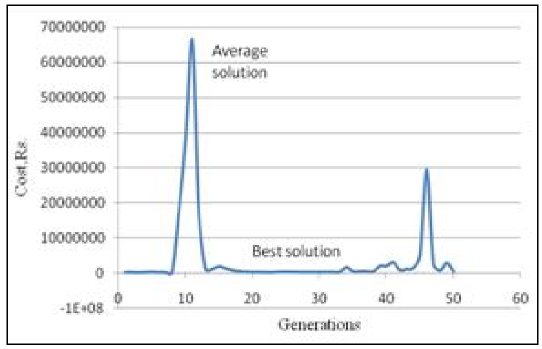

Fig.4 GA Convergence History for generations 50

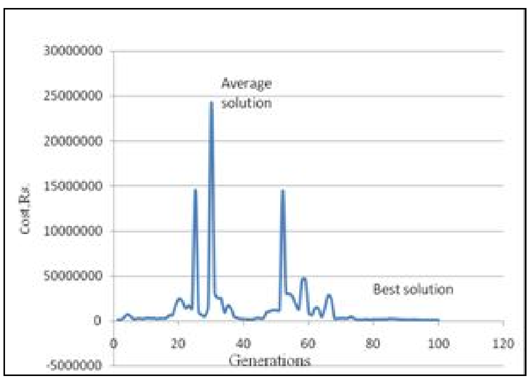

Fig.5 GA Convergence History for generations 100

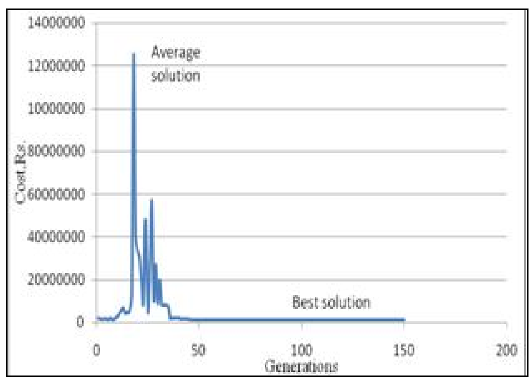

Fig.6 GA Convergence History for generations 150

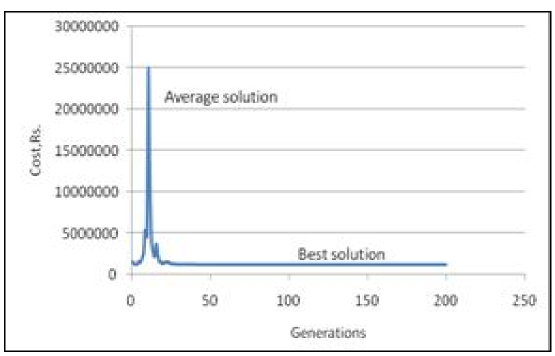

Fig.7 GA Convergence History for generations 200

Discussion about Fig. 3,4,5,6,7 graphs:

- Initially there may be violation in the constraints, but optimization proceeds smoothly to get the minimum cost without violation.

- From the graphs it is found that the improvement in the solution is very fast in the early generations and becomes slower in the later ones.

8.Conclusion

In the present thesis, it can be concluded that,

- It is possible to formulate and to obtain solution for the minimum cost design for R.C.C. Dome using Genetic algorithm
- Significant savings in cost over the normal design can be achieved by the optimization.

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