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基于遗传算法和 Matlab的一种可靠度计算方法

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摘要: 利用由 Matlab语言编制的遗传算法优化工具箱计算工程结构的可靠度,给出了设计验算点,避免了非线性功能函数的泰勒级数展开及遗传算法程序的编制。

关键词: 可靠度指标; 设计验算点; 功能函数; 遗传算法; Matlab优化工具箱

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在可靠度分析中,目前常用的方法有一次二阶矩法(FOSM)、JC法、几何法等。这些方法对于极限状态方程是线性的,各随机变量服从正态分布,得到的可靠度指标和设计验算点是精确的。本文基于可靠度指标的几何含义,采用新型优化算法——遗传算法(GA),结合 Matlab优化工具箱计算工程的可靠度,期望在避开极限状态方程的二级偏导数化解的同时能够在不多的迭代计算中得到满足精度要求的结果,并给出可靠度指标和设计验算点,以适应工程功能函数高次非线性和复杂性的情形。

1 可靠度指标的含义

从可靠性分析的一次二阶矩理论可知,对于独立正态分布的变量,在极限状态方程为线性时,可靠度指标在标准正态系中等于原点到极限状态曲面(或直线)的最短距离。可以证明该距离是可靠度分析中的一个重要指标——可靠度指标 β。

可靠度指标标准正态空间计算的数学模型为

$$\beta = \min\left\{\sum_{i=1}^{n} x_i^{*2}\right\}^{1/2} \qquad (1)$$

$$Z = g(x_1^*, x_2^*, \cdots, x_n^*) = 0 \qquad (2)$$

式中, x_n^* 为 n个标准正态分布变量; Z为 n个正态分布变量的功能函数。

如果各个随机变量不是服从正态分布,则可以对随机变量进行高斯变换(将一般分布当量化为正态分布):

$$x_i^* = \Phi^{-1}(F_i(x_i)) \qquad (3)$$

式中, $F_i(\cdot)$为随机变量 x_i的 CDF; $\Phi(\cdot)$为标准正态分布的 CDF。

由于极限状态方程 $Z(x)$在工程中不一定为线性,有时为高次非线性,因此必须对 $Z(x)$在基本变量的中心点(即均值) $\mu_1, \mu_2, \cdots, \mu_n$处作泰勒级数展开,并取级数的一次项作为近似式,结果是近似的。

2 遗传算法的基本原理

遗传算法[1~3]是一种具有高度并行、随机、自适应搜索的新计算方法,与常规的优化方法相比,遗传算法不直接和模型参数打交道,而是处理代表参数的编码;遗传算法在整个操作过程中同时控制着一个种群,而不是局限于一个点,大大提高了搜索效率,避免了陷入局部极值;求解时不计算目标函数的微分,只计算目标函数值,这种群体搜索策略和优化计算不依赖于目标函数梯度信息,增加了解题能力。由于不计算目标函数的微分,故对目标函数和约束条件没有苛刻要求,在处理高度非线性时与传统方法相比具有明显的优势。

本文不单独编制遗传算法程序计算,而利用 Matlab的遗传算法优化工具箱计算。

3 Matlab优化计算

Matlab的遗传算法工具箱[4,5]是共享软件,核心程序是 initializega. m和 ga. m,可在网上免费下载,且有详细使用说明。

在计算工程可靠度时只需要编制模型函数的

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Matlab代码和遗传算法求解模型函数最小值的Matlab代码。

4 工程算例分析

4.1 算例 1

某工程[6]极限状态方程为 $g = R - G - Q = 0$，永久荷载效应 G服从正态分布，$\mu_G = 5.3$，$\sigma_G = 0.371$；可变荷载效应 Q服从正态分布，$\mu_Q = 7.0$，$\sigma_Q = 2.03$；抗力 R服从对数正态分布，$\mu_R = 30.92$，$\sigma_R = 5.26$。

本文中随机变量 x的边界取为 $[\mu - 4\sigma, \mu + 4\sigma]$。

假设验算点落在失效边界上，令第 i个变量用 $(n - i)$个变量表示，则有

$$R = G + Q \tag{4}$$

将各个随机变量转化为标准正态分布变量。

对于 G、Q：

$$\begin{cases} G^* = (G - \mu_G)/\sigma_G \\ Q^* = (Q - \mu_Q)/\sigma_Q \end{cases} \tag{5}$$

对于 R：

$$\begin{cases} \sigma_{R'} = [\ln(1 + V_R^2)]^{1/2} \\ \mu_{R'} = \ln\mu_R - \frac{1}{2}\sigma_{R'}^2 \end{cases} \tag{6}$$

$$R^* = \frac{\ln(G + Q) - \mu_{R'}}{\sigma_{R'}} \tag{7}$$

式中，V_R为 R的变异系数。

可靠度指标：

$$\beta = (Q^{*2} + G^{*2} + R^{*2})^{1/2} \tag{8}$$

遗传算法参数设置为：采用二进制编码；种群大少 pop-size = 40；最大迭代次数 gen-max = 100；变异率 $p_m = 0.05$；交叉率 $p_c = 0.3$。

图 1为遗传算法的寻优性能，表 1为可靠度计算结果。

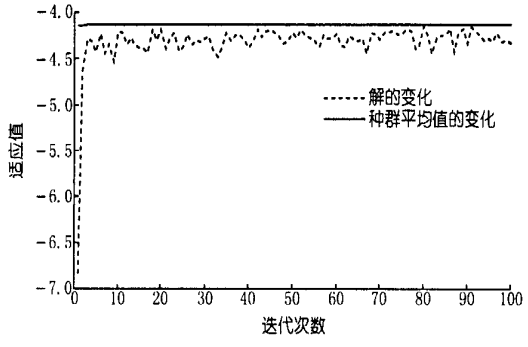

图 1 遗传算法的寻优性能 (例 1)

表 1 算例 1可靠度计算

计算方法	β	R^*	G^*	Q^*	迭代次数
几何法	4.137 1	17.237 0	5.459 6	11.777	8
遗传算法	4.134 8	17.233 1	5.459 4	11.774	2

4.2 算例 2

弯曲荷载作用下的薄壁型钢梁[7]，极限状态方程为 $g(W, f, M) = Wf - M = 0$。其中，截面抗弯模量 W为正态分布，$\mu_W = 54$，$\sigma_W = 2.7$；材料屈服强度 f为对数正态分布，$\mu_f = 38$，$\sigma_f = 3.04$；截面弯矩 M为正态分布，$\mu_M = 1\,282.5$，$\sigma_M = 102.6$。图 2为遗传算法的寻优性能，表 2为可靠度计算结果(遗传算法参数设置同例 1)。

表 2 算例 2可靠度计算

计算方法	β	W^*	f^*	M^*	迭代次数
几何法	3.875 2	49.144	30.739	1 510.60	6
遗传算法	3.874 6	49.145	30.737	1 510.57	4

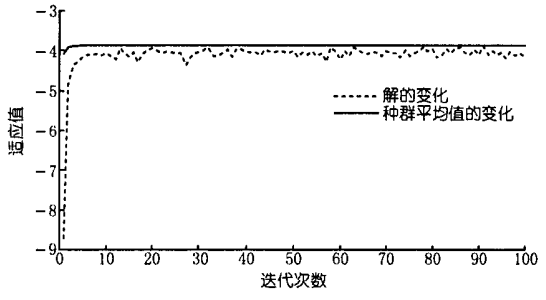

图 2 遗传算法的寻优性能 (例 2)

5 结语

a. 遗传算法的强大寻优功能可以很好地适应可靠度计算与分析的要求，计算的可靠度指标与用几何法及 JC算法非常接近。由于遗传算法不需对非线性功能函数进行泰勒级数展开，因而误差小于 JC算法。

b. 利用 Matlab的遗传算法优化工具箱可以避免遗传算法程序的编制。

c. 在标准正态分布中随机变量理论上是上下无界的。在确定随机变量的边界时，一般取 $\mu \pm 4\sigma$，如取值过大，则将增大遗传算法的搜索难度，甚至可能会搜索到局部最优解。

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tages are discussed. As a result, with the performance of high speed, high integration and high reliability, the on-line monitoring technique based on DSP + CPLD mode will play a very important role in the field of electrical apparatus condition monitoring.

Key words: substaion; DSP + CPLD; on-line monitoring; acquisition system; circuit breaker

Discussion on Application of Distributed Power Generation in China CHEN Jinfu (College of Computer Sci. & Tech., HUST., Wuhan 430074, China) LU Yansheng p61-63

Abstract: As one of an additional power supply manner, distributed power generation will play an important role in using renewable energy and reducing environment pollution, and it is regarded as one of the key technologies of power system in this century. The necessity and requirement of developing distributed power generation in China were discussed in this paper. And it has been concluded that it is necessary to study the interaction between distributed power generation and network when the distributed power generation operates integratedly into power system in order to exert the effect of distributed power generation in China, such as voltage regulation, power quality, short-circuit current and protection, etc.

Key words: power system; distributed power generation; power quality; relay protection; reactive power and voltage; oveview

Idea of "Three Parts" Electricity Tariff Structure for Pumped-storage Plant CHENG Fang (Guangzhou Water Conservancy Bureau, Guangzhou 510640, China) GAO Longhua p64-66

Abstract: The emphasis on the auxiliary services and its pricing brings good chance for the pumped-storage plant to change its unreasonable electricity tariff policy. This article firstly gives a brief introduction for the now existing electricity tariff policy and its influence on the PS plant, and analyses its insufficiency in its structure. Analysis on the practice both at home and abroad showed the necessity for the innovation. Finally, an idea for reasonable electricity tariff structure was put forward.

Key words: electricity market; pumped-storage plant; electricity tariff structure

Economical Study on Gaobazhou Hydropower Station Capacity Increase WANG Lijuan (School of Water Resource and Hydropower, Wuhan Univ., Wuhan 430072, China) CHEN Min WAN Jun TAN Shaohua CHENG Yunyue p67-68

Abstract: There is surplus water in operation of Gaobazhou hydropower station. In order to make the best use of the water resource, considerable capacity increase can be put in practice. Based on the hydropower computation the author indicates several possible methods, the economical calculation and synthetical analysis are the emphasis in the text, and the author provides valuable reference to the establishment of capacity increase in Gaobazhou hydropower station.

Key words: hydropower station; capacity increase; economical analysis

Parallel Feedback Analysis for Thermal Characteristic Parameters of Concrete ZHU Yueming (College of Water Conservancy & Hydroelectric Eng., Hohai Univ., Nanjing 210098, China) LIN Zhixiang p69-72

Abstract: Selecting thermal characteristic parameters of concrete according to the feedback analysis of the data determined in spot is a kind of reliable method when big physical volume concrete temperature field is in simulative calculation. A kind of Improved Accelerating Genetic Algorithm and its parallel method are introduced. The good result is obtained with the application of the method in feedback analysis for the rmnal chatacteristic porameters of concrete in some actual engineerings.

Key words: temperature of concrete thermal characteristic parameters; improved accelerating genetic algorithm; parallel; feedback analysis calculation

Precise of Calcution Temperature Field of Concrete with Water-cooling Pipe and Its Application LIN Zhixiang (College of Water Conservancy & Hydroelectric Eng., Hohai Univ., Nanjing 210098, China) ZHU Yueming p73-76

Abstract: An iterative FEM procedure for solution of thermal problem in concrete with water-cooling pipes is introduced. The procedure is theoretically strict, totally solves the problem and has high accuracy and efficiency. Using the method and the calculation code, the results from three dams are given and illustrated.

Key words: temperature field in concrete; water pipe cooling; finite element method; simulative calculation; iterative solution; temperature control and cracking prevention

Reliability Analysis Based on Genetic Algorithm

Abstract: This paper calculates the reliability of engineering structure by using the optimization toolbox of Genetic algorithm which is compiled by Matlab program, and gives the designcheck point. The method in this paper can avoid not only the Taylor series expansion of non-linear performance function, but also the compilation of Genetic Algorithm program.

Key words: reliability index; designcheck point; performance function; genetic algorithm; matlab optimization toolbox

Abstract: The elastic and elastoplastic finite element method has been adopted to analysis the stress and deformation of the earth dam of Feilaixia Multipurpose Project under no water level, normal flood level, design flood level and check flood level. The stress and deformation of these characteristic nodes and the position of the stress and deformation extremum have been obtained. Based on the analysis of the stress and deformation of the dam and the work station of the dam, the results show that the stress and deformation of the dam satisfied the safety, which provide important resources for the power station management and the decision-making of flood-prevention.

Key words: earth dam; stress; deformation; stability

Abstract: In the preliminary design stage, one scheme of Haidianxia Hydropower Station is that the concrete facing rockfill dam is parallelly arranged together with the concrete overflow gravity dam, in which a gravity high-toe wall with the height of nearly 50m is used, which is the highest one in China now. The stability and safety of the gravity high-toe wall is the key problem of the project. This paper performs a 3-D FEM calculation for the concrete facing rockfill dam and the gravity high-toe wall, analyzes the deformation and stress distribution of the gravity high-toe wall in detail, and researches the working behavior of gravity high-toe wall under design and check conditions. It is proved that the design scheme is reasonable and feasible.

Key words: concrete facing rockfill dam; gravity high-toe wall; face slab; working behavior

Abstract: There are many structural types of sluices. And it complicates the foundation treatment. Thereby how to establish a finite element model rapidly, efficiently and reasonably is a question concerning many engineering technicians. Many works are needed for establishing finite element grid models rapidly, efficiently and precisely by the existed finite element softwares. The powerful forward and post processing and solution functions of ANSYS makes it able to be used in intricate structure computing work, but its applications in the sluice structures of water conservancy show that they are not flexible and convenient enough. The methods and steps of secondary development of ANSYS Graphical User Interface by UIDL are introduced in this article, and the parameterized visualization analysis system of sluice based on ANSYS is developed which have much economic significance and practical values.

Key words: sluice; ANSYS; UIDL; secondary development; visualization