

回归分析模型在大坝变形监测中应用

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摘要: 着重介绍了回归分析在大坝变形监测方面的应用, 先介绍了回归模型的定义, 接着说明了多元回归方程的建立, 回归方程的显著性和回归系数的显著性, 最后结合具体的实例对回归方程进行分析, 建立模型, 通过图表表示出预测值和真实值的曲线图, 以及残差值曲线图, 说明回归分析模型的实际应用价值。

关键词: 回归分析; 变形监测; 模型

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随着现代科学技术的发展和计算机应用水平的提高, 各种理论和方法为变形分析和变形预报提供了广泛的研究途径。由于变形体变形机理的复杂性和多样性, 对变形分析与建模理论和方法的研究, 需要结合地质、力学、水文等相关学科的信息和方法, 引入数学、数字信号处理、系统科学以及非线性科学的理论, 采用数学模型来逼近、模拟和揭示变形体的变形规律和动态特征, 为工程设计和灾害防治提供科学的依据^[1]。本文主要采用回归分析模型来对大坝进行预测, 通过对模型分析, 回归因子对位移的影响可以充分的体现。

1 回归分析

回归分析法作为一种统计分析方法, 需要效应量 and 环境量具有较长且一致性较好的观测值序列。这种函数关系可以解释变形产生的主要原因, 也可以进行预报, 同时也给出估计精度^[2-3]。

1.1 多元线性回归

它是研究一个变量与多个因子之间非确定关系的最基本方法^[4]。其数学模型是:

$$y_t = \beta_0 + \beta_1 x_{t1} + \beta_2 x_{t2} + L + \beta_p x_{tp} + \varepsilon_t, \quad (1)$$

$(t = 1, 2, L, n), \varepsilon_t \sim N(0, \sigma^2)$

式中, 下标 t 表示观测值变量, 共有 n 组观测数据, p 表示因子个数。分析步骤如下:

1) 建立多元线性回归方程。多元线性回归数学模型如式 (1) 所示, 用矩阵表示为

$$y = x\beta + \varepsilon \quad (2)$$

式中, y 为 n 维变形量的观测向量, $y = (y_1, y_2, L, y_n)^T$; x 是一个 $n \times (p+1)$ 矩阵, 其形式为:

$$x = \begin{bmatrix} 1 & x_{11} & x_{12} & L & x_{1p} \\ 1 & x_{21} & x_{22} & L & x_{2p} \\ M & M & M & & M \\ 1 & x_{n1} & x_{n2} & L & x_{np} \end{bmatrix}$$

β 是回归系数向量, $\beta = (\beta_0, \beta_1, L, \beta_p)^T$; ε 是服从同一正态分布 $N(0, \sigma^2)$ 的 n 维随机向量, $\varepsilon = (\varepsilon_1, \varepsilon_2, L, \varepsilon_n)^T$ 。

由最小二乘原理可求得 β 的估值 $\hat{\beta}$ 为

$$\hat{\beta} = (x^T x)^{-1} x^T y$$

2) 回归方程显著性检验^[5]。如果因变量 y 与自变量 x_1, x_2, L, x_p 之间不存在线性关系, 则式 (1) 中的 β 为零向量, 即有原假设:

$$H_0: \beta_1 = 0, \beta_2, L, \beta_p = 0$$

将此原假设作为式 (1) 的约束条件, 求得统计量。

$$F = \frac{S_{\text{回}} / p}{S_{\text{剩}} / (n - p - 1)}$$

式中, $S_{\text{回}} = \sum_{i=1}^n (\hat{y}_i - \bar{y})^2$; $S_{\text{剩}} = \sum_{i=1}^n (y_i - \hat{y}_i)^2$;

$$\bar{y} = \frac{1}{n} \sum_{i=1}^n y_i$$

在原假设成立时, 统计量 F 应服从 $F(p, n - p - 1)$ 分布, 故在选择显著水平 α 后, 可用式 (3) 检验原假设:

$$p\{ |F| \geq F_{1-\alpha, p, n-p-1} | H_0 \} = \alpha \quad (3)$$

若式 (3) 成立, 即认为在显著水平 α 下, y 对 x_1, x_2, L, x_p 有显著的线性关系, 回归方程是显著的。

3) 回归系数显著性检验^[6]。检验因子 x_j 是否显著的原假设应为:

$$H_0: \beta_j = 0$$

由式 (1) 可估算求得:

$$E(\hat{\beta}_j) = \beta_j$$

$$D(\hat{\beta}_j) = c_{jj} \sigma^2$$

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式中, c_{ij} 为矩阵 $(x^T x)^{-1}$ 中主对角线上第 j 个元素。于是在原假设成立时, 统计量

$$(\hat{\beta}_j - \beta_j) / \sqrt{c_{jj}\sigma^2} \sim N(0, 1)$$

$$(\hat{\beta}_j - \beta_j)^2 / c_{jj}\sigma^2 \sim \chi^2(1)$$

$$S_{\text{剩}} / \sigma^2 \sim \chi^2(n - p - 1)$$

故可组成检验原假设的统计量

$$\frac{\hat{\beta}_j^2 / c_{jj}}{S_{\text{剩}} / (n - p - 1)} \sim F(1, n - p - 1)$$

它在原假设成立时服从 $F(1, n - p - 1)$ 分布。分子 $\hat{\beta}_j^2 / c_{jj}$ 通常又称为因子 x_j 的偏回归平方和。

2 实测数据建模分析

某水利枢纽工程以防洪为主, 兼具发电、灌溉、供水及航运等综合效益。该坝为一座高 75 m、坝顶长 220

m 的面板堆石坝, 1985 年开始施工、1989 年蓄水、1990 年竣工、1999 年开始进行了较为规范的安全监测。监测水库在运行期间坝体的变形, 预防坝体变形对大坝及有关建筑物运行安全的影响。

大坝安全监测项目包括内部观测和外部观测两部分。其中内部观测项目有应力应变观测、温度观测、渗压观测、裂缝观测; 外部观测项目有变形观测、渗流观测和水文观测等。

现以坝段 2# 垂直位移观测值, 建立的回归模型进行实测位移计算。

用本研究编制了回归模型计算程序对该坝进行坝顶垂直位移建模, 所用数据是自动化采集系统 1999 年 1 月到 2001 年 7 份的数据。下面仅坝体 2# 垂直位移计算结果进行分析。观测资料见表 1。

表 1 2# 垂直位移观测值

观测日期	2#垂直位移 Y/mm	月降雨量 Yu/mm	水库月平均水位 H/m	月平均气温 T/	时效因子 t	时效因子 lnt	时效因子 t/(t+1)
1999-01-2	12.5	36.65	328.88	6.9	1	0.000	36.65
1999-2-13	14.1	72.13	329.99	8.5	2	0.693	72.13
1999-3-12	14.3	143.26	333.21	13.2	3	1.098	143.26
1999-4-11	14.7	111.32	338.98	16.9	4	1.386	111.32
1999-5-3	14.8	111.23	331.62	21.8	5	1.609	111.23
1999-6-15	15.3	340.00	333.95	25.2	6	1.756	340.00
1999-7-26	15.6	437.11	344.74	26.1	7	1.945	437.11
1999-8-28	17.0	219.04	342.21	26.9	8	2.079	219.04
1999-9-26	17.1	105.69	335.88	21.7	9	2.197	105.69
1999-10-22	17.3	22.80	325.86	18.7	10	2.302	22.80
1999-11-17	19.6	261.95	312.62	13.6	11	2.397	261.95
1999-12-21	20.4	91.94	330.28	8.6	12	2.484	91.94
2000-2-6	22.6	103.98	332.02	9.5	14	2.639	103.98
2000-3-16	23.3	169.98	338.21	20.8	16	2.772	169.98
2000-6-23	24.1	572.98	338.60	24.2	18	2.890	572.98
2000-7-17	24.6	204.32	341.49	27.7	19	2.944	204.32
2000-8-27	24.5	111.13	334.60	28.3	20	2.995	111.13
2000-10-11	27.0	14.57	306.46	20.1	22	3.091	14.57
2000-11-20	28.9	50.20	297.33	14.2	23	3.135	50.20
2000-12-24	30.6	37.25	301.90	9.3	24	3.178	37.25
2001-4-30	33.5	202.32	339.50	18.2	28	3.332	202.32
2001-5-28	33.5	235.59	341.45	20.7	29	3.367	235.59
2001-6-29	33.0	231.32	342.12	24.9	30	3.401	231.32
2001-7-30	32.1	384.55	340.22	26.5	31	3.433	384.55

模型共选 6 回归因子、水库月平均水位 H、月降雨量 Yu、月平均气温 T、时效因子 t、时效因子 lnt、时效因子 t/(t+1) (t 为时间间隔) 等计算。

首先对所选因子进行共线性诊断, 发现因子之间有较弱共线性, 模型推荐用多元回归分析或者逐步回归分析。

如果不希望多选因子进行回归方程, 可将 F 取得大一些。下面是 a 取 0.05, 多元回归分析计算结果:

$$Y = 1.1337 - 0.002Yu - 0.132T + 0.904t - 3.378lnt + 17.215t / (t+1)$$

通过回归方程可看出: 复相关系数为 0.997, 剩余标准差为 0.054, 除了第二个因子不显著外, 剔除, 其

他的几个变化因子都显著，所以方程总体回归效果显著。垂直位移实测数据和预测数据见图 1，残差图见图 2。

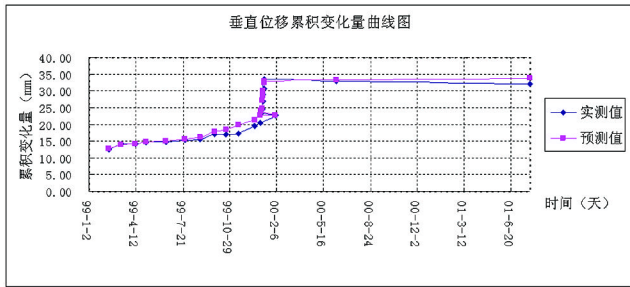


图 1 多元回归分析曲线图

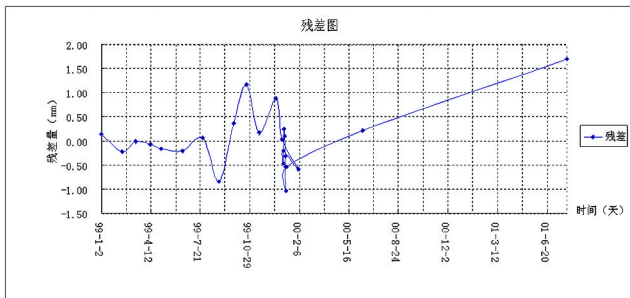


图 2 多元回归分析残差图

通过图 1、图 2 我们可以得到：在建模之前或根据特定坝体进行科学分析选取回归因子，由所得回归方程可见降雨量、气温、和时间对变形有着显著的影响。回归方程都剔除了库水位，由表可看出，库水位一直变化不大，这可能是对变形影响不显著的原因，从分析结果看多元回归分析结果多纳入了时效因子 $\ln t$ 与时效因子 $t / (t+1)$ ，因为时效因子 $\ln t$ 和时效因子 $t / (t+1)$ 与时效因子 t 有微弱的共线性。

3 结 语

本文以某水库上#垂直位移为观测值为例，建立回归因子与变形量的回归方程，运算结果表明多元回归模型能很好地建立数学模型，多元回归模型对位移有影响的回归因子，而剔除了对位移影响不显著的因子，这样的模型具有很好的复相关性和预报能力，通过对模型分析，回归因子对位移的影响可以充分的体现，进而深入认识变形体的内在规律。当然，变形监测和数据分析的方法还有很多，例如，时序分析法、灰色系统理论、卡尔曼滤波模型、小波分析理论等，采用这些模型也可以建立很好的预测模型，还有待于进一步的探索 [7]。

参考文献

- [1] 张正禄等编著. 工程测量学[M].武汉:武汉大学出版社,2002
- [2] 黄生享,尹辉. 变形检测数据处理[M]. 武汉:武汉大学出版社,2003
- [3] 陈永奇,吴子安. 变形检测分析与预报[M]. 北京:测绘出版社,1998
- [4] 徐兮,曾繁祥.最佳回归分析法在工程中的应用[J].重庆交通学院学报,2005,24(5):50-53
- [5] 冯元新.作图法与线性回归法的分析与运用[J].浙江科技学院学报,2004,16(1):25-27
- [6] 陈伟清.回归分析在建筑物沉降变形分析中的应用[J].测绘学院学报,2005,22(4):37-40
- [7] 张强勇,刘豆豆.重力坝变形统计回归分析模型及工程应用[J].水利水电工程,2005,18(3):42-45

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下期论文导读

洪德法 卢文喜 李伟 等：三维虚拟校园系统的设计与实现

从系统功能、实现技术等方面完成了虚拟校园系统的设计，并以吉林大学朝阳校区的校园场景作为数据，开发出了具有数据输入、查询、漫游、空间测算、数据更新、二三维交互、动画输出功能的原型系统，获得了满意的效果。

王战举 范玉茹：基于 ArcEngine 的供水管网 GIS 符号库的设计与实现

根据我国 GIS 技术规范和供水行业标准的要求，重点阐述了 ArcEngine 环境下供水管网地理信息系统地图符号库设计与制作的实现方法；在符号的制作过程中采用了抗锯齿的技术，减弱了 ArcGIS 平台下图形锯齿化的问题。

distributed points as a cluster, and then extract the target point clouds.
Key words Density-based clustering algorithms, the density distribution of point cloud, noise remove (Page:101)

Method of Basic Geographical Information Module Implementation Based on Google Earth by YIN Qiang

Abstract This paper introduced the mentality and the implementation method of kinds application subsystem general modul redevelopment based on Google Earth platform. It elaborated the implementation method of control and browse module and geographical information module, and implemented format conversion of the shp to kml file in the system.

Key words GE , basic geographical information modul , kml , format conversion (Page:105)

Establishment of the Geographical Name Inquiring System of Fuxin City Based on MO by REN Dongfeng

Abstract This paper talked about establishing the geographical name inquiring system of Fuxin city based on MapObjects controlling and VB language and in the foundation of the geographical name geodatabase of Fuxin city. The system achieved the function of brose, layers management, drawing, the geographical name inquiring, the buffer analysis, the shortest path analysis.

Key words geographical name inquiring system; system design;buffer analysis; path analysis (Page:107)

Formulas of Calculation of Road Horizontal Curve Coordinates in the Route Plane Control Survey Coordinate System by ZHEN Dengchun

Abstract A method of direct calculation of road horizontal curve coordinates in the route plane control survey coordinate system is introduced, and the related formulas, compact and practical, can be referenced for setting out of road horizontal curve, are derived.

Key words road;horizontal curve;coordinate calculation (Page:111)

Calculation and Application of Various Area in the Second Land Investigation by ZHANG Hui

Abstract This paper analyzed working method and mathematical models of line and sporadic feature, summary the advantages and disadvantages of various area proposed the improving and using direction, by Comparison between calculation formula of ellipsoid area and working method and precision assessment in the first land using status investigation.

Key words land investigation; area mature; precision assessment (Page:115)

Investigation about the Subdivision of the Digital Estate Figure of Wuhan by CHEN Zhen

Abstract The subdivision of the estate figure is apart of the plan of the real estate framing, and it's the basic figure of drawing and issuing the figure of the license of the estate. According to the provision of the property management at Wuhan, there are two ways of surveying and mapping the subdivision the figure. Framing is the basic unit of surveying and checking of the estate which is a very important code at surveying and management, and it is also the major index at the management of the records. The standardization of surveying and mapping the subdivision the estate figure is benefit for the department of the estate management, which can also support the service of the department. This thesis showed us some research about the surveying of boundary points, the coordination of the corner of the buildings, the serial number of the buildings and so on.

Key words the subdivision of the estate figure, express content, in-

vestigate of the technique (Page:118)

Role of Detection of Underground Pipeline in Municipal Engineering Design by XIAO Shun

Abstract Underground pipeline survey before carrying out municipal engineering is very important. This issue illustrated this significance by explaining the important role detailed municipal pipeline survey plays in municipal engineering, comparing between detailed municipal pipeline survey and underground pipeline survey and their pre- and follow-up services. Several illustrative cases were provided to enhance the conclusion.

Key words municipal engineering design, detailed municipal pipeline survey ,detection of underground pipeline (Page:121)

Design and Analysis of the Deformation Monitoring Program about a Foundation Ditch in Chengdu by LI Yong

Abstract This paper summarized the foundation excavation monitor need pay attention to in the basic problems and general principles and combining QingyangQu red east street in a Chengdu deformation observation projects analyzed the project operation processes involved with some typical problems including project profiles , benchmark layout ,observation period and so on contents and combined with actual situation corresponding conclusion.

Key words foundation ditch ,benchmark ,observation period (Page:125)

Optimum Design of CP Plane Control Network for High Speed Railway by XIAO Daiwen

Abstract By doing the simulation optimum design, the positional accuracy ,relative positional accuracy and reliability of CP networks was analysed, and the result showed the reliability of CP network was bader. The optimum scheme of CP network was presented. And frequency of repeatable measurement of this CP network may was reduced.

Key words CP plane control network ,positional accuracy ,reliability ,optimum design ,ballastless track (Page:127)

Thoughts of Surveying and Mapping Engineering Supervision by PENG Songlin

Abstract This paper starts with the analyzing the origin of relation and distinction of engineering supervision and project supervision, to discuss the need for the implementation of mapping and project supervision, and how could it be practiced. The focus is on how important the organization, legal system, market construction and other work are in promoting mapping and project supervision.

Key words supervision ; engineering supervision of surveying and mapping ,organization construction ,legal system construction ,market construction (Page:130)

Design and Practice of Deformation Monitoring of Building by FU Hai'ou

Abstract This paper expounded the design of the building's settlement monitoring process to Chengdu general tablet research building structural template Co., LTD as an example, the level of the stability analysis, combining results point on the watch for observation data statistics and analysis, and a detailed corresponding conclusion.

Key words subsidence monitoring ,baseline point , stability (Page:133)

Application of Regession Analysis Model in Dam Deformation Monitor by YANG Yongchao

Abstract This article focused on a regression analysis to monitor dam

deformation in the application, which first introduced the definition of regression model, and then described the multiple regression equations, the regression equation was significant and the regression coefficient was significant, the last light of the specific examples of the regression equation analysis, modeling, and forecast charts to show the true value of the curve, as well as the remnant of the margin curve on regression analysis model of the actual value.

Key words regression analysis , deformation monitor, model
(Page:136)

Method of GPS-RTK Technique to Route Cross-section Survey
by YANG Kang

Abstract The paper introduced the basic ideas and operation method of measuring route cross-section with GPS-RTK, including how to figure out tangent azimuth angle of random central stake points and cross-sectional line in the work with GPS-RTK. It would improve the efficiency and data accuracy in the cross-section survey.

Key words GPS-RTK technique , cross-section survey , tangent azimuth angle
(Page:139)

Research on Short-distance Precise Trigonometric Leveling Instead of Second-class Leveling
by Han Junsheng

Abstract The traditional geometrical leveling is inconvenient in fluctuating area .This article discussed the viability of monitoring the vertical displacement in small area, using the common Total Station instead of second-class leveling. Base on the formula of precise trigonometric leveling, it discussed the error resources and accuracy in Short-distance. Observed data were acquired by the common Total Station, and then verified the reliability of this method. At last it also gave out several precise measures, strengths and weaknesses.

Key words Total Station , trigonometric leveling ,short-distance , second-class leveling , precise leveling
(Page:141)

Transformation of Coordinate Axis between ITRF2008 and CGCS2000
by MIAO Long

Abstract Based ITRF2008 reference frame on ITRF frame coordinate which is related to present precise ephemeris ,and the achievement of CGCS2000 coordinate axis which is required in the basic mapping producing project about scale of one to a ten thousand, the thesis mainly discussed the conversion method of frame from ITRF2008 to CGCS2000 and the precision analysis after conversion. It also mainly analysed some key problems about transformation.

Key words ITRF2008 , CGCS2000 , frame conversion , epoch conversion , speed field
(Page:144)

Research and Practice for the Independent Experimental Course of Remote Sensing
by XU Yongming

Abstract This paper analyzed the defects of traditional teaching mode which used in remote sensing experimental courses and the necessity of establishing independent experimental courses. Teaching reform and practice were carried out in the independent experimental course of Comprehensive Practice of Using Remote Sensing Software. The teaching reform of the course content, teaching method, teaching material and assessment model were clearly discussed, and the comprehensiveness characteristic of the course was highlighted. Practices show that the teaching mode of this independent experimental course can effectively promote students' technology level and application capability, and improve the teaching quality.

Key words Remote Sensing ,Comprehensive Practice ,independent course ,teaching practice
(Page:146)

Application of Project Study to Teaching of Remote Sensing Major Courses
by SUN Deyong

Abstract This paper takes ocean remote sensing as an example, and shows the application of project study in remote sensing major courses. Teaching practice results demonstrate that this method can obtain good teaching effect. Students' learning interest can be stimulated, and their capability in problem analysis and solving can be greatly improved.

Key words Project study; Remote sensing major courses; Teaching design; Practical ability
(Page:148)

Analysis of the Progress of Compelling 《Atlas of Republic of China Province District Border》's Examination and Receive
by CHEN Zhongyuan

Abstract This article introduced the progress of comparing 《Detailed Atlas》's necessary and principle, examing and receieving the result of the work. Beside that, it also give us the details of main idea and implementation plan.

Key words 《Detailed Atlas》, examing, receieving
(Page:150)

Research on Several Issues of Map Annotation Design
by HE Lihua

Abstract Map is marked by Annotation for identifying object. The choice of the font style and size is an important part of map design. The paper described the importance of Annotation on the map, and introduced the design of the font style, size and color etc. And the general design principles and the transform between several kinds of annotation sizes were summarized further. Finally, it investigated several factors which had impact on the color design of annotations.

Key words map, Annotation, design
(Page:153)

Data Conversion from MapGIS to ArcGIS Using FME
by ZHENG Shike

Abstract Through the analysis of data formats of MapGIS and ArcGIS and the discussion of traditional methods of data conversion, the paper proposed the technical route of using FME to achieve the transition from MapGIS data to ArcGIS data.Comparative analysed the differences of point,line,surface elements in target data and source data.A lot of practice shows that by converting into Geodatabase (MDB) is the best way to achieve the transition from MapGIS data format to ArcGIS data format.

Key words FME ,MapGIS ,ArcGIS ,Data conversion
(Page:155)

Electronic Tachometer Eccentric Lofting New Method for Measuring and its Reliability
by WU Wei

Abstract Currently in engineering surveying, electronic tachometer has been widely used, based on electronic tachometer lofting applications in engineering requirements for lofting points with measurement site must pass visual, however, in the actual work of these two points are often impassability visual. Therefore, this paper presents a new electronic tachometer lofting method, and a detailed discussion on the lofting principle, accuracy and reliability. At the same time, this paper based on the Datang crown close mountain GongSiJi units on the big power limited pressure small project main workshop of pile foundation A standard engineering projects, demonstrates the method of lofting results within and outside precision. It has been found that, this paper expounds the lofting method in different accuracy requirements engineering is feasible and reliable.

Key words eccentric lofting; precision estimation; error analysis; mean square error of a point
(Page:158)