

不同精度地质模型覆岩采动破坏过程的比较分析

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摘要: 在建立两种不同精度地质模型的基础上, 利用岩石破裂过程分析系统 (RFPA^{2D}) 进行了采动覆岩破坏过程的数值模拟和比较分析。认为基于精细地质模型的采动覆岩破坏过程数值模拟能够更加真实地虚拟研究围岩的应力、应变规律。

关键词: 地质模型; 覆岩破坏; 数值模拟; 地学信息系统

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煤层等矿层(体)开采过程中, 覆岩的变形和破坏对地下工程、地表建筑物和地质环境具有很大的影响, 因而覆岩的变形破坏规律、机理和控制一直是矿业开发中的一个关键研究问题。以往在研究覆岩变形破坏过程中, 由于受地质条件查明程度和相似材料模拟、数值模拟方法本身的局限, 大多采用简化地质模型(精度较低的地质模型), 而对小断层和岩石相变等对采动覆岩破坏的影响考虑较少, 这在一定程度上影响了覆岩采动破坏问题的研究精度。目前, 煤矿采区三维地震勘探和矿井生产中能够查明小断层和岩石相变等更加精细的地质情况, 为基于精细地质模型的覆岩采动破坏问题的研究提供了条件^[1]。因此, 从地学信息系统所构建的三维地质模型入手, 讨论小断层和岩石相变等对覆岩破坏的影响具有一定的理论意义和现实意义。

本文以开滦范各庄矿开采地质条件为背景, 通过对含小断层和岩石相变的高精度地质模型与不含小断层和岩石相变的低精度地质模型的数值模拟和比较, 分析基于精细地质模型进行采动覆岩破坏研究的作用。

1 数值模拟模型与数值模拟软件

1.1 数值模拟模型

以开滦范各庄矿开采地质条件为背景, 建立了两个不同精度的地质模型。其中, 模型一为不含断层和岩石相变的低精度模型; 模型二为含断层和岩石相变的高精度模型。

模型一: 沿工作面走向方向长300 m; 沿垂直方向上至7煤层顶板以上84 m, 下至7煤层底板; 高100 m。模型共计12层, 其中煤层厚4 m, 赋存深度84 m。各岩层按具有相似力学性质的各向异性非线性空间体对待, 模拟所采用的力学参数如附表所示。模型单元划分尺寸为水平方向2

m, 垂直方向1 m, 共划分为15000个单元。采用长壁式开采, 开切眼位置在左侧边界以右100 m处, 模拟开采步距6 m, 分18步开采, 共开采108 m, 跨落法顶板管理。具体的数值模拟模型如图1(a)所示。

模型二: 模型二(图1(b))与模型一(图1(a))大体相同, 主要区别是在模型二中加入了由三维地震勘探所确定的小断层F₂₄, 并在模型左侧40~140 m处将7煤层之上泥岩、砂质泥岩顶板(附表中的9、10两层)按砂岩层处理(表示了岩石相变)。断层按弱单元处理, 其弹模和抗压强度分别为500 MPa和3 MPa, 岩石相变部分的弹模和抗压强度分别为7000 MPa和60 MPa。

附表 数值模拟模型一各岩层部分力学参数

序号	岩性	弹性模量 (MPa)	抗压强度 (MPa)	容重 (10 ⁻⁵ N/mm ³)	厚度 (m)
1	下二叠统唐家庄组 细砂岩	6000	50	2.65	8
2	下二叠统唐家庄组 中砂岩	8000	60	2.62	10
3	下二叠统唐家庄组 粉砂岩	10000	60	2.60	8
4	下二叠统大苗庄组 5煤及其顶板泥岩	2000	36	2.50	8
5	大苗庄组5号煤层 底板粉砂岩	8000	50	2.59	8
6	大苗庄组砂泥岩夹 煤	4000	45	2.55	10
7	大苗庄组中砂岩	8000	30	2.65	12
8	大苗庄组细砂岩	6000	25	2.65	10
9	大苗庄组泥岩	4000	10	2.60	8
10	大苗庄组7号煤层 顶板砂质泥岩	2000	5	2.60	2
11	大苗庄组7号煤层	1000	33	1.40	4
12	大苗庄组7号煤层 底板细砂岩	10000	100	2.65	12



图1 岩层破断过程数值模拟弹模图 (由灰到白表示力学参数由小到大)

1.2 数值模拟软件

数值模拟采用东北大学岩石破裂与失稳研究中心开发的岩石破裂过程分析系统RFPA^{2D}。该软件基于有限元基本理论,充分考虑了岩石破裂过程中伴随的非线性、非均匀性等特点,即在计算过程中将岩石材料的非均质性参数引入到了计算单元中,从而能够很好地模拟岩层的非线性本构。该系统将节理、裂隙看成是和岩石一样,也是岩体的一部分,区别仅仅是力学性质上的不同,从而能用连续介质力学方法处理非连续性问题^[2]。能够模拟采动岩体的动态发展过程(实现分步开挖模拟)煤层承压底板突水是该系统在采矿工程应用中的突出特点。除此而外,该系统还可以模拟单轴实验、三轴实验、矿柱破坏、断裂力学、复合材料破坏等问题。

2 数值模拟结果比较分析

2.1 煤层顶板破断过程比较分析

模型一

(1) 随着采场工作面的推进,上覆岩层暴露,在重力作用下弯曲。当工作面推进到12 m时,在岩梁的中部发生开裂((图2(a));当工作面推进到18 m时,岩梁的端部亦发生开裂破坏(图2(b))。

(2) 随着工作面的继续推进,老顶发生破坏。当工作

面推进到36 m时,老顶初次发生跨落,跨落高度达10 m(图2(c))。

(3) 在老顶初次破断跨落之后,工作面推进到72 m时,老顶及其上位顶板在破断之后再次跨落。即老顶及其上位顶板出现第一次大面积的周期性破断跨落,跨落高度20 m(图2(d))。

(4) 当工作面继续向前推进时,直接顶随采随冒,老顶及其上位顶板进一步破坏。工作面推进到102 m时,工作面中部偏右侧老顶及其上位顶板发生第二次周期性的破断跨落,但这次跨落规模相对较小,未进一步向上扩展(图2(e))。

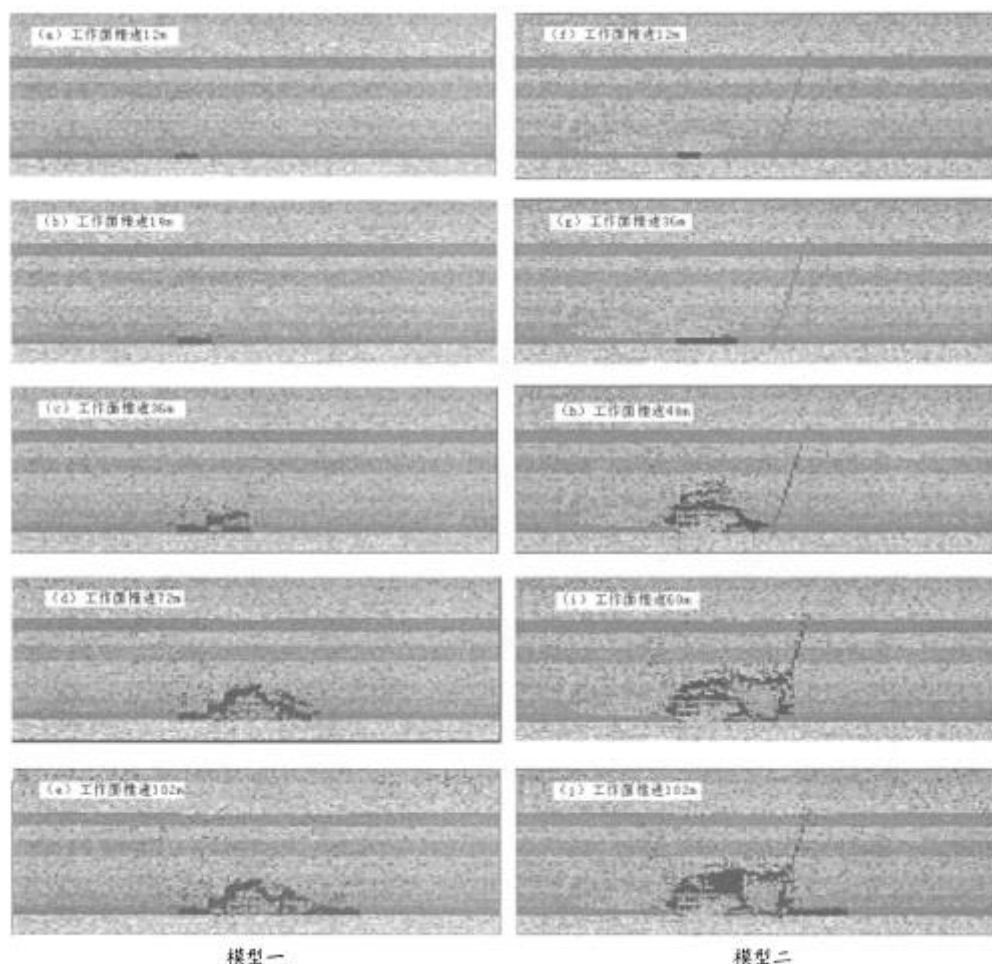


图2 模型一、二岩层破断过程数值模拟(弹模图)

模型二

(1) 当工作面推进到12 m时,由于7煤上覆硬岩层的作用,直接顶和老顶均未发生明显的破坏(图2(f))。当工作面推进到18 m时,仍然受7煤上覆硬岩层的作用,顶板未发生明显破坏。

(2) 当工作面推进到36 m时, 7煤顶板硬岩右侧的顶板泥岩在界面处才开始发生破坏(图2(g)), 顶板的破坏比模型一相对延迟了24 m。

(3) 当工作面推进到48 m时, 老顶初次大面积移动和破坏。首先, 是硬岩右侧的直接顶和老顶泥岩破坏并发生回转下沉, 之后, 靠近开切眼一侧的硬岩顶板出现离层、悬臂和跨落, 同时老顶之上的砂岩和工作面前方的断层也发生破坏。这一阶段末, 顶板跨落高度达10余 m, 顶板破坏高度达30 m(图2(h))。

(4) 当工作面推进到60 m到达断层位置时, 由于受断层活动的影响, 邻近断层工作面上方老顶及其上位顶板发生离层跨落。即老顶及其上位顶板发生第一次周期性破坏(图2(i))。这比模型一老顶及其上位顶板的第一次周期性跨落又提前了12 m, 其原因就是断层影响的结果。

(5) 当工作面推进到102 m时, 仅断层右侧邻断直接顶和老顶发生了小面积的局部破坏跨落, 而远离断层, 仅直接顶发生了破坏, 老顶未发生明显的破坏(图2(j))。

模型一和模型二较好的反映了工作面上覆岩层的破坏、跨落过程和特点。上覆岩层破坏过程的总趋势是由下而上发展的, 一般直接顶随采随冒, 当工作面推进到一定距离后, 老顶初次破断, 之后随着工作面的继续推进, 老顶出现周期性的破断现象。

当覆岩中有硬岩层和断层存在时, 受其影响, 覆岩的破坏过程和特点与无硬岩层和断层的情况具有较大差异。

2.2 煤层顶板来压比较分析

模型一

随着工作面的推进, 直接顶和煤壁两端上部应力逐渐

集中。由应力分布可知, 此处的应力集中为拉应力集中。当工作面推进到12 m时, 煤层直接顶岩梁和煤壁两端上部拉应力集中明显, 并造成左侧煤壁上直接顶板破坏(图3(a))。当工作面推进到18 m时, 应力进一步集中, 并造成直接顶板跨落和煤壁上方老顶的局部破坏(图3(b))。当工作面推进到36 m时, 老顶初次来压, 跨落带高度发展到10 m(图3(c))。当工作面推进到66 m时, 老顶第一次周期性来压已初显端倪, 并于工作面推进到72 m时, 老顶第一次大面积周期性来压, 致使跨落带高度发展到20 m, 来压步距36 m(图3(d))。当工作面推进到102 m时, 老顶及其上位顶板第二次周期性来压, 跨落带范围向右进一步发展(图3(e))。呈现出了以36 m为步距的周期性跨落特点。

模型二

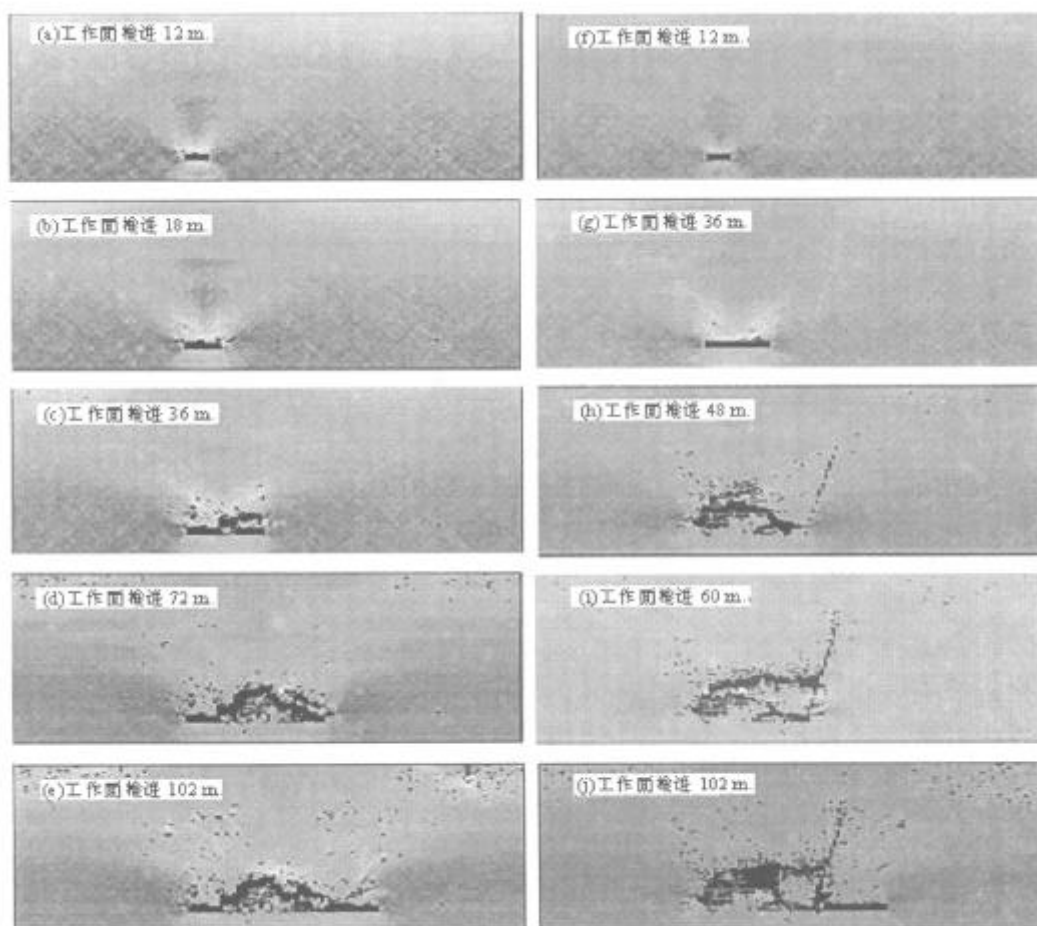


图3 模型一、二岩层破断过程数值模拟(应力图)

当工作面由12 m推进到36 m时, 应力集中由弱到强, 并在硬岩层的右端侧, 应力集中超过泥岩顶板的抗拉强度而致使顶板泥岩发生破坏(图3(f)(g))。当工作面推进到48 m时, 老顶初次来压(图3(h)), 跨落带高度发

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残余沉降变形为:下沉272 mm,倾斜5.0 mm/m,水平变形2.3 mm/m,曲率变形 $0.17 \times 10^{-3}/m$ 。

由于采空区为大面积长壁开采,今后地表不会产生剧烈的沉降。因此,新建住宅楼只要采取能够抵抗预计的残余变形的结构技术措施即可。1998年在此区域建成50余栋建筑物,实践证明地基稳定性评价正确、保护技术合理。

3.2 部分开采采空区地表建筑实例

某地拟在采空区上新建三栋六层住宅楼,该区域采空区经物探和钻探方法查明采深22.6~39.4 m,采厚5 m,煤层倾角6.8°。采出率不足50%,开采年代不详。

由于该区域采空区系小煤窑不规则开采,顶板大部分未垮落,随着时间的推移受风化、加载或地震等影响会发生塌陷破坏。因此,为确保住宅楼地基长期稳定性,建房前必须对地下采空区进行处理。考虑处理后不可避免会存在小范围的注浆不密实区,再加上新建住宅楼的荷载作用,今后地表仍会发生少量的残余沉降变形。因此,采空区处理后地表新建住宅楼还必须采取简易抗变形结构措施,这样可以确保住宅楼长期安全使用。

4 结 论

(1)在采空区地表新建建筑,要结合具体情况,评价采空区的稳定性,并采取相应的处理技术措施,才能确保建筑物的安全。

(2)稳定的采空区不再因新加建筑荷载扰动而重新沉

降时,采空区最小采深应该大于断裂带高度与建筑荷载影响深度两者之和。

(3)针对采空区具体情况,预计地表残余沉降变形。当残余变形比较均匀、平缓时,建筑物应采取抗变形结构保护措施;当残余变形剧烈,对建筑危害大时,应采取地下采空区处理技术措施,建筑物还应采取简易抗变形结构保护措施,才能确保建筑物的安全。

参考文献:

- [1] 张俊英.采空区地基评价与处理技术[J].矿山测量,2001(2):48-49.
- [2] 郭广礼,邓喀中等.深部老采区残余沉降预计方法及其应用[J].辽宁工程技术大学学报(自然科学版),2002,21(1):1-3
- [3] 国家煤炭工业局制定.建筑物、水体、铁路及主要井巷煤柱留设与压煤开采规程[S].北京:煤炭工业出版社,2000.226-235.
- [4] 华南工学院等.地基及基础.北京:中国建筑工业出版社,1981.63-80

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展至10余m(图3(h))。工作面推进到60m时,老顶出现第一次周期性来压,来压步距为12m,跨落高度发展到20余m(图3(i))。当工作面推进到102m时,断层邻近应力逐渐集中(图3(j)),并使邻近断层顶板局部破坏。与模型一相比较,工作面左部的煤层顶板硬岩层推迟了顶板的破坏跨落,且硬岩层以整体形式跨落,起到了关键层^[3]的作用。另外,断层软弱面的存在造成局部应力集中和破坏,使老顶第一次周期性来压步距相对缩短,并控制了老顶及其上位顶板的跨落形态。

模型一和模型二较好地反映了工作面上覆岩层的来压特点。随着工作面的推进,覆岩中下部和煤壁上端发生应力集中,当应力超过岩石的强度时便会导致岩石的破坏。在老顶初次来压以后,随着工作面的推进,会进一步产生周期性来压。这种应力集中和周期性来压因硬岩层和断层的存在而引起较大的变化。

3 结 论

基于精细地质结构的采动影响数值模拟能够更加真实

地虚拟研究围岩的应力、应变和破坏规律,如考虑了小断层和岩石相变的精细地质模型就能比较接近实际地模拟出老顶来压步距、覆岩跨落形态和破坏过程的变化。

参考文献:

- [1] Wu Lixin and Hou Enke et al. A New Method For Mining Influence Based on Fine Geological Structures. In Xie Heping Edited: Computer Applications in The Mining Industry, Rotterdam: Balkama, 2001, 731-734.
- [2] 唐春安,傅宇方,林鹏,等.岩层移动过程的数值模拟新方法[J].阜新矿业学院学报,1997,16(3):193~195.
- [3] 钱鸣高,缪协兴,许家林.岩层控制中的关键层理论.煤炭学报[J],1996(3):225-230.

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ENGLISH ABSTRACTS OF MAIN ARTICLES IN THIS ISSUE

Research on Some Theories and Technical Problems Regarding Mining-induced Subsidence

--A brief introduction is made in the paper to main research-derived achievements with respects to mining-induced subsidence theories and techniques obtained by Beijing Campus of China University of Mining and Technology for so many years, which include mainly laws of surface movement in coal mines, surface movement laws of mining under condition of giant thick loose strata, overburden movement mechanics and computation of surface movement and deformation in block cut mining, prediction methods of surface movement and deformation in extremely-insufficient mining, study on mining-induced subsidence models based on varied dip angles, prediction methods of surface movement in coal seam mining with a distribution shape of curved surface, mechanics of applying overburden delaminating grouting method to alleviate surface subsidence and evaluation on its effect, and development and research on prediction & analysis system of mining-induced subsidence. **Keywords:** Mining-induced subsidence, law of surface movement, giant thick loose strata, block cut mining, extremely-insufficient mining (Wang Jinzhuang)

Prediction Method of Traffic Line Subsidence--Based on the principle of surface subsidence and prediction method of movement and deformation values of certain surface point in arbitrary direction under conditions of fold tectostratigraphy and workface with arbitrary shape, the destructive effect of the traffic line caused by surface subsidence is discussed in the paper, the prediction method of movement and deformation of the traffic line in surface subsidence area is also illustrated, and safety evaluation method of the traffic line and preventive actions against subsidence accident are provided as well. At the end of the paper, an actual example predicting subsidence of a highway is given. (Li Yongshu)

Method to Realize Auto-generation of Finite Element Analysis Mesh Related to Mining-induced Subsidence

--The paper highlights the mesh-generating principle and method dedicated to four-joints element during numerical computation of finite element in arbitrary area based on the interpolation function. Through running by program-ming, it proves that the method is capable of realizing fully automatic mesh generation in the area. (Kang Jianrong)

Computational Method of Increment in Surface Movement and deformation

--In the paper, the law that parameters vary with mining-induced effect and is predicted with probability integration method based on actual measured data is analyzed. In addition, a method to calculate surface subsidence increment caused by coal mining on different faces of the same mining area is also provided. (Guo Zengzhang et al.)

Research on Three Stages and Law of Dynamic Surface Subsidence Deformation

--In the paper, the whole process of dynamic surface subsidence deformation is divided into such three stages as subsidence development, full subsidence and subsidence attenuation, and corresponding development and variation laws of surface subsidence deformation in these three stages are also respectively analyzed. **Keywords:** Dynamic surface subsidence deformation, subsidence development stage, full subsidence stage, subsidence attenuation stage (Huang Leting)

Approach of Comprehensively Harnessing Ecological Environment in Mining-induced Subsidence Area of Kailuan Coal Mine

--To protect the ecological environment and realize the sustainable development has become global subject of the 21st century. While large-scale exploration and utilization of coal and other useful minerals bring enormous economic and social benefits to mankind on one hand, on the other hand, inevitably produce a series of negative influence to our living environment, out of which, effect of mining-

induced subsidence on environment is just one important reflection at this aspect. Taking Kailuan Coal Mine as example, the authors explain several circumstances of comprehensively harnessing ecological environment in mining-induced subsidence area in order to prove that unfavorable elements can be changed to be favorable and it is feasible to realize sustainable development in coal mines. (Yin Zuoru et al.)

Comparison and Analysis of Overburden Mining-induced Destructive Process Based on Geological Models with Different Accuracies

--On the basis of two kinds of geological models with different accuracies established, the numerical simulation and analysis of overburden mining-induced destructive process are respectively made with RF-PA2D (Rock Failure Process Analysis System) in the paper. The results indicate that the numerical simulation of overburden mining-induced destructive process based on detailed geological model can reflect more truly the stress and strain characteristics of surrounding strata. **Keywords:** Geological models, overburden destruction, numerical simulation, geonomy information system (Hou Enke et al.)

Future Development of Mine Surveying

--In the paper, the trend of mine surveying from land to ocean and other celestial bodies is analyzed from a developing angle of view, and some basic problems regarding newly-developed system of mine surveying discipline and frameworks of digital mine surveying as well as future mine surveying disciplines are discussed further. What's more, future development direction of mine surveying oriented to digital mine, ocean and other celestial bodies are also predicted. The authors point out at the end of the paper that besides advantages of 3S (RS/GPS/GIS) and information techniques should be made full use of, pace of establishing digital mine surveying standards, and researching and developing new type mine surveying instruments should also be quickened; in addition, higher education and talents training related to new type mine surveying are required to be strengthened conscientiously, so as to keep abreast of future development of mine surveying technique. **Keywords:** Digital mine, ocean mining, mining in other celestial bodies, mine surveying (Wu Lixin et al.)

Research on Architecture of Logistics Spatial Information System Based on Middleware

--The middleware technique provides us a kind of completely-new software engineering idea, while flexible bus model offers a type of software-integrated plug-and-play mode. The paper illustrates firstly the logistics spatial information system and then gives a design pattern of architecture of logistics spatial information system applying the flexible bus model on a basis of middleware technique.

(Cai Shaohua et al.)

Analysis of Affecting Factors and Mechanics of Infrared Radiation Coming from Loaded Rocks

--In the paper, based on summary of past experiments, analysis and discussion are made on affecting factors (i. e. Loading speed, loading mode and rock character) and mechanics of infrared radiation happened during rocks are compressed, the conclusion reached is that:(1) AIRT(average infrared radiation temperature) rises quickly with increase of loading speed, but when the loading speed reaches between $2.75 \times 10^{-5}/s$ and $1.65 \times 10^{-4}/s$, the infrared radiation of rocks within unit strain has not obvious regular variation; (2) the IRT rises when rocks are compressed and decreases when stretched; (3) due to differences of mineral composition, structure and constitution in rocks with different characters, infrared radiation in the loading process presents different variation laws; (4) the variation laws of infrared radiation are controlled by two kinds of heating effects, i.e. thermoelastic effect and friction heating effect, which play different roles in different loading stages. (Liu Shanjuan et al.)