Note: This document lists all the papers published in Journal of Rock Mechanics and Geotechnical Engineering (JRMGE) since 2009. Please frequently cite them when preparing manuscripts.

Contents

Basic Theories of Rock Mechanics

Constitutive Relations and Failure Criteria

Heping Xie, Liyun Li, Ruidong Peng, et al. Energy analysis and criteria for structural failure of rocks. Journal of Rock Mechanics and Geotechnical Engineering. 2009, 1 (1): 11–20.

http://www.rockgeotech.org/qikan/manage/wenzhang/20090013.pdf

Abstract: The intrinsic relationships between energy dissipation, energy release, strength and abrupt structural failure are key to understanding the evolution of deformational processes in rocks. Theoretical and experimental studies confirm that energy plays an important role in rock deformation and failure. Dissipated energy from external forces produces damage and irreversible deformation within rock and decreases rock strength over time. Structural failure of rocks is caused by an abrupt release of strain energy that manifests as a catastrophic breakdown of the rock under certain conditions. The strain energy released in the rock volume plays a pivotal role in generating this abrupt structural failure in the rocks. In this paper, we propose criteria governing (1) the deterioration of rock strength based on energy dissipation and (2) the abrupt structural failure of rocks based on energy release. The critical stresses at the time of abrupt structural failure under various stress states can be determined by these criteria. As an example, the criteria have been used to analyze the failure conditions of surrounding rock of a circular tunnel.

Maohong Yu, Guiyun Xia, Vladimir A Kolupaev. Basic characteristics and development of yield criteria for geomaterials. Journal of Rock Mechanics and Geotechnical Engineering. 2009, 1 (1): 71–88.

http://www.rockgeotech.org/qikan/manage/wenzhang/20090018.pdf

Abstract: The yield criteria of geomaterials play a crucial role in studying and designing the strength of materials and structures. The basic characteristics of yield criteria for geomaterials need to be studied under the framework of continuum mechanics. These characteristics include the effects of strength difference (SD) of materials in tension and compression, normal stress, intermediate principal stress, intermediate principal shear stress, hydrostatic stress, twin-shear stresses, and the convexity of yield surface. Most of the proposed yield criteria possess only one or some of these basic characteristics. For example, the Tresca yield criterion considers only single-shear stress effect, and ignores the effect of SD, normal stress, intermediate principal stress, intermediate principal shear stress, hydrostatic stress, and twin-shear stresses. The Mohr-Coulomb yield criterion accounts for the effect of SD, normal stress, single-shear stress and hydrostatic stress, but disregards the effect of intermediate principal stress, intermediate principal shear stress, and twin-shear stresses. The basic characteristics remain to be fully addressed in the development of yield criterion. In this paper, we propose a new yield criterion with three features, that is, newly developed, better than existing criteria and ready for application. It is shown that the proposed criterion performs better than the existing ones and is ready for application. The development of mechanical models for various yield criteria and the applications of the unified strength theory to engineering are also summarized. According to a new tetragonal mechanical model, a tension-cut condition is added to the unified strength theory. The unified strength theory is extended to the tension-tension region.

Xingguang Zhao, Meifeng Cai, M. Cai. Considerations of rock dilation on modeling failure and deformation of hard rocks—a case study of the mine-by test tunnel in Canada. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (4): 338–349.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-04-07.pdf

Abstract: For the compressive stress-induced failure of tunnels at depth, rock fracturing process is often closely associated with the generation of surface parallel fractures in the initial stage, and shear failure is likely to occur in the final process during the formation of shear bands, breakouts or V-shaped notches close to the excavation boundaries. However, the perfectly elastoplastic, strain-softening and elasto-brittle-plastic models cannot reasonably describe the brittle failure of hard rock tunnels under high in-situ stress conditions. These approaches often underestimate the depth of failure and overestimate the lateral extent of failure near the excavation. Based on a practical case of the mine-by test tunnel at an underground research laboratory (URL) in Canada, the influence of rock mass dilation on the depth and extent of failure and deformation is investigated using a calibrated cohesion weakening and frictional strengthening (CWFS) model. It can be found that, when

modeling brittle failure of rock masses, the calibrated CWFS model with a constant dilation angle can capture the depth and extent of stress-induced brittle failure in hard rocks at a low confinement if the stress path is correctly represented, as demonstrated by the failure shape observed in the tunnel. However, using a constant dilation angle cannot simulate the nonlinear deformation behavior near the excavation boundary accurately because the dependence of rock mass dilation on confinement and plastic shear strain is not considered. It is illustrated from the numerical simulations that the proposed plastic shear strain and confinement-dependent dilation angle model in combination with the calibrated CWFS model implemented in FLAC can reasonably reveal both rock mass failure and displacement distribution in vicinity of the excavation simultaneously. The simulation results are in good agreement with the field observations and displacement measurement data.

S. V. Lavrikov, O. A. Mikenina, A. F. Revuzhenko. A non-Archimedean number system to characterize the structurally inhomogeneous rock behavior nearby a tunnel. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (2): 153–160.

http://www.rockgeotech.org/qikan/manage/wenzhang/2011-02-04.pdf

Abstract: The development of mathematical models of structurally inhomogeneous media leads to the necessity to consider structure of space itself where deformation occurs, i.e. change of mathematical apparatus itself. The space, whose coordinate axes are non-Archimedean straight lines, has been considered. Refusing the fulfillment of Archimedes's law allows to describe multi-scaling of the space, and so to consider deformation processes on different scale levels. The construction of two-scale mathematical model of rock masses has been considered as an example. The constitutive equations have been formulated on micro- and macro-levels and interaction condition between different levels as well. On micro-level, the elastic behavior of grains and plastic sliding between grains with possible softening are taken into account. On macro-level, the model represents a nonlinear system of equations describing the anisotropic rock mass behavior. On the basis of model, the numerical algorithm and code have been carried out to solve the plane boundary value problems. Examples of numerical simulations of stress-strain state of structural rock masses nearby a tunnel opening are presented. The deformation contours and isolines of stresses are plotted.

Hossein Bineshian, Abdolhadi Ghazvinian, Zahra Bineshian. Comprehensive compressive-tensile strength criterion for intact rock. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (2): 140–148.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120204.pdf

Abstract: This paper presents a strength criterion for intact rock, which can well describe triaxial test data under compressive or tensile stress state. The proposed criterion is defined in terms of three parameters. One parameter expresses the apparent unconfined compressive strength (AUCS), obtained from the Coulomb-Mohr criterion, as a regulated unconfined compressive strength (RUCS). Two other parameters, λ and ζ, are material-dependent that can be determined by regression analysis. The proposed criterion is compared with selected applicable strength criteria separately for compressive and tensile strengths. Coefficient of determination and accordance coefficient are considered in comparisons between the proposed and selected strength criteria.

Ashok Jaiswal, B. K. Shrivastva. A generalized three-dimensional failure criterion for rock masses. Journal of Rock Mechanics and Geotechnical Engineering 2012; 4 (4): 333–343.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120405.pdf

Abstract: The smooth convex generalized failure function, which represents 1/6 part of envelope in the deviatoric plane, is proposed. The proposed function relies on four shape parameters (Ls, a, b and c), in which two parameters (a and b) are dependent on the others. The parameter Ls is called extension ratio. The proposed failure function could be incorporated with any two-dimensional (2D) failure criteria to make it a three-dimensional (3D) version. In this paper, a mathematical formulation for incorporation of Hoek-Brown failure criterion with the proposed function is presented. The Hoek-Brown failure criterion is the most suited 2D failure criterion for geomaterials. Two types of analyses for best-fitting solution of published true tri-axial test data were made by considering (1) constant extension ratio and (2) variable extension ratio. The shape and strength parameters for different types of rocks have been determined by best-fitting the published true tri-axial test data for both the analyses. It is observed from the best-fitting solution by considering uniform extension ratio (Ls) that shape constants have a correlation with Hoek-Brown strength parameters. Thus, only two parameters (c and m) are needed for representing the 3D failure criterion for intact rock. The statistical expression between shape and Hoek-Brown strength parameters is given. In the second analysis, when considering varying extension ratio, another parameter f is introduced.

The modified extension ratio is related to f and extension ratio. The results at minimum mean misfit for all the nine rocks indicate that the range of f varies from 0.7 to 1.0. It is found that mean misfit by considering varying extension ratio is lower than that in the first analysis. But it requires three parameters. A statistical expression between f and Hoek-Brown strength parameters has been established. Though coefficient of correlation is not reasonable, we may eliminate it as an extra parameter. At the end of the paper, a methodology has also been given for its application to isotropic jointed rock mass, so that it can be implemented in a numerical code for stability analysis of jointed rock mass structures.

Nick Barton. Shear strength criteria for rock, rock joints, rockfill and rock masses: Problems and some solutions. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (4): 249–261.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130401.pdf

Abstract: Although many intact rock types can be very strong, a critical confining pressure can eventually be reached in triaxial testing, such that the Mohr shear strength envelope becomes horizontal. This critical state has recently been better defined, and correct curvature or correct deviation from linear Mohr–Coulomb (M-C) has finally been found. Standard shear testing procedures for rock joints, using multiple testing of the same sample, in case of insufficient samples, can be shown to exaggerate apparent cohesion. Even rough joints do not have any cohesion, but instead have very high friction angles at low stress, due to strong dilation. Rock masses, implying problems of large-scale interaction with engineering structures, may have both cohesive and frictional strength components. However, it is not correct to add these, following linear M-C or nonlinear Hoek–Brown (H-B) standard routines. Cohesion is broken at small strain, while friction is mobilized at larger strain and remains to the end of the shear deformation. The criterion ‘c then σn tan φ’ should replace ‘c plus σntan φ’ for improved fit to reality. Transformation of principal stresses to a shear plane seems to ignore mobilized dilation, and caused great experimental difficulties until understood. There seems to be plenty of room for continued research, so that errors of judgement of the last 50 years can be corrected.

Mingqing You. Discussion on “A generalize three-dimensional failure criterion for rock masses”. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (5): 412–416.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130510.pdf

Abstract: There are many methods to construct true triaxial strength criteria for rocks. Jaiswal and Shrivastva (2012) proposed a strength criterion, named J–S criterion, in the deviatoric plane, which provides nearly the same misfits for true triaxial test data as the exponential criterion. It is difficult to calculate the strength at given σ_2 and σ_3 using the J–S criterion, and themultiple solutions to the nonlinear equation may induce confusion and mistake. Strength envelopes in deviatoric planes are not geometric similar; therefore, true triaxial test data cannot be grouped in the mean stress to check strength criteria in the deviatoric plane.

Ashok Jaisal, B.K.Shriasta. Reply to Discussion on “A generalized three-dimensional failure criterion for rock masses”. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (5): 417–418.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130511.pdf

R. Gholami, A. Moradzadeh, V. Rasouli, J. Hanachi. Practical application of failure criteria in determining safe mud weight windows in drilling operations. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (1): 13–25.

http://www.sciencedirect.com/science/article/pii/S1674775513001169 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140102.pdf

Abstract: Wellbore instability is reported frequently as one of the most significant incidents during drilling operations. Analysis of wellbore instability includes estimation of formation mechanical properties and the state of in situ stresses. In this analysis, the only controllable parameter during drilling operation is the mud weight. If the mud weight is larger than anticipated, the mud will invade into the formation, causing tensile failure of the formation. On the other hand, a lower mud weight can result in shear failures of rock, which is known as borehole breakouts. To predict the potential for failures around

the wellbore during drilling, one should use a failure criterion to compare the rock strength against induced tangential stresses around the wellbore at a given mud pressure. The Mohr–Coulomb failure criterion is one of the commonly accepted criteria for estimation of rock strength at a given state of stress. However, the use of other criteria has been debated in the literature. In this paper, Mohr–Coulomb, Hoek–Brown and Mogi–Coulomb failure criteria were used to estimate the potential rock failure around a wellbore located in an onshore field of Iran. The log based analysis was used to estimate rock mechanical properties of formations and state of stresses. The results indicated that amongst different failure criteria, the Mohr–Coulomb criterion underestimates the highest mud pressure required to avoid breakouts around the wellbore. It also predicts a lower fracture gradient pressure. In addition, it was found that the results obtained from Mogi–Coulomb criterion yield a better comparison with breakouts observed from the caliper logs than that of Hoek–Brown criterion. It was concluded that the Mogi–Coulomb criterion is a better failure criterion as it considers the effect of the intermediate principal stress component in the failure analysis.

Basic Properties of Rocks

Guojian Shao, Jingbo Su. Sensitivity and inverse analysis methods for parameter intervals. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (3): 274–280.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-03-08.pdf

Abstract: This paper proposes a sensitivity analysis method for engineering parameters using interval analyses. This method substantially extends the application of interval analysis method. In this scheme, parameter intervals and decision-making target intervals are determined using the interval analysis method. As an example, an inverse analysis method for uncertainty is presented. The intervals of unknown parameters can be obtained by sampling measured data. Even for limited measured data, robust results can also be obtained with the inverse analysis method, which can be intuitively evaluated by the uncertainty expressed in terms of an interval. For complex nonlinear problems, an iteratively optimized inverse analysis model is proposed. In a given set of loose parameter intervals, all the unknown parameter intervals that satisfy the measured information can be obtained by an iteratively optimized inverse analysis model. The influences of measured precisions and the number of parameters on the results of the inverse analysis are evaluated. Finally, the uniqueness of the interval inverse analysis method is discussed.

Mingqing You. Three independent parameters to describe conventional triaxial compressive strength of intact rocks. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (4): 350–356.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-04-08.pdf

Abstract: The strengths of 12 rocks cited from literatures increase in a nonlinear way with increasing confining pressure against the Coulomb criterion. The criteria with power forms like the generalized Hoek-Brown criterion are not available for describing the strength properties in the whole test range for Indiana limestone, Yamaguchi marble and Vosges sandstone, of which the differential stresses are approximately constant at high confining pressures. The exponential criterion with three parameters fits the test data of those 12 rocks well with a low misfit. The three parameters are independent of the uniaxial compressive strength (UCS), the initial increasing rate of strength with confining pressure, and the limitation of differential stress.

Mingqing You. Strength and damage of marble in ductile failure. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (2): 161–166.

http://www.rockgeotech.org/qikan/manage/wenzhang/2011-02-05.pdf

Abstract: To study the effects of loading paths and stress states on rock strength and deformation, marble specimens were axially compressed to various displacements under a confining pressure (CP) firstly, and then the damaged specimens were recompressed under another CP. The bearing capacity of a marble specimen depends merely on CP at the stage of ductile deformation, and it has no relation with the loading history when CP keeps constant or increases. However, the damaged specimen turns into brittle when it is recompressed uniaxially or at a lower CP, and the Young's modulus and strength are lower than those of a dense specimen. The increasing ratio of triaxial strength to CP has a close relation with the areas of fissures in the damaged specimens but not the internal friction angle. Material strength and bearing capacity are two

different conceptions for rocks. Material strength decreases continually as the plastic deformation increases; however, the bearing capacity is determined by both the stress state and the material strength.

Heping Xie, Jianliang Pei, Jianping Zuo, Ru Zhang. Investigation of mechanical properties of fractured marbles by uniaxial compression tests. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (4): 302–313.

http://www.rockgeotech.org/qikan/manage/wenzhang/20110402.pdf

Abstract: Uniaxial compression tests (UCTs) on 34 naturally fractured marble samples taken from the transportation tunnels of Jinping II hydropower station were carried out using the MTS815 Flex test GT rock testing system. Rockburst proneness index WET is determined for the marble samples with the UCTs. According to the number, size and spatial structure characteristics of the internal natural fractures of the marble samples, fractures are basically divided into 4 types, namely, single fracture, parallel fracture, intersectant fracture and mixed fracture. The mechanical properties of naturally fractured rocks (4 types) are analyzed and compared with those of intact rock samples (without natural fractures). Experimental results indicate that failure characteristics of fractured rocks are appreciably controlled by fracture distribution or fracture patterns. Comparison with intact rocks shows that the failure of fractured marbles is a locally progressive failure process and finally rocks fail abruptly. Statistically, the uniaxial compressive strengths (UCSs) of rocks with single, parallel, intersectant and mixed fractures are 0.72, 0.69, 0.59 and 0.46 times those of the intact rocks, respectively. However, the elastic modulus of the fractured Yantang marbles is generally not different from that of intact rocks. But the elastic moduli of Baishan marble with single, intersectant and mixed fractures are 0.61, 0.62 and 0.45 times those of intact rocks, respectively. Experimental results also reveal that WET of fractured marbles is generally smaller than that of intact marbles, which implies that rockburst intensity of fractured marble in field may be controlled to some extent. In addition, the bearing capacity of surrounding rocks is also reduced, thus the surrounding rocks should be supported or reinforced timely according to practical conditions.

Weiguo Liang, Chuanda Zhang, Hongbo Gao, Xiaoqin Yang, Suguo Xu, Yangsheng Zhao. Experiments on mechanical properties of salt rocks under cyclic loading. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (1): 54–61.

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-01-06.pdf

Abstract: The primary purpose of underground gas storages is to provide gas for seasonal consumptions or strategic reserve. The periodical operations of gas injection and extraction lead to cyclic loading on the walls and surrounding rocks of gas storages. To investigate the mechanical behaviors of different host rocks in bedded salt deposit, laboratory experiments were conducted on the samples of rock salt, thenardite, glauberite and gypsum. The mechanical properties of rock samples under monotonic and cyclic loadings were studied. Testing results show that, under monotonic loading, the uniaxial compressive stress (UCS) of glauberite is the largest (17.3 MPa), while that of rock salt is the smallest (14.0 MPa). The UCSs of thenardite and gypsum are 16.3 and 14.6 MPa, respectively. The maximum strain at the peak strength of rock salt (halite) is much greater than those of the other three rocks. The elastic moduli of halite, thenardite, glauberite and gypsum are 3.0, 4.2, 5.1 and 6.8 GPa, respectively. Under cyclic loading, the peak strengths of the rock specimens are deteriorated except for rock salt. The peak strengths of thenardite, glauberite and gypsum decrease by 33.7%, 19.1% and 35.5%, respectively; and the strains of the three rocks at the peak strengths are almost the same. However, the strain of rock salt at the peak strength increases by 1.98%, twice more than that under monotonic loading. Under monotonic loading, deformation of the tested rock salt, thenardite and glauberite shows in an elastoplastic style. However, it changes to a ductile style under cyclic loading. Brittle deformation and failure are only observed for gypsum. The results should be helpful for engineering design and operation of gas storage in bedded salt deposit.

Xiaojun Zhao, Bingrui Chen, Hongbo Zhao, Binghui Jie, Zhengfang Ning. Laboratory creep tests for time-dependent properties of a marble in Jinping II hydropower station. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (2): 168–176.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120207.pdf

Abstract: In order to investigate the time-dependent behaviors of deep hard rocks in the diversion tunnel of Jinping II hydropower station, uniaxial creep tests were carried out by using the triaxial testing machine RC-2000. The axial compressive load was applied step by step and each creep stage was kept for over several days. Test results show that: (1) The lateral deformation of rock specimens is 2–3 times the axial compressive deformation and accelerates drastically before

damage, which may be employed as an indicator to predict the excavation-induced instability of rocks. (2) The resultant deformation changes from compression to expansion when the Poisson's ratio is larger than 0.5, indicating the starting point of damage. (3) In the step-loading stages, the Poisson's ratio approximately remains constant; under constantly imposed load, the Poisson's ratio changes with elapsed time, growing continuously before the specimen is damaged. (4) When the applied load reaches a certain threshold value, the rock deteriorates with time, and the strength of rocks approximately has a negative exponent relation with time. (5) The failure modes of the deep marble are different in long- and short-term loading conditions. Under the condition of short-term loading, the specimen presents a mode of tensile failure; while under the condition of long-term loading, the specimen presents a mode of shear failure, followed by tensile failure.

M. Gasc-Barbier, T. T. N. Hoang, A. Marache, J. Sulem, J. Riss. Morphological and mechanical analysis of natural marble joints submitted to shear tests. Journal of Rock Mechanics and Geotechnical Engineering 2012; 4 (4): 296–311.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120402.pdf

Abstract: In order to evaluate the influence of the surface morphology on the mechanical behavior of twelve natural marble joints, very accurate topography measurements of joint surfaces under constant normal load (CNL) conditions were performed before and after shear tests. The surface topography was carried out using a three-dimensional (3D) laser-scanning profilometer with a parallel grid at a regular interval of 500 μm. Each surface before shearing was reconstructed by geostatistical methods according to eight different directions. A quantitative description of surfaces was performed using global and directional statistical parameters. These parameters allow to determine the surface anisotropy and to divide the joints into three groups of similar morphology according to a given direction. Each sample of the same group is submitted to the same normal stress but to different shear rates ranging from 5 to 20 μm/s. The influences of normal stress and shear rate on the mechanical behavior of the discontinuities were investigated, as well as the influence of the sample morphology on its dilatancy behavior. The morphology data of upper and lower walls also permit to quantify the contact areas before testing. After the shear tests, sheared surfaces were scanned again and reconstructed according to the shearing direction. Based on the topography data of joint surfaces obtained before and after shearing, damage zones that occurred during shearing were located for both walls of each joint. These characterizations of joint surfaces contribute to a better understanding of the shearing behavior of natural discontinuities.

Hongyun Guo, Manchao He, Chonghua Sun, Bing Li, Feng Zhang. Hydrophilic and strength-softening characteristics of calcareous shale in deep mines. Journal of Rock Mechanics and Geotechnical Engineering 2012; 4 (4): 344–351.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120406.pdf

Abstract: To better understand the mechanism of the strength weakening process of soft rocks in deep mines after interacting with water, a self-developed experimental system, Intelligent Testing System for Water Absorption in Deep Soft Rocks (ITSWADSR), is employed to analyze the hydrophilic behavior of deep calcareous shale sampled from Daqiang coal mine. Experimental results demonstrate that the relation between water absorption and time can be expressed by power functions, and the soakage rate decreases while the soakage increases with time. In order to quantitatively calculate the weight coefficients of the influential factors for water absorbing capacity of rocks, a series of testing methods are adopted, including scanning electron microscope (SEM), X-ray diffraction and mercury injection test. It is demonstrated that the effective porosity has a positive correlation with the water absorbing capacity of rocks and the contents of illite and illite/smectite. The initial water content presents a negative correlation with the water absorption capacity of rocks. According to the absolute value of weight coefficients of various influential factors, the order of magnitude from high to low is captured: initial water content, illite, illite/smectite formation (S=5%), and the effective porosity. After water absorption tests, uniaxial compressive strength (UCS) tests were performed on rock specimens allowing a linear relationship between the UCS and the water content of rock to be established, indicating that the strength of calcareous shale decreases linearly with the increasing water content.

Ahmet Ozbek, Mehmet Unsal, Aydin Dikec. Estimating uniaxial compressive strength of rocks using genetic expression programming. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (4): 325–329.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130409.pdf

Abstract: The aim of this paper is to estimate the uniaxial compressive strength (UCS) of rocks with different characteristics

by using genetic expression programming (GEP). For this purpose, five different types of rocks including basalt and ignimbrite (black, yellow, gray, brown) were prepared. Values of unit weight, water absorption by weight, effective porosity and UCS of rocks were determined experimentally. By using these experimental data, five different GEP models were developed for estimating the values of UCS for different rock types. Good agreement between experimental data and predicted results is obtained.

AbbassTaallali, Andre Veroort. Behaviour of layered sandstone under Brazilian test conditions: Layer orientation and shape effects. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (5): 366–377.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130505.pdf

Abstract: The experimental study in this paper focuses on the effects of the layer orientation and sample shape on failure strength and fracture pattern of samples tested under Brazilian test conditions (i.e. diametrical loading of cylindrical discs) for one particular layered sandstone which is from Modave in the south of Belgium. The variations of the strength in combination with the failure patterns are examined as a function of the inclination angle between the layer plane and the loading direction. The experimental, results clearly show that the induced fracture patterns are a combination of tensile and/or shear fractures. In shape effect experiments the layer thickness and the number of layer boundaries are investigated. Different blocks of Modave sandstone are used to prepare samples. The layer thickness is different among the various blocks, but the layer thickness in each studied rock block can be considered to be constant; hence, the number of layer boundaries changes according to the sample diameter for samples of the same block. The experimental study shows that the layer thickness plays a more important role than the number of layer boundaries per sample.

T. Kaerani. A discontinuum-based model to simulate compressive and tensile failure in sedimentary rock. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5(5): 378–388.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130506.pdf

Abstract: The study presented in this paper discusses a discontinuum-based model for investigating strength and failure in sedimentary rocks. The model has been implemented by UDEC to incorporate an innovative orthotropic cohesive constitutive law for contact. To reach this purpose, a user-defined model has been established by creating dynamic link libraries (DLLs) and attaching them into the code. The model reproduces rock material by a dense collection of irregular-sized deformable particles interacting at their cohesive boundaries which are viewed as flexible contacts whose stress-displacement law is assumed to control the fracture and the fragmentation behaviours of the material. The model has been applied to a sandstone. The individual and interactional effects of the microstructural parameters on the material compressive and tensile failure responses have been examined. In addition, the paper presents anew methodical calibration procedure to fit the modelling microparameters. It is shown that the model can successfully reproduce the rock mechanical behaviour quantitatively and qualitatively. The study also shows how discontinuum-based modelling can be used to characterize the relation between the microstructural parameters and the macro-scale properties of a material.

Majid NoorianBidgoli, Zhihong Zhao, Lanru Jing. Numerical evaluation of strength and deformability of fractured rocks. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (6): 419–430.

http://www.sciencedirect.com/science/article/pii/S1674775513001054 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20130601.pdf

Abstract: Knowledge of the strength and deformability of fractured rocks is important for design, construction and stability evaluation of slopes, foundations and underground excavations in civil and mining engineering. However, laboratory tests of intact rock samples cannot provide information about the strength and deformation behaviors of fractured rock masses that include many fractures of varying sizes, orientations and locations. On the other hand, large-scale in situ tests of fractured rock masses are economically costly and often not practical in reality at present. Therefore, numerical modeling becomes necessary. Numerical predicting using discrete element methods (DEM) is a suitable approach for such modeling because of their advantages of explicit representations of both fractures system geometry and their constitutive behaviors of fractures,

besides that of intact rock matrix. In this study, to generically determine the compressive strength of fractured rock masses, a series of numerical experiments were performed on two-dimensional discrete fracture network models based on the realistic geometrical and mechanical data of fracture systems from field mapping. We used the UDEC code and a numerical servo-controlled program for controlling the progressive compressive loading process to avoid sudden violent failure of the models. The two loading conditions applied are similar to the standard laboratory testing for intact rock samples in order to check possible differences caused by such loading conditions. Numerical results show that the strength of fractured rocks increases with the increasing confining pressure, and that deformation behavior of fractured rocks follows elasto-plastic model with a trend of strain hardening. The stresses and strains obtained from these numerical experiments were used to fit the well-known Mohr-Coulomb (MC) and Hoek-Brown (H-B) failure criteria, represented by equivalent material properties defining these two criteria. The results show that both criteria can provide fair estimates of the compressive strengths for all tested numerical models. Parameters of the elastic deformability of fractured models during elastic deformation stages were also evaluated, and represented as equivalent Young's modulus and Poisson's ratio as functions of lateral confining pressure. It is the first time that such systematic numerical predicting for strength of fractured rocks was performed considering different loading conditions, with important findings for different behaviors of fractured rock masses, compared with testing intact rock samples under similar loading conditions.

C. Lambert, C. Coll. Discrete modeling of rock joints with a smooth-joint contact model. Journal of Rock Mechanics and Geotechnical Engineering 2014; 6 (1): 1–12.

http://www.sciencedirect.com/science/article/pii/S1674775513001194 or
http://www.rockgeotech.org/qikan/manage/wenzhang/20140101.pdf

Abstract: Structural defects such as joints or faults are inherent to almost any rock mass. In many situations those defects have a major impact on slope stability as they can control the possible failure mechanisms. Having a good estimate of their strength then becomes crucial. The roughness of a structure is a major contributor to its strength through two different aspects, i.e. the morphology of the surface (or the shape) and the strength of the asperities (related to the strength of the rock). In the current state of practice, roughness is assessed through idealized descriptions (Patton strength criterion) or through empirical parameters (Barton JRC). In both cases, the multi-dimensionality of the roughness is ignored. In this study, we propose to take advantage of the latest developments in numerical techniques. With 3D photogrammetry and/or laser mapping, practitioners have access to the real morphology of an exposed structure. The derived triangulated surface was introduced into the DEM (discrete element method) code PFC3D to create a synthetic rock joint. The interaction between particles on either side of the discontinuity was described by a smooth-joint model (SJM), hence suppressing the artificial roughness introduced by the particle discretization. Shear tests were then performed on the synthetic rock joint. A good correspondence between strengths predicted by the model and strengths derived from well-established techniques was obtained for the first time. Amongst the benefits of the methodology is the possibility offered by the model to be used in a quantitative way for shear strength estimates, to reproduce the progressive degradation of the asperities upon shearing and to analyze structures of different scales without introducing any empirical relation.

Majid Noorian Bidgoli, Lanru Jing. Anisotropy of strength and deformability of fractured rocks. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (2): 156–164.

http://www.sciencedirect.com/science/article/pii/S1674775514000183 or
http://www.rockgeotech.org/qikan/manage/wenzhang/20140210.pdf

Abstract: Anisotropy of the strength and deformation behaviors of fractured rock masses is a crucial issue for design and stability assessments of rock engineering structures, due mainly to the non-uniform and non-regular geometries of the fracture systems. However, no adequate efforts have been made to study this issue due to the current practical impossibility of laboratory tests with samples of large volumes containing many fractures, and the difficulty for controlling reliable initial and boundary conditions for large-scale in situ tests. Therefore, a reliable numerical predicting approach for evaluating anisotropy of fractured rock masses is needed. The objective of this study is to systematically investigate anisotropy of

strength and deformability of fractured rocks, which has not been conducted in the past, using a numerical modeling method. A series of realistic two-dimensional (2D) discrete fracture network (DFN) models were established based on site investigation data, which were then loaded in different directions, using the code UDEC of discrete element method (DEM), with changing confining pressures. Numerical results show that strength envelopes and elastic deformability parameters of tested numerical models are significantly anisotropic, and vary with changing axial loading and confining pressures. The results indicate that for design and safety assessments of rock engineering projects, the directional variations of strength and deformability of the fractured rock mass concerned must be treated properly with respect to the directions of in situ stresses. Traditional practice for simply positioning axial orientation of tunnels in association with principal stress directions only may not be adequate for safety requirements. Outstanding issues of the present study and suggestions for future study are also presented.

Rock Dynamics

Qihu Qian, Chengzhi Qi, Mingyang Wang. Dynamic strength of rocks and physical nature of rock strength. Journal of Rock Mechanics and Geotechnical Engineering. 2009, 1 (1): 1–10.

http://www.rockgeotech.org/qikan/manage/wenzhang/20090001.pdf

Abstract: Time-dependence of rock deformation and fracturing is often ignored. However, the consideration of the time-dependence is essential to the study of the deformation and fracturing processes of materials, especially for those subject to strong dynamic loadings. In this paper, we investigate the deformation and fracturing of rocks, its physical origin at the microscopic scale, as well as the mechanisms of the time-dependence of rock strength. Using the thermo-activated and macro-viscous mechanisms, we explained the sensitivity of rock strength to strain rate. These mechanisms dominate the rock strength in different ranges of strain rates. It is also shown that a strain-rate dependent Mohr-Coulomb-type constitutive relationship can be used to describe the influence of strain rate on dynamic rock fragmentation. A relationship between the particle sizes of fractured rocks and the strain rate is also proposed. Several time-dependent fracture criteria are discussed, and their intrinsic relations are discussed. Finally, the application of dynamic strength theories is discussed.

Xibing Li, Zilong Zhou, Fujun Zhao, et al. Mechanical properties of rock under coupled static-dynamic loads. Journal of Rock Mechanics and Geotechnical Engineering. 2009, 1 (1): 41–47.

http://www.rockgeotech.org/qikan/manage/wenzhang/20090019.pdf

Abstract: Rock drilling machine, INSTRON testing system, and SHPB device are updated to investigate the characteristics of rocks at great depth, with high loads from overburden, tectonic stresses and dynamic impacts due to blasting and boring. It is verified that these testing systems can be used to study the mechanical properties of rock material under coupled static and dynamic loading condition and give useful guidance for the deep mining and underground cavern excavation. Various tests to determine the rock strength, fragmentation behavior, and energy absorption were conducted using the updated testing systems. It is shown that under coupled static-dynamic loads, if the axial prestress is lower than its elastic limit, the rock strength is higher than the individual static or dynamic strength. At the same axial prestress, rock strength under coupled loads rises with the increasing strain rates. Under coupled static and dynamic loads, rock is observed to fail with tensile mode. While shear failure may exist if axial prestress is high enough. In addition, it is shown that the percentage of small particles increases with the increasing axial prestress and impact load based on the analysis of the particle-size distribution of fragments. It is also suggested that the energy absorption ratio of a specimen varies with coupled loads, and the maximum energy absorption ratio for a rock can be obtained with an appropriate combination of static and dynamic loads.

S. Huang, Rong Chen, K. W. Xia. Quantification of dynamic tensile parameters of rocks using a modified Kolsky tension bar apparatus. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (2): 162–168.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-02-10.pdf

Abstract: For brittle materials, the tensile strength plays an important role in mechanical analyses and engineering applications. Although quasi-static direct and dynamic indirect tensile strength testing methods have already been developed for rocks, the dynamic direct pull test is still necessary to accurately determine the tensile strength of rocks. In

this paper, a Kolsky tension bar system is developed for measuring the dynamic direct tensile strength of rocks. A dumbbell-shaped sample is adopted and attached to the bars using epoxy glue. The pulse shaping technique is utilized to eliminate the inertial effect of samples during test. The single pulse loading technique is developed for the effective microstructure analyses of tested samples. Two absorption devices are successfully utilized to reduce the reflection of waves in the incident bar and transmitted bar, respectively. Laurentian granite (LG) is tested to demonstrate the feasibility of the proposed method. The tensile strength of LG increases with the loading rate. Furthermore, the nominal surface energy of LG is measured, which also increases with the loading rate.

Jianchun Li, Haibo Li, Guowei Ma. Stochastic seismic wave interaction with a rock joint having Coulomb-slip behavior. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (4): 321–330.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-04-05.pdf

Abstract: Seismic wave interaction with a slippery rock joint with an arbitrary impinging angle is analytically studied based on the conservation of momentum on the wave fronts. Based on the displacement discontinuity method, the wave propagation equations are derived for incident P- and S-waves. By comparison, the calculated transmission and reflection coefficients for normal incident waves are the same as the existing results, which proves the wave propagation equation obtained in the paper is correct. The wave propagation derived in the context can be applied to incident waves with different waveforms. Stochastic seismic waves are then used to analyze the seismic wave interaction with the slippery rock joint, where the stochastic seismic waves are generated from frequency spectra. The parametric studies are carried out to investigate the effect of type, intensity and impinging angle of the incident seismic waves on the wave propagation across the slippery rock joint.

G.W. Ma, H. Hao, F. Wang. Simulations of explosion-induced damage to underground rock chambers. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (1): 19–29.

http://www.rockgeotech.org/qikan/manage/wenzhang/2011-01-03.pdf

Abstract: A numerical approach is presented to study the explosion-induced pressure load on an underground rock chamber wall and its resultant damage to the rock chamber. Numerical simulations are carried out by using a modified version of the commercial software AUTODYN. Three different criteria, i.e. a peak particle velocity (PPV) criterion, an effective strain (ES) criterion, and a damage criterion, are employed to examine the explosion-induced damaged zones of the underground rock chamber. The results show that the charge chamber geometry, coupling condition and charge configuration affect significantly the dynamic pressure exerted on the rock chamber wall. Thus the chamber is damaged. An inaccurate approximation of pressure boundary ignoring the influences of these factors would result in an erroneous prediction of damaged area and damage intensity of the charge chamber. The PPV criterion yields the largest damaged zone while the ES criterion gives the smallest one. The presented numerical simulation method is superior in consideration of the chamber geometry, loading density, coupling condition and rock quality. The predicted damage intensity of rock mass can be categorized quantitatively by an isotropic damage scalar. Safe separation distance of adjacent chambers for a specific charge weight is also estimated.

L.F. Fan, F. Ren, G.W. Ma. An extended displacement discontinuity method for analysis of stress wave propagation in viscoelastic rock mass. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (1): 73–81.

http://www.rockgeotech.org/qikan/manage/wenzhang/2011-01-08.pdf

Abstract: An extended displacement discontinuity method (EDDM) is proposed to analyze the stress wave propagation in jointed viscoelastic rock mass (VRM). The discontinuities in a rock mass are divided into two groups. The primary group with an average geometrical size larger than or in the same order of magnitude of wavelength of a concerned stress wave is defined as “macro-joints”, while the secondary group with a high density and relatively small geometrical size compared to the wavelength is known as “micro-defects”. The rock mass with micro-defects is modeled as an equivalent viscoelastic medium while the macro-joints in the rock mass are modeled explicitly as physical discontinuities. Viscoelastic properties of a micro-defected sedimentary rock are obtained by longitudinally impacting a cored long sedimentary rod with a pendulum. Wave propagation coefficient and dynamic viscoelastic modulus are measured. The EDDM is then successfully employed to analyze the wave propagation across macro-joint in VRM. The effect of the rock viscosity on the stress wave propagation is evaluated by comparing the results of VRM from the presented EDDM with those of an elastic rock mass (ERM) from the conventional displacement discontinuity method (CDDM). The CDDM is a special case of the EDDM under the condition

that the rock viscosity is ignored. Comparison of the reflected and transmitted waves shows that the essential rock viscosity has a significant effect on stress wave attenuation. When a short propagation distance of a stress wave is considered, the results obtained from the CDDM approximate to the EDDM solutions, however, when the propagation distance is sufficiently long relative to the wavelength, the effect of rock viscosity on the stress wave propagation cannot be ignored.

Chun'an Tang, Shibin Tang. Applications of rock failure process analysis (RFPA) method. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (4): 352–372.

http://www.rockgeotech.org/qikan/manage/wenzhang/20110406.pdf

Abstract: Brittle failure of rocks is a classical rock mechanical problem. Rock failure not only involves initiation and propagation of single crack, but also is a complex problem associated with initiation, propagation and coalescence of many cracks. The rock failure process analysis (RFPA) tool has been proposed since 1995. The heterogeneity of rocks at a mesoscopic level is considered by assuming that the material properties conform to the Weibull distribution. Elastic damage mechanics is used for describing the constitutive law of the meso-level element, the finite element method (FEM) is employed as the basic stress analysis tool, and the maximum tensile strain criterion and the Mohr-Coulomb criterion are utilized as the damage threshold. In order to solve the stability analysis problem related to rock engineering structures, fundamental principles of strength reduction method (SRM) and gravity increase method (GIM) are introduced into the RFPA. And the acoustic emission (AE) event rate is employed as the criterion for rock engineering failure. The prominent feature of the RFPA-SRM and RFPA-GIM for stability analysis of rock engineering is that the factor of safety can be obtained without any presumption for the shape and location of the failure surface. In this paper, several geotechnical engineering applications that use the RFPA method to analyze their stability are introduced to provide some references for relevant researches. The principles of the RFPA method in engineering are introduced firstly, and then the stability analysis of tunnel, slope and dam is focused on. The results indicate that the RFPA method is capable of capturing the mechanism of rock engineering stability and has the potential for application in a larger range of geo-engineering.

Dunfu Zhang, Weishen Zhu, Shucai Li, Bo Zhang, Weidong Wang. A modified maximum tangential tensile stress criterion for three-dimensional crack propagation. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (1): 62–72

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-01-07.pdf

Abstract: The three-dimensional (3D) crack propagation is a hot issue in rock mechanics. To properly simulate 3D crack propagation, a modified maximum tangential tensile stress criterion is proposed. In this modified criterion, it is supposed that cracks propagate only at crack front in the principal normal plane. The tangential tensile stress at crack front in the principal normal plane in local coordinates is employed to determine crack propagation, which is calculated through coordinate transformation from global to local coordinates. New cracks will propagate when the maximum tangential tensile stress at crack front in the principal normal plane reaches the tensile strength of rock-like materials. Compared with the previous crack propagation criteria, the modified crack propagation criterion is helpful in calculating 3D crack stress intensity factor, and can overcome the limitations of propagation step determined by individual experiences in previous studies. Finally, the 3D crack propagation process is traced by element-free Galerkin method. The numerical results agree well with the experimental ones for a frozen resin sample with prefabricated 3D cracks.

S.Y. Wang, L. Sun, C. Yang, S.Q. Yang, C.A. Tang. Numerical study on static and dynamic fracture evolution around rock cavities. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (4): 262–276.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130402.pdf

Abstract: In this paper, a numerical code, RFPA2D (rock failure process analysis), was used to simulate the initiation and propagation of fractures around a pre-existing single cavity and multiple cavities in brittle rocks. Both static and dynamic loads were applied to the rock specimens to investigate the mechanism of fracture evolution around the cavities for different lateral pressure coefficients. In addition, characteristics of acoustic emission (AE) associated with fracture evolution were simulated. Finally, the evolution and interaction of fractures between multiple cavities were investigated with consideration of stress redistribution and transference in compressive and tensile stress fields. The numerically simulated results reproduced primary tensile, remote, and shear crack fractures, which are in agreement with the experimental results. Moreover, numerical results suggested that both compressive and tensile waves could influence the propagation of tensile cracks; in

particular, the reflected tensile wave accelerated the propagation of tensile cracks.

Rockburst and Micro-seismic Monitoring

Chun'an Tang, Jimin Wang, Jingjian Zhang. Preliminary engineering application of microseismic monitoring technique to rockburst prediction in tunneling of Jinping II project. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (3): 193–208.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-03-01.pdf

Abstract: Monitoring and prediction of rockburst remain to be worldwide challenges in geotechnical engineering. In hydropower, transportation and other engineering fields in China, more deep, long and large tunnels have been under construction in recent years and underground caverns are more evidently featured by "long, large, deep and in group", which bring in many problems associated with rock mechanics problems at great depth, especially rockburst. Rockbursts lead to damages to not only underground structures and equipments but also personnel safety. It has been a major technical bottleneck in future deep underground engineering in China. In this paper, compared with earthquake prediction, the feasibility in principle of monitoring and prediction of rockbursts is discussed, considering the source zones, development cycle and scale. The authors think the feasibility of rockburst prediction can be understood in three aspects: (1) the heterogeneity of rock is the main reason for the existence of rockburst precursors; (2) deformation localization is the intrinsic cause of rockburst; and (3) the interaction between target rock mass and its surrounding rock mass is the external cause of rockburst. As an engineering practice, the application of microseismic monitoring techniques during tunnel construction of Jinping II Hydropower Station was reported. It is found that precursory microcracking exists prior to most rockbursts, which could be captured by the microseismic monitoring system. The stress concentration is evident near structural discontinuities (such as faults or joints), which shall be the focus of rockburst monitoring. It is concluded that, by integrating the microseismic monitoring and the rock failure process simulation, the feasibility of rockburst prediction is expected to be enhanced.

Faquan Wu, Jie Wu, Shengwen Qi. Phenomena and theoretical analysis for the failure of brittle rocks. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (4): 331–337.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-04-06.pdf

Abstract: Rockburst, an unstable failure of brittle rocks, has been greatly concerned in rock mechanics and rock engineering for more than 100 years. The current understanding on the mechanical mechanism of rockburst is based on the Coulomb theory, i.e. compressive-shear failure theory. This paper illustrates a series of tensile and tensile-shear fracture phenomena of rockburst, and proposes a methodology for the analysis of fracture mode and its energy dissipation process based on Griffith theory. It is believed that: (1) the fracture modes of rockburst should include compressive-shear, tensile-shear and pure tensile failures; (2) the rupture angle of rock mass decreases with the occurrence of tensile stress; (3) the proportion of kinetic energy in the released strain energy from a rockburst may be much larger than that transferred into surface energy; and (4) the understanding on the tensile and tensile-shear failure modes of rockburst may change the basic thinking of rockburst control, i.e. from keeping the reduction in initial compressive stress σ_3 to restricting the creation of secondary tensile stress.

Qihu Qian, Xiaoping Zhou. Quantitative analysis of rockburst for surrounding rocks and zonal disintegration mechanism in deep tunnels. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (1): 1–9.

http://www.rockgeotech.org/qikan/manage/wenzhang/2011-01-01.pdf

Abstract: Rock masses without pre-existing macrocracks can usually be considered as granular materials with only microcracks. During the excavation of the tunnels, microcracks may nucleate, grow and propagate through the rock matrix; secondary microcracks may appear, and discontinuous and incompatible deformation of rock masses may occur. The classical continuum elastoplastic theory is not suitable for analyzing discontinuous and incompatible deformation of rock masses. Based on non-Euclidean model of the discontinuous and incompatible deformation of rock masses, the distribution of stresses in the surrounding rock masses in deep tunnels is fluctuant or wave-like. The stress concentration at the tips of microcracks located in vicinity of stress wave crest is comparatively large, which may lead to the unstable growth and coalescence of secondary microcracks, and consequently the occurrence of fractured zones. On the other hand, the stress concentration at the tips of microcracks located around stress wave trough is relatively small, which may lead to the arrest of

microcracks, and thus the non-fractured zones. The alternate appearance of stress wave crest and trough thus may induce the alternate occurrence of fractured and non-fractured zones in deep rock masses. For brittle rocks, the dissipated energy of microcrack growth is small, but the elastic strain energy stored in rock masses may be larger than the dissipated energy growths of pre-existing microcracks and secondary microcracks. The sudden release of the residual elastic strain energy may lead to rockburst. Based on this understanding, the criteria of rockburst are established. Furthermore, the relationship between rockbursts and zonal disintegration in the surrounding rock masses around deep tunnels is studied. The influences of the in-situ stresses and the physico-mechanical parameters on the distribution of rockburst zones and the ejection velocity of rock fragments are investigated in detail.

Manchao He, Yu Wang, Zhigang Tao. A new early-warning prediction system for monitoring shear force of fault plane in the active fault. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (3): 223–231.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-03-03.pdf

Abstract: The most common method used to describe earthquake activity is based on the changes in physical parameters of the earth's surface such as displacement of active fault and seismic wave. However, such approach is not successful in forecasting the movement behaviors of faults. In the present study, a new mechanical model of fault activity, considering the shear strength on the fault plane and the influence of the resistance force, is established based on the occurrence condition of earthquake. A remote real-time monitoring system is correspondingly developed to obtain the changes in mechanical components within fault. Taking into consideration the local geological conditions and the history of fault activity in Zhangjiakou of China, an active fault exposed in the region of Zhangjiakou is selected to be directly monitored by the real-time monitoring technique. A thorough investigation on local fault structures results in the selection of two suitable sites for monitoring potential active tectonic movements of Zhangjiakou fault. Two monitoring curves of shear strength, recorded during a monitoring period of 6 months, turn out to be steady, which indicates that the potential seismic activities hardly occur in the adjacent region in the near future. This monitoring technique can be used for early-warning prediction of the movement of active fault, and can help to further gain an insight into the interaction between fault activity and relevant mechanisms.

Lipeng Liu, Xiaogang Wang, Yizhong Zhang, Zhixin Jia, Qingwei Duan. Tempo-spatial characteristics and influential factors of rockburst: a case study of transportation and drainage tunnels in Jinping II hydropower station. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (2): 179–185.

http://www.rockgeotech.org/qikan/manage/wenzhang/2011-02-07.pdf

Abstract: Jinping II hydropower station is located in a high in-situ stress region in Southwest China. During the excavations of the transportation and drainage tunnels, more than 460 rockburst events were recorded in the transportation tunnel and 110 in the drainage tunnel, which has a serious and negative influence on the tunnels' construction and the safety of staff and equipment. In the paper, the characters of rockburst patterns are analyzed for the transportation and drainage tunnels. The results are illustrated as follow: (1) Most of intensive rockbursts occur in the layer T_{2b}, and continuous occurrences of rockbursts are more frequently observed than those in other layers. (2) The critical overburden depth of rockburst in the transportation tunnel is 600 m, and the length of the continuous occurrence section of rockburst is smaller than 25 m. The damaged depth of the rockburst has the tendency to increase with the increasing overburden depth, and the maximum damaged depth is over 3.5 m. (3) From east to west (west to east) in Jinping II hydropower station, the rockburst usually takes place in the right (left) side of tunnel working face, and then the left (right) or roof of the tunnel. The total length of the continuous occurrence section of rockburst is 57.4%–62.2% of the overall rockburst length, followed by the rockbursts of flake-splitting type and other types. (4) Compared with the transportation tunnel, the intensity of rockburst in the drainage tunnel is higher while the length of the continuous occurrence section of rockburst is smaller. The rockburst section with length less than 10 m and depth of 1 m mainly occurs in the layer at a depth of 1 800–2 000 m. The influences of opening geometry and excavation method on the characteristics of the adjacent zone are great, but the influence of the stress among the tunnel group induced by excavation is relatively low.

Maochen Ge. Source location error analysis and optimization methods. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (1): 1–10.

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-01-01.pdf

Abstract: The efficiency of an optimization method for acoustic emission/microseismic (AE/MS) source location is

determined by the compatibility of its error definition with the errors contained in the input data. This compatibility can be examined in terms of the distribution of station residuals. For an ideal distribution, the input error is held at the station where it takes place as the station residual and the error is not permitted to spread to other stations. A comparison study of two optimization methods, namely the least squares method and the absolute value method, shows that the distribution with this character constrains the input errors and minimizes their impact, which explains the much more robust performance by the absolute value method in dealing with large and isolated input errors. When the errors in the input data are systematic and/or extreme in that the basic data structure is altered by these errors, none of the optimization methods are able to function. The only means to resolve this problem is the early detection and correction of these errors through a data screening process. An efficient data screening process is of primary importance for AE/MS source location. In addition to its critical role in dealing with those systematic and extreme errors, data screening creates a favorable environment for applying optimization methods.

Manchao He, Hongman Xia, Xuena Jia, Weili Gong, Fei Zhao, Kangyuan Liang. Studies on classification, criteria and control of rockbursts. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (2): 97–114.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120201.pdf

Abstract: This paper attempts to present the findings involving rockbursts classification, rockburst failure criteria, and related control measures. Experimental investigations were performed using the strainburst testing machine and impact-induced rockburst testing machine. According to the stress paths and experimental methods, rockbursts were classified into two major groups, i.e. the strainbursts and impact-induced bursts. The mechanisms and criteria of rockburst obtained from experimental investigations were discussed. Then, the developments of constant-resistance and large-deformation bolt (CRLDB), which can adapt itself to the external loading at a constant resistance by elongating continually, were introduced. The deformation energy of country rocks with large deformation can be absorbed by CRLDBs. Finally, the principles and the experimental results for control and prevention of rockburst using the CRLDBs were presented.

M. Ge, H. R. Hardy Jr., H. Wang. A retrievable sensor installation technique for acquiring high frequency signals. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (2): 127–139.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120203.pdf

Abstract: The use of in-seam waves for void detection in mines requires the capability of capturing high frequency signals over large distances. For instance, the Airy phase of Love waves which are used for void detection in coal mines ranges from several hundred to over one thousand Hertz and the expected travel distance of these signals is at least 90 m (equivalent to a detection distance of 45 m) for the technique to be considered practical. In order to obtain high quality and broadband signals, sensors are conventionally grouted at the bottom of boreholes so that the attenuation due to the fractured surface is minimized and the coupling effect is improved. However, to be economically feasible, the expensive and high sensitive sensors must be retrievable so that they can be used repeatedly at the same or other locations. Because of these concerns, a retrievable sensor installation technique was developed. This paper provides a detailed review of the technique as well as a brief discussion of its applications. The technique is simple and reliable for both installation and retrieval operations and can be used for boreholes oriented in any directions. The technique has been demonstrated in over 200 sensor installation/retrieval operations under various borehole conditions, including bituminous coal, anthracite coal, shale, sandstone and trona. With this technique, we were able to detect the high frequency signals required for our projects. For instance, the signals used at a trona mine for void detection have a typical frequency of 5 kHz with the travel distance of 150–200 m. The results of these operations have shown that sensors installed in the prescribed manner exhibit predictable, consistent, and repeatable performance. The technique also provides an economical and reliable means for many other field seismic monitoring applications where high quality and broadband signals are essential, such as microseismic monitoring and geotomography studies.

Peter K. Kaiser, Ming Cai. Design of rock support system under rockburst condition. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (3): 215–227.

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-03-03.pdf

Abstract: As mining and civil tunneling progresses to depth, excavation-induced seismicity and rockburst problems increase and cannot be prevented. As an important line of defense, ground control measures and burst-resistant rock

support are used to prevent or minimize damage to excavations and thus to enhance workplace safety. Rock support in burst-prone ground differs from conventional rock support where controlling gravity-induced rockfalls and managing shallow zones of loose rock are the main target. Rock support in burst-prone ground needs to resist dynamic loads and large rock dilation due to violent rock failure. After reviewing the rockburst phenomenon, types of rockbursts, damage mechanisms, and rockburst support design principles and acceptability criteria, this paper describes that the support selection process in burst-prone ground is iterative, requiring design verification and modification based on field observations. An interactive design tool for conducting rockburst support design in underground tunnels is introduced to facilitate cost-effective design.

K. L. Riemer, R. J. Durrheim. Mining seismicity in the Witwatersrand Basin: monitoring, mechanisms and mitigation strategies in perspective. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (3): 228–249.

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-03-04.pdf

Abstract: The Kaapvaal Craton in South Africa hosts one of the largest gold placer deposits in the world. Mining in the Witwatersrand Basin here has been the source of about one third to one half of the gold ever produced in the world. Gold was discovered in the Johannesburg area in 1886 and after 120 years of continuous operation, mining is currently approaching depths of 4 000 m. In spite of the challenges and risks that the industry has had to deal with including rock temperature, ventilation and water, one of the most feared hazards in the basin has been the threat from the ongoing occurrence of seismicity and rockbursts. The problem first manifested itself by way of the occurrence of tremors roughly twenty years after the commencement of mining operations. This paper traces the history of the approach to rockbursts and seismicity during the 120 year history of mining in the basin. It portrays a picture of the mining seismicity in terms of monitoring phases, mechanisms and mitigation strategies. The work of research organizations over the years is highlighted with a brief mention of current regulation strategies on the part of the mining inspectorate.

Jimin Wang, Xionghui Zeng, Jifang Zhou. Practices on rockburst prevention and control in headrace tunnels of Jinping II hydropower station. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (3): 258–268.

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-03-06.pdf

Abstract: Rockburst problems induced by high in-situ stresses were prominent during construction of the headrace tunnels of Jinping II hydropower station. The rockbursts occurred in various forms, and it is necessary to take pertinent measures for integrated prevention and control of rockbursts. In view of the rockburst characteristics during tunnel construction of Jinping II hydropower station, the engineering geological conditions were presented, and the features, mechanisms and forms of rockbursts observed during construction were analyzed in detail. A large number of scientific researches, experiments and applications were conducted. Multiple measures were adopted to prevent and control rockbursts, including the prediction and early warning measures, stress relief by blasting in advance, optimized blasting design and optimized tunnel support in the tunnel sections prone to strong rockbursts. The effectiveness of these prevention and control measures was evaluated. Experiences have been accumulated through a great number of helpful explorations and practices for rockburst prevention and control. A comprehensive rockburst prevention and control system has been gradually established.

Xiating Feng, Bingrui Chen, Shaojun Li, et al. Studies on the evolution process of rockbursts in deep tunnels. Journal of Rock Mechanics and Geotechnical Engineering 2012; 4 (4): 289–295.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120401.pdf

Abstract: This paper focuses on the evolution processes of different types of rockbursts occurring in deep tunnels. A series of laboratory tests and in-situ monitoring in deep tunnels excavated by tunnel boring machine (TBM) and drill-and-blast (D&B) method have been conducted to understand the mechanisms and processes of the evolution of different types of rockbursts, including strain rockburst, strain-structure slip rockburst, immediate rockburst and time-delayed rockburst. Three different risk assessment methods are proposed to evaluate the intensity and potential failure depth of rockbursts. These methods can be applied before excavation and the results can be updated according to the real-time information during excavation. Two micro-seismicity based real-time warning systems have been established for predicting various intensities of rockbursts, such as slight, moderate, intensive and extremely intensive rockbursts. Meanwhile, the probability and intensity of the rockburst are also given. The strategy for excavation and support design has been suggested for various intensities of rockbursts before excavation. The strategy for dynamic control of the rockburst evolution process is also proposed according to the monitoring results. The methodology has been successfully applied to rockburst risk reduction for deep tunnels at Jinping II hydropower project. The results have illustrated the applicability of the proposed methodology and

techniques concerning rockbursts.

Wuwei Cheng, Wenyou Wang, Shiqiang Huang, Peng Ma. Acoustic emission monitoring of rockbursts during TBM-excavated headrace tunneling at Jinping II hydropower station.Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (6): 486–494.

http://www.sciencedirect.com/science/article/pii/S1674775513000899 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20130608.pdf

Abstract: To better understand the mechanical properties of marble at Jinping II hydropower station, this paper examines the changes of brittle rocks in excavation damaged zones (EDZs) before and after excavation of tunnel with the tunnel boring machine (TBM). The paper attempts to employ the acoustic emission (AE) to study the AE characteristics and distribution of rockburst before and after TBM-excavated tunnel. It is known that the headrace tunnel #2, excavated by the drill-and-blast (D&B) method, is ahead of the headrace tunnel #3 that is excavated by TBM method. The experimental sub-tunnel #2–1, about 2000 m in depth and 13 m in diameter, between the two tunnels is scheduled. In the experimental sub-tunnel #2–1, a large number of experimental boreholes are arranged, and AE sensors are installed within 10 m apart from the wall of the headrace tunnel #3. By tracking the microseismic signals in rocks, the location, frequency, quantity, scope and intensity of the microseismic signals are basically identified. It is observed that the AE signals mainly occur within 5 m around the rock wall, basically lasting for one day before tunnel excavation and a week after excavation. Monitoring results indicate that the rockburst signals are closely related to rock stress adjustment. The rock structure has a rapid self-adjustment capacity before and after a certain period of time during tunneling. The variations of rock stresses would last for a long time before reaching a final steady state. Based on this, the site-specific support parameters for the deep tunnels can be accordingly optimized.

Dongqiao Liu, Dejian Li, Fei Zhao, Chengchao Wang. Fragmentation characteristics analysis of sandstone fragments based on impact rockburst test. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (3): 251–256.

http://www.sciencedirect.com/science/article/pii/S1674775514000377 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140309.pdf

Abstract: Impact rockburst test on sandstone samples with a central hole is carried out under true triaxial static loads and vertical dynamic load conditions, and rock fragments after the test are collected. The fragments of sandstone generated from strain rockburst test and uniaxial compression test are also collected. The fragments are weighed and the length, width and thickness of each piece of fragments are measured respectively. The fragment quantities with coarse, medium, fine and micro grains in different size ranges, mass and particles distributions are also analyzed. Then, the fractal dimension of fragments is calculated by the methods of size-frequency, mass-frequency and length-to-thickness ratio-frequency. It is found that the crushing degree of impact rockburst fragments is higher, accompanied with blocky characteristics observably. The mass percentage of small grains, including fine and micro grains, in impact rockburst test is higher than those in strain rockburst test and uniaxial compression test. Energy dissipation from rockburst tests is more than that from uniaxial compression test, as the quantity of micro grains generated does.

Mikhail A. Guzev. Non-classical solutions of a continuum model for rock descriptions. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (3): 180–185.

http://www.sciencedirect.com/science/article/pii/S1674775514000420 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140302.pdf

Abstract: The strain-gradient and non-Euclidean continuum theories are employed for construction of non-classical solutions of continuum models. The linear approximation of both models' results in identical structures in terms of their kinematic and stress characteristics. The solutions obtained in this study exhibit a critical behaviour with respect to the external loading parameter. The conclusions are obtained based on an investigation of the solution for the scalar curvature

in the non-Euclidean continuum theory. The proposed analysis enables us to use different theoretical approaches for description of rock critical behaviour under different loading conditions.

Hydraulic Rock Mechanics

Chunhsien Wu, Chihkuan Ni, Honyim Ko. Seismic response of an earth dam: finite element coupling analysis and validation from centrifuge tests. Journal of Rock Mechanics and Geotechnical Engineering. 2009, 1 (1): 56–70.
http://www.rockgeotech.org/qikan/manage/wenzhang/20090017.pdf
Abstract: Variations in acceleration and excess pore water pressure during a seismic event are critical early-warning indicators of an impending dam collapse. To assess these variations, the seismic responses for three simplified model dams, based on cross-sections through a real earthen dam, were assessed with numerical simulations and centrifuge tests. A normalized root-mean-square error was utilized as a comparison index to assess the closeness between simulated and the recorded values. Assuming that the experimental records are reliable, the reliability of the numerical program was evaluated using this root-mean-square error estimation approach. Explanations for inconsistency between the two approaches are presented. The conclusions are drawn from the results of the three model dams.

Qiang Yang, Yaoru Liu, Yingru Chen, et al. Stability and reinforcement analyses of high arch dams by considering deformation effects. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (4): 305–313.
http://www.rockgeotech.org/qikan/manage/wenzhang/2010-04-03.pdf
Abstract: The strict definition and logical description of the concept of structure stability and failure are presented. The criterion of structure stability is developed based on plastic complementary energy and its variation. It is presented that the principle of minimum plastic complementary energy is the combination of structure equilibrium, coordination condition of deformation and constitutive relationship. Based on the above arguments, the deformation reinforcement theory is developed. The structure global stability can be described by the relationship between the global degree of safety of structure and the plastic complementary energy. Correspondingly, the new idea is used in the evaluations of global stability, anchorage force of dam-toe, fracture of dam-heel and treatment of faults of high arch dams in China. The results show that the deformation reinforcement theory provides a uniform and practical theoretical framework and a valuable solution for the analysis of global stability, dam-heel cracking, dam-toe anchorage and reinforcement of faults of high arch dams and their foundations.

Chunsheng Zhang, Weijiang Chu, Ning Liu, et al. Laboratory tests and numerical simulations of brittle marble and squeezing schist at Jinping II hydropower station, China. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (1): 30–38.
http://www.rockgeotech.org/qikan/manage/wenzhang/2011-01-04.pdf
Abstract: Four 16.7 km-long tunnels with diameters ranging from 12.4 to 14.6 m are now under construction at Jinping II hydropower station along the Yalong River. The tunnels pass through Triassic rocks below Jinping Mountain. The tunnels are characterized with high overburden, long alignment and complex geological conditions. Brittle failure in marble and squeezing in schist are the primary problems in tunnelling. This paper introduces the studies of laboratory tests on Jinping II marble as well as numerical prediction of excavation damaged zone (EDZ) of tunnel section in brittle marble and determination of reinforced concrete lining thickness for restraining time-dependent deformation in the schist tunnel section. Laboratory tests indicate that Jinping II marble presents a complex brittle-ductile-plastic transition behavior of post-peak response with increasing confining pressure. Such behavior can be described numerically with the Hoek-Brown model. The EDZ was calibrated and predicted using both fast Lagrangian analysis of continua (FLAC) and particle flow code (PFC). The predicted result of EDZ in sections with different qualities of rock mass under various overburden pressures is quite helpful in understanding EDZ characterization and support design. A power-law creep model was used to support the lining design, especially in determining the lining thickness. Field convergence measurement data over 19 months were used to calibrate the creep model properties, followed by a sensibility analysis of reinforced concrete lining thickness that was launched to present the maximum lining compressive stress.

Aiqing Wu, Qigui Yang, Xiuli Ding, et al. Key rock mechanical problems of underground powerhouse in Shuibuya

hydropower station. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (1): 64–72.
http://www.rockgeotech.org/qikan/manage/wenzhang/2011-01-07.pdf
Abstract: The complicated rock structures and the stability of surrounding rocks of the underground powerhouse were the key rock mechanical problems in Shuibuya hydropower station. In order to overcome the related rock mechanical problems encountered during its construction, a comprehensive research was carried out for the underground powerhouse in Shuibuya hydropower station based on a detailed geological survey. It covers the investigations on the initial in-situ stress distribution features, rock mechanical properties, engineering rock mass classifications by different methods, numerical modeling for stability and support analysis, proper measures for rock excavation and support. The results show that the rock excavations of the underground powerhouse under the given geological conditions can be controlled effectively. Some measures, suggested by the designers, are proved to be rational and effective. These measures mainly consist of: (1) the soft rock replacements by concrete in local area below the crane beam, (2) the shotcrete and reinforcement by rock bolts and anchor cables in surrounding rocks, and (3) 2 m concrete placement on the rock bench between adjacent tailrace tubes. The engineering practice shows that the treated surrounding rocks have a good overall stability. The deformation behaviors observed by safety equipments are within the designing limits. The research conclusions on the related rock mechanical problems, prior to the underground powerhouse excavations, are reliable.

Shengwu Song, Dewen Cai, Xuemin Feng, Xiaopeng Chen, Dikai Wang. Safety monitoring and stability analysis of left abutment slope of Jinping I hydropower station. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (2): 117–130.
http://www.rockgeotech.org/qikan/manage/wenzhang/2011-02-02.pdf
Abstract: Safety monitoring and stability analysis of high slopes are important for high dam construction in high mountainous regions or precipitous gorges. In this paper, deformation characteristics of toppling block at upper abutment, deforming tensile rip wedge in the middle part and deep fractures are comprehensively analyzed based on the geological conditions, construction methods and monitoring results of left abutment slope in Jinping I hydropower station. Safety analyses of surface and shallow-buried rock masses and the corresponding anchorage system are presented. The monitoring results indicate that the global stability of the large wedge block in the left abutment is effectively under control, and the abutment slope is stable in a global sense. After the completion of excavation, the deformations of toppling block at the top of the slope and deep fracture zone continue at a very low rate, which can be explained as “rock mass creep”. Further monitoring and analysis are needed.

Chaoyang Fang, Zhenzhen Liu. Stress-strain analysis of Aikou rockfill dam with asphalt-concrete core. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (2): 186–192.
http://www.rockgeotech.org/qikan/manage/wenzhang/2011-02-08.pdfhttp://www.rockgeotech.org/qikan/manage/wenzhang/2011-02-08.pdf
Abstract: Aikou rockfill dam with asphalt-concrete core is situated in a karst area in Chongqing City, China. In order to study the operative conditions of the rockfill dam, especially those of the asphalt-concrete core, the Duncan model is adopted to compute the stress and strain of both the rockfill dam and the asphalt-concrete core after karst grouting and other treatments. The results indicate that the complicated stress and deformation of both the dam body and the core are within reasonable ranges. It is shown that structure design and foundation treatment of the dam are feasible and can be used as a reference for other similar projects.

Xuechao Wang. Geological conditions and key rock mechanics issues in the Western Route of South-to-North Water Transfer Project. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (3): 234–243.
http://www.rockgeotech.org/qikan/manage/wenzhang/20110304.pdf
Abstract: In terms of special geological conditions of the Western Route of South-to-North Water Transfer Project, the classification method for surrounding rocks is discussed by combining with the construction method of tunnel boring machine (TBM). The classification standard of surrounding rocks is put forward on the basis of physical simulations and engineering practices. Damage, deformation and evolution of surrounding rocks induced by TBM excavation are discussed. Meanwhile, the long-term deformation mechanisms and stability of surrounding rocks are also studied. On this basis, a three-dimensional constitutive model for interbedded sandstone slate and a flat shell-joint element-foundation system for calculating internal forces of segment lining are established. The deformation features of surrounding rocks of deep and

steep interbedded sandstone slate and their influences on internal forces of segment lining are presented. Finally, the design methods of segment lining constructed in deep and steep flysch are proposed.

Chuangbing Zhou, Yifeng Chen, Qinghui Jiang, Wenbo Lu. A generalized multi-field coupling approach and its application to stability and deformation control of a high slope. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (3): 193–206.

http://www.rockgeotech.org/qikan/manage/wenzhang/20110301.pdf

Abstract: Human activities, such as blasting excavation, bolting, grouting and impounding of reservoirs, will lead to disturbances to rock masses and variations in their structural features and material properties. These engineering disturbances are important factors that would alter the natural evolutionary processes or change the multi-field interactions in the rock masses from their initial equilibrium states. The concept of generalized multi-field couplings was proposed by placing particular emphasis on the role of engineering disturbances in traditional multi-field couplings in rock masses. A mathematical model was then developed, in which the effects of engineering disturbances on the coupling-processes were described with changes in boundary conditions and evolutions in thermo-hydro-mechanical (THM) properties of the rocks. A parameter, ***d***, which is similar to damage variables but has a broader physical meaning, was conceptually introduced to represent the degree of engineering disturbances and the couplings among the material properties. The effects of blasting excavation, bolting and grouting in rock engineering were illustrated with various field observations or theoretical results, on which the degree of disturbances and the variations in elastic moduli and permeabilities were particularly focused. The influences of excavation and groundwater drainage on the seepage flow and stability of the slopes were demonstrated with numerical simulations. The proposed approach was further employed to investigate the coupled hydro-mechanical responses of a high rock slope to excavation, bolting and impounding of the reservoir in the dam left abutment of Jinping I hydropower station. The impacts of engineering disturbances on the deformation and stability of the slope during construction and operation were demonstrated.

Shiyong Wu, Ge Wang. Rock mechanical problems and optimization for the long and deep diversion tunnels at Jinping II hydropower station. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (4): 314–328.

http://www.rockgeotech.org/qikan/manage/wenzhang/20110403.pdf

Abstract: According to site-specific environments such as high water pressures, high in-situ stresses, strong rockbursts, etc., the design scheme of the long and deep diversion tunnels at Jinping II hydropower station was optimized to ensure construction safety. New drainage tunnels were considered, and lining structures and grouting pressures were modified during the excavation of tunnels. The construction scheme was adjusted dynamically based on the complex geological conditions. For instances, the diversion tunnels were first excavated with drilling and blasting method at the first stage of construction, and then with the combination method of tunnel boring machine (TBM) and drilling and blasting, and finally only considering drilling and blasting method. Through optimized scheme and adjustment of the construction scheme, the excavation of diversion tunnel #1 was successfully completed in June, 2011. On this basis, this paper analyzes and summarizes the key rock mechanics issues encountered in construction of the long and deep diversion tunnels at Jinping II hydropower station. The experiences of design and construction obtained in this project could be referred to other similar projects.

Qixiang Fan, Hongbing Zhu, Xuchun Chen. Key issues in rock mechanics of the Three Gorges Project in China. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (4): 329–342.

http://www.rockgeotech.org/qikan/manage/wenzhang/20110404.pdf

Abstract: The Three Gorges Project is one of the essential key projects for flood controlling and water resources regulation in the Yangtze River. The project includes a river-crossing dam, underground powerhouses, and navigation structures. Because of the huge size and complicated construction technologies, the project faced a series of challenging engineering issues. In terms of rock mechanics, there are many key technical issues, including the sliding resistance and stability of the dam section along the foundations of powerhouses No.1–5, the slope stability of the double-line five-stage ship lock, excavation of large-scale underground powerhouses, and curtain grouting under the dam. With decades of scientific research and 16 years of practical construction experiences and reservoir operations, these key technical issues in construction of the Three Gorges Project are successfully resolved, which will attribute to the development of hydropower technology. On the basis of the monitoring data during construction and normal operation periods of the Three Gorges

Project, this paper presents a systematic analysis of these key rock mechanical issues in terms of behaviors, solutions, dynamic controlling, monitoring arrangement and integrated assessment.

Lin Zhang, Yuan Chen, Baoquan Yang, Jianye Chen, Chengqiu Hu. A comprehensive testing method for global stability analysis of high arch dams. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (1): 73–81.
http://www.rockgeotech.org/qikan/manage/wenzhang/2012-01-08.pdf
Abstract: Hydropower projects are rapidly developing in China at present, and a number of high dams and large reservoirs are currently under construction or will soon be built. These large projects are mainly located on the great rivers in West China with complicated topographical and geological conditions. Evaluation of stability and safety of these high dam projects is an important topic. Geomechanical model test is one of the main methods to study the global stability of high dam and foundation. In this paper, a comprehensive testing method that combines overloading and strength reduction in a model is proposed. In this method, both the influence of excessive flooding and the effects of strength reduction of rock masses and weak structural planes on dam stability are considered. Thus, the comprehensive testing method can accurately incorporate multiple factors that affect the global stability of high dam and its foundation. Based on the failure testing principle and model similarity theory, a similarity relation formula for safety evaluation through comprehensive test is established. A new model material, temperature-dependent analogous material, is also developed. By rising the temperature and reducing the strength of the model material, the mechanical behaviors resulting from gradual strength reduction can be simulated. Thus, the comprehensive testing method is realized in a single model. For case studies, the comprehensive geomechanical model test is conducted for Jinping I and Xiaowan high arch dam projects.

Zhongming Jiang, Shurong Feng, Sheng Fu. Coupled hydro-mechanical effect of a fractured rock mass under high water pressure. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (1): 88–96.
http://www.rockgeotech.org/qikan/manage/wenzhang/2012-01-10.pdf
Abstract: To explore the variation of permeability and deformation behaviors of a fractured rock mass in high water pressure, a high pressure permeability test (HPPT), including measuring sensors of pore water pressure and displacement of the rock mass, was designed according to the hydrogeological condition of Heimifeng pumped storage power station. With the assumption of radial water flow pattern in the rock mass during the HPPT, a theoretical formula was presented to estimate the coefficient of permeability of the rock mass using water pressures in injection and measuring boreholes. The variation in permeability of the rock mass with the injected water pressure was studied according to the suggested formula. By fitting the relationship between the coefficient of permeability and the injected water pressure, a mathematical expression was obtained and used in the numerical simulations. For a better understanding of the relationship between the pore water pressure and the displacement of the rock mass, a 3D numerical method based on a coupled hydro-mechanical theory was employed to simulate the response of the rock mass during the test. By comparison of the calculated and measured data of pore water pressure and displacement, the deformation behaviors of the rock mass were analyzed. It is shown that the variation of displacement in the fractured rock mass is caused by water flow passing through it under high water pressure, and the rock deformation during the test could be calculated by using the coupled hydro-mechanical model.

Yufei Zhao, Xiaogang Wang, Xiaohui Zhang, Zhixin Jia, Xiangxi Zeng, Hongtao Zhang. Rock borehole shear tests in dam foundation of Xiangjiaba hydropower station.
http://www.rockgeotech.org/qikan/manage/wenzhang/20120408.pdf
Abstract: Xiangjiaba hydropower station is one of the cascade power stations on the Jinsha River, China. Due to the complicated geological conditions of its dam foundation, evaluating the rock mass quality and determining the mechanical parameters of rock masses are very important issues. To address these issues, several groups of rock borehole shear tests (RBSTs) were conducted on the black mudstone in the dam foundation of Xiangjiaba hydropower station in the second construction phase. Forty three groups of shear strengths of black mudstone samples were obtained from RBSTs, and the shear strength parameters (c and f) were calculated using the least squares method. In addition, the limitations and merits of RBST employed in the Xiangjiaba hydropower station were discussed. Test results indicate that the shear strength parameters obtained from RBST have a good correlation with the results from sound wave test in borehole. It is believed that RBST has a good adaptability and applicability in geotechnical engineering.

Pierre Duffaut. The traps behind the failure of Malpasset arch dam, France, in 1959.Journal of Rock Mechanics and

Geotechnical Engineering. 2013, 5 (5): 334–341.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130501.pdf

Abstract: The case of the Malpasset arch dam failure in 1959 has been widely exposed in scientific and technicalforums and papers. The focus here is on the many traps which have confused the whole chain of bodies and persons involved, owner, designer, geologist, contractor, up to the state management officers. When the first traps were hidden inside geology, many more appeared, as well geotechnical, technical, fortuitous, and administrative. In addition to such factual factors, human and organizational factors may be today easily identified, when none of them was yet suspected. Both dam safety and rock mechanics benefited from the studies done since the Malpasset case, most of them within one decade.

Shengu Song, Xuemin Feng, Hongling Rao and HanhuaiZheng. Treatment design of geological defects in dam foundation of Jinping I hydropower station. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (5): 342–349.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130502.pdf

Abstract: Jinping I hydropower station is one of the most challenging projects in China due to its highest arch damand complex geological conditions for construction. After geological investigation into the dam foundation, a few large-scale weak discontinuities are observed. The rock masses in the left dam foundation areintensively unloaded, approximately to the depth of 150–300m. These serious geological defects lead toa geological asymmetry on the left and right banks, and thus some major difficulties of dam constructionare encountered. In this paper, the influences of geological defects on the project are analyzed, followedby the concepts and methods of treatment design. Based on the analysis, the treatment methods of theweak rock masses and discontinuities are carefully determined, including the concrete cushion, concretereplacement grids, and consolidation grouting. They work together to enhance the strength and integrityof the dam foundation. Evaluations and calibrations through geo-mechanical model tests in combinationwith field monitoring results in early impoundment period show that the arch dam and its foundationare roughly stable, suggesting that the treatment designs are reasonable and effective. The proposedtreatment methods and concepts in the context can be helpful for similar complex rock projects.

Yuzhu Zhang, Wenbo Lu, Ming Chen, Peng Yan, Yingguo Hu. Dam foundation excavation techniques in China: A review. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (6): 460–467.

http://www.sciencedirect.com/science/article/pii/S1674775513001005 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20130605.pdf

Abstract: A protective layer (PL) is commonly reserved above foundation surface to protect the underlying rock mass during dam foundation excavation. In China, the PL of dam foundation is conventionally subdivided into two or three thin layers and excavated with the shallow-hole blasting method, even by pneumatic pick method in case of soft rock mass. The aforementioned layered excavation of the PL delays the construction of the whole project. After nearly 30-year practices, several safe and efficient methods for the PL excavation of dam foundation are gradually developed. They include shallow-hole bench blasting with cushion material (SBC) at the bottom of the hole, and horizontal smooth blasting (HSB). The PL is even cancelled on the condition that horizontal pre-split technique is employed during dam foundation excavation. This paper introduces the aforementioned two PL excavation methods (shallow-hole blasting and bench blasting) and horizontal pre-split technique of dam foundation without protective layer (HPP). The basic principles of blasting method, blasting geometry, charge structure, drill-and-blast parameters of typical projects are examined. Meanwhile, the merits and limitations of each method are compared. Engineering practices in China show that HSB is basically the optimal method for dam foundation PL excavation in terms of foundation damage control and rapid construction. Some new problems for dam foundation PL excavation arising, such as strong unloading and relaxation phenomenon that encountered in the gorge region of southwest China, are needed to be addressed; and the corresponding countermeasures are discussed as well.

Hui Zhou, Chuanqing Zhang, Zhen Li, Dawei Hu, Jing Hou. Analysis of mechanical behavior of soft rocks and

stability control in deep tunnels. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (3): 219–226.
http://www.sciencedirect.com/science/article/pii/S1674775514000328 or
http://www.rockgeotech.org/qikan/manage/wenzhang/20140306.pdf

Abstract: Due to the weakness in mechanical properties of chlorite schist and the high in situ stress in Jinping II hydropower station, the rock mass surrounding the diversion tunnels located in chlorite schist was observed with extremely large deformations. This may significantly increase the risk of tunnel instability during excavation. In order to assess the stability of the diversion tunnels laboratory tests were carried out in association with the petrophysical properties, mechanical behaviors and water-weakening properties of chlorite schist. The continuous deformation of surrounding rock mass, the destruction of the support structure and a large-scale collapse induced by the weak chlorite schist and high in situ stress were analyzed. The distributions of compressive deformation in the excavation zone with large deformations were also studied. In this regard, two reinforcement schemes for the excavation of diversion tunnel bottom section were proposed accordingly. This study could offer theoretical basis for deep tunnel construction in similar geological conditions.

Mining Rock Mechanics

Richard Šňupárek, Petr Konečný. Stability of roadways in coalmines alias rock mechanics in practice. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (3): 281–288.
http://www.rockgeotech.org/qikan/manage/wenzhang/2010-03-09.pdf

Abstract: This paper describes the procedures for design of supports and stabilization measures in the roadways. The procedures are based on the system developed in Ostrava-Karvina coal basin in Czech Republic. The calculation of load bearing capacity of roadway supports contains the period of roadway construction and mining in the vicinities, based on the size of the natural rock arch. The loading of supports during mining comes from a stress wave in the rock mass in the forefront of coalface and the caving area of mined-out panel. The input data for the calculation method are deduced according to in-situ measurements of convergence and displacement in the roadways.

Hongpu Kang, Yongzheng Wu, Fuqiang Gao. Deformation characteristics and reinforcement technology for entry subjected to mining-induced stresses. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (3): 207–219.
http://www.rockgeotech.org/qikan/manage/wenzhang/20110302.pdf

Abstract: The entry at Zhangcun coal mine in Lu'an coal mining area in Shanxi Province suffered from severe mining-induced stresses with the heading face driven oppositely to an adjacent working face. In this paper, the characteristics of deformation and failure of the entry were investigated in terms of the tempo-spatial relations between heading and working faces through field study and numerical modeling. The three-dimensional (3D) finite difference models were built to investigate stresses, displacements and damages in the surrounding rocks of the entry and the working face. The field study includes selection of reinforcing methods and materials, design parameters, and determination of cable prestress. The monitoring data of entry deformation and stress along the cables during every stage were presented. The state of the reinforced entry was evaluated based on the monitoring data. The results demonstrate that before the heading face of the entry crosses the adjacent working face, the influence of advanced abutment pressure caused by adjacent working face upon the entry is not significant. After they cross each other, however, the lateral abutment pressure will have an evident impact on the entry. The displacement rate of the entry will be greatly increased and reaches a certain value within a certain distance between the heading face and the working face. Then, it will increase again with the presence of secondary mining-induced pressure on the entry when the present working face advances. The fully-grouted cable with short length, high strength and high prestress is an effective way to reinforce the entry suffering from severe mining-induced stresses, which greatly reduces the displacement and failure possibility of the entry. Finally, the principles and recommendations for reinforcing design of entries suffering from severe mining-induced stresses were proposed according to field study, numerical modeling and experiences from other coal mines. Problems encountered in field study and suggestions for reinforcement were also discussed.

Yangsheng Zhao, Zijun Feng, Baoping Xi, Jinchang Zhao, Zhijun Wan, Anchao Zhou. Prospect of HDR geothermal

energy exploitation in Yangbajing, Tibet, China, and experimental investigation of granite under high temperature and high pressure. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (3): 260–269.

http://www.rockgeotech.org/qikan/manage/wenzhang/20110307.pdf

Abstract: Hot dry rock (HDR) geothermal energy, almost inexhaustible green energy, was first put forward in the 1970s. The development and testing of HDR geothermal energy are well reported in USA, Japan, UK, France and other countries or regions. In this paper, the geological characters of Yangbajing basin were first analyzed, including the continental dynamic environments to form HDR geothermal fields in Tibet, the tectonic characteristics of south slope of Nyainqêntanglha and Dangxiong-Yangbajing basin, and the in-situ stresses based on the investigations conducted, and then the site-specific mining scheme of HDR geothermal resources was proposed. For the potential development of HDR geothermal energy, a series of experiments were conducted on large-scale granite samples, 200 mm in diameter and 400 mm in length, at high temperature and high triaxial pressure for cutting fragmentation and borehole stability. For the borehole stability test, a hole of 40 mm in diameter and 400 mm in length was aforehand drilled in the prepared intact granite sample. The results indicate that the cutting velocity obviously increases with temperature when bit pressure is over a certain value, while the unit rock-breaking energy consumption decreases and the rock-breaking efficiency increases with temperature at the triaxial pressure of 100 MPa. The critical temperature and pressure that can result in intensive damage to granite are 400–500 °C and 100–125 MPa, respectively.

Liang Yuan. Theories and techniques of coal bed methane control in China. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (4): 343–351.

http://www.rockgeotech.org/qikan/manage/wenzhang/20110405.pdf

Abstract: Coal bed methane control with low permeability is a hot issue at present. The current status of coal bed methane control in China is introduced, and government-support policies on coal bed methane control are presented. The theories of methane control in depressurized mining, including methane extraction in depressurized mining, simultaneous mining technique of coal and methane without coal pillar, and circular overlying zone for high-efficiency methane extraction in coal seams with low permeability, are proposed. The techniques of methane control and related instruments and equipments in China are introduced. On this basis, the existing problems on coal bed methane control are addressed and further studies are pointed out accordingly.

Fengshan Ma, Haijun Zhao, Yamin Zhang, Jie Guo, Aihua Wei, Zhiquan Wu, Yonglong Zhang. GPS monitoring and analysis of ground movement and deformation induced by transition from open-pit to underground mining. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (1): 82–87

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-01-09.pdf

Abstract: To trace the potential hazards of open-pit slope in Longshou mine, global positioning system (GPS) is applied to monitoring ground movement and deformation induced by transition from open-pit to underground mining. Through long-term monitoring from 2003 to 2008, huge amounts of data were acquired. Monitoring results show that large-scale ground movement and deformation have occurred in mining area, and the movement area is ellipse-shaped. The displacement boundary of settlement trough is 2.0 km long along the exploratory line, and 1.5 km long along the strike of ore body. GPS monitoring results basically agree with the practical deformation state of open-pit slope. It is indicated that the long-term GPS monitoring is an effective way to understand the mechanism of ground movement and deformation in mine area.

A. Sayadi, M. Monjezi, N. Talebi, Manoj Khandelwal. A comparative study on the application of various artificial neural networks to simultaneous prediction of rock fragmentation and backbreak. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (4): 318–324.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130408.pdf

Abstract: In blasting operation, the aim is to achieve proper fragmentation and to avoid undesirable events such as backbreak. Therefore, predicting rock fragmentation and backbreak is very important to arrive at a technically and economically successful outcome. Since many parameters affect the blasting results in a complicated mechanism, employment of robust methods such as artificial neural network may be very useful. In this regard, this paper attends to simultaneous prediction of rock fragmentation and backbreak in the blasting operation of Tehran Cement Company

limestone mines in Iran. Back propagation neural network (BPNN) and radial basis function neural network (RBFNN) are adopted for the simulation. Also, regression analysis is performed between independent and dependent variables. For the BPNN modeling, a network with architecture 6-10-2 is found to be optimum whereas for the RBFNN, architecture 6-36-2 with spread factor of 0.79 provides maximum prediction aptitude. Performance comparison of the developed models is fulfilled using value account for (VAF), root mean square error (RMSE), determination coefficient (R2) and maximum relative error (MRE). As such, it is observed that the BPNN model is the most preferable model providing maximum accuracy and minimum error. Also, sensitivity analysis shows that inputs burden and stemming are the most effective parameters on the outputs fragmentation and backbreak, respectively. On the other hand, for both of the outputs, specific charge is the least effective parameter.

C.Dinis da Gama. Easy profit maximization method for open-pit mining. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (5): 350–353.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130503.pdf

Abstract: A methodology applicable at any phase of a surface mining project for evaluating its current technical and economic feasibility is presented. It requires the typically available quantitative data on the ore-body, with its three-dimensional block model developed upon accurate interpolations. Thus it allows estimations of exploitable reserves in function of various cut-off grades, such as the average grade of mineable ore, the tonnages of ore and waste rock, stripping ratios and profit estimates for different production levels. If cost evaluations of essential mine operations are available (such as ore mining, waste removal, ore concentration, transportation, indirect project costs and expected concentrate selling prices), the methodology will provide clear indications on the economic feasibility of mining, including the best available options at any moment. Simple expressions are developed on the basis of a profit mathematical function and an application example is presented with data available from an existing iron ore deposit.

Ping Wang, Huiqiang Li,Yan Li, Bo Cheng. Stability analysis of backfilling in subsiding area and optimization of the stoping sequence.Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (6): 478–485.

http://www.sciencedirect.com/science/article/pii/S1674775513001030 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20130607.pdf

Abstract: In underground mining by sublevel caving method, the deformation and damage of the surface induced by subsidence are the major challenging issues. The dynamic and soft backfilling body increases the safety risks in the subsiding area. In this paper, taking Zhangfushan iron mine as an example, the ore body and the general layout are focused on the safety of backfilling of mined-out area. Then, we use the ANSYS software to construct a three-dimensional (3D) model for the mining area in the Zhangfushan iron mine. According to the simulation results of the initial mining stages, the ore body is stoped step by step as suggested in the design. The stability of the backfilling is back analyzed based on the monitored displacements, considering the stress distribution to optimize the stoping sequence. The simulations show that a reasonable stoping sequence can minimize the concentration of high compressive stress and ensure the safety of stoping of the ore body.

Mahdi Saadat, Manoj Khandelwal, M. Monjezi. An ANN-based approach to predict blast-induced ground vibration of Gol-E-Gohar iron ore mine, Iran. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (1): 67–76.

http://www.sciencedirect.com/science/article/pii/S1674775513001157 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140108.pdf

Abstract: Blast-induced ground vibration is one of the inevitable outcomes of blasting in mining projects and may cause substantial damage to rock mass as well as nearby structures and human beings. In this paper, an attempt has been made to present an application of artificial neural network (ANN) to predict the blast-induced ground vibration of the Gol-E-Gohar (GEG) iron mine, Iran. A four-layer feed-forward back propagation multi-layer perceptron (MLP) was used and trained with Levenberg–Marquardt algorithm. To construct ANN models, the maximum charge per delay, distance from blasting face to

monitoring point, stemming and hole depth were taken as inputs, whereas peak particle velocity (PPV) was considered as an output parameter. A database consisting of 69 data sets recorded at strategic and vulnerable locations of GEG iron mine was used to train and test the generalization capability of ANN models. Coefficient of determination (R2) and mean square error (MSE) were chosen as the indicators of the performance of the networks. A network with architecture 4-11-5-1 and R2 of 0.957 and MSE of 0.000722 was found to be optimum. To demonstrate the supremacy of ANN approach, the same 69 data sets were used for the prediction of PPV with four common empirical models as well as multiple linear regression (MLR) analysis. The results revealed that the proposed ANN approach performs better than empirical and MLR models.

Kegong Fan, Hongguang Liang, Chishuai Ma, Chuanwei Zang. Non-harmonious deformation controlling of gob-side entry in thin coal seam under dynamic pressure. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (3): 269–274.

http://www.sciencedirect.com/science/article/pii/S1674775514000419 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140311.pdf

Abstract: The behavior of gob-side entry under dynamic pressure is totally different from the one driven after the movement of overlying strata above the adjacent coalface goaf. The gob-side entry will experience severe roof lateral structural adjustments caused by adjacent coalface mining. Thus the deformation and failure characteristics of narrow coal pillar along the gob should be carefully considered. On the basis of the data of the gob-side entry obtained in a thin coal seam under dynamic pressure, the measures to reinforce the narrow coal pillar are put forward. In addition, the non-harmonious controlling of the rock structures and non-equilibrium gob-side entry deformation is proposed to avoid potential failure. Field practices show that the supporting problems of the gob-side entry under dynamic pressure can be well addressed, which could be used in other similar mining cases.

In-situ Stress Measurement

Meifeng Cai, Hua Peng. Advance of in-situ stress measurement in China. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (4): 373–384.

http://www.rockgeotech.org/qikan/manage/wenzhang/20110407.pdf

Abstract: In-situ stress is an essential parameter for design and construction of most engineering projects that involve excavation in rocks. Progress in in-situ stress measurement from the 1950s in China is briefly introduced. Stress relief by overcoring technique and hydraulic fracturing technique are two main techniques for in-situ stress measurement in China. To make them suitable for application at great depth and to increase their measuring reliability and accuracy, a series of improving techniques have been developed. Applications and achievements of in-situ stress measurement in Chinese rock engineering, including mining, geotechnical and hydropower engineering, and earthquake prediction, are introduced. Suggestions for further development of in-situ stress measurement are also proposed.

Peng Yan, Wenbo Lu, Ming Chen, Zhigang Shan, Xiangrong Chen, Yong Zhou. Damage-free coring technique for rock mass under high in-situ stresses. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (1): 44–53

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-01-05.pdf

Abstract: Rock sampling with traditional coring method would cause initial damage to rock samples induced by in-situ stress relief during coring. To solve this problem, a damage-free coring method is proposed in this paper. The proposed coring scheme is numerically modeled first, and then it is verified by comparative laboratory tests using rock samples both obtained by conventional coring method and the proposed damage-free coring method. The result indicates that the in-situ stresses in sampling area could be reduced by 30%–50% through drilling a certain number of destressing holes around the whole sampling area. The spacing between adjacent destressing holes is about 10 cm. The average uniaxial compressive strength (UCS) of rock samples obtained by the damage-free coring method in Jinping II hydropower station with overburden depth of 1 900 m is higher than that of samples obtained by the conventional coring method with the same depth by 5%–15% and an average of 8%. In addition, the effectiveness of damage-free coring method can also be verified by

acoustic emission (AE) monitoring. The AE events monitored during uniaxial compression test of damage-free coring samples is fewer than that of conventional coring samples at the primarily loading phase.

Unloading Rock Mass Mechanics

Jianlin Li, Lehua Wang, Xingxia Wang, et al. Research on unloading nonlinear mechanical characteristics of jointed rock masses. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (4): 357–364.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-04-09.pdf

Abstract: Geological environments of rock mass projects are always very complicated, and further investigations on rock mechanical characteristics are needed. There are considerable distinctions in rock mechanical characteristics under unloading and loading conditions. A series of tests are conducted to study the stress-strain relationship of rock masses under loading and unloading conditions. Also, the anisotropy, the size effect, and the rheological property of unloading rock mass are investigated. The tests presented in the paper include model test and granite rheological test, which are conducted considering geological condition, rock mass structure, in-situ stress field of the permanent shiplock of the Three Gorges Project. The main differences between loading and unloading rock masses are stress paths, yield criteria, deformation and strength parameters, etc. Different structural plane directions affect unloading rock mass evidently. With increasing size, the tensile strength, the compressive strength, the deformation modulus, the Poisson's ratio and the anisotropy of rock mass all decrease. For sandstone samples with parallel bedding planes, the cohesion *c* increases but the internal friction angle φ decreases under unloading condition when compared with the values under loading condition. While for samples with vertical bedding planes, the trend is adverse. The rheological property of rocks has close relationship with the tensile stresses of rock masses. When the sandstone samples are tested under high stress condition, their rheological properties are very obvious with the unloading of confining pressure, and three typical rheological stages are shown. Rheological rate changes with the variations in axial stress and confining pressure.

Jie Li, Pengxian Fan, Mingyang Wang. Failure behavior of highly stressed rocks under quasi-static and intensive unloading conditions. Journal of Rock Mechanics and Geotechnical Engineering 2013; 5 (4): 287–293.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130404.pdf

Abstract: Unloading failure of rocks, especially highly stressed rocks, is one of the key issues in construction of underground structures. Based on this, analytical models for rocks under quasi-static and intensive unloading conditions are established to study the failure behavior of highly stressed rocks. In case of rock failure under quasi-static unloading, the rock mass ahead of working face is regarded as an elasto-brittle material, and the stress–displacement curves are used to characterize the tensile fracture of peak-stress area. It is observed that, when intensive unloading happens, there is an elastic unloading wave (perturbation wave) propagating in the rock mass. If the initial stress exceeds the critical stress, there will be a fracture wave, following the elastic unloading wave. To study the propagation feature of fracture wave, the conservation laws of mass, momentum and energy are employed. Results show that the post-peak deformation, strength and energy dissipation are essential to the failure process of highly stressed rocks.

Soft Rock Mechanics and Engineering

Manchao He. Latest progress of soft rock mechanics and engineering in China. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (3): 165–179.

http://www.sciencedirect.com/science/article/pii/S1674775514000420 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140301.pdf

Abstract: The progress of soft rock mechanics and associated technology in China is basically accompanied by the development of mining engineering and the increasing disasters of large rock deformation during construction of underground engineering. In this regard, Chinese scholars proposed various concepts and classification methods for soft rocks in terms of engineering practices. The large deformation mechanism of engineering soft rocks is to be understood through numerous experiments; and thus a coupled support theory for soft rock roadways is established, followed by the development of a new support material, i.e. the constant resistance and large deformation bolt/anchor with negative Poisson's ratio effect, and associated control technology. Field results show that large deformation problems related to numbers of engineering cases can be well addressed with this new technology, an effective way for similar soft rock deformation control.

Milton Assis Kanji. Critical issues in soft rocks. Journal of Rock Mechanics and Geotechnical Engineering. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (3): 186–195.

http://www.sciencedirect.com/science/article/pii/S1674775514000389 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140303.pdf

Abstract: This paper discusses several efforts made to study and investigate soft rocks, as well as their physico-mechanical characteristics recognized up to now, the problems in their sampling and testing, and the possibility of its reproduction through artificially made soft rocks. The problems in utilizing current and widespread classification systems to some types of weak rocks are also discussed, as well as other problems related to them. Some examples of engineering works in soft rock or in soft ground are added, with emphasis on their types of problems and solutions.

Yiwen Ju, Guochang Wang, Hongling Bu, Qingguang Li, Zhifeng Yan. China organic-rich shale geologic features and special shale gas production issues. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (3): 196–207.

http://www.sciencedirect.com/science/article/pii/S1674775514000316 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140304.pdf

Abstract: The depositional environment of organic-rich shale and the related tectonic evolution in China are rather different from those in North America. In China, organic-rich shale is not only deposited in marine environment, but also in non-marine environment: marine-continental transitional environment and lacustrine environment. Through analyzing large amount of outcrops and well cores, the geologic features of organic-rich shale, including mineral composition, organic matter richness and type, and lithology stratigraphy, were analyzed, indicating very special characteristics. Meanwhile, the more complex and active tectonic movements in China lead to strong deformation and erosion of organic-rich shale, well-development of fractures and faults, and higher thermal maturity and serious heterogeneity. Co-existence of shale gas, tight sand gas, and coal bed methane (CBM) proposes a new topic: whether it is possible to co-produce these gases to reduce cost. Based on the geologic features, the primary production issues of shale gas in China were discussed with suggestions.

C.F. Rodrigues, C. Laiginhas, M. Fernandes, M.J. Lemos de Sousa, M.A.P. Dinis. The coal cleat system: A new approach to its study. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (3): 208–218.

http://www.sciencedirect.com/science/article/pii/S1674775514000341 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140305.pdf

Abstract: After a general analysis regarding the concept of coal “cleat system”, its genetic origin and practical applications to coalbed methane (CBM) commercial production and to CO2 geological sequestration projects, the authors have developed a method to answer, quickly and accurately in accordance with the industrial practice and needs, the following yet unanswered questions: (1) how to define the spatial orientation of the different classes of cleats presented in a coal seam and (2) how to determine the frequency of their connectivites. The new available and presented techniques to answer these questions have a strong computer based tool (geographic information system, GIS), able to build a complete georeferentiated database, which will allow to three-dimensionally locate the laboratory samples in the coalfield. It will also allow to better understand the coal cleat system and consequently to recognize the best pathways to gas flow through the coal seam. Such knowledge is considered crucial for understanding what is likely to be the most efficient opening of cleat network, then allowing the injection with the right spatial orientation, of pressurized fluids in order to directly drain the maximum amount of gas flow to a CBM exploitation well. The method is also applicable to the CO2 geological sequestration technologies and operations corresponding to the injection of CO2 sequestered from industrial plants in coal seams of abandoned coal mines or deep coal seams.

V. Marinos. Tunnel behaviour and support associated with the weak rock masses of flysch. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (3): 227–239.

http://www.sciencedirect.com/science/article/pii/S1674775514000390 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140307.pdf

Abstract: Flysch formations are generally characterised by evident heterogeneity in the presence of low strength and tectonically disturbed structures. The complexity of these geological materials demands a more specialized geoengineering characterisation. In this regard, the paper tries to discuss the standardization of the engineering geological characteristics, the assessment of the behaviour in underground excavations, and the instructions–guidelines for the primary support measures for flysch layer qualitatively. In order to investigate the properties of flysch rock mass, 12 tunnels of Egnatia Highway, constructed in Northern Greece, were examined considering the data obtained from the design and construction records. Flysch formations are classified thereafter in 11 rock mass types (I–XI), according to the siltstone–sandstone proportion and their tectonic disturbance. A special geological strength index (GSI) chart for heterogeneous rock masses is used and a range of geotechnical parameters for every flysch type is presented. Standardization tunnel behaviour for every rock mass type of flysch is also presented, based on its site-specific geotechnical characteristics such as structure, intact rock strength, persistence and complexity of discontinuities. Flysch, depending on its types, can be stable even under noticeable overburden depth, and exhibit wedge sliding and wider chimney type failures or cause serious deformation even under thin cover. Squeezing can be observed under high overburden depth. The magnitude of squeezing and tunnel support requirements are also discussed for various flysch rock mass types under different overburdens. Detailed principles and guidelines for selecting immediate support measures are proposed based on the principal tunnel behaviour mode and the experiences obtained from these 12 tunnels. Finally, the cost for tunnel support from these experiences is also presented.

Mario Camilo Torres-Suarez, Adolfo Alarcon-Guzman, Rafael Berdugo-De Moya. Effects of loading– unloading and wetting–drying cycles on geomechanical behaviors of mudrocks in the Colombian Andes. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (3): 257–268.

http://www.sciencedirect.com/science/article/pii/S1674775514000407 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140310.pdf

Abstract: The mudrocks in the Colombian Andes, particularly those exhibiting low cementation (bonding), are susceptible to degradation when the environmental conditions change, which are challenging issues for engineering works. In this paper, the changes in physico-mechanical properties of mudrocks were monitored in laboratory, and some influential factors on the mechanical competence of geomaterials were studied. The geotechnical characteristics and experimental designs were developed from physical, chemical, mechanical and compositional points of view. In the tests, the techniques such as vapor

equilibrium technique (VET) were employed to apply wetting–drying cycles and to control relative humidity (suction-controlled) and loading–unloading cycles through ultrasonic wave velocities technique. The results show that the main failure mechanisms for the laminated mudrocks start on the microscopic scale by fissures coalescence, exhibiting physico-chemical degradation as well; the global geomechanical behavior presents a state between a ductile, like rock, and a fragile, like soil. The obtained results can provide engineering values according to monitoring laboratory set, when compared with in situ conditions.

Tao Wang, Yaodong Jiang, Shaojian Zhan, Chen Wang. Frictional sliding tests on combined coal-rock samples. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (3): 280–286.

http://www.sciencedirect.com/science/article/pii/S1674775514000407 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140313.pdf

Abstract: A test system was developed to understand the sliding mechanism of coal-rock structure. The test system was composed by a double-shear testing model and an acousto-optic monitoring system in association with a digital camera and an acoustic emission (AE) instrument. The tests can simulate the movement of activated faults and the sliding in coal-rock structure. In this regard, instable sliding conditions of coal-rock samples, sliding types under different conditions, displacement evolution law, and AE characteristics during sliding process were investigated. Several sliding types were monitored in the tests, including unstable continuous sliding, unstable discontinuous sliding, and stable sliding. The sliding types have close relation with the axial loads and loading rates. Larger axial load and smaller loading rate mean that unstable sliding is less likely to occur. The peak shear stress was positively correlated with the axial load when sliding occurred, whereas the displacement induced by unstable sliding was uncorrelated with the axial load. A large number of AE events occurred before sliding, and the AE rate decreased after stable sliding. The results show that the tests can well simulate the process of structural instability in a coal bump, and are helpful in the understanding of fault activation and the physical processes during squeezing process of roof and floor.

Seepage Mechanics

Weizhong Chen, Xianjun Tan, Hongdan Yu, et al. A fully coupled thermo-hydro-mechanical model for unsaturated porous media. Journal of Rock Mechanics and Geotechnical Engineering. 2009, 1 (1): 31–40.

http://www.rockgeotech.org/qikan/manage/wenzhang/20090020.pdf

Abstract: In examining potential host rocks for such purposes as the disposal of high-level radioactive wastes, it is important to understand the coupled thermo-hydro-mechanical (THM) behavior of a porous medium. A rigorous and fully unified coupled thermo-hydro-mechanical model for unsaturated porous media is required to simulate the complex coupling mechanisms involved. Based on modified Darcy's and Fourier's laws, equations of mechanical equilibrium, mass conservation and energy conservation are derived by introducing void ratio and volumetric liquid water content into the model. The newly derived model takes into account the effects of temperature on the dynamic viscosity of liquid water and void ratio, the influence of liquid flow on temperature gradient (thermo-osmosis), the influence on mass and heat conservation equations, and the influence of heat flow on water pressure gradient and thermal convection. The new coupled THM constitutive model is constructed by a finite element program and is used to simulate the coupled behavior of a tunnel during excavation, ventilation and concrete lining stages. Oil and gas engineering, underground disposal of nuclear waste and tunnel engineering may be benefited from the development of the new model.

Yifeng Chen, Ran Hu, Chuangbing Zhou, et al. A new classification of seepage control mechanisms in geotechnical engineering. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (3): 209–222.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-03-02.pdf

Abstract: Seepage flow through soils, rocks and geotechnical structures has a great influence on their stabilities and performances, and seepage control is a critical technological issue in engineering practices. The physical mechanisms associated with various engineering measures for seepage control are investigated from a new perspective within the framework of continuum mechanics; and an equation-based classification of seepage control mechanisms is proposed according to their roles in the mathematical models for seepage flow, including control mechanisms by coupled processes, initial states, boundary conditions and hydraulic properties. The effects of each mechanism on seepage control are illustrated with examples in hydroelectric engineering and radioactive waste disposal, and hence the reasonability of classification is demonstrated. Advice on performance assessment and optimization design of the seepage control systems in geotechnical engineering is provided, and the suggested procedure would serve as a useful guidance for cost-effective control of seepage flow in various engineering practices.

Zhihong Zhao, Lanru Jing, Ivars Neretnieks. Evaluation of hydrodynamic dispersion parameters in fractured rocks. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (3): 243–254.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-03-05.pdf

Abstract: A numerical procedure to determine the equivalent hydrodynamic dispersion coefficients and Péclet number (*Pe*) of a fractured rock is presented using random walk particle tracking method. The geometrical effects of fracture system on hydrodynamic dispersion are studied. The results obtained from the proposed method agree well with those of empirical models, which are the scale-dependent hydrodynamic dispersion coefficients in an asymptotic or exponential form. A variance case is added to investigate the influence of longitudinal hydrodynamic dispersion in individual fractures on the macro-hydrodynamic dispersion at the fracture network scale, and its influence is demonstrated with a verification example. In addition, we investigate the influences of directional flow and stress conditions on the behavior of hydrodynamic dispersion in fracture networks. The results show that the magnitudes of the hydrodynamic dispersion coefficients are relatively smaller when the flow direction is parallel to the dip directions of fracture sets. Compressive stresses significantly reduce hydrodynamic dispersion. However, the remaining questions are: (1) whether the deformed fracture network under high stress conditions may make the scale-dependent hydrodynamic dispersion coefficients have asymptotic or exponential forms, and (2) what the conditions for existence of a well-defined equivalent hydrodynamic dispersion tensor are. They need to be further investigated.

Soil Mechanics and Foundation

Ordinary Soil

Mingjing Jiang, Zhifu Shen, Liqing Li, Jiaxing Su. A novel specimen preparation method for TJ-1 lunar soil simulant in hollow cylinder apparatus. Journal of Rock Mechanics and Geotechnical Engineering 2012; 4 (4): 312–325.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120403.pdf

Abstract: Conventional methods for hollow cylinder apparatus (HCA) specimen preparation are not applicable for TJ-1 lunar soil simulant due to its wide particle size distribution. A novel method to prepare uniform TJ-1 specimen for HCA tests is put forward. The method is a combination of the multi-layering dry-rodding method and a new under-compaction criterion in the multi-layer with under-compaction method (UCM). In the novel method, the specimen is prepared with 5 layers by dry-rodding and the UCM is used to determine the height after each layer is compacted. The density uniformity of specimen is evaluated by the freezing method to find out the best under-compaction criterion. Two HCA specimens with the same target density are prepared by the novel method and examined in the tests of pure rotation of the principal stresses. Their conformable mechanical behaviors ascertain the effectiveness of the method to produce uniform and reproducible HCA specimens. Four groups of HCA tests are carried out to investigate the anisotropic and non-coaxial behaviors of TJ-1 lunar soil simulant. The results indicate that the principal stress direction, the deviator stress ratio, the stress level and the coefficient of the intermediate principal stress significantly influence the strength and deformation properties of TJ-1 lunar soil simulant.

Linwei Wang, Weiya Xu, Anquan Xu. Three-dimensional cellular automata based particle flow simulations of mechanical properties of talus deposit. Journal of Rock Mechanics and Geotechnical Engineering 2012; 4 (4): 375–384.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120410.pdf

Abstract: Based on three-dimensional cellular automata (CA), a new stochastic simulation model to simulate the microstructures and particle flow of talus deposit is proposed. In addition, an auto-modeling program CARS is developed, with which numerical simulations can be conducted conveniently. For the problem of simulating mechanical behaviors of talus deposit, spatial arrangement or sphere shapes should be considered. In the new modeling method, four sphere arrangement models are developed for the particle flow simulation of talus deposit. Numerical results show that the talus deposit has the mechanical characteristics of typical stress-strain curves, as other rock-like materials. The cohesion of talus deposit decreases with increasing rock content, while the internal friction angle increases with increasing rock contents. Finally, numerical simulation is verified with the results of field test.

Enlong Liu, Qing Nie, Jianhai Zhang. A new strength criterion for structured soils. Journal of Rock Mechanics and Geotechnical Engineering 2013; 5 (2): 156–161.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130207.pdf

Abstract: Existing strength criteria are mostly formulated to describe the mechanical properties of reconstituted soils. However, the engineering characteristics of structured soils are different from those of reconstituted soils in many aspects, especially in their strength properties. Thus, the influence of soil structure (bonding and fabric) on the mechanical properties of structured soils cannot be correctly described. By analyzing the breakage mechanism of natural soils, the structured soils can be conceptualized as binary medium materials consisting of bonded blocks and weakened bands. On this basis, a new strength criterion is proposed for structured soils. The expressions of the strength criterion on both meridian and deviator planes are given to describe the strength properties of structured soils on these planes. The proposed strength criterion is compared with available test data under conventional and true triaxial stress conditions in the literature. It is observed that the proposed strength criterion agrees well with the test data.

Guoxing Chen, Hua Pan, Hui Long, Xiaojun Li. Dynamic constitutive model for soils considering asymmetry of skeleton curve. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (5): 400–405.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130508.pdf

Abstract: Based on the asymmetric characteristic of skeleton curve obtained from dynamic tests on soils, a function with double asymptotes is proposed for describing the dynamic constitutive relations of soils. The hysteresis loops observed during unloading and reloading show the same form as the skeleton curve and are constructed by taking the ultimate stress as the corresponding asymptote. The coefficient of initial unloading modulus is used to ensure that the constructed hysteresis loop fits well with the experimental data. Then, a new dynamic constitutive model considering the asymmetry of skeleton curve is elaborated. The verification tests on saturated Nanjing fine sand are performed using a hollow cylinder apparatus to verify the applicability of the UD model. It is found that the predicted curves by the UD model agree well with the test data.

Jian Li, Chaosheng Tang, Deying Wang, Xiangjun Pei, Bin Shi. Effect of discrete fibre reinforcement on soil tensile strength. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (2): 133–137.

http://www.sciencedirect.com/science/article/pii/S1674775514000122 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140207.pdf

Abstract: The tensile behaviour of soil plays a significantly important role in various engineering applications. Compacted soils used in geotechnical constructions such as dams and clayey liners in waste containment facilities can suffer from cracking due to tensile failure. In order to increase soil tensile strength, discrete fibre reinforcement technique was proposed. An innovative tensile apparatus was developed to determine the tensile strength characteristics of fibre reinforced soil. The effects of fibre content, dry density and water content on the tensile strength were studied. The results indicate that the developed test apparatus was applicable in determining tensile strength of soils. Fibre inclusion can significantly increase soil tensile strength and soil tensile failure ductility. The tensile strength basically increases with increasing fibre content. As the fibre content increases from 0% to 0.2%, the tensile strength increases by 65.7%. The tensile strength of fibre reinforced soil increases with increasing dry density and decreases with decreasing water content. For instance, the tensile strength at a dry density of 1.7 Mg/m3 is 2.8 times higher than that at 1.4 Mg/m3. It decreases by 30% as the water content increases from 14.5% to 20.5%. Furthermore, it is observed that the tensile strength of fibre reinforced soil is dominated by fibre pull-out resistance, depending on the interfacial mechanical interaction between fibre surface and soil matrix.

L.J. Prendergast, K. Gavin. A review of bridge scour monitoring techniques. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (2): 138–149.

http://www.sciencedirect.com/science/article/pii/S167477551400016X or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140208.pdf

Abstract: The high profile failure of the Malahide Viaduct in Dublin, Ireland, which is a part of the EU TEN-T network of critical transport links, was caused by foundation scour. Scour is a common soil-structure interaction problem. In light of current changes in climate, increasing frequency of flooding, coupled with the increasing magnitude of these flood events, will lead to a higher risk of bridge failure. Monitoring scour is of paramount importance to ensure the continued safe operation of the aging bridge asset network. Most monitoring regimes are based on expensive underwater instrumentation that can often be subjected to damage during times of flooding, when scour risk is at its highest. This paper presents a critical review of existing scour monitoring equipments and methodologies with a particular focus on those using the dynamic response of the structure to indicate the existence and severity of the scour phenomenon affecting the structure. A sensitivity study on a recently developed monitoring method is also undertaken.

Michael R. Lodahl, Kristian T. Brødbæk, Carsten S. Sørensen. Calibrating partial factors for Danish railway embankments using probabilistic analyses. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (2):

150–155.

http://www.sciencedirect.com/science/article/pii/S1674775514000171 or
http://www.rockgeotech.org/qikan/manage/wenzhang/20140209.pdf

Abstract: High costs are connected with upgrading railway embankments throughout Denmark using the partial factors for geotechnical design calibrated for general application. One way to reduce the costs is reliability-based calibration of the partial factors to a reasonable safety level taking into account the specific design situations and uncertainties relevant to railway embankments. A reliability-based design has been investigated, resulting in an optimal partial factor for the considered subsoil. With a stochastic soil model to simulate the undrained shear strength of soft soil deposits, the partial factor is calibrated using asymptotic sampling for the reliability assessment. The calibration shows that the partial factor can be reduced significantly compared to the value specified in the Danish National Annex to DS/EN 1997-1 (2007), Eurocode 7.

Special Soil

A. M. Tang, Y. J. Cui. Experimental study on hydro-mechanical coupling behaviours of highly compacted expansive clay. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (1): 39–43.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-01-04.pdf

Abstract: Highly compacted expansive clays have been usually considered as a possible material for sealing and backfill in deep geological disposal of radioactive waste. In this condition, the material is simultaneously subjected to water infiltration from the geological barrier and stresses generated by the swelling of engineered barriers in confined conditions. Its behaviour under hydro-mechanical loading is essential to the safe design of the whole storage system. In the present work, MX80 bentonite, a kind of expansive clay from Wyoming, USA, was studied. After compaction, its dry density was 1.8 Mg/m^3 and its initial suction was 110 MPa. Firstly, the soil was humidified under controlled suction and free-swelling conditions. Significant swelling was observed. Secondly, four values of suction of 110, 39, 9 and 0 MPa were employed to perform isotropic compressive tests at constant suction conditions. That allowed studying the effect of suction on the yield pressure, elastic and plastic compressibility parameters. The results show that the elastic and plastic compressibility parameters increase when the suction decreases. The relationship between these parameters and the logarithm of suction can be linearly correlated. The yield stress drastically decreases upon wetting under free-swelling conditions, from 12 – 18 MPa (at an initial suction of 110 MPa) to 0.2 MPa at saturated state.

C. L. Zhang, K. Wieczorek, M. L. Xie. Swelling experiments on mudstones. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (1): 44–51.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-01-05.pdf

Abstract: This paper studies the swelling of highly consolidated mudstones by theoretical considerations and laboratory experiments. A key assumption was made that saturated and uncemented clays behave as heavily dense colloid without direct contacts among solid particles. It leads to an important conclusion that the swelling pressure acting on adsorbed interparticle water-films is equivalent to the effective stress. This so-called clay-colloid concept is validated by various swelling experiments on two kinds of mudstones, the Callovo-Oxfordian argillite in France and the Opalinus clay in Switzerland. In the tests, water adsorption-desorption, swelling pressure and strain were measured on the samples at various suctions and load-controlled conditions. Results suggest that: (1) the mudstones can take up great amounts of water from the humid environment, much more than the water content in the natural and saturated states; (2) the swelling pressure increases with water uptake to high levels of the overburden stresses at the sampling depths of 230 to 500 m, indicating that the adsorbed water-films are capable of carrying the lithostatic stress; and (3) the large amount of water uptake causes a significant expansion of mudstones even under the lithostatic stresses.

A. Lima, E. Romero, A. Gens, et al. Heating pulse tests under constant volume on Boom clay. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (2): 124–128.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-02-04.pdf

Abstract: Boom clay formation is a potential natural host rock for geological disposal of high-level nuclear waste in Belgium. Heating pulse tests with controlled power supply (maximum temperature was limited to 85 °C) and controlled hydraulic boundary conditions were performed under nearly constant volume conditions to study the impact of thermal loading on the

clay formation. Selected test results of intact borehole samples retrieved in horizontal direction are presented and discussed. The study focuses on the time evolution of temperature and pore water pressure changes along heating and cooling paths, i.e. pore pressure build-up during quasi-undrained heating and later dissipation at constant temperature.

H. Nowamooz, F. Masrouri. Suction variations and soil fabric of swelling compacted soils. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (2): 129–134.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-02-05.pdf

Abstract: This study addresses firstly the soil fabric variations of loose and dense compacted soil samples during a single wetting/drying cycle at suctions between 0 and 287.9 MPa using mainly the mercury intrusion porosimetry (MIP) tests. Two suction techniques were employed to apply this wide suction range: the osmotic technique for suctions less than 8.5 MPa, and the vapor equilibrium or salt solution technique for suctions higher than 8.5 MPa. Secondly, the soil water retention curves (SWRCs) were predicted by the MIP test results for both loose and dense soil samples. A reasonable correspondence between MIP results and SWRCs was found on the wetting path at lower suctions close to saturation and on drying path at higher suctions.

Kanghe Xie, Chuanxun Li, Xingwang Liu, Yulin Wang. Analysis of one-dimensional consolidation of soft soils with non-Darcian flow caused by non-Newtonian liquid. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (3): 250–257.

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-03-05.pdf

Abstract: Based on non-Darcian flow caused by non-Newtonian liquid, the theory of one-dimensional (1D) consolidation was modified to consider variation in the total vertical stress with depth and time. The finite difference method (FDM) was adopted to obtain numerical solutions for excess pore water pressure and average degree of consolidation. When non-Darcian flow is degenerated into Darcian flow, a comparison between numerical solutions and analytical solutions was made to verify reliability of finite difference solutions. Finally, taking into account the ramp time-dependent loading, consolidation behaviors with non-Darcian flow under various parameters were analyzed. Thus, a comprehensive analysis of 1D consolidation combined with non-Darcian flow caused by non-Newtonian liquid was conducted in this paper.

Ying Li, Xiaonan Gong, Mengmeng Lu, Yanli Tao. Non-mechanical behaviors of soft clay in two-dimensional electro-osmotic consolidation. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (3): 282–288.

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-03-09.pdf

Abstract: To investigate the soil behaviors in a direct current field on both spatial and temporal scales, a 1: 5 scale model test was conducted in laboratory to simulate the two-dimensional (2D) electro-osmotic consolidation of soft clay foundation. Volume of drainage, intensity, voltage, water content and pH value of water collected in the cathodes were monitored. The pH values of soil and the mass of anodes were measured before and after the test. The test results indicate that the unsaturated state, resultant from fissures induced by the differences in water contents, is favorable to dynamic compaction of soil during electro-osmotic drainage. The results also demonstrate that water content, degree of saturation and electric potential distributions can be used to deduce the electro-osmotic drainage process. Water content of soil decreases first near electrodes, while keeps nearly constant in the center of the model. The area with constant water content is larger than half of the sample surface. Moving anodes towards cathodes by about one third of the electrode spacing is effective to improve the treatment effect after electro-osmosis stops due to the large resistance. Moreover, it is observed that during electro-osmosis, the corrosion rate of anodes becomes smaller, while the variation in pH values of soil near anodes becomes larger.

Min Wang, Lingwei Kong, Chong Zhao, Meng Zang. Dynamic characteristics of lime-treated expansive soil under cyclic loading. Journal of Rock Mechanics and Geotechnical Engineering. 2012; 4 (4): 352–359.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120407.pdf

Abstract: To better understand the dynamic properties of expansive clay treated with lime, a series of laboratory tests were conducted using a dynamic triaxial test system. The influential factors, including moisture content, confining pressure, vibration frequency, consolidation ratio, and cycle number on the dynamic characteristics were discussed. Experimental results indicate that specimens at low moisture contents tend to damage along the 30° shear plane and they present brittle failure, while saturated specimens show swelling phenomenon and plastic failure. A reduction in cohesion has been

observed for unsaturated samples at large number of cycles, while it is opposite for the internal friction angle. For the saturated specimens, both the cohesion and internal friction angle decrease with increasing number of cycles.

Mingwu Wang, Guangyi Chen, Susumu Iai. Seismic performances of dyke on liquefiable soils. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (4): 294–305.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130405.pdf

Abstract: Various field investigations of earthquake disaster cases have confirmed that earthquake-induced liquefaction is a main factor causing significant damage to dyke, research on seismic performances of dyke is thus of great importance. In this paper, seismic responses of dyke on liquefiable soils were investigated by means of dynamic centrifuge model tests and three-dimensional (3D) effective stress analysis method which is based on a multiple shear mechanism model and a liquefaction front. For the prototype scale centrifuge tests, sine wave input motions with peak accelerations 0.806 m/s2, 1.790 m/s2 and 3.133 m/s2 of varied amplitudes were adopted to study the seismic performances of dyke on the saturated soil layer foundation with relative density of approximately 30%. Then, corresponding numerical simulations were conducted to investigate the distribution and variations of deformation, acceleration, excess pore-water pressure (EPWP), and behaviors of shear dilatancy in the dyke and the liquefiable soil foundation. Moreover, detailed discussions and comparisons between numerical simulations and centrifuge tests were also presented. It is concluded that the computed results have a good agreement with the measured results by centrifuge tests. The physical and numerical models both indicate that the dyke hosted on liquefiable soils subjected to earthquake motions has exhibited larger settlement and lateral spread: the stronger the motion is, the larger the dyke deformation is. Compared to soils in the deep ground under the dyke and the free field, the EPWP ratio is much smaller in the shallow liquefiable soil beneath the dyke in spite of large deformation produced. For the same overburden depth soil from free site and the liquefiable foundation beneath dyke, the characteristics of effective stress path and stress-strain relations are different. All these results may be of theoretical and practical significance for seismic design of the dyke on liquefiable soils.

Yinghe Wang, Xinyi Zhao, Baotian Wang. LS-SVM and Monte Carlo methods based reliability analysis for settlement of soft clayey foundation. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (4): 312–317.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130407.pdf

Abstract: A method which adopts the combination of least squares support vector machine (LS-SVM) and Monte Carlo (MC) simulation is used to calculate the foundation settlement reliability. When using LS-SVM, choosing the training dataset and the values for LS-SVM parameters is the key. In a representative sense, the orthogonal experimental design with four factors and five levels is used to choose the inputs of the training dataset, and the outputs are calculated by using fast Lagrangian analysis continua (FLAC). The decimalant colony algorithm (DACA) is also used to determine the parameters. Calculation results show that the values of the two parameters, γ and δ^2 have great effect on the performance of LS-SVM. After the training of LS-SVM, the inputs are sampled according to the probabilistic distribution, and the outputs are predicted with the trained LS-SVM, thus the reliability analysis can be performed by the MC method. A program compiled by Matlab is employed to calculate its reliability. Results show that the method of combining LS-SVM and MC simulation is applicable to the reliability analysis of soft foundation settlement.

Wei Bai, Lingei Kong, Aiguo Guo. Effects of physical properties on electrical conductivity of compacted lateritic soil. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (5): 406–411.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130509.pdf

Abstract: Natural soils of various types have different electrical properties due to the composition, structure, water content, and temperature. In order to investigate the electrical properties of lateritic soil, electrical conductivity experiments have been conducted on a self-developed testing device. Test results show that the electrical conductivity of laterite increases with the increase of water content, degree of saturation and dry density. When the water content is below the optimum water content, the electrical conductivity of soils increases nonlinearly and the variation rate increases dramatically. However,

when the water content, degree of saturation, or dry density increases to a certain value, the electrical conductivity tends to be a constant. In addition, soil electrical conductivity increases with the increase of temperature, and it is observed that the electrical conductivity decreases with the increase of the number of wetting–drying cycles.

Chunlin Li. A simplified method for prediction of embankment settlement in clays. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (1): 61–66.

http://www.sciencedirect.com/science/article/pii/S1674775513001182 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140107.pdf

Abstract: The prediction of embankment settlement is a critically important issue for the serviceability of subgrade projects, especially the post-construction settlement. A number of methods have been proposed to predict embankment settlement; however, all of these methods are based on a parameter, i.e. the initial time point. The difference of the initial time point determined by different designers can definitely induce errors in prediction of embankment settlement. This paper proposed a concept named “potential settlement” and a simplified method based on the in situ data. The key parameter “b” in the proposed method was verified using theoretical method and field data. Finally, an example was used to demonstrate the advantages of the proposed method by comparing with other methods and the observation data.

Unsaturated Soil

H. Wong, M. Morvan, D. Branque. A 13-parameter model for unsaturated soil based on bounding surface plasticity. Journal of Rock Mechanics and Geotechnical Engineering. 2010; 2 (2): 135–142.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-02-06.pdf

Abstract: A few constitutive models for unsaturated soils have already been proposed, however, many classic models such as the Barcelona basic model can simulate neither complex volumetric soil behaviour (without forgetting its supreme merit of being the first consistently and rigorously formulated model) nor post-peak softening, and most advanced models generally comprise a large number of parameters making them more difficult to be applied to practical situations. In this paper, we present a new model for unsaturated soils based on an existing model developed originally for saturated soils. It comprises a minimum number of constitutive parameters. The extension to unsaturated state is achieved by following a general methodology previously developed in our laboratory. The capacities of this simple model are tested. With only 13 parameters, it can reproduce the basic behaviour of unsaturated soils such as rebound or collapse upon wetting, depending on the stress levels. It can also reproduce post-peak softening and transition from contractant to dilatant volumetric behaviour during undrained shear. Overall, the first tentative of validation gives a good correlation between simulations and experimental data, and shows encouraging signs for future developments.

Yingfa Lu, Xinxing Wu, Yujun Cui. On the thermo-mechanical properties of unsaturated soils. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (2): 143–148.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-02-07.pdf

Abstract: The establishment of energy balance equation is necessary to study the thermo-mechanical properties of unsaturated soils. To solve this equation, the determination of two fundamental parameters as volumetric specific parameter and thermal conductivity coefficient is essential. In this paper, the effective thermal conductivity coefficient of dry soil grain is analyzed for soils with different compositions, and the thermo-mechanical properties of porous media with water and gas are studied by considering the soil water retention curve (SWRC). Different methods, i.e. volumetric average method, self-consistent method, Hashin-Strikman method, are employed to calculate thermal conductivity coefficients, and a new method is proposed to determine the thermo-mechanical parameters. Comparison of the results obtained by different methods shows that the proposed method is in a good agreement with the experimental results and is suitable for describing the main properties of the thermo- mechanical behaviors of soils. The relationship between the SWRC and the seepage curve is further studied by the natural proportional rule. The characteristics of the SWRC, its differential coefficient and the seepage curve, are investigated by considering the physico-mechanical mechanism; the limit scopes of the indices of the SWRC and the seepage curve are also given.

Weimin Ye, Yawei Zhang, Bao Chen, et al. Shear strength of an unsaturated weakly expansive soil. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (2): 155–161.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-02-09.pdf

Abstract: To study the weakly expansive clay obtained from a slope along Wuhan—Shiyan expressway in Hubei Province, soil-water property tests and some unsaturated triaxial tests with suction control were conducted, and the soil-water retention curve (SWRC) and unsaturated shear strength of this soil were obtained. Results show that the air-entry suction and the residual degree of saturation of the tested soil are 106 kPa and 8%, respectively. The boundary effect zone and the transition zone can be identified on the desorption curve, but the residual zone is not so obvious. The unsaturated shear strength increases as suction increases within the range of controlled suction in the test, and friction angle, φ^b, in the triaxial shear test is 17.6°. Based on the results, constitutive models for predicting the unsaturated shear strength using the SWRC were evaluated, and comparisons between prediction and measurement were made. It is concluded that for engineering purpose, the constitutive model should be carefully selected based on soil properties when predicting the unsaturated shear strength using the SWRC.

Feng Zhang, Yonglin Xiong, Sheng Zhang, Bin Ye. Thermo-hydro-mechanical-air coupling finite element method and its application to multi-phase problems. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (2): 77–98.

http://www.sciencedirect.com/science/article/pii/S1674775514000195 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140201.pdf

Abstract: In this paper, a finite element method (FEM)-based multi-phase problem based on a newly proposed thermal elastoplastic constitutive model for saturated/unsaturated geomaterial is discussed. A program of FEM named as SOFT, adopting unified field equations for thermo-hydro-mechanical-air (THMA) behavior of geomaterial and using finite element-finite difference (FE-FD) scheme for soil–water–air three-phase coupling problem, is used in the numerical simulation. As an application of the newly proposed numerical method, two engineering problems, one for slope failure in unsaturated model ground and another for in situ heating test related to deep geological repository of high-level radioactive waste (HLRW), are simulated. The model tests on slope failure in unsaturated Shirasu ground, carried out by Kitamura et al. (2007), is simulated in the framework of soil–water–air three-phase coupling under the condition of constant temperature. While the in situ heating test reported by Munoz (2006) is simulated in the same framework under the conditions of variable temperature but constant air pressure.

Pipejacking and Structure

K. J. Shou, J. M. Jiang. A study of jacking force for a curved pipejacking. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (4): 298–304.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-04-02.pdf

Abstract: For a pipejacking, the jacking force is critical to balance the resistance force and to move the pipe string forwards. The driving mechanism of a curved pipejacking is more complicated than a straight-line pipejacking, and its jacking force is also more difficult to be determined. The paper theoretically studies the jacking force of a curved pipejacking by considering the static equilibrium of earth pressure, resistance at cutting face, friction at pipe surface, and the driving force behind the pipe string. The derived theoretical formula can be used to estimate the driving forces of a straight-line or a curved pipejacking. Case study was performed by applying the theoretical and empirical formulae. After calibration, the corrected formula is more accurate and more applicable.

Foundation

Baotian Wang, M. Q. Vu. Improvement of silty clay by vacuum preloading incorporated with electroosmotic method. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (4): 365–372.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-04-10.pdf

Abstract: A laboratory test was performed to assess the effectiveness of vacuum preloading incorporated with electroosmotic (EOM) treatment on silty clay (combined method) for reclamation projects like new disposal ponds, where the horizontal electrode configurations beneath the soil layer were possible and the drainage pipes and the prefabricated vertical drains (PVDs) system could be easily installed in advance before the sludge dragged from sea bed or river bed was filled into the site. Three groups of tests were conducted on the silty clay from Qinhuai River in Nanjing, China. The model is able to apply vacuum pressure at the bottom of the soil layer and a direct current electric field simultaneously. It is also possible to measure the pore pressures at different depths of soil column, and the changes in settlement and volume with the elapsed time. In this study, the vacuum preloading method, vacuum preloading applied at the bottom (VAB method), was applied and the cathodes were installed beneath the soil layer. The results obtained indicate substantial reduction in water content, and increases in dry density and undrained shear strength in comparison with those obtained by the vacuum preloading only, particularly at the positions close to the anode. The combined method utilizes the vertical drainage flow created by the electroosmosis integrating the horizontal drainage flow created mostly by the vacuum pressure. The total drainage flow can be calculated as a result of the vertical drainage flow by electroosmosis only and the horizontal drainage flow by the vacuum preloading only. The way of placement of the cathode and the anode in the combined method also overcomes the disadvantage of EOM method itself, i.e. the appearance of cracks between the anode and the surrounding soil. Moreover, it is observed that the vacuum preloading plays a primary role in earlier stage in deduction of free pore water; meanwhile, the electroosmotic method is more efficient in later stage for absorbing water in the diffused double layers of soil.

Xiaolin Weng, Wei Wang. Influence of differential settlement on pavement structure of widened roads based on large-scale model test. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (1): 90–96.
http://www.rockgeotech.org/qikan/manage/wenzhang/2011-01-10.pdf

Abstract: This study introduced at first the background of numerous highway widening projects that have been developed in recent years in China. Using a large ground settlement simulator and a fiber Bragg grating (FBG) strain sensor network system, a large-scale model test, with a similarity ratio of 1:2, was performed to analyze the influence of differential settlement between new and old subgrades on pavement structure under loading condition. The result shows that excessive differential settlement can cause considerable tensile strain in the pavement structure of a widened road, for which a maximum value (*S*) of 6 cm is recommended. Under the repetitive load, the top layers of pavement structure are subjected to the alternate action of tensile and compressive strains, which would eventually lead to a fatigue failure of the pavement. However, application of geogrid to the splice between the new and the old roads can reduce differential settlement to a limited extent. The new subgrade of a widened road is vulnerable to the influence of dynamic load transferred from the above pavement structures. While for the old subgrade, due to its comparatively high stiffness, it can well spread the load on the pavement statically or dynamically. The test also shows that application of geogrid can effectively prevent or defer the failure of pavement structure. With geogrid, the modulus of resilience of the subgrade is increased and inhomogeneous deformation can be reduced; therefore, the stress/strain distribution in pavement structure under loading condition becomes uniform. The results obtained in this context are expected to provide a helpful reference for structural design and maintenance strategy for future highway widening projects.

Endi Zhai. An overview of seismic ground motion design criteria for transportation infrastructures in USA. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (3): 244–249.
http://www.rockgeotech.org/qikan/manage/wenzhang/20110305.pdf

Abstract: This paper provides an overview of current seismic ground motion criteria for transportation infrastructures in USA. This is to facilitate an understanding of current seismic performance levels and design practices in USA for transportation professionals world-wide, especially those in Asian and Pacific regions. Seismic vulnerability of a transportation infrastructure is determined by the risk associated with the seismic ground motion and specified performance criteria. Determining an acceptable seismic risk is a very complex task that must consider both social and economic aspects. Obviously, the amount of risk that a railway bridge can accept may be different from that of a highway bridge. The economic tolerance in one country may be different from that in another country for the same type of infrastructure. In this paper, seismic performance levels and design criteria of ground motion for highway bridges, railway bridges and ports' container wharves in USA are reviewed, and design examples are presented to demonstrate how to develop the code-based and site-specific design acceleration response spectra and time histories.

Mohammed Y. Fattah, Kais T. Shlash, Madhat S. M. Al-Soud. Pile-clayey soil interaction analysis by boundary element method. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (1): 28–43

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-01-04.pdf

Abstract: This paper is an attempt to solve the soil-pile interaction problems using the boundary element method (BEM). A computer package called PGroupN, which deals mainly with the analysis of the pile group problem, is employed in this study. Parametric studies are carried out to assess the impacts of the pile diameter, pile length, ratio of spacing to diameter and the thickness of soil stratum. The external load is applied incrementally and, at each increment, a check is made that the stress state at the pile-soil interfaces does not violate the yield criteria. This is achieved by specifying the limited stresses of the soil for the axial pile shaft capacity and end-bearing resistance. The elements of the pile-soil interface yielded can take no additional load, and any increase in load is therefore redistributed between the remaining elements until all elements have failed. Thus, by successive application of loading increments, the entire load-displacement relationship for the pile group is determined. It is found that as the applied load reaches the ultimate bearing capacity of the pile group, all the piles will share the same amount of load. An exception to this case is for the center pile in a group of 9 piles embedded in clay, which is not consistent with the behaviors of the other piles in the group even if the load reaches the ultimate state. For the 4 piles group embedded in clay, the maximum load carried by the base does not exceed 8% of the load carried by each pile with different diameters. This low percentage ascertains that the piles embedded in cohesive soils carry most of the load throughout their shafts.

Guoliang Dai, Weiming Gong. Application of bi-directional static loading test to deep foundations. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (3): 269–275.

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-03-07.pdf

Abstract: Bi-directional static loading test adopting load cells is widely used around the world at present, with increase in diameter and length of deep foundations. In this paper, a new simple conversion method to predict the equivalent pile head load-settlement curve considering elastic shortening of deep foundation was put forward according to the load transfer mechanism. The proposed conversion method was applied to root caisson foundation in a bridge and to large diameter pipe piles in a sea wind power plant. Some new load cells, test procedure, and construction technology were adopted based on the applications to different deep foundations, which could enlarge the application scopes of bi-directional loading test. A new type of bi-directional loading test for pipe pile was conducted, in which the load cell was installed and loaded after the pipe pile with special connector has been set up. Unlike the conventional bi-directional loading test, the load cell can be reused and shows an evident economic benefit.

F. Schlosser, C. Servant, A. Guilloux, A. Bergere. Millau viaduct geotechnical studies and foundations.Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (3): 243–247.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130308.pdf

Abstract: The Millau viaduct over the Tarn River is an exceptional bridge considering the height under the deck and the 2.5 km total length. Each of the seven high piers is founded on a thick raft setting on four large piles of 5 m in diameter and 10–15 m deep. The ground schematically consists of limestone in the north and of marls in the south. As the bridge is very sensitive to foundation settlements, the concessionary company decided to use the observational method for controlling the displacements and if necessary stabilize the foundations. The measurements show that the movements have remained small and admissible, particularly in terms of the rotations. The settlements have not occurred continuously under the load, but by steps.

Renpeng Chen, Xing Zhao, Zuozhou Wang, Hongguang Jiang, Xuecheng Bian. Experimental study on dynamic load magnification factor for ballastless track-subgrade of high-speed railway. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5(4): 306–311.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130406.pdf

Abstract: The magnitude of dynamic load produced by high-speed trains depends on many factors, of which train speed is the most critical one. However, it is quite difficult to determine the effect of train speed on dynamic load using the theoretical

methods due to the complexity of the interaction between vehicle and track-subgrade. Thus large-scale model test has gradually become an important approach for studying dynamic responses of ballastless track-subgrade of high-speed railway. In this study, a full-scale model of ballastless track-subgrade was constructed in accordance with the design and construction standards for Shanghai–Nanjing intercity high-speed railway line firstly. Then, the dynamic strain of slab and the dynamic earth pressure of subgrade were measured by conducting single wheel axle excitation test. In addition, the relationship between the dynamic load magnification factor (DLF) and the train speed was obtained. Finally, the DLF of track-subgrade under different train speeds was proposed, similar to that given by German Railway Standard.

Basuon El-Garh, Ahmed Abdel Galil, Abdel-Fattah Youssef, Mohamed Abo Raia. Behavior of raft on settlement reducing piles: Experimental model study. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (5): 389–399.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130507.pdf

Abstract: An experimental program is conducted on model piled rafts in sand soil. The experimental program is aimed to investigate the behavior of raft on settlement reducing piles. The testing program includes tests on models of single pile, unpiled rafts and rafts on 1, 4, 9, or 16 piles. The model piles beneath the rafts are closed ended displacement piles installed by driving. Three lengths of piles are used in the experiments to represent slenderness ratio, L/D, of 20, 30 and 50, respectively. The dimensions of the model rafts are 30 cm× 30 cm with different thickness of 0.5 cm, 1.0 cm or 1.5 cm. The raft-soil stiffness ratios of the model rafts ranging from 0.39 to 10.56 cover flexible to very stiff rafts. The improvement in the ultimate bearing capacity is represented by the load improvement ratio, LIR, and the reductions in average settlement and differential settlement are represented by the settlement ratio, SR, and the differential settlement ratio, DSR, respectively. The effects of the number of settlement reducing piles, raft relative stiffness, and the slenderness ratio of piles on the load improvement ratio, settlement ratio and differential settlement ratio are presented and discussed. The results of the tests show the effectiveness of using piles as settlement reduction measure with the rafts. As the number of settlement reducing piles increases, the load improvement ratio increases and the differential settlement ratio decreases.

Aleksandra Chepurnova. Assessing the influence of jet-grouting underpinning on the nearby buildings. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (2): 105–112.

http://www.sciencedirect.com/science/article/pii/S1674775514000146 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140203.pdf

Abstract: This paper focuses on the underpinning-induced ground movement due to jet-grouting. Jet-grouting technique can cause distortions as a result of an inaccurate processing sequence and/or errors made at different stages of work execution. The aim of this paper is to determine the minimum value of such movement on the basis of the findings obtained at two similar construction sites located in the Historical Center of Moscow, considering that the maximum value is usually unpredictable. Numerical simulation of the process of soil eroding agrees well with the observational data at the current stage. It was found that the minimum value of deformations (only settlement was considered in this study) due to jet-grouting is no less than 2–3 mm. By contrast, the negative scenario of deformation due to foundation underpinning is clearly demonstrated. Also, this paper provides some general solutions for excavation supporting system as well as for underpinning design.

Slope Engineering

Yingren Zheng, Xiaosong Tang, Shangyi Zhao, et al. Strength reduction and step-loading finite element approaches in geotechnical engineering. Journal of Rock Mechanics and Geotechnical Engineering. 2009, 1 (1): 21–30.

http://www.rockgeotech.org/qikan/manage/wenzhang/20090014.pdf

Abstract: The finite element limit analysis method has the advantages of both numerical and traditional limit equilibrium techniques and it is particularly useful to geotechnical engineering. This method has been developed in China, following well-accepted international procedures, to enhance understanding of stability issues in a number of geotechnical settings. Great advancements have been made in basic theory, the improvement of computational precision, and the broadening of practical applications. This paper presents the results of research on (1) the efficient design of embedded anti-slide piles, (2) the stability analysis of reservoir slopes with strength reduction theory, and (3) the determination of the ultimate bearing capacity of foundations using step-loading FEM (overloading). These three applications are evidence of the design improvements and benefits made possible in geotechnical engineering by finite element modeling.

Xiaoling Lai, Shimei Wang, Hongbin Qin, et al. Unsaturated creep tests and empirical models for sliding zone soils of Qianjiangping landslide in the Three Gorges. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (2): 149–154.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-02-08.pdf

Abstract: Creep of sliding zone soils may cause significant displacement in large-scale landslides in the Three Gorges reservoir area. To investigate the effects of water on the soil creep behavior of the Qianjiangping landslide, a series of unsaturated triaxial creep tests on the sliding zone soils were performed. Based on the analyses of testing results, a new stress intensity incorporating matric suction was defined and an unsaturated Singh-Mitchell creep model was developed. Predicted results are in good agreement with the experimental results, which indicates that the established unsaturated model can reasonably simulate the effects of water on the soil creep behavior of the landslide. Finally, relationships between matric suction and the parameters of the model were analyzed. This study provides a calculation model and parameters for the evaluation of long-term stability of landslides under the influence of water.

Yueping Yin. Recent catastrophic landslides and mitigation in China. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (1): 10–18.

http://www.rockgeotech.org/qikan/manage/wenzhang/2011-01-02.pdf

Abstract: Increasing population density and development of mountainous terrain have brought human settlements within reach of landslide hazards. In recent years, due to the shortening of return period for severe natural events such as heavy rainfall, snowline retreating, great earthquake together with human activities, catastrophic landslides happened more frequently than before, resulting in large-scale casualties due to the increasing occurrences of rapid long-runout rock avalanches, especially in China. This paper presents some typical case histories related to the catastrophic landslides, including the Guanling rock avalanche, the Yigong rockslide-debris avalanche, the Wenchuan earthquake-induced landslides and the Danba landslide. They occurred in the last decade. Moreover, taking the Jiweishan catastrophic rockslide-fragment flow and the Yuhuangge landslide located in the new Wushan Town for examples, early-warning system and risk management on landslides are discussed in detail.

Mowen Xie, Zengfu Wang, Xiangyu Liu, et al. Three-dimensional critical slip surface locating and slope stability assessment for lava lobe of Unzen volcano. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (1): 82–89.

http://www.rockgeotech.org/qikan/manage/wenzhang/2011-01-09.pdf

Abstract: Even Unzen volcano has been declared to be in a state of relative dormancy, the latest formed lava lobe No.11 now represents a potential slope failure mass based on the latest research. This paper concentrates on the stability of the lava lobe No.11 and its possible critical sliding mass. It proposes geographic information systems (GIS) based three-dimensional (3D) slope stability analysis models. It uses a 3D locating approach to identify the 3D critical slip surface and to analyze the 3D stability of the lava lobe No.11. At the same time, the new 3D approach shows the effectiveness in

selecting the range of the Monte Carlo random variables and locating the critical slip surface in different parts of the lava lobe No.11. The results are very valuable for judging the stability of the lava lobe and assigning the monitoring equipments.

Runqiu Huang, Weile Li. Formation, distribution and risk control of landslides in China. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (2): 97–116.

http://www.rockgeotech.org/qikan/manage/wenzhang/2011-02-01.pdf

Abstract: China is a country with a large population as well as frequent landslides. The formation and distribution of landslides in China are determined by its special topography, complex geological environment, active earthquake environment and unusual climate features. This paper analyzes the main features and distribution of 200 catastrophic landslides that occurred in China since 1900. The relationships among the distribution of landslides and topographic conditions, geological structure, climate features and strong earthquake environment are analyzed. The features of landslide-triggering factors and critical conditions in different areas have also been considered. Based on the above-mentioned work, the authors have undertaken the studies of landslide susceptibility assessment. The study is performed according to the topographic and geological features, which are the main triggering factors that affect the landslides. The Mainland China can be divided into 12 zones, including 4 high susceptibility zones, 7 medium susceptibility zones and 1 low susceptibility zone, according to landslide proneness. Considering the number of life loss and extent of property loss caused by landslides in those 12 zones, the risk evaluation results are listed as follows: 2 extremely high-risk zones, 5 high-risk zones, 2 medium-risk zones and 3 low-risk zones. Taking the number of life loss caused by landslides as the standard of risk level, the paper also analyzes the change in landslide risk level and main risk control measures in China since 1990s. Based on the risk level of landslides in other countries or regions, the acceptable landslide risk level in China has been proposed.

Mingwei Guo, Xiurun Ge, Shuilin Wang. Slope stability analysis under seismic load by vector sum analysis method. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (3): 282–288.

http://www.rockgeotech.org/qikan/manage/wenzhang/20110309.pdf

Abstract: The vibration characteristics and dynamic responses of rock and soil under seismic load can be estimated with dynamic finite element method (DFEM). Combining with the DFEM, the vector sum analysis method (VSAM) is employed in seismic stability analysis of a slope in this paper. Different from other conventional methods, the VSAM is proposed based on the vector characteristic of force and current stress state of the slope. The dynamic stress state of the slope at any moment under seismic load can be obtained by the DFEM, thus the factor of safety of the slope at any moment during earthquake can be easily obtained with the VSAM in consideration of the DFEM. Then, the global stability of the slope can be estimated on the basis of time-history curve of factor of safety and reliability theory. The VSAM is applied to a homogeneous slope under seismic load. The factor of safety of the slope is 1.30 under gravity only and the dynamic factor of safety under seismic load is 1.21. The calculating results show that the dynamic characteristics and stability state of the slope with input ground motion can be actually analyzed. It is believed that the VSAM is a feasible and practical approach to estimate the dynamic stability of slopes under seismic load.

Gang Luo, Xiewen Hu, Chengzhuang Gu, Ying Wang. Numerical simulations of kinetic formation mechanism of Tangjiashan landslide. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (2): 149–159.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120205.pdf

Abstract: Tangjiashan landslide is a typical high-speed landslide hosted on consequent bedding rock. The landslide was induced by Wenchuan earthquake at a medium-steep hill slope. The occurrence of Tangjiashan landslide was basically controlled by the tectonic structure, topography, stratum lithology, slope structure, seismic waves, and strike of river. Among various factors, the seismic loading with great intensity and long duration was dominant. The landslide initiation exhibited the local amplification effect of seismic waves at the rear of the slope, the dislocation effect on the fault, and the shear failure differentiating effect on the regions between the soft and the hard layers. Based on field investigations and with the employment of the distinct element numerical simulation program UDEC (universal distinct element code), the whole kinetic sliding process of Tangjiashan landslide was represented and the formation mechanism of the consequent rock landslide under seismic loading was studied. The results are helpful for understanding seismic dynamic responses of consequent bedding rock slopes, where the slope stability could be governed by earthquakes.

Fanyu Zhang, Gao Liu, Wenwu Chen, Shouyun Liang, Ransheng Chen, Wenfeng Han. Human-induced landslide on a high cut slope: a case of repeated failures due to multi-excavation. Journal of Rock Mechanics and Geotechnical Engineering 2012; 4 (4): 367–374.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120409.pdf

Abstract: The paper attempts to represent a case of repeated failures on a high cut slope due to multi-excavation. The characteristics of each failure induced by excavation are analyzed through geological investigation, and then a geological model at different failure stages is proposed. The geological analysis shows that the excavation-induced repeated failures are related to the exposure of the weak bedding plane and the toe unloading of the cut slope. Numerical modeling is conducted based on a sequential method, taking into account the main failure stages of cut slope. The simulation results fairly coincide with the practical phenomena observed in field. It is shown that the decrease in normal stress of displaced mass on cut slope will induce the increase in shear stress in bedding planes and that at the toe of the cut slope. The released stress leads to repeated gravitational instabilities of cut slope due to the decrease in normal stress and the increase in shear stress along the bedding planes of mudstone.

LiangchaoZou, Shimei Wang, Xiaoling Lai. Creep model for unsaturated soils in sliding zone of Qianjiangping landslide. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (3): 162–167.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130208.pdf

Abstract: The mechanical behavior of sliding zone soils plays a significant role in landslide. In general, the sliding zone soils are basically in unsaturated state due to rainfall infiltration and reservoir water level fluctuation. Meanwhile, a large number of examples show that the deformation processes of landslides always take a long period of time, indicating that landslides exhibit a time-dependent property. Therefore, the deformation of unsaturated soils of landslide involves creep behaviors. In this paper, the Burgers creep model for unsaturated soils under triaxial stress state is considered based on the unsaturated soil mechanics. Then, by curve fitting using the least squares method, creep parameters in different matric suction states are obtained based on the creep test data of unsaturated soils in the sliding zones of Qianjiangping landslide. Results show that the predicted results are in good agreement with the experimental data. Finally, to further explore the creep characteristics of the unsaturated soils in sliding zones, the relationships between parameters of the model and matric suction are analyzed and a revised Burgers creep model is developed correspondingly. Simulations on another group of test data are performed by using the modified Burgers creep model and reasonable results are observed.

K.Y. Chio, Ramond W.M. Cheung. Landslide disaster prevention and mitigation through works in Hong Kong. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (5): 354–365.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130504.pdf

Abstract: Hong Kong has a high concentration of developments on hilly terrain in close proximity to man-made slopes and natural hillsides. Because of the high seasonal rainfall, these man-made slopes and natural hillsides would pose a risk to the public as manifested by a death toll of 470 people due to landslides since the late 1940s. In 1977, the Government of the Hong Kong SAR embarked on a systematic programme, known as the Landslip Preventive Measure (LPM) Programme, to retrofit substandard man-made slopes. From 1977 to 2010, about 4500 substandard government man-made slopes have been upgraded through engineering works. During the period, the Programme had evolved progressively in response to Government's internal demand for continuous improvement and rising public expectation for slope safety. In 2010, the Government implemented the Landslip Prevention and Mitigation (LPMit) Programme todovetail with the LPM Programme, with the focus on retrofitting the remaining moderate-risk substandard man-made slopes and mitigating systematically the natural terrain landslide risk pursuant to the"react-to-known" hazard principle. This paper presents the evolution of the LPM and LPMitProgrammesas well as the insight on landslide prevention and mitigation through engineering works.

J. González-Cao, F. Varas, F.G. Bastante, L.R. Alejano. Ground reaction curves for circular excavations in non-homogeneous, axisymmetric strain-softening rock masses. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (6): 431–442.

http://www.sciencedirect.com/science/article/pii/S1674775513000991 or
http://www.rockgeotech.org/qikan/manage/wenzhang/20130602.pdf

Abstract: Fast methods to solve the unloading problem of a cylindrical cavity or tunnel excavated in elasto-perfectly plastic, elasto-brittle or strain-softening materials under a hydrostatic stress field can be derived based on the self-similarity of the solution. As a consequence, they only apply when the rock mass is homogeneous and so exclude many cases of practical interest. We describe a robust and fast numerical technique that solves the tunnel unloading problem and estimates the ground reaction curve for a cylindrical cavity excavated in a rock mass with properties depending on the radial coordinate, where the solution is no longer self-similar. The solution is based on a continuation-like approach (associated with the unloading and with the incremental formulation of the elasto-plastic behavior), finite element spatial discretization and a combination of explicit sub-stepping schemes and implicit techniques to integrate the constitutive law, so as to tackle the difficulties associated with both strong strain-softening and elasto-brittle behaviors. The developed algorithm is used for two practical ground reaction curve computation applications. The first application refers to a tunnel surrounded by an aureole of material damaged by blasting and the second to a tunnel surrounded by a ring-like zone of reinforced (rock-bolted) material.

Morteza Abdi Cherlo, Hamid Hashemolhosseini, MasoudCheraghi, Saeed Mahdevari. Feasibility evaluation for excavation of NaghsheJahan Square subway station by underground methods. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (6): 452–459.

http://www.sciencedirect.com/science/article/pii/S1674775513001066 or
http://www.rockgeotech.org/qikan/manage/wenzhang/20130604.pdf

Abstract: In recent years, in reaction to the increasing usage of urban areas, the excavation of underground spaces has been developed. One of the most challenging issues encountered by engineers is the construction of subway stations as large underground spaces at shallow depth with soft surrounding soils. In this paper, NaghsheJahan Square subway station located in Isfahan, Iran, has been simulated by geomechanical finite difference method (FDM). This station is located under important historical structures. Therefore, the ground displacement and surface settlement induced by the excavation of the subway station should be strictly controlled. Many of such problems are affected by selected excavation method. For these reasons, different underground excavation methods associated with construction have been studied. In this study, sequential excavation method and large-diameter curved pipe roofing method are used and the numerical results of the two methods are compared. The presence of groundwater table obliges us to choose special techniques for the stability of the ground around the subway station during construction; hence compressed air and ground freezing techniques are utilized in the simulations of the subway station. Finally, after choosing appropriate support systems, the large-diameter curved pipe roofing method with 1.5 m spacing between curved pipes is proposed.

Chun Feng, Shihai Li, Xiaoyu Liu, Yanan Zhang. A semi-spring and semi-edge combined contact model in CDEM and its application to analysis of Jiweishan landslide. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (1): 26–35.

http://www.sciencedirect.com/science/article/pii/S1674775513001170 or
http://www.rockgeotech.org/qikan/manage/wenzhang/20140103.pdf

Abstract: Continuum-based discrete element method (CDEM) is an explicit numerical method used for simulation of progressive failure of geological body. To improve the efficiency of contact detection and simplify the calculation steps for contact forces, semi-spring and semi-edge are introduced in calculation. Semi-spring is derived from block vertex, and formed by indenting the block vertex into each face (24 semi-springs for a hexahedral element). The formation process of semi-edge is the same as that of semi-spring (24 semi-edges for a hexahedral element). Based on the semi-springs and semi-edges, a new type of combined contact model is presented. According to this model, six contact types could be reduced to two, i.e. the semi-spring target face contact and semi-edge target edge contact. By the combined model, the contact force could be calculated directly (the information of contact type is not necessary), and the failure judgment could be executed in a straightforward way (each semi-spring and semi-edge own their characteristic areas). The algorithm has

been successfully programmed in C++ program. Some simple numerical cases are presented to show the validity and accuracy of this model. Finally, the failure mode, sliding distance and critical friction angle of Jiweishan landslide are studied with the combined model.

Aijun Yao, Zhizhou Tian, Yongjun Jin. Sliding surface searching method for slopes containing a potential weak structural surface. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (3): 275–279.

http://www.sciencedirect.com/science/article/pii/S167477551400033X or
http://www.rockgeotech.org/qikan/manage/wenzhang/20140312.pdf

Abstract: Weak structural surface is one of the key factors controlling the stability of slopes. The stability of rock slopes is in general concerned with set of discontinuities. However, in soft rocks, failure can occur along surfaces approaching to a circular failure surface. To better understand the position of potential sliding surface, a new method called simplex-finite stochastic tracking method is proposed. This method basically divides sliding surface into two parts: one is described by smooth curve obtained by random searching, the other one is polyline formed by the weak structural surface. Single or multiple sliding surfaces can be considered, and consequently several types of combined sliding surfaces can be simulated. The paper will adopt the arc-polyline to simulate potential sliding surface and analyze the searching process of sliding surface. Accordingly, software for slope stability analysis using this method was developed and applied in real cases. The results show that, using simplex-finite stochastic tracking method, it is possible to locate the position of a potential sliding surface in the slope.

Predrag Miščević, Goran Vlastelica. Impact of weathering on slope stability in soft rock mass. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (3): 240–250.

http://www.sciencedirect.com/science/article/pii/S1674775514000353 or
http://www.rockgeotech.org/qikan/manage/wenzhang/20140308.pdf

Abstract: Weathering of soft rocks is usually considered as an important factor in various fields such as geology, engineering geology, mineralogy, soil and rock mechanics, and geomorphology. The problem of stability over time should be considered for slopes excavated in soft rocks, in case they are not protected against weathering processes. In addition to disintegration of material on slope surface, the weathering also results in shear strength reduction in the interior of the slope. Principal processes in association with weathering are discussed with the examples of marl hosted on flysch formations near Split, Croatia.

Tunneling and Underground Space

Shucai Li, Shuchen Li, Qingsong Zhang, et al. Predicting geological hazards during tunnel construction. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (3): 232–242.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-03-04.pdf

Abstract: The complicated geological conditions and geological hazards are challenging problems during tunnel construction, which will cause great losses of life and property. Therefore, reliable prediction of geological defective features, such as faults, karst caves and groundwater, has important practical significances and theoretical values. In this paper, we presented the criteria for detecting typical geological anomalies using the tunnel seismic prediction (TSP) method. The ground penetrating radar (GPR) signal response to water-bearing structures was used for theoretical derivations. And the 3D tomography of the transient electromagnetic method (TEM) was used to develop an equivalent conductance method. Based on the improvement of a single prediction technique, we developed a technical system for reliable prediction of geological defective features by analyzing the advantages and disadvantages of all prediction methods. The procedure of the application of this system was introduced in detail. For prediction, the selection of prediction methods is an important and challenging work. The analytic hierarchy process (AHP) was developed for prediction optimization. We applied the newly developed prediction system to several important projects in China, including Hurongxi highway, Jinping II hydropower station, and Kiaochow Bay subsea tunnel. The case studies show that the geological defective features can be successfully detected with good precision and efficiency, and the prediction system is proved to be an effective means to minimize the risks of geological hazards during tunnel construction.

Yubing Yang, Xiongyao Xie, Rulu Wang. Numerical simulation of dynamic response of operating metro tunnel induced by ground explosion. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (4): 373–384.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-04-11.pdf

Abstract: To evaluate the effects of possible ground explosion on a shallow-buried metro tunnel, this paper attempts to analyze the dynamic responses of the operating metro tunnel in soft soil, using a widely applied explicit dynamic nonlinear finite element software ANSYS/LS-DYNA. The blast induced wave propagation in the soil and the tunnel, and the von Mises effective stress and acceleration of the tunnel lining were presented, and the safety of the tunnel lining was evaluated based on the failure criterion. Besides, the parametric study of the soil was also carried out. The numerical results indicate that the upper part of the tunnel lining cross-section with directions ranging from 0° to 22.5° and horizontal distances 0 to 7 m away from the explosive center are the vulnerable areas, and the metro tunnel might be safe when tunnel depth is more than 7 m and TNT charge on the ground is no more than 500 kg, and the selection of soil parameters should be paid more attentions to conduct a more precise analysis.

A. C. Adoko, Li Wu. Estimation of convergence of a high-speed railway tunnel in weak rocks using an adaptive neuro-fuzzy inference system (ANFIS) approach. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (1): 11–18

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-01-02.pdf

Abstract: Estimation of tunnel diameter convergence is a very important issue for tunneling construction, especially when the new Austrian tunneling method (NATM) is adopted. For this purpose, a systematic convergence measurement is usually implemented to adjust the design during the whole construction, and consequently deadly hazards can be prevented. In this study, a new fuzzy model capable of predicting the diameter convergences of a high-speed railway tunnel was developed on the basis of adaptive neuro-fuzzy inference system (ANFIS) approach. The proposed model used more than 1 000 datasets collected from two different tunnels, i.e. Daguan tunnel No. 2 and Yaojia tunnel No. 1, which are part of a tunnel located in Hunan Province, China. Six Takagi-Sugeno fuzzy inference systems were constructed by using subtractive clustering method. The data obtained from Daguan tunnel No. 2 were used for model training, while the data from Yaojia tunnel No. 1 were employed to evaluate the performance of the model. The input parameters include surrounding rock masses (SRM) rating index, ground engineering conditions (GEC) rating index, tunnel overburden (H), rock density (ρ), distance between monitoring station and working face (D), and elapsed time (T). The model's performance was assessed by the variance account for (VAF), root mean square error (RMSE), mean absolute percentage error (MAPE) as well as the coefficient of determination (R^2) between measured and predicted data as recommended by many researchers. The results showed excellent prediction

accuracy and it was suggested that the proposed model can be used to estimate the tunnel convergence and convergence velocity.

Xin Huang, Zixin Zhang. Stress arch bunch and its formation mechanism in blocky stratified rock masses. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (1): 19–27

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-01-03.pdf

Abstract: Stress arch is a common phenomenon occurring in continuous materials and has also been proved to have great influences on the self-stabilization of soils or rock masses after excavation. In this paper, based on UDEC simulation, stress redistribution after excavation is investigated for a kind of special discontinuous material, i.e. blocky stratified rock mass. A layered stress arch system is observed with each stress arch lying over another. This special phenomenon is defined herein as “stress arch bunch”. Effects of dip angle of bedding plane, lateral pressure and joint offset on this stress arch bunch are studied. Its formation mechanism is also discussed based on voussoir beam theory.

Nick Barton. Reducing risk in long deep tunnels by using TBM and drill-and-blast methods in the same project–the hybrid solution. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (2): 115–126.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120202.pdf

Abstract: There are many examples of TBM tunnels through mountains, or in mountainous terrain, which have suffered the ultimate fate of abandonment, due to insufficient pre-investigation. Depth-of-drilling limitations are inevitable when depths approach or even exceed 1 or 2 km. Uncertainties about the geology, hydro-geology, rock stresses and rock strengths go hand-in-hand with deep or ultra-deep tunnels. Unfortunately, unexpected conditions tend to have a much bigger impact on TBM projects than on drill-and-blast projects. There are two obvious reasons. Firstly the circular excavation maximizes the tangential stress, making the relation to rock strength a higher source of potential risk. Secondly, the TBM may have been progressing fast enough to make probe-drilling seem to be unnecessary. If the stress-to-strength ratio becomes too high, or if faulted rock with high water pressure is unexpectedly encountered, the “unexpected events” may have a remarkable delaying effect on TBM. A simple equation explains this phenomenon, via the adverse local Q-value that links directly to utilization. One may witness dramatic reductions in utilization, meaning ultra-steep deceleration-of-the-TBM gradients in a log-log plot of advance rate versus time. Some delays can be avoided or reduced with new TBM designs, where belief in the need for probe-drilling and sometimes also pre-injection, have been fully appreciated. Drill-and-blast tunneling, inevitably involving numerous “probe-holes” prior to each advance, should be used instead, if investigations have been too limited. TBM should be used where there is lower cover and where more is known about the rock and structural conditions. The advantages of the superior speed of TBM may then be fully realized. Choosing TBM because a tunnel is very long increases risk due to the law of deceleration with increased length, especially if there is limited pre-investigation because of tunnel depth.

Peng Yan, Wenbo Lu, Ming Chen, Zhigang Shan, Xiangrong Chen, Yong Zhou. Energy release process of surrounding rocks of deep tunnels with two excavation methods. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (2): 160–167.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120206.pdf

Abstract: Numerical analysis of the total energy release of surrounding rocks excavated by drill-and-blast (D&B) method and tunnel boring machine (TBM) method is presented in the paper. The stability of deep tunnels during excavation in terms of energy release is also discussed. The simulation results reveal that energy release during blasting excavation is a dynamic process. An intense dynamic effect is captured at large excavation footage. The magnitude of energy release during full-face excavation with D&B method is higher than that with TBM method under the same conditions. The energy release rate (ERR) and speed (ERS) also have similar trends. Therefore, the rockbursts in tunnels excavated by D&B method are frequently encountered and more intensive than those by TBM method. Since the space after tunnel face is occupied by the backup system of TBM, prevention and control of rockbursts are more difficult. Thus, rockbursts in tunnels excavated by TBM method with the same intensity are more harmful than those in tunnels by D&B method. Reducing tunneling rate of TBM seems to be a good means to decrease ERR and risk of rockburst. The rockbursts observed during excavation of headrace tunnels at Jinping II hydropower station in West China confirm the analytical results obtained in this paper.

Yanjun Shang, Yongyue Shi, Weijun Jin, Daming Lin, Fengbo Wu, Wei Zhang. Identification of weathered troughs in granites for tunneling at Daya Bay reactor-neutrino experiment site. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (2): 177–182.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120208.pdf

Abstract: Weathered troughs are frequently encountered in granites. They can cause problems to tunneling in the rocks and have to be properly addressed. The structures or spatial shapes of weathered troughs were seldom clarified in the past. In this paper, four weathered troughs are identified by means of geophysical exploration, core drilling, logging, and in-situ stress measurement at Daya Bay reactor-neutrino experiment site in Shenzhen, China. The weathered troughs are exposed on the ground or partially covered by grass and soils, which will threaten the safety of horizontal tunneling at a shallow depth. High electrical resistivity (HER) method is adopted for its feasibility and practicality, in combination with field geological observation, ultrasonic televiewer in boreholes and in-situ stress measurement. By comparing the HER values of completely decomposed to fresh rocks, it is indicated that the HER values of weathered troughs in natural state are 0.4–100 Ω·m, and the in-situ stress is abnormally lower than those at upper and lower layers. Field investigations show that the depths of the four weathered troughs are 30–182 m, with bottom elevation over 10 m. The volume of each weathered trough is mostly over 1×10^6 m^3 in inverted conic form. The weathered troughs often occur in various kinds of landforms, such as ridges, gullies or gently dipping dish-like depression areas. Faults and boundaries of different granitic plutons as well as joints govern the formation, locations and strikes of these troughs under development.

Edwin T Brown. Risk assessment and management in underground rock engineering—an overview. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (3): 193–204.

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-03-01.pdf

Abstract: This paper attempts to provide an overview of risk assessment and management practice in underground rock engineering based on a review of the international literature and some personal experience. It is noted that the terminologies used in risk assessment and management studies may vary from country to country. Probabilistic risk analysis is probably the most widely-used approach to risk assessment in rock engineering and in geotechnical engineering more broadly. It is concluded that great potential exists to augment the existing probabilistic methods by the use of Bayesian networks and decision analysis techniques to allow reasoning under uncertainty and to update probabilities, material properties and analyses as further data become available throughout the various stages of a project. Examples are given of the use of these methods in underground excavation engineering in China and elsewhere, and opportunities for their further application are identified.

John A. Hudson. Design methodology for the safety of underground rock engineering. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (3): 205–214.

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-03-02.pdf

Abstract: In order to optimise the safety of underground rock engineering construction and the long-term security of the resultant facilities, it is necessary to have a knowledge of the likely hazards. These risks or hazards fall into the four categories of “known beforehand and relatively easily addressed”, “known beforehand and not easily addressed”, “not known beforehand and relatively easily addressed”, and “not known beforehand and not easily addressed”. This paper describes how these four types of hazard can be incorporated into a design methodology approach, including the process by which the relevant mechanical rock mass parameters can be recognised for modelling and hence predictive purposes. In particular, there is emphasis on the fact that information and judgement are the keys to safety—whether the hazards are known or unknown before construction proceeds.

Yong Zhao, Pengfei Li, Siming Tian. Prevention and treatment technologies of railway tunnel water inrush and mud gushing in China. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5(6): 468–477.

http://www.sciencedirect.com/science/article/pii/S1674775513001042or

http://www.rockgeotech.org/qikan/manage/wenzhang/20130606.pdf

Abstract: Water inrush and mud gushing are one of the biggest hazards in tunnel construction. Unfavorable geological sections can be observed in almost all railway tunnels under construction or to be constructed, and vary in extent. Furthermore, due to the different heights of mountains and the lengths of tunnels, the locations of the unfavorable geological

sections cannot be fully determined before construction, which increases the risk of water inrush and mud gushing. Based on numerous cases of water inrush and mud gushing in railway tunnels, the paper tries to classify water inrush and mud gushing in railway tunnels in view of the conditions of the surrounding rocks and meteorological factors associated with tunnel excavation. In addition, the causes of water inrush and mud gushing in combination of macro- and micro-mechanisms are summarized, and site-specific treatment method is put forward. The treatment methods include choosing a method of advance geological forecast according to risk degrees of different sections in the tunnel, determining the items of predictions, and choosing the appropriate methods, i.e. draining-oriented method, blocking-oriented method or draining-and-blocking method. The treatment technologies of railway water inrush and mud gushing are also summarized, including energy relief and pressure relief technology, advance grouting technology, and advance jet grouting technology associated with their key technical features and applicable conditions. The results in terms of treatment methods can provide reference to the prevention and treatment of tunnel water inrush and mud gushing.

Prasnna Jain, A.K. Naithani, T.N. Singh. Performance characteristics of tunnel boring machine in basalt and pyroclastic rocks of Deccan traps – A case study. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (1): 36–47.

http://www.sciencedirect.com/science/article/pii/S1674775513001066 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140104.pdf

Abstract: A 12.24 km long tunnel between Maroshi and Ruparel College is being excavated by tunnel boring machine (TBM) to improve the water supply system of Greater Mumbai, India. In this paper, attempt has been made to establish the relationship between various litho-units of Deccan traps, stability of tunnel and TBM performances during the construction of 5.83 km long tunnel between Maroshi and Vakola. The Maroshi–Vakola tunnel passes under the Mumbai Airport and crosses both runways with an overburden cover of around 70 m. The tunneling work was carried out without disturbance to the ground. The rock types encountered during excavation are fine compacted basalt, porphyritic basalt, amygdaloidal basalt, pyroclastic rocks with layers of red boles and intertrappean beds consisting of various types of shales. Relations between rock mass properties, physico-mechanical properties, TBM specifications and the corresponding TBM performance were established. A number of support systems installed in the tunnel during excavation were also discussed. The aim of this paper is to establish, with appropriate accuracy, the nature of subsurface rock mass condition and to study how it will react to or behave during underground excavation by TBM. The experiences gained from this project will increase the ability to cope with unexpected ground conditions during tunneling using TBM.

Environmental Geotechnical Engineering

Underground Storage of Oil, Gas and Carbon Dioxide

Zhongkui Li, Kezhong Wang, Anmin Wang, et al. Experimental study of water curtain performance for gas storage in an underground cavern. Journal of Rock Mechanics and Geotechnical Engineering. 2009, 1 (1): 89–96.
http://www.rockgeotech.org/qikan/manage/wenzhang/20090005.pdf
Abstract: An artificial water curtain system is composed of a network of underground galleries and horizontal boreholes drilled from these galleries. Pre-grouting measures are introduced to keep the bedrock saturated all the time. This system is deployed over an artificial or natural underground cavern used for the storage of gas (or some other fluids) to prevent the gas from escaping through leakage paths in the rock mass. An experimental physical modeling system has been constructed to evaluate the performance of artificial water curtain systems under various conditions. These conditions include different spacings of caverns and cavern radii located below the natural groundwater level. The principles of the experiment, devices, design of the physical model, calculation of gas leakage, and evaluation of the critical gas pressure are presented in this paper. Experimental result shows that gas leakage is strongly affected by the spacing of water curtain boreholes, the critical gas pressure, and the number and proximity of storage caverns. The hydraulic connection between boreholes is observed to vary with depth or location, which suggests that the distribution of water-conducting joint sets along the boreholes is also variable. When designing the drainage system for a cavern, drainage holes should be orientated to maximize the frequency at which they encounter major joint sets and permeable intervals studying in order to maintain the seal on the cavern through water pressure. Our experimental results provide a significant contribution to the theoretical controls on water curtains, and they can be used to guide the design and construction of practical storage caverns.

Ming Lu. Rock engineering problems related to underground hydrocarbon storage. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (4): 289–297.
http://www.rockgeotech.org/qikan/manage/wenzhang/2010-04-01.pdf
Abstract: Oil and gas can be stored underground by a variety of means, such as in depleted oil and gas fields, in aquifers, in rock salt caverns, in unlined mined rock caverns, in lined shallow caverns and abandoned mines. Different types of underground storages require different geological and hydrogeological conditions and are associated with different rock engineering problems. However, the common issue is to ensure the gas- and oil-tightness of storage caverns. In other words, the stored oil and gas must not escape from the storage caverns. This may be realized by different means according to the types of storages and the sites geological conditions. There are basically two approaches of gas leakage control, i.e. permeability control and hydrodynamic containment. The latter involves the use of a water curtain system in many cases, which creates an artificial hydraulic boundary condition and helps to establish the required groundwater condition when needed. In addition to the common problems, the underground storage of liquefied petroleum gas (LPG) requires special attentions to the opening of rock joints, which result from the tensile thermal stress induced by the low storage temperature. Great care must be taken in choosing abandoned mines for oil and gas-storage since it is quite rare that the natural site conditions can meet the usual requirements, in particular for the gas tightness. The paper provides a general description of the gas leakage control for underground oil and gas storage projects, and addresses various rock engineering problems associated with selected types of storages in detail.

Manchao He, Sousa Luis, Sousa Rita, et al. Risk assessment of CO2 injection processes and storage in carboniferous formations: a review. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (1): 39–56.
http://www.rockgeotech.org/qikan/manage/wenzhang/2011-01-05.pdf
Abstract: Over the last decades, people from almost all over the world have realized that it is necessary to quickly develop strategies for the control and reduction of greenhouse gases (GHG) emissions. Among various GHGs, carbon dioxide (CO_2) is the most abundant GHG. Its underground storage involves less risk and lower levels of dangerousness. The paper briefly describes the most effective technologies available in the market for background processes to storage (capture and transport) CO_2, as well as the more secure solutions for its storage, in particular for the geological storage in carboniferous formations. This paper also outlines the methodologies for the risk assessment involved in storage of CO_2, with a particular

focus on cases where the injection is made into unminable coal seams and in abandoned coal mines. Methodologies used for risk analysis are described in detail with particular emphasis on Bayesian network (BN). Some applications regarding the risk assessment of CO_2 injection processes and CO_2 storage in carboniferous formations and contamination of aquifers are presented and analyzed. Finally, based on the applications of BN, several conclusions are drawn.

Nuclear Waste Disposal

Ju Wang. High-level radioactive waste disposal in China: update 2010. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (1): 1–11.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-01-01.pdf

Abstract: For geological disposal of high-level radioactive waste (HLW), the Chinese policy is that the spent nuclear fuel (SNF) should be reprocessed first, followed by vitrification and final disposal. The preliminary repository concept is a shaft-tunnel model, located in saturated zones in granite, while the final waste form for disposal is vitrified high-level radioactive waste. In 2006, the government published a long-term research and development (R&D) plan for geological disposal of high-level radioactive waste. The program consists of three steps: (1) laboratory studies and site selection for a HLW repository (2006–2020); (2) underground in-situ tests (2021–2040); and (3) repository construction (2041–2050) followed by operation. With the support of China Atomic Energy Authority, comprehensive studies are underway and some progresses are made. The site characterization, including deep borehole drilling, has been performed at the most potential Beishan site in Gansu Province, Northwestern China. The data from geological and hydrogeological investigations, in-situ stress and permeability measurements of rock mass are presented in this paper. Engineered barrier studies are concentrated on the Gaomiaozi bentonite. A mock-up facility, which is used to study the thermo-hydro-mechano-chemical (THMC) properties of the bentonite, is under construction. Several projects on mechanical properties of Beishan granite are also underway. The key scientific challenges faced with HLW disposal are also discussed.

E. E. Alonso, C. Hoffmann, E. Romero. Pellet mixtures in isolation barriers. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (1): 12–31.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-01-02.pdf

Abstract: Granular mixtures made of high-density pellets of bentonite are being evaluated as an alternative buffer material for waste isolation. Ease of handling is an often-mentioned advantage. The paper describes the experimental program performed to characterize the hydro-mechanical (HM) behaviour of compacted pellet mixtures. Grain size distribution was adjusted to a maximum pellet size compatible with the specimen's dimensions. Dry densities of statically compacted specimens varied in most of the cases in the range from 1.3 to 1.5 Mg/m^3. Pellets had a very high dry density, close to 2 Mg/m^3. The outstanding characteristic of these mixtures is their discontinuous porosity. Pore sizes of the compacted pellets varied around 10 nm. However, the inter-pellet size of the pores was four to five orders of magnitude higher. This double porosity and the highly expansive nature of the pellets controlled all the hydraulic and mechanical properties of the mixture.

Performed tests include infiltration tests using different water injection rates and mechanisms of water transfer (in liquid and vapour phases), suction-controlled oedometer tests and swelling pressure tests. The interpretation of some performed tests required back analysis procedures using a hydro-mechanical (HM) computer code.

Material response was studied within the framework of the elastoplastic constitutive model proposed by Alonso et al. (1990) (Barcelona basic model, BBM). Parameters for the model were identified and also a set of hydraulic laws are necessary to perform coupled HM analysis.

A large scale in-situ test (the "EB" test in Mont Terri, Switzerland) was described and analyzed. Rock barrier parameters were adjusted on the basis of available tests. The test excavation, barrier emplacement and forced hydration were simulated by means of the CODE_BRIGHT program. The comparison between measurements and computed results include data on relative humidity in the rock and the buffer, swelling pressures and displacements.

T. Rothfuchs, D. Buhmann, C. L. Zhang. Long-term safety analysis and model validation through URL research. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (1): 32–38.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-01-03.pdf

Abstract: In Germany, all types of radioactive wastes will be disposed of in deep geological repositories. While a repository

for low-level radioactive waste (LLW) has recently been licensed, different host rock formations are considered for disposal of heat producing high-level waste (HLW). The latter includes directly disposed spent fuel (SF) and vitrified waste from its reprocessing. Different canisters and disposal concepts are considered for spent fuel disposal, i.e. thick-walled iron casks in horizontal drifts or thin-walled BSK3 steel casks in vertical boreholes.

GRS is the leading expert institution in Germany concerning nuclear safety and waste management. For the recent 30 years, GRS has developed and continuously improves a set of computer codes, which allow assessing the performance and the long-term safety of repositories in various host rocks (salt, clay or granite) adopting different technical options. Advanced methods for deterministic as well as probabilistic assessments are available. To characterize the host rocks and backfill/buffer materials and to develop disposal technologies, comprehensive laboratory experiments and a large number of in-situ tests have been performed at GRS' geo-laboratory and underground research laboratories in different host formations. Thermo-hydro-mechanico-chemical (THMC) processes occurring in the host rocks and engineered barrier systems are numerically simulated.

The paper presents an overview of GRS' work highlighting important results of performance assessment (PA) studies for both the salt and clay options. Also, recent results of in-situ investigations and laboratory studies are presented together with modeling results. Special emphasis is dedicated to the consideration of coupled THM processes which are of relevance in PA.

J. Delay, P. Lebon, H. Rebours. Meuse/Haute-Marne centre: next steps towards a deep disposal facility. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (1): 52–70.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-01-06.pdf

Abstract: This paper presents the main results obtained during a decade of scientific activities in the Meuse/Haute-Marne Underground Research Laboratory (URL) located on the eastern boundary of the Paris Basin, in the Callovo-Oxfordian clay rock formation. The URL was built in the framework of ANDRA's research program into the feasibility of a reversible deep geological disposal of high-level and intermediate-level long-lived radioactive (HL, ILLL) waste. Its underground drifts have been used to study a 160-million-year old clay layer. The 2006 Planning Act adopted this disposal concept as the reference solution for the long-term management of HL and ILLL radioactive waste. Today, research is continuing into the design and sitting of the disposal facility which could be commissioned by 2025 if its license is granted in 2016. Through these programs, the laboratory will help ANDRA develop a concrete approach with a view to proposing suitable architectures and management methods for a deep disposal facility, to allow by 2016 the decision for the start of the construction of the shafts and drifts of the new disposal facility.

M. V. Villar, R. Gómez-Espina, A. Lloret. Experimental investigation into temperature effect on hydro-mechanical behaviours of bentonite. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (1): 71–78.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-01-07.pdf

Abstract: The bentonite barrier of underground repositories for high-level radioactive waste will be hydrated by the groundwater while it is subjected to high temperatures due to the radioactive decay of the wastes. These changes of temperature affect the hydraulic and mechanical responses of bentonite, which has important effects on design and performance of repositories. The temperature influence on the hydro-mechanical behaviour of bentonite was studied in this paper by experiments, which were carried out with the Spanish FEBEX bentonite compacted at dry densities expected in the repository (from 1.5 to 1.8 Mg/m^3). The dependence of the swelling strains of bentonite on the temperature has been measured from 30 °C to 90 °C. At high temperatures the swelling capacity of clay slightly decreases. Also, a clear decrease of swelling pressure as a function of temperature was observed for the same dry densities. Nevertheless, the deformation of bentonite is more dependent on the stress than the temperature. An increase in the permeability of water saturated bentonite with temperature has also been detected. The water retention curves of bentonite compacted at different dry densities were determined under isochoric conditions and in the range of temperatures from 20 °C to 120 °C. For a given density and water content, the suction decreases as the temperature increases at a rate, which is larger than the one predicted on the basis of water surface tension changing with temperature. Mechanisms related to the physico-chemical interactions that take place at microscopic level, in particular the transfer of interlayer water to the macropores triggered by temperature, seem to explain qualitatively the experimental observations.

De'an Sun, Wenjing Sun, Wei Yan, et al. Hydro-mechanical behaviours of highly compacted sand-bentonite mixture.

Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (1): 79–85.
http://www.rockgeotech.org/qikan/manage/wenzhang/2010-01-08.pdf
Abstract: This paper presents the results of laboratory testing on a heavily compacted sand-bentonite mixture. To measure the soil-water retention curve (SWRC) of the mixture over a large range of suction, a pressure plate apparatus and filter papers were used. The obtained SWRC shows that the measurements via the two methods consistently agree with each other. By using a suction-controlled oedometer for unsaturated soils, a series of one-dimensional compression tests were performed on the unsaturated compacted sand-bentonite mixture at different constant suctions. The testing results indicate that the yield stress increases and compression index decreases with the increase of imposed suction. The results also demonstrate that the mixture wetted to saturation and subsequently dried to a certain suction level has a lower yield stress than that wetted directly to the same suction.

Chaosheng Tang, A. M. Tang, Y. J. Cui, et al. The coupled hydro-mechanical behaviours of compacted crushed Callovo-Oxfordian argillite. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (1): 86–90.
http://www.rockgeotech.org/qikan/manage/wenzhang/2010-01-09.pdf
Abstract: Callovo-Oxfordian (COx) argillite obtained from the excavation of high-level radioactive waste geological disposal has been evaluated as an alternative sealing/backfill material in France. This paper presents an experimental investigation into the hydro-mechanical behaviour of compacted crushed COx argillite. A series of oedometer compressive tests including various loading-unloading cycles were conducted on COx argillite powders at different initial water contents. After reaching the desired dry density (2.0 Mg/m^3), the vertical stress was reduced to different levels (7.0 and 0.5 MPa) and the compacted sample was then flooded under constant volume conditions while measuring the changes in the vertical stress. It was found that the initial water content significantly affects the compressive behaviour. The measured saturated hydraulic conductivity is less than 1×10^{-10} m/s.

A. M. Tang, Y. J. Cui. Effects of mineralogy on thermo-hydro-mechanical parameters of MX80 bentonite. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (1): 91–96.
http://www.rockgeotech.org/qikan/manage/wenzhang/2010-01-10.pdf
Abstract: Thermal conductivity, water retention curve and swelling behavior of two MX80 bentonite samples were studied in the present work. The difference obtained from these two MX80 bentonite samples was then analyzed in terms of mineralogical effects (effects of the proportion of quartz and montmorillonite). It was concluded that the mineralogical effect was significant on the thermal conductivity and the swelling capacity; on the contrary, it was negligible on the water retention property.

A. Gens, L. do N. Guimarães, S. Olivella, et al. Modelling thermo-hydro-mechano-chemical interactions for nuclear waste disposal. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (2): 97–102.
http://www.rockgeotech.org/qikan/manage/wenzhang/2010-02-01.pdf
Abstract: A fully coupled thermo-hydro-mechano-chemical (THMC) formulation is described in this paper. Special attention is paid to phenomena likely to be encountered in clay barriers used as engineered barriers in the disposal of nuclear radioactive waste. The types of processes considered in the chemical formulation include hydrolysis, complex formation, oxidation/ reduction reactions, acid/base reactions, precipitation/dissolution of minerals and cation exchange. Both kinetics- and equilibrium-controlled reactions are incorporated. The formulation is implemented in a numerical code. An application is presented concerning the performance of a large-scale in-situ heating test simulating high-level radioactive waste repository conditions.

X. L. Li, W. Bastiaens, P. Van Marcke, et al. Design and development of large-scale in-situ PRACLAY heater test and horizontal high-level radioactive waste disposal gallery seal test in Belgian HADES. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (2): 103–110.
http://www.rockgeotech.org/qikan/manage/wenzhang/2010-02-02.pdf
Abstract: In Belgium, the Boom clay was selected as a potential host formation for the disposal of high-level radioactive waste (HLW). To demonstrate the suitability of Boom clay for bearing thermal load induced by the HLW, a large-scale in-situ heater test, called PRACLAY heater test, will be conducted in the underground research laboratory (URL) in Mol. Owing to the limitations of the test (a short period of time compared with that considered in a real repository, different boundary

conditions, etc.), the test is designed to simulate, in a conservative way, the most critical state and phenomena that could occur in the host rock. The PRACLAY gallery was excavated at the end of 2007; the heating phase will begin in 2010 and will last for at least 10 years. The PRACLAY gallery itself leaves an opportunity to study the possibilities of sealing a disposal drift in Boom clay and testing the feasibility of hydraulic cut-off of any preferential pathway to the main access gallery through the excavation damage zone (EDZ) and the lining with a seal in a horizontal drift (horizontal seal). Indeed, this is a generic problem for all deep geological disposal facilities for HLW. An annular seal made of compacted swelling bentonite will be installed in the front of the heated part of the PRACLAY gallery for these purposes.

This paper provides detailed considerations on the thermo-hydro-mechanical (THM) boundary conditions for the design of the PRACLAY heater test and the seal test with the support of numerical calculations. It is believed that these important items considered in the PRACLAY heater test design also constitute key issues for the repository design. The outcome of the PRACLAY heater test will be an important milestone for the Belgian repository design.

P. Delage, Y. J. Cui, A. M. Tang. Clays in radioactive waste disposal. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (2): 111–123.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-02-03.pdf

Abstract: Clays and argillites are considered in some countries as possible host rocks for nuclear waste disposal at great depth. The use of compacted swelling clays as engineered barriers is also considered within the framework of the multi-barrier concept. In relation to these concepts, various research programs have been conducted to assess the thermo-hydro-mechanical properties of radioactive waste disposal at great depth. After introducing the concepts of waste isolation developed in Belgium, France and Switzerland, the paper describes the retention and transfer properties of engineered barriers made up of compacted swelling clays in relation to microstructure features. Some features of the thermo-mechanical behaviors of three possible geological barriers, namely Boom clay (Belgium), Callovo-Oxfordian clay (France) and Opalinus clay (Switzerland), are then described, including the retention and transfer properties, volume change behavior, shear strength and thermal aspects.

D. Deneele, O. Cuisinier, V. Hallaire, et al. Microstructural evolution and physico-chemical behavior of compacted clayey soil submitted to an alkaline plume. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (2): 169–177.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-02-11.pdf

Abstract: In the French concept of deep nuclear waste repositories, the galleries should be backfilled with excavated argillite after the site has been filled. Some additives like lime could be used to improve the mechanical characteristics of the argillite. After thousands of years, the degradation of the concrete lining of the galleries will generate an alkaline solution (pH value > 12) that will diffuse through the backfill. This study presents the effect of a saturated $Ca(OH)_2$ solution circulation through lime-treated sample at 60 °C for 3, 6 and 12 months, respectively. The effect of such circulation on the lime-treated Manois argillite (MA) was assessed by petrographical examination coupled to image analysis and scanning electron microscopy (SEM) equipped with energy dispersive X-ray (EDX) analyser of soil pieces. The objective of this study is to make the link among the mineralogical transformations, the textural and mechanical changes produced in the compacted clayey soil as a consequence of the alkaline solution circulation.

Yuemiao Liu. Influence of heating and water-exposure on the liquid limits of GMZ01 and MX80 bentonites. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (2): 188–192.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-02-13.pdf

Abstract: Bentonite has been considered as a buffer material for embedding canisters with high-level radioactive waste (HLW) in deep geological repositories. GMZ bentonite deposit, located in Xinghe County, Inner Mongolia Autonomous Region, China was proposed as a buffer/backfill material for HLW repository in China. The liquid limits of natural Na-bentonite GMZ01 and commercial Na-bentonite MX80, which are previously heated at 80 ^{o}C and 95 ^{o}C, respectively, and exposed to water for different times are measured. It is observed that the liquid limit of GMZ01 increases slightly at the beginning, and then decreases as the heating time increases, while the liquid limit of MX80 decreases with the heating time. The liquid limits of both GMZ01 and MX80 decrease with increasing water-exposure time. After the samples are heated at 80 ^{o}C and 95 ^{o}C for several months, the mineralogical composition of GMZ01 does not exhibit evident change, whereas MX80 experiences some changes. In addition, the chemical composition, cation exchange capacity (CEC) and

exchangeable cation of all the samples do not change significantly.

Sheng Zhang, Hirotomo Nakano, Yonglin Xiong, et al. Temperature-controlled triaxial compression/creep test device for thermodynamic properties of soft sedimentary rock and corresponding theoretical prediction. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (3): 255–261.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-03-06.pdf

Abstract: In deep geological disposal of high-level nuclear waste, one of the most important subjects is to estimate long-term stability and strength of host rock under high temperature conditions caused by radioactive decay of the waste. In this paper, some experimental researches on the thermo-mechanical characteristics of soft sedimentary rock have been presented. For this reason, a new temperature-controlled triaxial compression and creep test device, operated automatically by a computer- controlled system, whose control software has been developed by the authors, was developed to conduct the thermo-mechanical tests in different thermal loading paths, including an isothermal path. The new device is proved to be able to conduct typical thermo-mechanical element tests for soft rock. The test device and the related testing method were introduced in detail. Finally, some test results have been simulated with a thermo-elasto-viscoplastic model that was also developed by the authors.

Yifeng Chen, Chuangbing Zhou, Lanru Jing. Numerical modeling of coupled thermo-mechanical response of a rock pillar. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (3): 262–273.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-03-07.pdf

Abstract: Understanding the rock mass response to excavation and thermal loading and improving the capability of the numerical models for simulating the progressive failure process of brittle rocks are important for safety assessment and optimization design of nuclear waste repositories. The international cooperative DECOVALEX-2011 project provides a platform for development, validation and comparison of numerical models, in which the Äspö pillar stability experiment (APSE) was selected as the modeling target for Task B. This paper presents the modeling results of Wuhan University (WHU) team for stages 1 and 2 of Task B by using a coupled thermo-mechanical model within the framework of continuum mechanics. The rock mass response to excavation is modeled with linear elastic, elastoplastic and brittle-plastic models, while the response to heating is modeled with a coupled thermo-elastic model. The capabilities and limitations of the model for representation of the thermo- mechanical responses of the rock pillar are discussed by comparing the modeling results with experimental observations. The results may provide a helpful reference for the stability and safety assessment of the hard granite host rock in China's Beishan preselected area for high-level radioactive waste disposal.

O. Cuisinier, F. Masrouri. Chemo-mechanical couplings in compacted argillite submitted to high-pH environment. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (4): 314–320.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-04-04.pdf

Abstract: In the French concept of deep nuclear wastes repository, the galleries should be backfilled with excavated argillite after the site exploitation period. After several thousands of years, the degradation of the concrete lining of the galleries will generate alkaline fluid (pH > 12) that will diffuse through the backfill. The objective of the paper is to describe the influence of such solute diffusion on the microstructure and the mechanical behavior of compacted argillite. Saturated-portlandite water was circulated through compacted samples for 3, 6 and 12 months at 20 °C or 60 °C, respectively. The microstructures before and after fluid circulation were determined with mercury intrusion porosimetry. Since it was planned to introduce additives (bentonite or lime) in the remoulded argillite to backfill the deep galleries, such mixtures were also studied. The results show that the influence of the alkaline fluid on the properties of the argillite is a function of the nature of the additive. The pure argillite undergoes slight modifications that can be related to a limited dissolution of its clayey particles. Conversely, intense alteration of the bentonite-argillite mixture was observed. Lime addition improves the mechanical characteristics of the argillite through the precipitation of cementitious compounds.

Liang Chen, Ju Wang, Yuemiao Liu, Federic Collin, Jingli Xie. Numerical thermo-hydro-mechanical modeling of compacted bentonite in China-mock-up test for deep geological disposal. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (2): 183–192.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120209.pdf

Abstract: The China-mock-up test is to evaluate the performance of the compacted Gaomiaozi (GMZ) bentonite under

coupled thermo-hydro-mechanical (THM) conditions in deep geological disposal. A numerical study of the test is conducted in this paper. The principal THM characteristics of the bentonite are presented at first. A THM model is then presented to tackle the complex coupling behavior of the bentonite. The model of Alonso-Gens is incorporated to reproduce the mechanical behavior of the bentonite under unsaturated conditions. With the proposed model, numerical simulations of the China-mock-up test are carried out by using the code of LAGAMINE. The time variations associated with the temperature, degree of saturation, suction and swelling pressure of the compacted bentonite are studied. The results suggest that the proposed model is able to reproduce the mechanical behavior of the bentonite, and to predict moisture motion under coupled THM conditions.

B. Garitte, A. Bond, A. Millard, C. Zhang, C. Mcdermott, S. Nakama, A. Gens. Analysis of hydro-mechanical processes in a ventilated tunnel in an argillaceous rock on the basis of different modelling approaches. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (1): 1–17.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130101.pdf

Abstract: In this paper, a modelling benchmark exercise from the DECOVALEX-2011 project is presented. The benchmark is based on the performance and results of a laboratory drying test and of the ventilation experiment (VE) carried out in the Mont Terri Underground Rock Laboratory (URL). Both tests involve Opalinus clay. The work aims at the identification, understanding and quantification of mechanisms taking place during the ventilation of a gallery in argillaceous host rocks on one hand and at investigating the capacity of different codes and individuals to reproduce these processes on the other hand. The 4-year in situ VE took place in a 1.3 m diameter unlined tunnel and included two resaturation–desaturation cycles. The test area was equipped with over one hundred sensors (including the global water mass balance of the system, relative humidity (RH), water content, liquid pressure, relative displacement and concentration of some chemical species) to monitor the rock behaviour during ventilation. The laboratory drying experiment, carried out before the VE, was designed to mimic the in situ conditions. The work was organized in a progressive manner in terms of complexity of the computations to be performed, geared towards the full hydro-mechano-chemical (HMC) understanding of the VE, the final objective. The main results from the modelling work reported herein are that the response of the host rock to ventilation in argillaceous rocks is mainly governed by hydraulic processes (advective Darcy flow and non-advective vapour diffusion) and that the hydro-mechanical (TM) back coupling is weak. A ventilation experiment may thus be regarded as a large scale-long time pump test and it is used to determine the hydraulic conductivity of the rock mass.

Jonny Rutqvist, Colin Leung, Andrew Hoch, Yuan Wang, Zhen Wang. Linked multicontinuum and crack tensor approach for modeling of coupled geomechanics, fluid flow and transport in fractured rock. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (1): 18–31.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130102.pdf

Abstract: In this paper, we present a linked multicontinuum and crack tensor approach for modeling of coupled geomechanics, fluid flow, and solute transport in fractured rock. We used the crack tensor approach to calculate effective block-scale properties, including anisotropic permeability and elastic tensors, as well as multicontinuum properties relevant to fracture–matrix interactions and matrix diffusion. In the modeling, we considered stress dependent properties, through stress-induced changes in fracture apertures, to update permeability and elastic tensors. We evaluated the effectiveness and accuracy of our multicontinuum approach by comparing our modeling results with that of three independent discrete fracture network (DFN) models. In two of the three alternative DFN models, solute transport was simulated by particle tracking, an approach very different from the standard solute transport used in our multicontinuum modeling. We compared the results for flow and solute transport through a 20 m × 20 m model domain of fractured rock, including detailed comparison of total flow rate, its distribution, and solute breakthrough curves. In our modeling, we divided the 20 m × 20 m model domain into regular blocks, or continuum elements. We selected a model discretization of 40 × 40 elements (having a side length of 0.5 m) that resulted in a fluid-flow rate equivalent to that of the DFN models. Our simulation results were in reasonably good agreement with the alternative DFN models, for both advective dominated transport (under high hydraulic gradient) and matrix-diffusion retarded transport (under low hydraulic gradient). However, we found pronounced numerical

dispersion when using larger grid blocks, a problem that could be remediated by the use of a finer numerical grid resolution, while maintaining a larger grid for evaluation of equivalent properties, i.e. a property grid overlapping the numerical grid. Finally, we encountered some difficulties in using our approach when element sizes were so small that only one or a few fractures intersect an element—this is an area of possible improvement that will be pursued in future research.

Sangki Kwon, Changsoo Lee, SeokwonJeon, Heuijoo Choi. Thermo-mechanical coupling analysis of APSE using submodels and neural networks.Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (1): 32–43.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130103.pdf

Abstract: The Äspö Pillar Stability Experiment (APSE) is an in situ experiment for investigating the spalling mechanism under mechanical and thermal loading conditions in a crystalline rock. In this study, the thermo-mechanical behaviors in the APSE were investigated with three models: (1) a Full model with rough meshes for calculating the influence of tunnel excavation; (2) a Submodel with fine meshes for predicting the thermo-mechanical behavior in the pillar during the borehole drilling, heating, and cooling phases; and (3) a Thin model for modeling the effect of slot cutting for de-stressing around the pillar. In order to import the stresses calculated from the Full model to the Submodel and to define the complex thermal boundary conditions, artificial neural networks (NNs) were utilized. From this study, it was possible to conclude that the stepwise approach with the application of NNs was useful for predicting the complex response of the pillar under severe thermo-mechanical loading conditions.

Alexander Bond, Steven Benbow, James Wilson, Alain Millard, Shigeo Nakama, Myles English, Christopher McDermott, Benoit Garitte. Reactive and non-reactive transport modelling in partially water saturated argillaceous porous media around the ventilation experiment, Mont Terri. Journal of Rock Mechanics and Geotechnical Engineering.2013, 5 (1): 44–57.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130104.pdf

Abstract: At Mont Terri Underground Research Laboratory (URL) Switzerland, a specific experiment has been performed in a tunnel, in order to investigate the hydro-mechano-chemical (HMC) perturbations induced in the argillaceous formation by forced ventilation. This experiment has been selected in the international project DECOVALEX to be used for process model development and validation. The numerical simulation of the geochemical response to the ventilation experiment (VE) is the object of the present paper, focusing on the transport of chloride as a conservative species and sulphate as a reactive species. Utilising the validated hydro-mechanical (HM) results from earlier steps of the DECOVALEX task, reactive and non-reactive transport models, incorporating the current understanding of the geochemistry at the site, were successfully constructed for the whole experimental period. The associated parametric and process uncertainty analyses clearly demonstrate that the basic HM understanding must be sound. However, to demonstrate this degree of robustness, the explicit inclusion of process representations of water desaturation, liquid vaporisation, species exclusion porosity, and redox processes, is required.

T. Koyama, M. Chijimatsu, H. Shimizu, S. Nakama, T. Fujita, A. Kobayashi, Y. Ohnishi. Numerical modeling for the coupled thermo-mechanical processes and spalling phenomena in Äspö Pillar Stability Experiment (APSE).Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (1): 58–72.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130105.pdf

Abstract: In this paper, the coupled thermo-mechanical (TM) processes in the Äspö Pillar Stability Experiment (APSE) carried out by the Swedish Nuclear Fuel and Waste Management Company (SKB) were simulated using both continuum and discontinuum based numerical methods. Two-dimensional (2D) and three-dimensional (3D) finite element method (FEM) and 2D distinct element method (DEM) with particles were used. The main objective for the large scale in situ experiment is to investigate the yielding strength of crystalline rock and the formation of the excavation disturbed/damaged zone (EDZ) during excavation of two boreholes, pressurizing of one of the boreholes and heating. For the DEM simulations, the heat flow algorithm was newly introduced into the original code. The calculated stress, displacement and temperature

distributions were compared with the ones obtained from in situ measurements and FEM simulations. A parametric study for initial microcracks was also performed to reproduce the spalling phenomena observed in the APSE.

Mikael Rinne, Baotang Shen, Tobias Backers. Modelling fracture propagation and failure in a rock pillar under mechanical and thermal loadings. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (1): 73–83.
http://www.rockgeotech.org/qikan/manage/wenzhang/20130106.pdf
Abstract: The Äspö Pillar Stability Experiment (APSE) was conducted to study the rock mass response in a heated rock pillar between two large boreholes. This paper summarizes the back calculations of the APSE using a two-dimensional (2D) fracture propagation code FRACOD. To be able to model all the loading phases of the APSE, including the thermal loading, the code was improved in several ways. A sequential excavation function was developed to model promptly the stepwise changing loading geometry. Prior to the modelling, short-term compressive strength test models were set up aiming to reproduce the stress–strain behaviour observed for the Äspö diorite in laboratory. These models simulate both the axial and lateral strains of radial-controlled laboratory tests. The volumetric strain was calculated from the simulations and compared with the laboratory results. The pillar models include vertical and horizontal 2D models from where the stress in the pillar wall was investigated. The vertical model assesses the stability of the experimental rock volume and suggests the resultant stress below the tunnel floor in the pillar area. The horizontal model considers cross-sections of the pillar between the two large boreholes. The horizontal model is used to simulate the evolution of the stress in the rock mass during the excavation of the boreholes and during and the heating phase to give an estimation of the spalling strength. The modelling results suggest that the excavation-induced stresses will cause slight fracturing in the pillar walls, if the strength of the APSE pillar is set to about 123 MPa. Fracture propagation driven by thermal loading leads to minor spalling. The thermal evolution, elastic behaviour and brittle failure observed in the experiment are well reflected by the models.

Alexander Bond, Alain Millard, Shigeo Nakama, Chengyuan Zhang, Benoit Garritte. Approaches for representing hydro-mechanical coupling between sub-surface excavations and argillaceous porous media at the ventilation experiment, Mont Terri. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (2): 85–96.
http://www.rockgeotech.org/qikan/manage/wenzhang/20130201.pdf
Abstract: At the Mont Terri Underground Research Laboratory (Switzerland), a field-scale investigation has been conducted in order to investigate the hydro-mechanical and chemical perturbations induced in the argillaceous formation by forced ventilation through a tunnel. This experiment has been selected to be used for processing model development and validation in the international project DECOVALEX-2011. The conceptual and mathematical representation of the engineered void, which itself forms a major part of the experiment and is not simply a boundary condition, is the subject of this paper. A variety of approaches have been examined by the contributors to DECOVALEX and a summary of their findings is presented here. Two major aspects are discussed. Firstly, the approaches for the treatment of the surface condition at the porous media/tunnel interface are examined, with two equivalent but differing formulations successfully demonstrated. Secondly, approaches for representing the tunnel with associated air and water vapour movement, when coupled with the hydro-mechanical (HM) representation of the porous medium, are also examined. It is clearly demonstrated that, for the experimental conditions of the ventilation experiment (VE) that abstracted physical and empirical models of the tunnel, can be used successfully to represent the hydraulic behaviour of the tunnel and the hydraulic interaction between the tunnel and the surrounding rock mass.

Alain Millard, Alex Bond, Shigeo Nakama, Chengyuan Zhang, Jean-Dominique Barnichon, Benoit Garitte. Accounting for anisotropic effects in the prediction of the hydro-mechanical response of a ventilated tunnel in an argillaceous rock. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (2): 97–109.
http://www.rockgeotech.org/qikan/manage/wenzhang/20130202.pdf
Abstract: In order to investigate the hydro-mechanical (HM) and chemical perturbations induced in an argillaceous formation by forced ventilation during the operational period of a nuclear waste repository, a specific experiment has been

performed in a tunnel, at Mont Terri Underground Research Laboratory (URL) in Switzerland. This experiment has been selected in the international project DECOVALEX for model validation and the numerical simulation of this ventilation experiment (VE) is the object of the present paper. Since the argillaceous rock exhibits anisotropic properties, particular attention is given to the evaluation of the effects of various anisotropic features on the predicted results. In situ measurements such as relative humidity (RH), global water mass extracted, pore water pressure, water content, and relative displacements are compared to predictions using both isotropic and anisotropic parameters. Water permeability anisotropy is shown to be the most influencing parameter by far, whereas in situ stress anisotropy has an effect only during the excavation phase. The anisotropy for mechanical parameterization has also some influence, in particular through HM couplings. These HM couplings have the potential to be very significant in terms of providing confidence in describing the experimental observation, and should be considered for further investigation.

Zhihong Zhao, Jonny Rutqvist, Colin Leung, Milan Hokr, Quansheng Liu, IvarsNeretnieks, Andrew Hoch, Jirˇ́ıHavlícˇek, Yuan Wang, Zhen Wang, Yuexiu Wu, Robert Zimmerman. Impact of stress on solute transport in a fracture network: A comparison study. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (2): 110–123.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130203.pdf

Abstract: This paper compares numerical modeling of the effect of stress on solute transport (advection and matrix diffusion) in fractured rocks in which fracture apertures are correlated with fracture lengths. It is mainly motivated by the performance and safety assessments of underground radioactive waste repositories. Five research teams used different approaches to model stress/deformation, flow and transport processes, based on either discrete fracture network or equivalent continuum models. The simulation results derived by various teams generally demonstrated that rock stresses could significantly influence solute transport processes through stress-induced changes in fracture apertures and associated changes in permeability. Reasonably good agreement was achieved regarding advection and matrix diffusion given the same fracture network, while some observed discrepancies could be explained by different mechanical or transport modeling approaches.

R. Blaheta, P. Byczanski, M. Cˇ ermák, R. Hrtus, R. Kohut, A. Kolcun, J. Malík, S. Sysala. Analysis of Äspö Pillar Stability Experiment: Continuous thermo-mechanical model development and calibration. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (2): 124–135.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130204.pdf

Abstract: The paper describes an analysis of thermo-mechanical (TM) processes appearing during the Äspö Pillar Stability Experiment (APSE). This analysis is based on finite elements with elasticity, plasticity and damage mechanics models of rock behaviour and some least squares calibration techniques. The main aim is to examine the capability of continuous mechanics models to predict brittle damage behaviour of granite rocks. The performed simulations use an in-house finite element software GEM and self-developed experimental continuum damage MATLAB code. The main contributions are twofold. First, it is an inverse analysis, which is used for (1) verification of an initial stress measurement by back analysis of convergence measurement during construction of the access tunnel and (2) identification of heat transfer rock mass properties by an inverse method based on the known heat sources and temperature measurements. Second, three different hierarchically built models are used to estimate the pillar damage zones, i.e. elastic model with Drucker–Prager strength criterion, elasto-plastic model with the same yield limit and a combination of elasto-plasticity with continuum damage mechanics. The damage mechanics model is also used to simulate uniaxial and triaxial compressive strength tests on the Äspö granite.

Pengzhi Pan, Xiating Feng. Numerical study on coupled thermo-mechanical processes in Äspö Pillar Stability Experiment.Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (2): 136–144.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130205.pdf

Abstract: This paper presents a study of the full three-dimensional thermo-mechanical (TM) behavior of rock pillar in Äspö

Pillar Stability Experiment (APSE) using a self-developed numerical code TM-EPCA 3D . The transient thermal conduction function was descritized on space and time scales, and was solved by using cellular automaton (CA) method on space scale and finite difference method on time scale, respectively. The advantage of this approach is that no global, but local matrix is used so that it avoids the need to develop and solve large-scale linear equations and the complexity therein. A thermal conductivity versus stress function was proposed to reflect the effect of stress on thermal field. The temperature evolution and induced thermal stress in the pillar part during the heating and cooling processes were well simulated by the developed code. The factors that affect the modeling results were discussed. It is concluded that, the complex TM behavior of Äspö rock pillar is significantly influenced by the complex boundary and initial conditions.

Chengyuan Zhang, Xiaoyan Liu, Quansheng Liu. A thermo-hydro-mechano-chemical formulation for modeling water transport around a ventilated tunnel in an argillaceous rock.Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (2): 145–155.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130206.pdf

Abstract: Argillaceous rocks are being considered as potential host rocks for deep geological disposal. For the research work in DECOVALEX-2011, 5 participant research teams performed simulations of a laboratory drying test and a ventilation experiment for Mont Terri underground laboratory built in argillaceous rock formation. Our study starts with establishing a coupled thermo-hydro-mechano-chemical (THMC) processes model to simulate water transport in rock around the ventilated tunnel. Especially in this THMC formulation, a three-phase and two-constituent hydraulic model is introduced to simulate the processes which occur during tunnel ventilation, including desaturation/resaturation in the rock, phase change and air/rock interface, and to explore the Opalinus clay parameter set. It can be found that water content evolution is very sensitive to intrinsic permeability, relative permeability and capillary pressure in clay rock. Water loss from surrounding rock is sensitive to the change of permeability in clay which is induced by excavation damaged zone. Chemical solute transport in the rock near ventilation experiment tunnel is simulated based on the coupled THMC formulation. It can be estimated that chemical osmotic flow has little significance on water flow modeling. Comparisons between simulation results from 5 teams and experimental observations show good agreement. It increases the confidence in modeling and indicates that it is a good start for fully THMC understanding of the moisture transportation and mechanical behavior in argillaceous rock.

Yu-Jun Cui, Anh Minh Tang. On the chemo-thermo-hydro-mechanical behaviour of geological and engineered barriers.Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (3): 169–178.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130301.pdf

Abstract: An overview of the recent findings about the chemo-hydro-mechanical behaviour of materials used for both geological and engineered barriers in nuclear waste disposal is presented, through some examples about the natural Boom Clay (BC) and compacted bentonite-based materials. For the natural BC, it was found that compression index identified from both oedometer and isotropic compression tests is similar and the compressibility of BC from the Mol site is higher than that of BC from the Essen site; the shear strength of Mol BC is also higher than that of the Essen BC, suggesting a significant effect of carbonates content; the thermal volume change is strongly overconsolidation ratio (OCR) dependent—low OCR values promote thermal contraction while high OCR values favour thermal dilation; the volume change behaviour is also strongly time dependent and this time dependent behaviour is governed by the stress level and temperature; the effect of pore-water salinity on the volume change behaviour can be significant when the smectite content is relatively high. For the bentonite-based materials, it was found that thermal contraction also occurs at low OCR values, but this is suction dependent—suction promotes thermal dilation. Under constant volume conditions, wetting results in a decrease of hydraulic conductivity, followed by an increase. This is found to be related to changes in macro-pores size—wetting induces a decrease of macro-pores size, followed by an increase due to the aggregates fissuring. The presence of technological voids can increase the hydraulic conductivity but does not influence the swelling pressure.

P. Delage. On the thermal impact on the excavation damaged zone around deep radioactive waste disposal. Journal

of Rock Mechanics and Geotechnical Engineering. 2013, 5 (3): 179–190.
http://www.rockgeotech.org/qikan/manage/wenzhang/20130302.pdf

Abstract: Clays and claystones are considered in some countries (including Belgium, France and Switzerland) as a potential host rock for high activity long lived radioactive waste disposal at great depth. One of the aspects to deal with when assessing the performance of the disposal is related to the effects of the temperature elevation due to the placement of exothermic wastes on the host rock. The potential effects of the thermal impact on the excavation damaged zone (EDZ) in the near field are another important issue that was the goal of the TIMODAZ European research project. In this paper, some principles of waste disposal in clayey host rocks at great depth are first presented and a series of experimental investigations carried out on specific equipment specially developed to face the problem are presented. Both drained and undrained tests have been carried out to investigate the drained thermal volume changes of clays and claystone and the thermal pressurization occurring around the galleries. The importance of proper initial saturation (under in situ stresses) and of satisfactory drainage conditions (in spite of the significantly low permeability of claystones) is emphasized, leading to the development of a new hollow cylinder apparatus. It is observed that claystones cannot be considered as overconsolidated clays given that they can exhibit, as the Callovo-Oxfordian claystone does, a thermoplastic contraction. Mechanical and thermal hardenings are however observed, extending the knowledge already gained on clays to claystones. A new method of determining the thermal pressurization coefficient in the laboratory is described and the data obtained allow completing existing data in the field. Finally, the hollow cylinder apparatus makes it possible to demonstrate that the good self-sealing properties of clays and claystones can be extended to temperature effects, an important conclusion in terms of performance assessment.

A. Gens, B. Valleján, M.T. Zandarín, M. Sánchez. Homogenization in clay barriers and seals: Two case studies. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (3): 191–199.
http://www.rockgeotech.org/qikan/manage/wenzhang/20130303.pdf

Abstract: The paper presents two case studies that provide information on the process of homogenization of initially heterogeneous clay barriers and seals. The first case is the canister retrieval test performed in the Aspö Hard Rock Laboratory (Sweden). The heterogeneity arises from the use of a combination of blocks and pellets to construct the engineered barrier. The degree of homogenization achieved by the end of the tests is evaluated from data obtained during the dismantling of the test. To assist in the interpretation of the test, a fully coupled thermo-hydro-mechanical (THM) analysis has been carried out. The second case involves the shaft sealing test performed in the HADES underground research laboratory (URL) in Mol (Belgium). Here the seal is made up of a heterogeneous mixture of bentonite pellets and bentonite powders. In addition to the full scale test, the process of homogenization of the mixture has also been observed in the laboratory using X-ray tomography. Both field test and laboratory tests are successfully modelled by a coupled hydro-mechanical (HM) analysis using a double structure constitutive law. The paper concludes with some considerations on the capability of highly expansive materials to provide a significant degree of homogenization upon hydration.

E.E. Alonso, M.T. Zandarín, S. Olivella. Joints in unsaturated rocks: Thermo-hydro-mechanical formulation and constitutive behaviour. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (3): 200–213.
http://www.rockgeotech.org/qikan/manage/wenzhang/20130304.pdf

Abstract: A formulation for the coupled analysis of thermo-hydro-mechanical (THM) problems in joints is firstpresented. The work involves the establishment of equilibrium and mass and energy balance equations. Balance equations were formulated taking into account two phases: water and air. The joint element developed was implemented in a general purpose finite element computer code for THM analysis of porous media (Code Bright). The program was then used to study a number of cases ranging from laboratory tests to large scale in situ tests. A numerical simulation of coupled hydraulic shear tests of rough granite joints is first presented. The tests as well as the model show the coupling between permeability and the deformation of the joints. The experimental investigation was focused on the effects of suction on the mechanical behaviour of rock joints. Laboratory tests were performed in a direct shear cell equipped with suction control. Suction was imposed

using a vapour forced convection circuit connected to the cell and controlled by an air pump. Artificial joints of Lilla claystone were prepared. Joint roughness of varying intensity was created by carving the surfaces in contact in such a manner that rock ridges of different tip angles were formed. These angles ranged from 0◦ (smooth joint) to 45◦ (very rough joint profile). The geometric profiles of the two surfaces in contact were initially positioned in a “matching” situation. Several tests were performed for different values of suctions (200, 100, and 20 MPa) and for different values of vertical stresses (30, 60, and 150 kPa). A constitutive model including the effects of suction and joint roughness is proposed to simulate the unsaturated behaviour of rock joints. The new constitutive law was incorporated in the code and experimental results were numerically simulated.

Chun-Liang Zhang. Sealing of fractures in claystone.Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (3): 214–220.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130305.pdf

Abstract: The sealing behavior of fractures in clay rocks for deep disposal of radioactive waste has been comprehensively investigated at the GRS laboratory. Various sealing experiments were performed on strongly cracked samples of different sizes from the Callovo-Oxfordian argillite and the Opalinus clay under relevant repository conditions. The fractured samples were compacted and flowed through with gas or synthetic pore-water under confining stresses up to 18 MPa and elevated temperatures from 20 ◦C to90 ◦C. Sealing of fractures was quantified by measurements of their closure and permeability. Under the applied thermo-hydro-mechanical (THM) conditions, significant fracture closure and permeability decrease to very low levels of 10−19 to 10−21m2 were observed within time periods of months to years. The properties of the resealed claystones are comparable with those of the intact rock mass. All test results suggest high sealing potentials of the studied claystones.

G. Armand, A. Noiret, J. Zghondi, D.M. Seyedi. Short- and long-term behaviors of drifts in the Callovo-Oxfordian claystone at the Meuse/Haute-Marne Underground Research Laboratory. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (3): 221–230.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130306.pdf

Abstract: Since 2000, the French National Radioactive Waste Management Agency (ANDRA) has been constructing an Underground Research Laboratory (URL) at Bure (east of the Paris Basin) to perform experiments in order to obtain in situ data necessary to demonstrate the feasibility of geological repository in the Callovo-Oxfordian claystone. An important experimental program is planned to characterize the response of the rock to different drift construction methods. Before 2008, at the main level of the laboratory, most of the drifts were excavated using pneumatic hammer and supported with rock bolts, sliding steel arches and fiber shotcrete. Other techniques, such as road header techniques, stiff and flexible supports, have also been used to characterize their impacts. The drift network is developed following the in situ major stresses. The parallel drifts are separated enough so as they can be considered independently when their hydromechanical (HM) behaviors are compared. Mine-by experiments have been performed to measure the HM response of the rock and the mechanical loading applied to the support system due to the digging and after excavation. Drifts exhibit extensional (mode I) and shear fractures (modes II and III) induced by excavation works. The extent of the induced fracture networks depends on the drift orientation versus the in situ stress field. This paper describes the drift convergence and deformation in the surrounding rock walls as function of time and the impact of different support methods on the rock mass behavior. An observation based method is finally applied to distinguish the instantaneous and time-dependent parts of the rock mass deformation around the drifts.

Xiangling Li. TIMODAZ: A successful international cooperation project to investigate the thermal impact on the EDZ around a radioactive waste disposal in clay host rocks. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (3): 231–242.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130307.pdf

Abstract: Disposal of spent nuclear fuel and long lived radioactive waste in deep clay geological formations is one of the promising options worldwide. In this concept of the geological disposal system, the host clay formation is considered as a principal barrier on which the fulfillment of key safety functions rests. Between 2006 and 2010, the European Commission project TIMODAZ, which gathered 15 partners from8 countries, has investigated the coupled thermo-hydro-mechanical (THM) effects on clay for mations for geological disposal of radioactive waste, and specific attention was paid to investigating the thermal effect on the evolution of the damaged zone (DZ). Three types of potential host clay formations were investigated: the Boom Clay (Belgium), the Opalinus Clay (Switzerland) and the Callovo-Oxfordian argillite (France). Intensive experimental (laboratory and in situ in underground research laboratories) and numerical studies have been performed. Multi-scale approach was used in the course of the project. High degree of similarities between the failure modes, sealing process, stress paths, deformation, etc., observed in laboratories and in situ has been obtained, which increased the confidence in the applicability of laboratory test results and up-scaling perspective. The results of the laboratory and in situ tests obtained allowed the parameters for numerical models at various scales to be derived and provided the basis for the simplified performance assessment models that are used to assess the long-term safety of a repository. The good cooperation between the numerical modeler and experimenters has allowed an in-depth analysis of the experimental results and thus better understanding the underlying processes, and consequently increased the capabilities to model the THM effects in claystones. This paper presents the main achievements obtained by TIMODAZ project and shows how a European scientific community investigates a problem of concern in a collaborative way and how the obtained main results are applied to the performance assessment of a geological repository.

Xiaoshuo Li, Chunliang Zhang, Klaus-Jürgen Röhlig. Simulations of THM processes in buffer-rock barriers of high-level waste disposal in an argillaceous formation. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (4): 277–286.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130403.pdf

Abstract: The main objective of this paper is to investigate and analyse the thermo-hydro-mechanical (THM) coupling phenomena and their influences on the repository safety. In this paper, the high-level waste (HLW) disposal concept in drifts in clay formation with backfilled bentonite buffer is represented numerically using the CODE_BRIGHT developed by the Technical University of Catalonia in Barcelona. The parameters of clay and bentonite used in the simulation are determined by laboratory and in situ experiments. The calculation results are presented to show the hydro-mechanical (HM) processes during the operation phase and the THM processes in the after-closure phase. According to the simulation results, the most probable critical processes for the disposal project have been represented and analyzed. The work also provides an input for additional development regarding the design, assessment and validation of the HLW disposal concept.

Wenjing Sun, De'an Sun, Lei Fang, Shiqing Liu. Soil-water characteristics of Gaomiaozi bentonite by vapour equilibrium technique. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (1): 48–54.

http://www.sciencedirect.com/science/article/pii/S1674775513001200 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140105.pdf

Abstract: Soil-water characteristics of Gaomiaozi (GMZ) Ca-bentonite at high suctions (3–287 MPa) are measured by vapour equilibrium technique. The soil-water retention curve (SWRC) of samples with the same initial compaction states is obtained in drying and wetting process. At high suctions, the hysteresis behaviour is not obvious in relationship between water content and suction, while the opposite holds between degree of saturation and suction. The suction variation can change its water retention behaviour and void ratio. Moreover, changes of void ratio can bring about changes in degree of saturation. Therefore, the total change in degree of saturation includes changes caused by suction and that by void ratio. In the space of degree of saturation and suction, the SWRC at constant void ratio shifts to the direction of higher suctions with decreasing void ratio. However, the relationship between water content and suction is less affected by changes of void ratio. The degree of saturation decreases approximately linearly with increasing void ratio at a constant suction. Moreover, the slope of the line decreases with increasing suction and they show an approximately linear relationship in semi-logarithmical

scale. From this linear relationship, the variation of degree of saturation caused by the change in void ratio can be obtained. Correspondingly, SWRC at a constant void ratio can be determined from SWRC at different void ratios.

H.G. Zhao, H. Shao, H. Kunz, J. Wang, R. Su, Y.M. Liu. Numerical analysis of thermal process in the near field around vertical disposal of high-level radioactive waste. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (1): 55–60.

http://www.sciencedirect.com/science/article/pii/S1674775513001212 or
http://www.rockgeotech.org/qikan/manage/wenzhang/20140106.pdf

Abstract: For deep geological disposal of high-level radioactive waste (HLW) in granite, the temperature on the HLW canisters is commonly designed to be lower than 100 °C. This criterion dictates the dimension of the repository. Based on the concept of HLW disposal in vertical boreholes, thermal process in the near field (host rock and buffer) surrounding HLW canisters has been simulated by using different methods. The results are drawn as follows: (a) the initial heat power of HLW canisters is the most important and sensitive parameter for evolution of temperature field; (b) the thermal properties and variations of the host rock, the engineered buffer, and possible gaps between canister and buffer and host rock are the additional key factors governing the heat transformation; (c) the gaps width and the filling by water or air determine the temperature offsets between them.

Ju Wang. On area-specific underground research laboratory for geological disposal of high-level radioactive waste in China. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (2): 99–104.

http://www.sciencedirect.com/science/article/pii/S1674775514000110 or
http://www.rockgeotech.org/qikan/manage/wenzhang/20140202.pdf

Abstract: Underground research laboratories (URLs), including “generic URLs” and “site-specific URLs”, are underground facilities in which characterisation, testing, technology development, and/or demonstration activities are carried out in support of the development of geological repositories for high-level radioactive waste (HLW) disposal. In addition to the generic URL and site-specific URL, a concept of “area-specific URL”, or the third type of URL, is proposed in this paper. It is referred to as the facility that is built at a site within an area that is considered as a potential area for HLW repository or built at a place near the future repository site, and may be regarded as a precursor to the development of a repository at the site. It acts as a “generic URL”, but also acts as a “site-specific URL” to some extent. Considering the current situation in China, the most suitable option is to build an “area-specific URL” in Beishan area, the first priority region for China's high-level waste repository. With this strategy, the goal to build China's URL by 2020 may be achieved, but the time left is limited.

De'an Sun, Wenjing Sun, Lei Fang. Swelling characteristics of Gaomiaozi bentonite and its prediction. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (2): 113–118.

http://www.sciencedirect.com/science/article/pii/S1674775514000092 or
http://www.rockgeotech.org/qikan/manage/wenzhang/20140204.pdf

Abstract: Gaomiaozi (GMZ) bentonite has been chosen as a possible matrix material of buffers/backfills in the deep geological disposal to isolate the high-level radioactive waste (HLRW) in China. In the Gaomiaozi deposit area, calcium bentonite in the near surface zone and sodium bentonite in the deeper zone are observed. The swelling characteristics of GMZ sodium and calcium bentonites and their mixtures with sand wetted with distilled water were studied in the present work. The test results show that the relationship between the void ratio and swelling pressure of compacted GMZ bentonite-sand mixtures at full saturation is independent of the initial conditions such as the initial dry density and water content, but dependent on the ratio of bentonite to sand. An empirical method was accordingly proposed allowing the prediction of the swelling deformation and swelling pressure with different initial densities and bentonite-sand ratios when in saturated conditions. Finally, the swelling capacities of GMZ Na- and Ca-bentonites and Kunigel Na-bentonite are compared.

Yuemiao Liu, Like Ma, Dan Ke, Shengfei Cao, Jingli Xie, Xingguang Zhao, Liang Chen, Panpan Zhang. Design and validation of the THMC China-Mock-Up test on buffer material for HLW disposal. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (2): 119–125.

http://www.sciencedirect.com/science/article/pii/S1674775514000134 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140205.pdf

Abstract: According to the preliminary concept of the high-level radioactive waste (HLW) repository in China, a large-scale mock-up facility, named China-Mock-Up was constructed in the laboratory of Beijing Research Institute of Uranium Geology (BRIUG). A heater, which simulates a container of radioactive waste, is placed inside the compacted Gaomiaozi (GMZ)-Na-bentonite blocks and pellets. Water inflow through the barrier from its outer surface is used to simulate the intake of groundwater. The numbers of water injection pipes, injection pressure and the insulation layer were determined based on the numerical modeling simulations. The current experimental data of the facility are herein analyzed. The experiment is intended to evaluate the thermo-hydro-mechano-chemical (THMC) processes occurring in the compacted bentonite-buffer during the early stage of HLW disposal and to provide a reliable database for numerical modeling and further investigation of engineered barrier system (EBS), and the design of HLW repository.

Simona Saba, Jean-Dominique Barnichon, Yu-Jun Cui, Anh Minh Tang, Pierre Delage. Microstructure and anisotropic swelling behaviour of compacted bentonite/sand mixture. Journal of Rock Mechanics and Geotechnical Engineering. 2014, 6 (2): 126–132.

http://www.sciencedirect.com/science/article/pii/S1674775514000158 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20140206.pdf

Abstract: Pre-compacted elements (disks, torus) of bentonite/sand mixture are candidate materials for sealing plugs of radioactive waste disposal. Choice of this material is mainly based on its swelling capacity allowing all gaps in the system to be sealed, and on its low permeability. When emplaced in the gallery, these elements will start to absorb water from the host rock and swell. Thereby, a swelling pressure will develop in the radial direction against the host rock and in the axial direction against the support structure. In this work, the swelling pressure of a small scale compacted disk of bentonite and sand was experimentally studied in both radial and axial directions. Different swelling kinetics were identified for different dry densities and along different directions. As a rule, the swelling pressure starts increasing quickly, reaches a peak value, decreases a little and finally stabilises. For some dry densities, higher peaks were observed in the radial direction than in the axial direction. The presence of peaks is related to the microstructure change and to the collapse of macro-pores. In parallel to the mechanical tests, microstructure investigation at the sample scale was conducted using microfocus X-ray computed tomography (μCT). Image observation showed a denser structure in the centre and a looser one in the border, which was also confirmed by image analysis. This structure heterogeneity in the radial direction and the occurrence of macro-pores close to the radial boundary of the sample can explain the large peaks observed in the radial swelling pressure evolution. Another interesting result is the higher anisotropy found at lower bentonite dry densities, which was also analysed by means of μCT observation of a sample at low bentonite dry density after the end of test. It was found that the macro-pores, especially those between sand grains, were not filled by swelled bentonite, which preserved the anisotropic microstructure caused by uniaxial compression due to the absence of microstructure collapse.

Municipal Waste Disposal

Yunmin Chen, Deng Gao, Bin Zhu. Controlling strain in geosynthetic liner systems used in vertically expanded landfills. Journal of Rock Mechanics and Geotechnical Engineering. 2009, 1 (1): 48–55.

http://www.rockgeotech.org/qikan/manage/wenzhang/20090015.pdf

Abstract: According to relevant new regulations in China, a composite liner system involving geosynthetic materials must be installed at the bottom of an expanded landfill. The deformation and integrity of the composite liner under a variety of factors are important issue to be considered in the design of a landfill expansion. In this paper, we investigate the strain

distribution in geosynthetic materials within the composite liner system of expanded landfills, including strains in geosynthetic materials resulting from overall settlement and lateral movement of landfills, localized subsidence in landfills, and differential settlement around gas venting wells. The allowable strains of geosynthetic materials are discussed based on the results of tensile tests, and the corresponding design criteria for composite liner systems are proposed. Meanwhile, practical measures allowing strain control in geosynthetic materials used in landfill engineering are proposed.

C.T. Wong, M.K. Leung, M.K. Wong, W.C. Tang. Afteruse development of former landfill sites in Hong Kong. Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (6): 443–451.

http://www.sciencedirect.com/science/article/pii/S1674775513001017 or

http://www.rockgeotech.org/qikan/manage/wenzhang/20130603.pdf

Abstract: Landfill is one of the major methods in disposing of municipal solid waste (MSW) in Hong Kong. There are now 13 closed landfill sites in Hong Kong, and a restoration program has been launched since 1999 to transform the closed landfill sites back into recreational area. The MSW underneath these closed landfill sites will biodegrade slowly and gradually, releasing toxic gases and leachate. As there have only been a few afteruse development ever completed in Hong Kong, this paper describes the consideration in planning and design of two former landfill sites in Hong Kong – Ngau Chi Wan (NCW) and Jordan Valley (JV) landfills, in particular a discussion on the MSW settlement. Various models in predicting the long-term MSW settlement have been available. This paper reviews the applicability of these models to predict MSW settlement. However, as the predicted settlements can be significantly in error, they need site-specific calibration and validation. This paper therefore presents the settlement monitoring data in these former landfill sites over the last 30 years, and suggests modifying the Bjarngard and Edgers' method for estimating this long-term settlement as well as the effect of additional surcharge due to afteruse development. Based on the regression of these data, compression indices C_{ce} and C_{α} at different stages of the settlement in the modified method have been calibrated and validated.

Geotechnical Testing Devices

K. J. Shou, Y. W. Lin. Design and verification of portable direct shear tester with application to remolded colluvium geomaterials. Journal of Rock Mechanics and Geotechnical Engineering 2012; 4 (4): 326–332.

http://www.rockgeotech.org/qikan/manage/wenzhang/20120404.pdf

Abstract: The mechanical properties of colluvium strongly govern the stability of colluvial slopes, and they are essential for the related analysis and design. Nevertheless, their measurement is not easy on account of heterogeneity in property and difficulty of sampling. This study attempted to evaluate the shear strength of remolded colluvium by means of a simple direct shear test in the field. A portable direct shear tester was designed to overcome the inconvenience and expensiveness of the conventional large-scale in-situ direct shear test. It can be easily assembled and applied for the simple field direct shear test. For calibration, the results of the portable direct shear tester were compared with the results of the laboratory direct shear tester for four different types of soil samples, i.e. standard sand, slate debris, arenaceous shale debris and mixture of gravel and sand. Correlation formulas were established based on the calibration, enabling the portable direct shear tester to measure and estimate the shear strength of remolded colluvium in field. This study primarily focuses on the colluvium in Central Taiwan, including the lateritic Dadu Terrace and the arenaceous shale of Taiping-Wufeng mounts. The portable direct shear tester was applied to sites selected in these areas, and the results were further analyzed and discussed.

Support and Reinforcement

Yunming Yang, H. S. Yu. Finite element analysis of anchor plates using non-coaxial models. Journal of Rock Mechanics and Geotechnical Engineering. 2010, 2 (2): 178–187.

http://www.rockgeotech.org/qikan/manage/wenzhang/2010-02-12.pdf

Abstract: The non-coaxial model simulating the non-coincidence between the principal stresses and the principal plastic strain rates is employed within the framework of finite element method (FEM) to predict the behaviors of anchors embedded in granular material. The non-coaxial model is developed based on the non-coaxial yield vertex theory, and the elastic and conventional coaxial plastic deformations are simulated by using elasto-perfectly plastic Drucker-Prager yield function according to the original yield vertex theory. Both the horizontal and vertical anchors with various embedment depths are considered. Different anchor shapes and soil friction and dilation angles are also taken into account. The predictions indicate that the use of non-coaxial models leads to softer responses, compared with those using conventional coaxial models. Besides, the predicted ultimate pulling capacities are the same for both coaxial and non-coaxial models. The non-coaxial influences increase with the increasing embedment depths, and circular anchors lead to larger non-coaxial influences than strip anchors. In view of the fact that the design of anchors is mainly determined by their displacements, ignoring the non-coaxiality in finite element numerical analysis can lead to unsafe results.

Shikou Yang, Xuhua Ren, Jixun Zhang. Study on embedded length of piles for slope reinforced with one row of piles. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (2): 167–178.

http://www.rockgeotech.org/qikan/manage/wenzhang/2011-02-06.pdf

Abstract: The embedded length of anti-slide piles for slope is analyzed by three-dimensional elastoplastic shear strength reduction method. The effect of embedded pile length on the factor of safety and pile behavior is analyzed. Furthermore, the effects of pile spacing, pile head conditions, pile bending stiffness and soil properties on length and behavior of pile are also analyzed. The results show that the pile spacing and the pile head conditions have significant influences on the critical embedded length of pile. It is found that the critical embedded length of pile, beyond which the factor of safety does not increase, increases with the decrease in pile spacing. The smaller the pile spacing is, the larger the integrity of the reinforced slope will be. A theoretical analysis of the slip surface is also conducted, and the slip surface determined by the pressure on piles, considering the influences of both soil and piles for slope, is in agreement with the ones in previous studies.

Xianming Zeng, Zhenyu Wang, Junqi Fan, Lin Zhao, Dalu Lin, Jian Zhao. Problems of durability and reinforcement measures for underground structures in China. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (3): 250–259.

http://www.rockgeotech.org/qikan/manage/wenzhang/20110306.pdf

Abstract: In this paper, the bolt- and cable-supported structures mainly refer to anchored cables, anchored bolts, soil nails and other commonly used reinforcing and supporting structures in geotechnical engineering, as well as reinforced soil structures in permanent works. They are often used in combination, or formed into composite bolt- and cable-supported structures, with other traditional construction methods and relevant measures. Distinct characteristics of such structures are that they are most often invisible, exposed to more severe underground corrosive environments and with strict durability requirements. A number of serious durability problems of underground structures are discussed and major achievements and advances in China and abroad in terms of durability and reinforcement measures for underground structures are reviewed, followed by comprehensive analyses. Some suggestions for those problems are put forward.

Jun Sun. Durability problems of lining structures for Xiamen Xiang'an subsea tunnel in China. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (4): 289–301.

http://www.rockgeotech.org/qikan/manage/wenzhang/20110401.pdf

Abstract: Durability problem of reinforced concrete for underground structures is a hot issue in the field of structural engineering. For underground structures, the prediction of structural service life and methodology for durability design are needed to estimate structural durability. Taking the case of Xiamen Xiang'an subsea tunnel as background, which is designed to meet the requirement of 100-year service life, the influential factors of tunnel lining durability are analyzed. Under the criteria of crack controlling and bearing capacity of lining structures, the theoretical service life of Xiamen Xiang'an

subsea tunnel lining is studied. Simultaneously, the regulations, which are needed for the diffusion capability of chloride ions in concrete by the relevant diffusion tests, are proposed. After a quick corrosion test, the bearing capacity test on eccentric short columns is implemented to investigate the variation rules in the bearing capacity of models with time. The law, in which the corrosion degree of steel bars affects the bearing capacity of models, is investigated. Based on the results of model tests, the acceleration ratio describing the quick corrosion in laboratory test to the natural corrosion environments is established. As a result, the natural service life of subsea tunnel lining structures is obtained by means of laboratory tests. Then, the method using this modified model is employed to predict the service life of tunnel lining structures. Finally, the design and construction measures for improving the durability of lining structures of subsea tunnel are introduced. The results of the present study based on actual situation of the project are prior to those with single theorem, which could be better used as a reference to similar projects.

Relics Protection

Zhifa Yang, Zhongqi Yue, Lihui Li. Design, construction and mechanical behavior of relics of complete large Longyou rock caverns carved in argillaceous siltstone ground. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (2): 131–152.

http://www.rockgeotech.org/qikan/manage/wenzhang/2011-02-03.pdf

Abstract: This paper presents a comprehensive summary of data, analyses and findings from the investigations over the past twelve years about the relics of large Longyou rock caverns carved about 2 000 years ago at shallow depths in argillaceous siltstone. The paper presents the typical features associated with the rock caverns. They include structures, large spans, portals, extreme shallow-buried depths, imprints, drainages, inclined ceiling, inclined sidewalls, slender rock pillars, rock staircases, site and strata selections, caving lighting, carving method, and underground construction surveying. They are used to reconstruct and highlight the design and construction methods adopted by the ancients. The paper further demonstrates that the relics of the complete large rock caverns are a consequence of coincidental combinations of ancient human effort and natural factors. The full occupation of water with weak acidity in the large rock caverns with the soft surrounding rocks of weak alkalinity is found to be the main factor ensuring and preserving the caverns to have been stable and integral over 2 000 years. However, the five unwatered complete rock cavern relics have been experiencing various deteriorations and small failures including cracks, seepage, small rock falls and delaminating ceiling rocks. Although these deteriorations have been repaired and stabilized effectively, the paper demonstrates that an entire roof collapse failure is highly possible in the near future to each of the five unwatered rock cavern relics. The findings presented in this paper are also invaluable both to the long-term protection and preservation of the large rock cavern relics of national and international interests and importance, and to extend and enrich our experience and knowledge on the long-term stability and integrity of man-made underground rock cavern engineering projects.

Zuixiong Li, Xudong Wang, Manli Sun, Wenwu Chen, Qinglin Guo, Huyuan Zhang. Conservation of Jiaohe ancient earthen site in China. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (3): 270–281.

http://www.rockgeotech.org/qikan/manage/wenzhang/20110308.pdf

Abstract: Earthen sites, which are mainly made of earth, are cultural heritages with historical, artistic and scientific values. Many extremely valuable earthen sites have been preserved in the arid areas in China. The earthen site of Jiaohe Ancient City is one of the earliest National Protected Important Cultural Heritage Sites. The Jiaohe Ancient City site exhibits all kinds of deteriorations, which can be found in the earthen sites in arid environments in China. Through a case study of the Jiaohe ancient earthen site, we present in this paper the comprehensive conservation technologies, including the mud bricklaying and reparation, wooden rod anchorage, crack grouting, surface potassium silicate (PS) penetration consolidation, and suspended steel beam ceiling, etc. Results of this case study showed that better conservation effects could be achieved by selecting proper PS penetration and crack grouting processes based on the deterioration characteristics of the earthen sites. The technology of mud bricklaying and reparation was also an effective method for preventing the earthen body from collapsing. Compared with traditional conservation technologies, the suspended steel beam ceiling technology could effectively reduce the negative impacts to the original state of the earthen site. As for unstable cliffs, a new method using composite anchor rod of bamboo and steel with massive loose earth was applied. Deformation monitoring and temporary supports were critical and indispensable measures for the safe of site conservation projects. Through years of monitoring and practical operation at the Jiaohe ancient earthen site, deterioration at the site has been effectively controlled.

Digitization of Underground Engineering

Hehua Zhu, Xiaojun Li, Xiaoying Zhuang. Recent advances of digitization in rock mechanics and rock engineering. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (3): 220–233.
http://www.rockgeotech.org/qikan/manage/wenzhang/20110303.pdf

Abstract: In recent years, there are growing demands of representing rock mechanics and rock engineering in a digital format that can be easily managed, manipulated, analyzed and shared. The objective of this paper is to give a comprehensive review of the status quo and future trends of digitization in rock mechanics and rock engineering. Research topics essential to the process of digitization are firstly discussed, including data acquisition, data standardization, geological modeling, visualization and digital-numerical integration. New techniques that will play an important role in digitization process but require further improvement are then briefly proposed. Finally, achievements of present methods and techniques for digitization in substantial rock mechanics and rock engineering are presented.

Geological Hazards

Guichen Ma, Hiroyuki Matsuyama, Satoshi Nishiyama, et al. Practical studies on rockfall simulation by DDA. Journal of Rock Mechanics and Geotechnical Engineering. 2011, 3 (1): 57–63.

http://www.rockgeotech.org/qikan/manage/wenzhang/2011-01-06.pdf

Abstract: In this paper, simulations of real rockfall by discontinuous deformation analysis (DDA) are conducted. In the simulations, the energy losses of rockfall are categorized into three types, i.e. the loss by friction, the loss by collision, and the loss by vegetation. Modeling of the energy loss using absolute parameters is conducted by the DDA method. Moreover, in order to verify the applicability and validity of the proposed DDA, field tests on rockfall and corresponding simulations of rockfall tests by DDA are performed. The simulated results of rockfall velocity and rockfall jumping height agree well with those obtained from the field tests. Therefore, the new technique properly considers the energy-absorption ability of slope based on vegetation condition and shape of the rockfall, and provides a new method for the assessment and preventive design of rockfall.

Yuxiang Cheng, Jun Zhang, Jianbing Peng. ArcGIS-based evaluation of geo-hazards at Yaozhou County, Shaanxi, China.Journal of Rock Mechanics and Geotechnical Engineering. 2013, 5 (4): 330–334.

http://www.rockgeotech.org/qikan/manage/wenzhang/20130410.pdf

Abstract: In conventional susceptibility evaluation of geo-hazards, there are some limits, such as unreasonable division of evaluated region, difficulty in quantifying evaluation indicators, time-consuming calculation. To address these problems, we try to employ the software ArcGIS to evaluate geo-hazards susceptibility. The study area of Yaozhou County is automatically divided into 3562 units. Based on the spatial overlay analysis function of ArcGIS, quantitative evaluation of geo-hazards susceptibility is implemented in the study area, and the geo-hazards susceptibility zoning is mapped. It is observed that the evaluation results match well with field investigations.

Numerical Methods

Rui Gao, Xin Du, Yawu Zeng, Yong Li, Jing Yan. A new method to simulate irregular particles by discrete element method. Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (3): 276–281.

http://www.rockgeotech.org/qikan/manage/wenzhang/2012-03-08.pdf

Abstract: Granular materials are ubiquitous in nature and important in various applications such as road and railway engineering. Granular materials exhibit complicated mechanical behaviors, which are affected significantly by the irregular shape of particles. Currently, the discrete element method (DEM) has been accepted as an effective approach to investigate the mechanical behaviors of granular materials. However, there are scarce simulations based on DEM in literatures considering the irregularity of particle shape. A new method is proposed to simulate individual real particle with irregular shape using clump constituted by overlapping spheres. First, the geometric model of real particle with surface nodes and inner nodes is established through digitally processing the computerized tomography (CT) scanning data. Second, a clump consisting of spheres is generated to simulate the real particle using a minimum distance criterion. The criterion is implemented by tree optimization algorithm. Influential factors are also introduced to balance the model accuracy and computing cost. Effects of the influential factors, including the density of geometric grid and the minimum distance, on simulations are discussed. Results show that this new method is simpler and more efficient than the previous methods in terms of the model accuracy and computing cost.