Progress Report of the Commission on Application of Geophysics to Rock Engineering

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ABSTRACT: The Commission on Application of Geophysics to Rock Engineering was formed in the ISRM in 1996. The main objective of this commission is to promote the effective utilization of geophysical methods in rock engineering. In order to achieve this objective, the commission has urged the following tasks onward mainly: organization of a series of international workshops, publication of the special issues on the application of geophysics to rock engineering, and publication of ISRM Suggested Methods for Land and Borehole Geophysics in Rock Engineering. In this report, the activities of the commission since establishment are shown briefly.

1. INTRODUCTION

The geophysical methods are efficient and important techniques to obtain stratigraphic map and also two or three dimensional information on the geological character, physical, mechanical and hydraulic properties of underground. As the geophysical techniques are very useful tool to characterize in-situ rock masses, this techniques are to be utilized more widely in the field on rock engineering. From this standpoint, according to the ISRM By-Law, establishment of the Commission on the Application of Geophysics to Rock Engineering was proposed and Mr. ISRM president appointed Professor Koichi Sassa at Kyoto University as a president of this commission in 1996.

The objectives of this commission written in the proposal are as follows:

1) Summarize and introduce how can we utilize geophysical techniques to evaluate in situ rock and soil.
2) Organize an international workshop on the application of geophysics to rock engineering.
3) Establish closer relationship between ISRM members and exploration geophysicists who are interested in the academic field on the application of geophysics to rock engineering.

In order to achieve the objectives shown above, the commission has urged the following four tasks onward mainly. The first one is the organization of a series of international workshops. The second one is the standardization of geophysical methods for rock engineering. The third one is the publication of the commission's work, original papers and review papers on the application of geophysics in rock engineering. The fourth one is the organization of the specialized session in the 11th Congress of ISRM and the lecture meeting in Kyoto, Japan.

The progress of the activities since establishment is shown below.

2. INTERNATIONAL WORKSHOP ON THE APPLICATION OF GEOPHYSICS TO ROCK ENGINEERING

The 1st International Workshop on the Application of Geophysics to Rock Engineering was held as a pre-symposium workshop of the 1997 ISRM International Symposium - NYRock'97 at Columbia University in New York, U.S.A. on June 29th, 1997. The workshop chairperson of this workshop was Professor Koichi Sassa at Kyoto University, Japan. The main subjects chosen for this workshop were characterization of rock by use of geophysical methods and geophysical survey ahead and around a tunnel and a borehole. Fourteen very interesting papers were presented and the proceedings of 112 pages were published. The contents of the 1st workshop can be found at
http://web.kyoto-inet.or.jp/people/sassa/NYWS.htm.

The 2nd International Workshop was held as a pre-congress workshop of the 9th Congress of ISRM at Palais des Congres in Paris, France on August 24th, 1999. The workshop chairperson of this workshop was Professor Laura J. Pyrak-Nolte at Purdue University, USA. Twelve papers were presented. The presentations on the application of geophysical methods to assess rock around tunnel and boreholes, to estimate the mechanical properties of landslides, and to assess rock bursts were made in the morning session. The afternoon session focused on presentations that examine the effects of discontinuities on wave propagation from the field-scale to the laboratory-scale with specific focus on structural discontinuities such as micro-cracks, fractures, and faults. The proceedings of 75 pages were published. The contents of the 2nd workshop can be found at
http://web.kyoto-inet.or.jp/people/sassa/PRWS.htm.

The 3rd International Workshop was held as a pre-conference workshop of GeoEng2000 (International Conference on Geotechnical and Geological Engineering) at the University of Melbourne, in Melbourne, Australia on November 18th, 2000. This workshop was jointly organized by the ISRM Commission on the Application of Geophysics to Rock Engineering and the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) Technical Committee 10 on Geophysical Site Characterization. The workshop chairpersons of this workshop were Professor Laura J. Pyrak-Nolte from ISRM and Dr. K. Rainer Massarsch from ISSMGE. Thirteen papers were presented and proceedings of 82 pages were published. In this workshop, the morning session began with an overview of the applications of geophysical methods to Geotechnical applications and is followed by presentations on the application of geophysical methods to assess rock and soil masses, and by characterization of time-dependent changes around tunnels. The afternoon session focused on presentations that examine the use of geophysical methods for characterizing the hydraulic properties of rock, methods for site characterization of soils, laboratory-scale measurements of effects of weak granular rock and stress corrosion, and geophysical testing of

cultural stone. The proceedings of 82 pages were published. The contents of the 3rd workshop can be found at http://web.kyoto-inet.or.jp/people/sassa/3rdWS.htm.

The 4th International Workshop was held as a pre-symposium workshop of the 2001 ISRM International Symposium (2nd Asian Rock Mechanic Symposium) on 10th September in Beijing, China. This workshop was held at the same venue as the ISRM 2001 (2nd ARMS). The workshop chairpersons of this workshop were Professor Kunihisa Katsuyama at Ehime University, Japan and Professor Chang Xu at Chinese Academy of Sciences, China. Three keynote lectures from China, Japan and Korea, and also thirteen papers were presented. These key note lectures were published in the ISRM News Journal volume 7 number 1 December 2001. The proceedings of about 103 pages were published. Furthermore, a CD-R proceedings containing all papers presented at the workshop was made after the workshop. In this workshop, studies on the four kinds of tomography were presented, namely, IP and EM tomography, Resistivity tomography, and seismic tomography. Furthermore, near surface survey including array microtremor survey, high-resolution seismic methods, site characterization, fracture monitoring and also energy confinement between parallel fractures were presented. The contents and some other information of the 4th workshop can be found at http://web.agr.ehime-u.ac.jp/~chiiki/katsuyama/workshop/Workshop4.htm

The CD-R proceedings of the 4th International Workshop can be purchased by contact with Professor Kunihisa Katsuyama. His e-mail address is as follows: katsuyama@agr.ehime-u.ac.jp

The 5th International Workshop on the Application of Geophysics to Rock Engineering was held on 7th July 2002 at Delta Chelsea Hotel in Toronto, Canada, as part of NARMS-TAC 2002. The workshop chairpersons of this workshop were Professor R. Paul Young at University of Toronto, Canada and Professor Laura J. Pyrak-Nolte at Purdue University, USA. Ten excellent papers focused on seismic fracture imaging, fracture characterization and acoustic emission were presented. And also progress reports of the two working groups in the commission were presented. The titles were "Progress Report on the Proposed Suggested Methods of Geophysics for Rock Engineering" and "Suggested Method for in-situ stress measurement from rock core using the Acoustic Emission technique". The proceedings of about 77 pages were published. The contents of the 5th workshop can be found at http://web.kyoto-inet.or.jp/people/sassa/5thWS.html.

The 6th International Workshop on the Application of Geophysics to Rock Engineering was held on 29th November 2004 at Kyoto International Conference Hall in Kyoto, Japan, as a pre-symposium workshop of the 2004 ISRM International Symposium (3rd ARMS). The workshop chairperson of this workshop was Professor Yuzuru Ashida at Kyoto University, Japan. Twelve excellent papers and also a preliminary draft of the Suggested Methods for Borehole Geophysics in Rock Engineering were presented. The proceedings of about 73 pages were published. The CD-R proceedings of the 6th International Workshop can be purchased by contact with Professor Koichi Sassa. His e-mail address is as follows: sassa@mbox.kyoto-inet.or.jp

The contents of the proceedings of the 6th International Workshop are shown below.

(1) Heterogeneity and instability in geological deformations; Insights from sandbox experiments and particle simulations by *Y. Yamada, S. Ueda, K. Kaneda, and T. Matsuoka* (Kyoto University, Japan).

(2) Tomographic imaging of injected C02 migration in a porous sandstone by *T. Matsuoka, R. Kamei* and *Y. Minami* (Kyoto University, Japan), *and Z. Xue* (Research Institute of Innovative Technology for the Earth, Japan).

(3) Seismic refraction method with extrapolated first-arrival data by *Y. Sanada, J. Lee, T. Matsuoka, and A. Ashida* (Kyoto University, Japan).

(4) The application in strong noise background by using Mini-Sosie method by *C. Xu, L. Yike, W. Hongluo, and Y. Jianjun* (Chinese Academy of Sciences, China, Yangtze University, China)

(5) First draft of suggested methods for borehole geophysics in rock engineering (Version 1) by *T. Takahashi* (OYO Corporation, U.S.A.)

(6) Application of Love wave dispersion for improved shear-wave velocity imaging by *J. Safani, A. O'Neill, T. Matsuoka, and Y. Sanada* (Kyoto University, Japan)

(7) Joint analysis of multi-shot, multi-channel surface wave data and micro-gravity data by *K. Hayashi* (OYO Corporation, Japan), *T. Matsuoka* (Kyoto University, Japan), and *H. Hatakeyama* (OYO Corporation, Japan).

(8) Permeability distribution estimation for rock mass from P-wave velocity tomography using frequency-velocity dispersion relationship by *S. Uehara*, *Y. Ohnishi* and *S. Nishiyama* (Kyoto University, Japan), and *T. Yano* and *K. Ando* (Obayashi Co., Japan), *and K. Yoshimura* (Radioactive Waste Management Funding and Research Center, Japan).

(9) A case study of permeability analysis using frequency dependent acoustic wave velocity and applying in-situ data by *K. Yoshimura* (Radioactive Waste Management Funding and Research Center, Japan), and *K. Ando* and *H. Kim* (Obayashi Co., Japan), and *S Nishiyama, S. Uehara, K. Aoki* and *Y. Ohnishi* (Kyoto University, Japan).

(10) Anisotropic crosshole resistivity tomography for ground safety analysis of a high-storied building over an abandoned mine by *J. Kim, M. Yi, S. Cho, J. Son, W. Song, and K. Han* (Korea Institute of Geosciences and Mineral Resources (KIGAM), Korea)

(11) Simulation of earth tunnel excavation based on trop door test by Distinct Element Method by *H. Kusumi* (Kansai university, Japan), and *T. Matsuoka* and *Y. Ashida* (Kyoto University, Japan), *and K. Fuji* (Kansai university, Japan).

The 7th International Workshop was held on 8th July 2007 as a pre-congress workshop of the 11th Congress of ISRM in Lisbon Portugal. The workshop chairperson of this workshop was Professor Koichi Sassa at Geosystem Research Institute, Japan. In this workshop, one working group report and thirteen papers were presented. The 1st session in the morning consists of ISRM Suggested Methods and near surface geophysics. The 2nd session in the morning was focused on basic studies on the application of geophysics to rock engineering. The afternoon sessions were focused on the application of geophysics to tunneling and to construction of subsurface storages. Hard copy proceedings and CD-R proceedings including color illustrations were published. The CD-R proceedings of the 7th International Workshop can be purchased by contact with Professor Koichi Sassa.

The contents of the proceedings of the 7th International Workshop are shown below.

(1) ISRM Suggested methods for land and borehole geophysics in rock engineering by *Toru Takahashi* (Fukada Geological Institute, Japan)

(2) Near-surface seismic profile in the northern part of Beijing city by *Xu Chang, Yike Liu, Yanghua Wang* (Chinese Academy of Sciences, China)

(3) Reactive Flow in a Fracture: Scale Effects in the Interpretation of Seismic Measurements by *Angel Acosta-Colon, David D. Nolte and Laura J. Pyrak-Nolte* (Purdue University, USA)

(4) Issues for the inversion of seismic reflection data for geotechnical properties by *Binzhong Zhou* (CSIRO Exploration and Mining, Australia), *Peter Hatherly* (University of Sydney, Australia), *Milovan Urosevic* (Curtin University, Australia), *Troy Peters* (VelSeis Processing, Australia)
(5) Application of Seismic Interferometry to Cross-Well Seismology by *Toshifumi Matsuoka* (Kyoto University, Japan), *and Kazuya Shiraishi* (Japan Petroleum Exploration Co. Ltd., Japan)
(6) Cross-well Imaging by 2-D oriented migration by *Yike Liu* and *Xu Chang* (Chinese Academy of Sciences, China), and *Hongchuan Sun* (University of Utah, USA)
(7) Exploration of the tunnel alignment using geophysical methods to increase the safety for planning and respectively minimizing the risk by *Bodo Lehmann, Dirk Orlowsky and Rudiger Misiek* (Deutsche Montan Technolgie, Germany)
(8) The geostatistical prediction technique of geological conditions ahead of the TBM driven tunnel face by *Kenji Aoki, Yoshitada Mito and Chuan Sheng Chang* (Kyoto University, Japan)
(9) ISIS - Integrated Seismic Imaging System for geological Prediction ahead of Hard Rock Tunnels by *Rudiger Giese, Stefan Lueth, Kay Krueger, Sylvio Mielitz, Peter Otto and Gunter Borm* (GeoForschungsZentrum Potsdam, Germany)
(10) OnSITE: Development of an On-line Seismic Imaging System for Tunnel Excavation by *Guenter Borm, Rudiger Giese* and *Stefan Lueth* (GeoForschungsZentrum Potsdam, Germany), *Thomas Bohlen* (Technical University Freiberg, Germany), *Serge Shapiro* and *Stefan Buske* (Free University, Germany). *Ulrich Polom* (GGA Institute Hannover, Germany), *Edwin Fecker* (GIF Ettlingen, Germany), *Klaus-Wolfgang Becker* (Hochtief Construction AG, Germany), *Norbert Pralle* (Eduard Zublin AG, Germany), *Thomas Dickmann* (Amberg Technologies AG, Switzerland)
(11) Seismic prediction of hard rock fault zones and confirmation by tunnel observations by *Calin Cosma, Nicoleta Enescu* (Vibrometric Ltd, Finland), *Turo Ahokas* (Posiva Ltd, Finland) *and Eero Heikkinen* (Poyry Ltd, Finland).
(12) Current status of high-level radioactive waste disposal program and growing expectations for geophysical exploration technology in Japan by *Hiroyuki Tsuch* and *Junichi Goto* (The Nuclear Waste Management Organization of Japan, Japan)
(13) Cross-hole Seismic Survey for Spent Fuel Interim Storage Facility by *Yasushi Okajim* and *Jiro Tsuchiyama* (Recyclable-Fuel Storage Company, Japan), *Toshifumi Matsuoka* (Kyoto University, Japan), *Dai Nobuoka , Hiroyuki Azuma* and *Takeshi Iwamoto* (OYO Corporation, Japan)
(14) Study on creating hydraulic tomography for crystalline rock using frequency dependent elastic wave velocity by *Patric Bruines* and *Kenichi Ando* (Obayashi Corporation, Japan), *Kimitaka Yoshimura* and *Susumu Sakashita* (Radioactive Waste Management Funding and Research Center, Japan), *Hirofumi Okumura* (J-POWER, Japan), *Yuzo Ohnish* and *Satoshi Nishiyama* (Kyoto University, Japan)

3. ACTIVITIES OF WORKING GROUPS

There are three working groups in the commission.

The first one is the Working group on Standardization of Geophysical Methods for Rock Engineering. The proposed task of this working group is to make a suggested method for geophysical survey in rock engineering. This working group was coordinated by Mr. Toru Takahashi and consisting of 11 members from six countries. The working group members were as follows: P. Hatherly, M. S. King, H. Kusumi, B. Lehmann, L. Myer, L. Pyrak-Nolte, T. Takahashi, N. M. Toksoz, T. Uchida, T. Watanabe and X. Chang. The first task of this working group was to draft the Suggested Methods for Land Geophysics in Rock Engineering. The final draft submitted from the working group had been approved by a majority of the commission members and also Mr. ISRM Vice-President for Asia. Then, this final draft became one of the ISRM Suggested Methods in accordance with the ISRM By-law Number 3, clause 9. The second task of this working group was to draft the Suggested Methods for Borehole Geophysics in Rock Engineering. The final draft submitted from the working group had been approved by a majority of the commission members and also Mr. ISRM Vice-President for Asia. Then, this final draft became one of the ISRM Suggested Methods in accordance with the ISRM By-law Number 3, clause 9.

The second working group was the Working Group on Estimating Primary State of Stress in Rock Mass using Acoustic Emission Technique. The proposed task of this working group was to draft the Suggested Method for in-situ Rock Stress Estimation from a Rock Core using Acoustic Emission Technique. This working group was coordinated by Dr. Masahiro Seto and consisting of seven members. The working group members were as follows: E. Villaescusa, X. T. Feng, K. Shin, T. Yokoyama, K. Hata, M. Kwaniewski, H. R. Hardy, M. Seto. The final draft of the "Suggested Method for in-situ Rock Stress Estimation from a Rock Core using Acoustic Emission Technique" had been approved by a majority of the commission members and also Mr. ISRM Vice-President for Asia. Then, this final draft became one of the ISRM Suggested Methods in accordance with the ISRM By-law Number 3, clause 9.

The third working group is the working group on Wave Propagation in Fractured and Cracked Media. This working group is coordinated by Professor Laura J. Pyrak-Nolte. The objectives of this working group are to develop a series of articles on the application of seismic wave propagation to problems in rock engineering. The main multi-year project of the working group is to write a review article and develop a website on wave propagation in fractured and crack media. The goal of the article and the website is to provide an information source for ISRM members and others that contains (1) a comparison of theoretical and numerical models of wave propagation through fractured and cracked media, (2) important laboratory results from experiments on fractured and cracked media, (3) numerical models online for use, and (4) an extensive literature database.

4. PUBLICATIONS

The Commission took the effort for publishing an issue in the ISRM News Journal of which main contents were the articles on the application of geophysics to rock engineering, including the effort for getting advertisements from some companies. This issue was published as a Volume 7 Number 1 December 2001. The main contents of this issue are as follows:

"Seismic Imaging of Heterogeneity" by Laura J. Pyrak-Nolte, Xun Li and Changjin Xian (USA), "Geophysical Studies for Seismically-Designed Structures on Rock" by M. S. King and M. H. Worthington (UK), "Microseismic Investigation of Rock Fracture and its Application in Rock and Petroleum Engineering" by R. Paul Young and Calum Baker (Canada), "Prediction Ahead of the Tunnel Face by High-Resolution Seismic Refraction Method with Sources Placed in the Tunnel" by Koichi Hayashi and Hideki Saito

(Japan), "Application of Geophysical Techniques to Geotechnical Engineering" by Yuzuru Ashida (Japan), "Current Use of Geophysical Site Characterization Techniques for Civil Engineering in Korea" by Hyunsam Chang and Tai Sup Lee (Korea). "Near Surface Geophysical Imaging and its Application to Engineering Geology" by Wang Miaoyue and Di Qingyun (China).

The Commission took the effort for publishing a special issue on the application of geophysics to rock engineering in the International Journal of Rock Mechanics and Mining Sciences. The special issue was published as a Volume 38 Number 6, September 2001. Professor Koichi Sassa and Professor Laura J. Pyrak-Nolte were invited as guest editors of this issue. The contents of this special issue are mainly based on the studies presented at the 1st and the 2nd International Workshops on the Application of Geophysics to Rock Engineering. However, all papers have been significantly expanded to contain much new material and further considerations following the workshops. The contents of this special issue are shown below. "Preface" by K. Sassa and L. J. Pyrak-Nolte, "Compressional waves guided between parallel fractures" by C. Xian, D. D. Nolte and L. J. Pyrak-Nolte, "Active seismic monitoring of hydraulic fractures in laboratory experiments" by C. J. de Pater, J. Groenenboom, D. B. van Dam and R. Romijn. "Seismic studies of rock fracture at the Underground Research Laboratory, Canada" by R. P. Young and D. S. Collins, "Determining the damping factor of sedimentary rocks required for seismically designed structures" by M. H. Worthington, M. S. King and J. R. Marsden, "High resolution seismic refraction method using surface and borehole data for site characterization of rocks" by K. Hayashi and T. Takahashi, "Characterization of fractured rock in the vicinity of tunnels by the swept impact seismic technique" by C. Cosma and N. Enescu, "Seismic imaging ahead of a tunnel face with three-component geophones" by Y. Ashida, "A study of the application of VSP to exploration ahead of a tunnel" by E. Bruckl, W. Chwatal, J. Dolzlmuller and W. Jobstl, "VSP in crystalline rocks—from downhole velocity profiling to 3-D fracture mapping" by C. Cosma, P. Heikkinen, J. Keskinen and N. Enescu, "Borehole seismic characterization of a heterogeneous rock" by T. Takahashi, T. Imayoshi, H. Ishikawa and T. Takeda, "Seismic characterization of fracturing at the Aspo Hard Rock Laboratory. Sweden, from the kilometer scale to the meter scale" by C. Cosma, O. Olsson, J. Keskinen and P. Heikkinen, "Application of borehole logging, core imaging and tomography to geotechnical exploration" by R. Schepers, G. Rafat, C. Gelbke and B. Lehmann, "Estimation of large-scale mechanical properties of a large landslide on the basis of seismic results by E. Brueckl and M. Parotidis, "Delineation of rockburst fractures with ground penetrating radar in the Witwatersrand Basin, South Africa" by M. Grodner, "Prediction of rockbursts by analysis of induced seismicity data" by V. A. Mansurov, "Characterization of rock ahead and around tunnels and boreholes by use of geophysical and geological methods" by G. Rafat, B. Lehmann, A. Toumani and H. Rueter.

The ISRM Suggested Methods for Land Geophysics in Rock Engineering was published in the International Journal of Rock Mechanics and Mining Sciences, Volume 41, Number 6, pp. 885-914, September 2004. The contents of this Suggested Methods are as follows: 1. Introduction, 2. Seismic Refraction, 3. Shallow Seismic Reflection, 4. Electrical, 5. Electromagnetic, 6. Ground Penetrating Rader, 7. Gravity, 8. Radiometric, Acknowledgement and References.

The ISRM Suggested Methods for Borehole Geophysics in Rock Engineering was published in the International Journal of Rock Mechanics and Mining Sciences, Volume 43 Number 3, pp. 337-368, April 2006. The contents of this Suggested Methods are as follows: 1. Introduction, 2. Velocity Measurement along a Borehole, 3. Electrical & Electromagnetic Logging, 4. Nuclear Logging, 5. Vertical Seismic Profiling, 6. Seismic Tomography, 7. Resistivity Tomography, 8. Seismic ahead of a Tunnel Face, Acknowledgements and References.

The commission took an effort for publishing a special issue on Geophysical Methods as applied to tunneling in the Rock Mechanics and Rock Engineering Journal.

5. LECTURE MEETING AND SPECIALIZED SESSION

The lecture meeting on Rock Engineering was held under the auspices of the commission on 19th March 2003 at Kyodai-Kaikan, Kyoto, Japan. The titles and speakers of the meeting were as follows: "Fracture Heterogeneity and Seismic Wave Propagation" by Professor Laura J. Pyrak-Nolte, Purdue University, USA, and "The Design of Rock Engineering Structures: Current Capabilities and Likely Future Directions" by Professor John A. Hudson, Imperial College London and Rock Engineering Consultants, UK. The abstracts of these lectures can be found at the web page of the commission of which URL address is as follows: http://web.kyoto-inet.or.jp/people/sassa/.

The commission organizes a specialized session on the Application of Geophysics to Rock Engineering as one of the specialized sessions in the 11th Congress of ISRM. In this specialized session, progress report of the commission, five excellent papers and the ISRM Suggested Methods for land and borehole geophysics in rock engineering with some examples of field applications will be presented.

6. LIST OF COMMISSION MEMBERS (2003-2007)

The current commission members are shown below.

Yuzuru Ashida (Japan), Guenter Borm (Germany), Ewald Brueckl (Austria), Xu Chang (China), Calin Cosma (Finland), Peter James Hatherly (Australia), Jung-Ho Kim (Korea), Michael S. King (U.K.), Bodo Lehmann (Germany), Larry R. Myer (USA), C. J. de Pater (Netherlands), Bjorn N.P. Paulsson (U.S.A.), Laura J. Pyrak-Nolte (U.S.A.), Koichi Sassa (Japan), Soichi Tanaka (Japan), R. Paul Young (Canada), Jian ZHAO (Singapore).