Comparison between Russian Code of Practice and International Style Slope Stability Analysis

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Abstract

Knowledge gained from geotechnical and hydrogeological studies undertaken in parallel between an International mining consultancy (SRK Consulting UK Ltd) and a Russian design institute (Saint Petersburg State Mining Institute (SPMI)) has allowed for an insight into the contrasting techniques employed by both Russian and International analysis methodologies. Russian analytical methods, which are primarily based upon prescribed codes of practice that designate the processes for slope stability analysis and design are set out alongside the current International analytical approaches. Some stages of the slope design process are similar and can be compared; however as Russian and International geotechnical methods developed separately, direct comparisons cannot always be achieved.

1 Introduction

The paper compares and contrasts the data gathering, geomechanical testing, determination of geotechnical input parameters for stability modelling, methods of analysis and the acceptability of the outcomes in terms of the relevant mining safety codes. There is an increasing level of exposure for International mining consultancies in Russia and many projects will be financed by International funding companies thus resulting in projects that have to comply with both Russian standards, to achieve Russian permitting, and International standards, to secure funding. The objective of the paper is to provide International and Russian geotechnical design practitioners an insight into the requirements of both systems such that they derive acceptable mine design criteria catered to Russian/International standards. These systems are compared under the following topics:

- Reporting Steps;
- Data gathering: geotechnical logging and drilling;
- Geotechnical testing;
- Data evaluation (for input parameters) and hydrogeology;
- Analytical methods;
- Slope design acceptability criteria; and
- Trends and future developments.

Comparisons are made using tables which set the salient points from the Russian and FSU system alongside the International system for each topic. A short discussion is then given for each section.
Comparison of reporting steps between the systems

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<tr>
<th>Russian and FSU System</th>
<th>International System</th>
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<tr>
<td>Open pit slope parameters are calculated and refined through a number of design stages.</td>
<td>The numerous stages of a slope design for a mining project are:</td>
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<td>• <strong>Pre-design stage</strong>: the prospecting data is used to develop technical-economic considerations (TES) regarding the prospects of the deposit, which justify further resource evaluation. Completion of the evaluation is marked with preparation of a technical-economic justification (TEO), of the deposit which then justifies further exploration, and forms the basis for development of temporary exploration parameters which require appropriate approval from the State Reserve Committee (GKZ);</td>
<td>• <strong>Conceptual or scoping study</strong>: slope designs are preliminary, conducted with little data and primarily based upon the design practitioner’s experience with similar rock mass conditions;</td>
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<td>• <strong>TEO</strong>: the preliminary exploration data is used to identify geotechnical rock domains within pit slopes, which get assigned approximate slope angles using empirical tables;</td>
<td>• <strong>Pre-feasibility study</strong>: slope designs are based upon (sometimes limited) drilling and testing data. The project economics are assessed against the likely slope angles and mine design;</td>
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<td>• <strong>TEO Konditsii</strong>: results of detailed exploration are used to compile the technical-economic justification of permanent parameters for approval by the GKZ. These parameters are used to estimate reserves. The TEO Konditsii helps to decide on the practicability and economic viability of investing into the proposed mine;</td>
<td>• <strong>Feasibility study</strong>: update and refinement of the pre-feasibility study where costs are defined and slope angles are honed to within a 2°-3° accuracy; and</td>
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<td>• <strong>TEO Proekt</strong>: at the design stage slope angles are calculated based on detailed exploration data and incorporate information regarding the influence of structures on pit slope stability. Pit slope parameters are calculated on the basis of specialized geotechnical studies; the practicability of which is justified by the design institutions; and</td>
<td>• <strong>Detailed design, excavation and monitoring</strong>: once the project economics are finalised and financing has been achieved the detailed design and construction of the mine commences. Operating the mine allows for continued refinement of the pit slope parameters; exposure of the rock face gives insight into the rock mass conditions at depth. Slope performance during the operating stage gives an insight into the design for the remedial work required for when the mine closes.</td>
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<td>• <strong>Continuous assessment during mining</strong>: thorough evaluation of the rock mass properties, along with pit slope deformation surveys are carried out throughout the life of mine to revise pit slope parameters as necessary.</td>
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**Discussion**: The two systems have similar staged design approaches, however direct comparison of Russian and International reporting steps as equivalents cannot be drawn. The Russian approach is heavily regulated and must go through each stage whilst receiving approval from the regulator bodies, where the International approach is more fluid; putting an emphasis on geotechnical risk and sensitivity assessment, and the mitigation of these risks, throughout the project stages.
3 Comparison of data gathering: geotechnical drilling and logging

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<tr>
<td>Major structures in the rock mass are identified at the exploration stage and, if required by the design practitioner, can be further studied through additional geotechnical drilling. Core logging includes measurements of core pieces and finding the average length of a core piece, which is then used to forecast the average size of structural blocks. Strength properties of a fractured rock mass are defined by Fisenko’s relation (1965) between fracturing and rock genesis, composition and tectonic setting, which allows for the determination of the rock mass cohesion (depending on its fracture frequency). The input data includes intact sample strength, size and share of structural blocks and extent of the deformable rock mass. If required, exploration and geotechnical drillholes are used to supplement hydrogeological studies by completing pumping tests, among others. Pit slope angles are calculated for geologically uniform zones. Each zone is represented as a cross-section through the pit slope with detailed geological and other data that affects pit slope parameters.</td>
<td>To build an understanding of the rock mass orientated triple tube core drilling is undertaken. This data is used to create and continually update geotechnical, geological and structural models. Structural domains are decided upon after stereographic analysis. Logging of the core is performed using rock mass characterisation methods, such as: • RQD – Rock Quality Designation (Deere et al. 1967); • RMR – Rock Mass Rating (Bieniawski 1989); • MRMR – Mining Rock Mass Rating (Laubscher &amp; Jakubek 2001); • Q - Tunnelling Quality Index (Barton 1974); and • GSI (Hoek et al. 1995). Rock mass characterisation systems produce a single value to represent the strength properties of a rock mass. Geotechnical domains are delineated by assessing the distribution of the parameters in combination with structural data. When appropriate, geotechnical and exploration boreholes may be used to collect hydrogeological data through pumping tests and piezometer installations. The layout of the geotechnical boreholes has to ensure that their number and location are commensurate with the variability of the conditions and the geometry of the proposed pit. All of the gathered data is routinely recorded into database systems which allow for more efficient data analysis and QA/QC of data.</td>
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Discussion: A similar volume of data is collected to identify the factors that will influence slope stability and mining conditions, however it should be noted, that Russian and International approaches largely evolved independently. International data collection methods are quantitative wherever possible, where Russian logging is more descriptive. Russian drilling equipment and data collection techniques would benefit from modernisation, such as triple tube drilling.

Both approaches are heavily based on studying rock mass strength properties, but both use different ways of data gathering and material testing; subsequent analytical calculations are done differently and direct comparisons are difficult.
4 Comparison of geotechnical testing

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<th>Geotechnical properties are defined using core samples from exploration and geotechnical boreholes. Common parameters used for slope stability calculations obtained from laboratory tests are as follows:</th>
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<td>• UCS and tensile strength;</td>
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<td>• Young’s Modulus and Poisson’s Ratio;</td>
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<td>• Cohesion and angle of internal friction; and</td>
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<td>• moisture content and density.</td>
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<td>Ultimate tensile strength is defined in a number of ways, such as:</td>
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<td>• direct tensile test;</td>
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<td>• Brazilian tensile test;</td>
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<tr>
<td>• point load test using two opposite spherical indenters (GOST 21153.3-85).</td>
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<td>Direct tensile tests are used rarely. The leading methods are the Brazilian and point load tensile tests. The Brazilian tensile test involves compressing the sample between flat plates or cylindrical rods. Young’s Modulus and Poisson’s ratio are determined from samples with height to diameter ratio of 2 (GOST 28985-91). The values are recommended to be measured in the stress range of 5% to 50% of the peak strength on the unloading branch of the deformation curve. Cohesion and internal angle of friction for hard rock are determined using a number of methods (GOST 21153.8-88, GOST 21153.5-88): based on results of triaxial compression and slanted shear tests or a shear test along a plane of weakness. Hard and transitional rock samples are mainly tested using the slanted shear method (25°/35°/45°), developed by VNIMI. Saw cut shear tests are not used. Strength properties of weak surfaces are determined by shearing a sample along a natural fracture. Weak rocks (soils) are tested in triaxial cells and direct shear boxes (GOST 12248-96). Triaxial tests are completed using three options: UU, CU and CD.</td>
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<th>The engineering properties of the proposed pit slopes are assessed at an early stage of a project using empirical methods and simple field tests. These are subsequently quantified using controlled testing in soils and rock mechanics laboratories. To develop an appropriate testing schedule the likely behaviour of the rock mass and the likely failure modes are assessed. Structure will likely play an important role in the stability of strong rock, whereas in weaker rock and soils, the internal strength of the rock mass will be the controlling factor. The most common rock tests undertaken during an International testing program would include:</th>
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<td>Rock Tensile Strength CD, UU, or CU Triaxial Test Uniaxial Compressive Strength CD Shear Test Triaxial Compressive Strength Residual Shear Test Young’s Modulus and Poisson’s Ratio Index Testing (LL, PL, PI) Direct Shear Test Particle size distribution Point Load Strength Index</td>
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Laboratories undertaking the rock and soil tests generally follow procedures developed by ASTM International (ASTM 2010), the International Society for Rock Mechanics (ISRM) (Ulusay & Hudson 2007) and British Standards (BS 1999).

Pore pressures can have a significant influence on the behaviour of the material, and as such effective stress testing and analysis are required to develop material inputs for stability analyses.

Discussion: Both geomechanical testing procedures are regulated by respective standards. Compressive and tensile strength testing and the determination of elastic moduli procedures are similar and results can be interchanged. Care should be taken when comparing effective stress tests. Despite detailed GOST procedures for these tests, problems can arise during saturation of the sample and speed of shearing. As a result, results from GOST effective stress tests should be used with caution in any International analysis.
Discussion: Fundamentals of the data evaluation in Russian and International approaches have a lot in common; the use of cohesion and friction angle to describe rock mass strength. However International approaches make use of differing strength criterion to accommodate differing rock mass types. Both approaches carefully assess the interaction and interconnection of geotechnical and hydrogeological conditions at the deposit. An International approach to determining the rock mass strength would be to use data from UCS testing in a scaling criterion such as Hoek-Brown and as such, an internal cohesion and friction angle would not be a direct input into the stability analysis of a strong rock mass. Conversely, Russian analysis uses the Mohr-Coulomb criterion for input into the geotechnical model and as a result, internal friction angles and cohesion for rock and transitional material (weak rock) are determined from the slanted shear test. The results from this test are not recognised in an International approach. International methods use statistical analysis to describe the distribution of the rock mass parameters; Russian practices involve averaging the data, sometimes across multiple material types before conducting analysis.
6 Comparison of analytical methods

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<th>International System</th>
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| Pit slope stability analysis methods primarily depend on the accepted calculation model, the distribution of stresses in the rock slope and the anticipated mode of failure. The current method used in Russia for evaluation of pit slope stability in a homogenous rock mass was developed by the SPMI Scientific Centre (VNIMI) on the basis of the force polygon technique (Kartashov et al. 1979). Principal provisions of this technique are:  
  • the calculation is based on limit equilibrium conditions;  
  • slip surface in the limit equilibrium slope rock mass is constructed based on Fisenko’s (1965) method; and  
  • wedge of failure, delineated by the failure surface, is divided into blocks in limit equilibrium state; block boundaries are drawn along second order failure element surfaces (as in the ultimate stress method).  
| The critical analytical method is dictated by the expected failure mode; using the geotechnical design practitioner’s experience helps define initial analysis focus. The critical failure mode can be controlled structurally, by the rock mass, or both; usually a combination of both methods is used to design robust slopes. Kinematic analysis is used to assess structurally controlled instability. The geometry of the benches and the inter-ramps (and occasionally the overall slope) are assessed against the discontinuities within the rock.  
| Slope stability calculations for saturated homogenous and quasi-homogenous medium can be completed in MOFIS software, developed by SPMI Open Pit Slope Stability Laboratory. In cases where a rock slope is complicated with a major fault, seismicity, weak bedding surfaces or other adversely-oriented planes, which can coincide with the highest stresses slip surface, slope stability calculations are completed using the force polygon method. Apart from the overall slope stability analysis, individual sections of the slope (thick beds, group of benches, etc.) are also assessed for their geomechanical peculiarities, assuring the required Factor of Safety (FoS) for that part of the slope. Presently, numerical modelling does not get wide practical appreciation in Russian pit slope stability analysis due to insufficiently developed criteria for assessment of slope stability analysis results and has yet attained approval status. |  
| Discussion: Russian and International slope stability evaluation methods evolved independently. Both approaches tend to use software; however specialised commercial geotechnical software is more commonly used by International geotechnical practitioners. Software packages must be approved by the Russian regulatory bodies before they can be accepted; it is common that design institutes produce their own software programs as these are more easily accepted by the regulatory bodies. Russian practitioners are increasingly using numerical modelling software in their evaluations, although slope design criteria approval by the regulatory bodies requires that only accepted software results are reported. It is considered that numerical modelling requires further testing in practical conditions, along with continued development, before becoming accepted by regulatory bodies and subsequently becoming routinely used by Russian geotechnical practitioners. |
Comparison of slope design acceptability criteria

The pit slope Factor of Safety (FoS) is considered a design reliability criterion. The acceptable pit slope FoS is set depending on:

- reliability of rock strength test results;
- reliability of input geological data;
- method of hydrogeological coupling; and
- accuracy of slope stability calculation method.

The factor of safety depends on the deposit evaluation stage and the level of reliability of obtained input data used in calculations. The FoS amounts to:

- FoS 1.5 is used at a stage of the open pit design based on drilling data and analysis method (and/or if the slope is in tectonically disturbed hard or semi-hard rock masses);
- FoS 1.3: the deposit mining stage based on rock slope face observations and deformation analysis (and/or if the slope is composed of weak sandy and clay material); and
- FoS 1.2: at the end of the mine life and for ultimate pit slopes based on long-term survey monitoring data.

Stability of open pit slopes at the above prescribed FoS does not completely rule out potential deformation of the rock slope, but the likelihood of development of dangerous failure displacement is eliminated. The forecasted magnitude of pit slope deformation at various factors of safety, accepted based on Russian Regulations, is estimated as follows:

- FoS ≥ 1.3: the rock slope dominantly experiences elastic deformation, relative horizontal deformation of surface at the open pit surface outline does not exceed 1x10^{-3}m;
- FoS 1.3 – 1.2: relative horizontal deformation reaches the value of 1– 5x10^{-3} m; the ground surface becomes fractured, overall long-term displacement for slope higher than 100 m amounts to 200-300 mm; and
- FoS 1.2 – 1.1: horizontal deformation can reach 30x10^{-3} m; toppling failure is possible, overall displacement becomes critical.

Slope design acceptance criteria are evolving based on monitoring technology, and regulation and mine owner safety philosophy. Internationally, Factor of Safety (FoS) and Probability of Failure (PoF) continue to be the routine acceptance criteria for pit slope design. Numerical analysis can be used to provide a FoS by using the strength reduction factor technique. Variations to the resisting forces (shear strength, surface roughness, etc.) and driving forces (pore pressures, seismic coefficients, etc.) require that a FoS of greater than 1.0 achieved through design (usually 1.2 – 1.5).

The variability in the resisting and driving forces is used to calculate the Probability of Failure. Each variable is randomly selected using its statistical distribution, and a FoS is calculated for thousands of iterations; the PoF is the ratio of the number of FoS results below 1.0, over the number of calculations run. The advantage of a PoF calculation is that the variation of the input parameters is accounted for. Acceptable FoS and PoF values are shown below (after Priest & Brown 1983, cited Read & Stacey 2009).

<table>
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<tr>
<th>Consequence of Failure</th>
<th>Description</th>
<th>Mean FoS</th>
<th>Min PoF</th>
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<tr>
<td>Not serious</td>
<td>Failure of bench or temporary slope</td>
<td>1.3</td>
<td>10%</td>
</tr>
<tr>
<td>Moderately serious</td>
<td>Any permanent slope</td>
<td>1.6</td>
<td>1.0%</td>
</tr>
<tr>
<td>Very serious</td>
<td>Greater than 50m high slope or slopes affecting major mine structures (e.g. haul road)</td>
<td>2.0</td>
<td>0.3%</td>
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</table>

It is accepted that some pit slopes are designed with an anticipated slope deformation. In such instances risk/consequence analysis is carried out with the objective of ensuring the risk of injury to personnel, equipment loss and force majeure will be within internationally acceptable levels.

Discussion: The closest parameter in comparing Russian and International approaches is acceptability criteria for the open pit design. The general evaluation concept is very similar; differences are minor and are mainly associated with ranges of acceptable factor of safety for different mining conditions. The approaches differ in the use of PoF; International practitioners, using the power of computer packages, can calculate PoF values from model simulations. Even though the input data is used as average values, Russian methods incorporate the variability of input data into the decision of the appropriate FoS value to be used as the acceptance criteria.
8 Trends and future developments

**Russian and FSU System**

In order to improve reliability of slope stability analysis and determine the optimal open pit slope parameters, scientific research and practical developments should concentrate on the following aspects.

- Improvement of the quality of core recovered from geotechnical boreholes and collected for laboratory tests. Assessment of geomechanical properties of rocks requires uniform introduction of the advanced triple tube drilling method;
- Enhancement of methods of photogrammetry and laser scanning applied in rock face mapping;
- Development of 3D slope stability analysis and its integration in the open pit design practice;
- Further development and perfection of the pit slope optimization method, assuming economic viability and safety;
- Development of a method for calculation of probability of failure of the pit slope;
- Development of methods for forecasting and calculation rock slope deformation, as well as methods for assessment of slope stability based on observed displacements; and
- Development of methods and instruments for automated remote monitoring of rock slope deformation, including techniques for in-situ monitoring of displacement within the rock mass.

**International System**

International slope design techniques and methodologies are continually developed to take advantage of advancements in technology and research. Advancing technology, along with its benefits, requires increased training and time in which the geotechnical design practitioner must invest to obtain the benefits.

There is a trend for automated and digital methods to be used for data collection. Digital photographs of core can be automatically scaled and ordered for ease of logging using programs such as ScanLIM (EPC 2010) and CoreProfiler (CSIRO 2007). Acoustic televiewer systems are able to scan the sides of a drilled borehole from which structural data can be collected. These systems are able to capture some data (aperture, spacing, basic infill), however roughness and joint strength will continue to be logged by traditional methods. Rock face mapping is now being undertaken using remote data capture techniques; photogrammetry and laser scanning.

Studies are more focused on economic impacts of slope failures using cost/benefit analysis. By introducing risk as a factor whilst optimising the slope angle, safety can be quantified against economic impact. This actively looks at acceptable levels of slope failure as long as they can be managed safely whilst ensuring that the potential slope failure mode is quantified and understood.

Three dimensional analysis is becoming prevalent for modelling rock slopes as it can represent geotechnical zones that vary with depth, along strike of the pit wall and anisotropic situations. Advancement in computing power has allowed for the coupling of the geomechanical and the hydrogeological model, such as FLAC 7.0 (Itasca, 2011) and COMSOL Multiphysics 4.2 (COMSOL AB, released mid 2011).

**Discussion:** Both approaches indicate the need for further improvement of existing methods of rock mass assessment, analytical methods and calculations. Expected Russian advancements in slope stability design methods and techniques, such as remote data capture, automated slope monitoring and incorporation of PoF into analyses are already being routinely used in International projects. Specialised software packages indicate that there is convergence of approaches; integration of these into routine geotechnical practices will continue internationally. Advancement of Russian slope design methodologies and the acceptance of these new methods by the regulatory bodies can be anticipated in the short to medium term.
9 Conclusions

International geotechnical studies are self-regulating; the Russian approach is structured, controlled and regulated by state authorities. The International approach allows for continuous and timely improvement of existing methods based on practicability and necessity of such changes. Russian and International approaches are quite comparable on many aspects, but it should be noted that many of criteria described are not compulsory for Russian regulatory and supervisory authorities; consequently, these are not routinely used by Russian geotechnical practitioners, not least for regulatory approval.

The reporting steps go through similar stages using increased confidence in pit slope parameters to refine the design. Russian and International testing methods differ so that some results are not useable in the other’s analysis stage. However, some rock mass parameters are universal and are routinely measured by both methods and are interchangeable. Differences in the two techniques are shown during the data evaluation stage; where International approaches use varying strength criteria to reduce testing data (depending on rock mass type), Russian approaches use a structural weakening factor based upon the block size of the rock mass (which in turn is catered to the specific rock mass). It is the analytical methods where the largest difference is present. International approaches routinely use LEA and numerical modelling for rock mass slope stability analysis, where Russian analysis is primarily conducted using LEA. Both Russian and International designs are based upon the FoS as the acceptance criteria; there are differences in the choices of the FoS value used for a particular slope, however the values chosen are very similar. The comparatively unregulated nature of the International approach allows for the introduction and rapid acceptance of new technologies and methodologies. Russian regulatory bodies prefer to carefully evaluate before accepting new techniques, slowing their use by Russian practitioners for official geotechnical studies. It must be noted that Russian use of numerical geomechanical modelling, and other geotechnical software is however significantly increasing.

There is a need for both International and Russian geotechnical design practitioners to have a good and robust understanding of both geotechnical analysis systems. This allows for continued inter-cooperation, and creation of mine design criteria that is tailored to the specific mining region, regardless of the origin of the geotechnical practitioners working on the project.

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