ROCK BOLTS TESTING UNDER DYNAMIC CONDITIONS AT CANMET-MMSL

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Abstract

Increasingly, dynamic capabilities of ground support are becoming key design parameters when selecting yielding elements for highly stressed, burst-prone or high deformation environments. Moreover, the influence of parameters such as hole diameter, environmental factors, corrosion, resin or cement quality control tolerances must be known, and whether these factors and parameters differ from the static values.

Determining the dynamic ground support demand is highly complex, considering that it varies with the proximity of blasting and seismicity, and excavation geometry and geology – among other factors. Typically, ground support is designed for the worst-case scenario, which is either based on back-analyses of previous case studies, in situ simulated dynamic events or laboratory dynamic testing.

CANMET Mining and Mineral Sciences Laboratories (CANMET-MMSL) chose the latter option to fulfil this aspect of their mandate related to the safety of underground workers. The ownership of the impact-testing apparatus developed by Noranda in the late 1990s was acquired by CANMET-MMSL in 2003, and moved to Ottawa, Ontario. Since its move, the apparatus was greatly modified, with the latest changes involving the instrumentation for measuring loads and displacements.

The paper presents the actual status of the CANMET-MMSL impact-testing apparatus, and summarizes some results of the testing carried out until now. The energy balance of the system, needed to validate measurements done and test results achieved, will be presented as well. A high-strength concrete holding tube was developed to simulate the rock mass while testing friction bolts, where steel tubes were clearly not appropriate. This latter development and future research avenues will be discussed.

1 Introduction

Most underground excavations require ground support to maintain excavation stability and to ensure a safe environment for the personnel and equipment. An appropriate ground support design matches the characteristics of support elements (e.g. steel tendons, screen, straps, shotcrete, etc.) with the anticipated rock mass behaviour (e.g. the response to variations of

loads and displacements over time). Engineers must consider both static (i.e. supporting the weight of the surrounding rock with stiff ground support systems) and dynamic conditions (i.e. surviving additional forces, which may be imposed instantaneously and without warning, such as a rockburst, using yielding ground support systems). In practice, the dynamic conditions are extremely difficult to predict and to design for.

When properly accounted for, well-designed dynamic/yielding ground support systems can dramatically improve the excavation stability. The importance of the appropriate ground support selection and design is crucial to ensure personnel safety in seismically active areas.

The static behaviour of the most commonly-used support elements have been widely researched and documented, and this information is readily available for the mining industry. This information includes data on maximum, yield and ultimate loads; yield and maximum displacements; as well as, the influences of the quality control on these parameters.

Increasingly, the dynamic capabilities are becoming key design parameters for the selection of yielding ground support elements in highly stressed, burst-prone or high deformation environments. Ideally, the engineer needs to know the influence of parameters such as hole diameter, environmental factors (heat and humidity), corrosion, resin or cement quality control tolerances for dynamic support application, and to determine whether these factors and parameters differ from the static ones. The situation is further complicated as new dynamic/yielding support elements (i.e. modified cone bolts, yielding cables, etc.) arrive on the market, and as these products are refined to meet the mining industry's needs (i.e. to meet specific equipment requirements, greater load and displacement capacities, specialized steel characteristics, etc.).

2 Determination of dynamic parameters

To determine the demand placed on the ground support by dynamic loading, it is assumed that a certain volume of rock will be subject to vibrations for which the intensity can be characterized by an acceleration or a velocity. To effectively maintain a safe working environment, the ground support must be able to withstand the additional loads and displacements in order to dissipate the energy (demand) released by the dynamic event. Determining the dynamic support demand is highly complex, considering that it will vary with the proximity to blasting and seismicity, and excavation geometry and geology – among other factors. Typically, for dynamic conditions, the ground support is designed for the worst-case scenario based on back-analyses of previous case histories, on in situ simulated dynamic events (i.e. instrumented blasts) [Tannant and McDowell (1992); Tannant et al. (1992a; 1992b); McDowell and Tannant (1995); Hagan et al. (2001); Moreau et al. (2003); Archibald et al. (2003); Heal (2005); Andrieux et al. (2005)], or on laboratory dynamic testing.

This latter option was chosen by the CANMET Mining and Mineral Sciences Laboratories (CANMET-MMSL) to fulfil their mandate on the safety of underground workers and to develop appropriate knowledge given the increase in demand for this research niche. With the closure of the Noranda Technology Centre in 2003, the ownership of the impact-testing

rig previously developed by Noranda [Gaudreau et al. (2004); Falmagne and Simser (2004)] was acquired and the rig moved to the Bells Corners Complex in Ottawa, Ontario. It was understood in CANMET-MMSL that, while not entirely representative of in situ conditions, laboratory testing does allow many scenarios which affect the safety and performance of support tendons to be investigated and compared in a controlled, repeatable and cost-effective manner.

A number of other similar types of apparatus were developed in the last years and some are still being operated and upgraded [Kaiser et al. (1996); Ortlepp and Stacey (1997, 1998); Ortlepp (2001); Güler et al. (2002); Ortlepp and Swart (2002), Player et al. (2004); Thompson et al. (2004); Ansell (2005, 2006)].

3 The CANMET-MMSL dynamic testing rig

In the laboratory, dynamic loading of ground support tendons could be simulated by dropping a mass over a selected distance, onto a support tendon installed in a simulated borehole. The tendon's behaviour under dynamic loading is then analyzed in terms of loads, displacements and energy dissipated. This allows for comparative analysis of different tendon supports, as well as, detailed analysis of the factors affecting the overall quality and performance of the ground support (e.g. hole diameter, environmental factors, installation method, etc.). Individual mine sites must consider these factors when selecting the most-appropriate ground support to ensure the safety of the workforce.

Figure 1. CANMET-MMSL test rig.

Since its move to CANMET-MMSL, the dynamic testing rig was greatly modified. The height of drop of the mass can reach up to 2.1 m. The drop test rig has a present capacity of 3 Tons from a height of 2 m. Thus, the maximum energy available and the maximum impact velocity that each drop can reach are 62 kJoules and 6.5 m/s, respectively. Thus, with these latest modifications, CANMET-MMSL possess a world-class dynamic testing facility (Figure 1) and are continually investing in, developing and expanding the capabilities of the facility.

The latest changes were related to the instrumentation used to measure the loads and the displacements. These parameters are usually measured at the plate and at the end of the simulated borehole. The displacements are measured using Dalsa SP-14-02K40 linescan cameras. The cameras are sampled at 10,000 lines per second to match the sampling of the analog signals. The lines are amalgamated to form an image of distance vs. time. The location of black and white targets (Figure 2), attached to the plate nut or to the bolt end, is detected

within the image. The loads are measured using arrays of four PCB 205C/FCS-5 ICP piezoelectric force sensors, sandwiched between two platen rings (Figure 2).

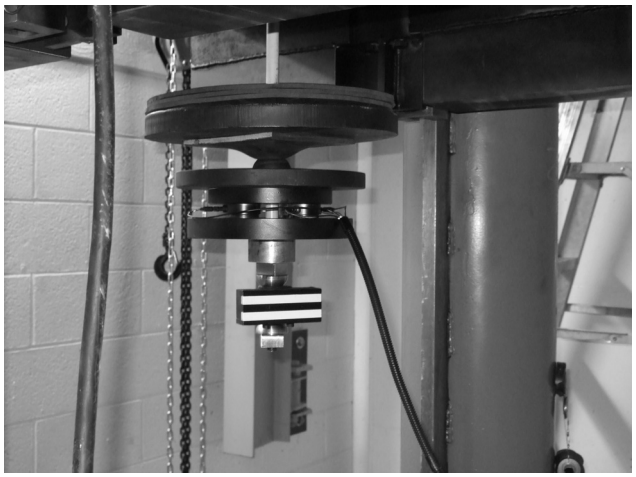

Figure 2. View of the displacement target and the load cells at the plate.

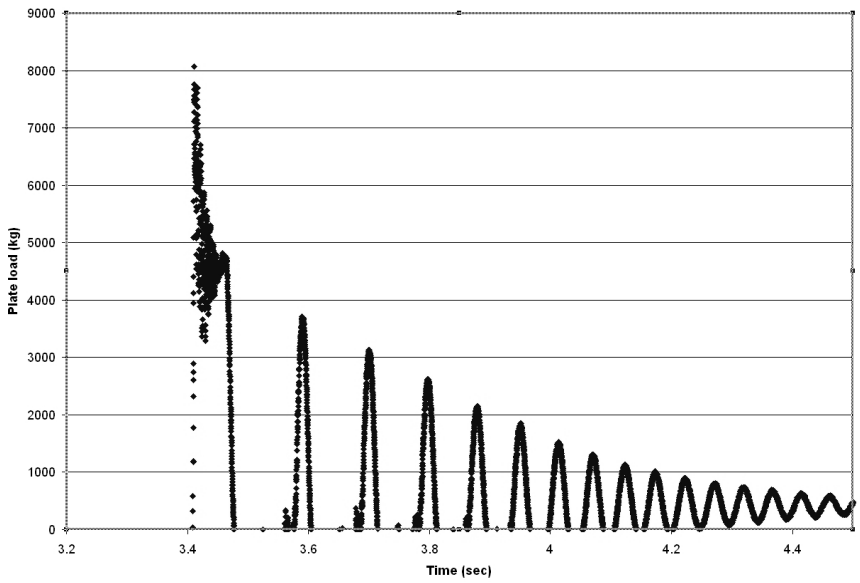

Figure 3. Typical load – time result (6 seconds of data recorded). Impact occurred just after 3.4 seconds, followed by the rebounds of the weights on the impact plate).

Manual measurements of the displacements are recorded before and after the test to verify the electronic data. All instruments are connected to a LabView® (National Instruments) data acquisition system. Currently, no hardware filtering is used for the tests. A sample rate of 10,000 samples/second is used for all tests and the data are not decimated. The impact

duration is typically 60 ms, but data are recorded for about 1.5 s before and up to 5 s after the impact to ensure that all instruments have stabilized (Figure 3).

4 Energy balance

Using the CANMET-MMSL dynamic testing system, Saint-Pierre et al. (2007) analyzed the energy at different stages during a test to verify if the principle of energy conservation is respected according to the experimental measurements. Their analyses were conducted on resin bolts.

Four states of energy were analysed during this study:

- The first state was the potential energy of the mass, where zero level was the position of the plate after the drop test;
- The second state was the maximum kinetic energy, when the mass hits the plate. This state also has a small potential energy. To calculate the kinetic energy, the velocity of the mass is obtained by differentiating the digitally filtered displacement measurements.
- Then, the energy transferred from the drop weight to the reinforcement system is calculated by integrating the load over the plate displacement. This quantity was designated as the plate work.
- The latter has to be compared with the energy absorbed by the bolt. Also, the energy dissipated by the bolt sliding in the resin is calculated by integrating the load cell values over the cone displacement.

For most tests, the potential and kinetic energies were extremely close, meaning that the energy dissipated by friction of the mass on the guiding rails was negligible. Comparing the kinetic energy to the plate work shows that, generally, not all the energy is transferred to the support element. The energy lost produces noise and also permanent deformation of the domed plate. Otherwise, the plate work and the energy absorbed by the bolt are close with an average difference of only 730 J. This energy balance proves that the experimental measurements are accurate [(Saint-Pierre et al. (2007)].

5 Latest testing results

On behalf of the Deep Mining Research Consortium, CANMET-MMSL conducted a series of tests on ground support fixtures as part of a set of activities that are intended to help define priorities and approaches for R&D in mining at depth.

The first objective of this project was to carry out a number of static and dynamic tests on Modified Cone Bolts (MCB), to eliminate gaps in our current knowledge and answer the following questions [Plouffe et al. (2007a)]:

- Is grease (debonding agent) necessary to ensure MCB performance?
- Does the resin "set" time vary with temperature?
- How do MCB bolts perform at higher temperatures (e.g. 40°C)?
- How do the performance characteristics of MCB33 (average borehole diameter: 34.7 mm) and MCB38 (average borehole diameter: 37.8 mm) bolts compare?

5.1 Static Pull test results

Regarding the static tests, for the range of displacements considered (150 mm), a greater portion of the plate displacement is due to the cone displacement in the greased tests. In the non-greased tests, under static loading, the steel elongation is responsible for a greater portion of the plate displacement. No obvious difference in cone and plate load-displacement behaviour was noted between results from greased and non-greased tests, different curing times (1, 3 and 7 days) or between MCB33 and MCB38. It should be remembered that grease being largely rubbed off during installation, could explain this. No difference was observed between tests at 40°C and 7-day curing and other tests at ambient temperature. However, for shorter curing time, loads were significantly lower.

5.2 Impact test results

No difference was obvious between greased and non-greased samples of MCB38 and MCB33, under impact testing. As far as temperature is concerned, there is no difference in plate displacement and load between samples at ambient temperature and at 40°C. However, at 40°C, the cone stops moving after a few drops thus increasing steel elongation or fatigue. A different trend in plate displacement is observed for MCB38 and MCB33 (Figure 4). This trend is a function of the transverse stiffness and the resin (a MCB volumetric relationship).

The current MCB38 testing configuration is 53% stiffer than a very stiff rock mass; while the transverse stiffness for the MCB33 samples is about 20% higher than that of the MCB38. The effect of the stiffness of the surrounding medium on the results has not yet been investigated by CANMET-MMSL.

It was recommended to conduct additional dynamic tests at 40°C to confirm trends and verify the resin behaviour at this temperature, as it is a likely temperature encountered at great depth. Additional testing using a larger stroke ram or additional pulling collars should be carried out to determine whether the ultimate static (displacement and energy absorption) capacities of non-greased MCB are limited, due to preferential steel elongation rather than cone plowing displacement. It was also recommended that bolts performance be tested in different rock mass stiffnesses in order to reflect more ‘realistic’ rock mass conditions.

6 Development of a dynamic testing protocol for friction bolts

6.1 Background

The major difference between resin bolts, for example, and friction bolts is that the frictional interface between the bolt and the rock mass must be simulated. Installing a friction bolt in a

steel tube is clearly not an acceptable solution as the coefficient of friction between two metal objects will differ greatly from that between rock and metal. In agreement with our partners of the Deep Mining Research Consortium, a Swellex friction bolt was chosen for this attempt to define an acceptable dynamic testing protocol [Plouffe et al. (2007b)].

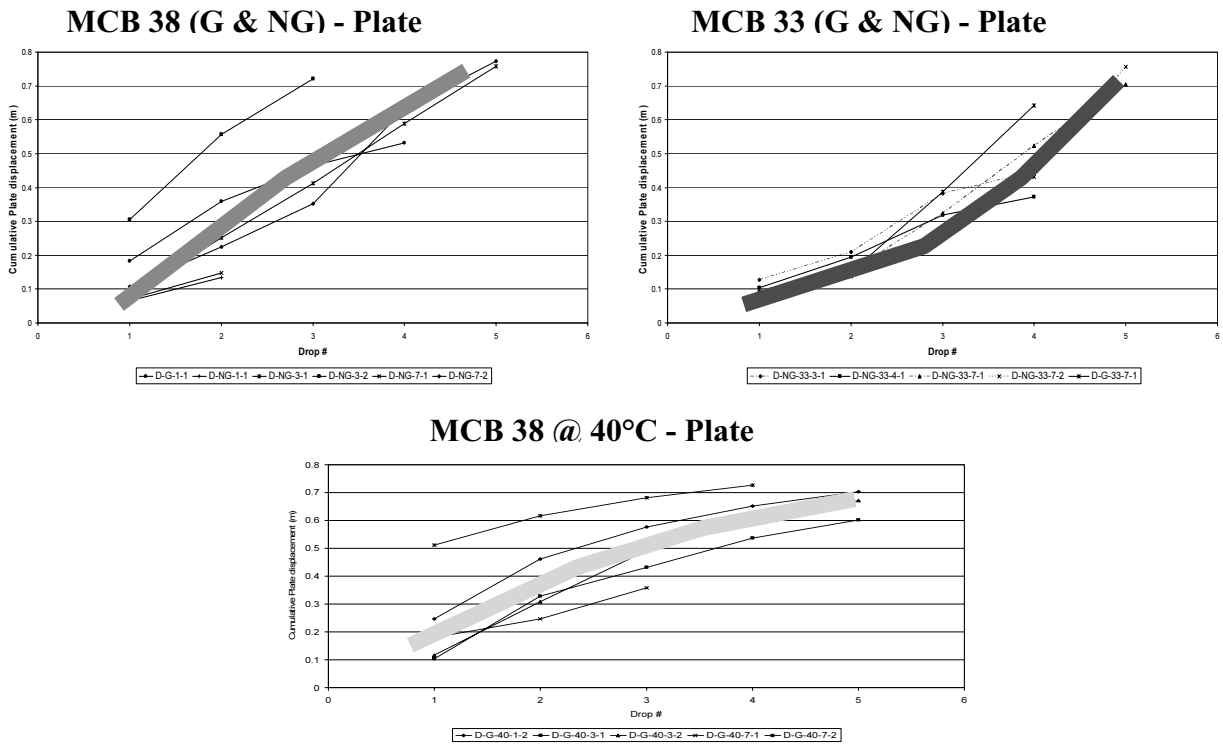

Figure 4. Cumulative plate displacement versus drop for MCB33 and MCB38.

Ortlepp and Stacey (1998) conducted impact testing on Swellex bolts with weights dropping on the head bushings. Failure was then encountered, as expected, on the welded section of the bushing. However, this type of failure seems inconsistent with failure underground. The Swellex bolts themselves usually fail at some distance from the bushing in rock bursting conditions.

6.2 Concrete preparation

After consulting previous work [Kaiser et al. (1996); Ortlepp and Stacey (1998); Charette (2004)] and preliminary discussions with suppliers and industry representatives, two options were identified to simulate the rockmass-friction bolt interface: high-strength concrete or rock tubing. Due to technical and financial issues associated with the preparation of long rock tubing, it was decided to develop a high-strength concrete. After several trials with lower strength concrete mixes, a reactive powder concrete was selected.

A reactive powder concrete is unique in that all of its components are smaller than 600 μm in diameter. According to Malier et al. (1995), this type of concrete has three main characteristics:

- Higher homogeneity as larger particles are removed;
- Higher compact property because of an optimal particle distribution;
- Thermal treatment to refine the microstructure.

Table 1 presents a typical mix for a reactive powder concrete. Within the scope of this project, up to 25 different recipes were prepared and cast. A typical cylindrical sample was 190 mm in height and 100 mm in diameter. After casting, the samples were cured in a water bath, at temperatures varying between 70 and 90°C in order to allow for better reaction of the silica fume, for at least three days, after which they were either tested or stored in a curing room until testing.

Table 1- Typical mix for a reactive powder concrete [after Delagrave et al. (1998)]

Component	**Quantity (kg/m^3)**
Concrete	705
Silica fume	230
Silica flour	210
Silica sand	1010
Superplastifier	17
Steel fibers	140
Water	185

Table 2 - Failure loads as a function of curing time for various concrete samples

Sample	**Curing time (day)**	**Confining pressure (MPa)**	**Failure load (MPa)**
12	6	2.4	74.5
41	28	2.4	90
44	30	2.4	87
68	47	2.4	120
76	47	2.4	127
90	3	2.4	155
91	21	2.4	147
94	3	2.4	152
98	3	2.4	129
99	29	2.4	132

The mechanical properties of each mix were determined with triaxial loading with a confining pressure of 2.4 MPa. This confining pressure is representative of the normal force to be

applied in order to have an anchorage capacity of 200 kN/m. This latter value, though higher than the theoretical one (150 kN/m), was chosen during the initial discussions with the supplier. Table 2 presents some results, as a function of curing time. Concrete mix used for samples 90 and 91 was chosen for the development of the testing protocol, due to its strength of approximately 150 MPa, as no major improvement in the concrete strength was achieved after several other trials.

6.3 Results and discussion

6.3.1 Static pull tests

The first step in the development of a protocol for the testing of Swellex bolts was to develop a concrete capable of producing anchorage capacities comparable to in situ pull tests. It was thus important that the concrete had sufficient frictional capacity that anchorage capacity measurements would approach or exceed the theoretical pullout resistance of the Swellex (150 kN/m). A series of tests were performed to assess the performance of the concrete under static loading of Swellex bolts. For each test, a detailed analysis was conducted to identify several parameters.

The anchorage capacity - displacement graph (Figure 5) shows that the test results have some consistency and repeatability. Six of them reached a value close to or above the theoretical value. This first step in developing the protocol was achieved.

The average value for Maximum Anchorage is 186 kN/m. The average steel elongation (stretching) values (plate displacement minus end displacement) at End Anchorage and Max Anchorage are limited (approximately 2 mm). This value must be compared with the average plate displacement (elongation and sliding) values at End Anchorage and Max Anchorage of about 28 – 31 mm. All tests were performed with an embedded length of 35 cm.

Some samples show strain hardening and creeping combined with an increase of the traction capacity. Their anchorage capacity is similar to very hard rock. The other samples show anchorage capacity values similar to much softer rock. The concrete could have been broken when the Swellex was inflated, especially with anchorage capacity values close to 100 kN/m.

For most of the samples, it is likely that anchorage capacity increases until asperities on the concrete-Swellex frictional interface are broken and the Swellex is free to slide. The Maximum Anchorage can be reached at different displacements.

The results obtained show that high-strength concrete can be used to obtain realistic anchorage capacity values for the testing of friction bolts. However, due to the variability of the results, it is recommended that future laboratory pull tests of friction bolts be conducted in series of at least three. Also, for future samples, it would be worthwhile to run a geocamera down the concrete borehole, prior to the installation, to detect perceptible differences in surface roughness.

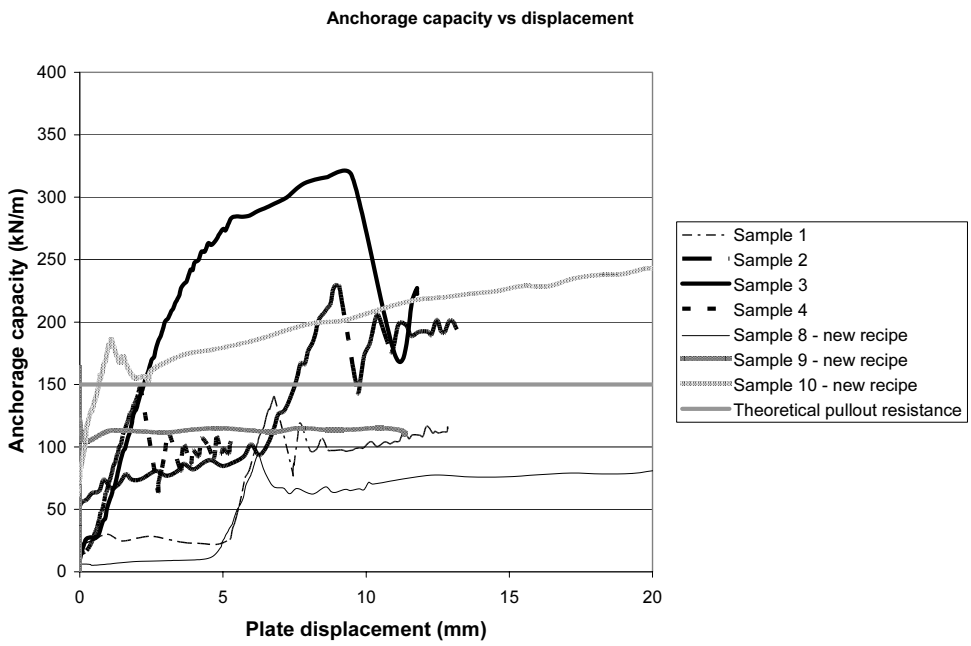

Figure 5. Anchorage capacity – displacement graph for the Swellex bolts.

For future static tests, a longer embedment length should be used. The length used could be sensitive to minor variations in some factors. A longer embedment would also be less susceptible to differences in borehole preparation. Since the target is to quantify anchoring capacity without breaking the bolts, the embedment length should be close to, but less than the theoretical breaking length of a Swellex (about 0.8 m).

6.3.2 Dynamic drop tests

Contrary to resin bolt testing where impacts occur on the bolt plate, it was decided to have the impacts occur at approximately one third of the length of the Swellex bolt from the bushing (Figure 6) in order to simulate the behaviour of the Swellex bolt regularly encountered underground by the supplier. It was reported that Swellex bolts failed at a similar depth as slabs of rock created and/or ejected, around the openings during a rockburst. These slabs of rock have a thickness varying between 15 and 30 cm. Thus, for this particular situation, tangent and normal stresses located between 15 or 30 cm should be equal to zero (Charette, 2007). A similar distance was applied to locate the impacts along the bolt.

The frame and plate load curves show some resonance (high amplitude vibrations) as presented in the load – time graphs (Figure 7). This could be explained by vibrations of the long, unsupported upper and lower sections of the samples, after the impacts. As expected, the impact load curves show higher Peak Loads (Figure 7). Even if the amplitude variations are more pronounced for the frame load curves, the Average Loads are of the same order of magnitude as the ones recorded by the impact ring. Almost no load is recorded at the plate. As expected, the Average Loads are higher for drops where stretching occurred, since more energy is being absorbed.

Two samples were tested at lower energy levels (between 2 and 8.5 kJ) than the one used for the MCBs (16 kJ). Both cumulative displacements (at the plate and at the end) were close, meaning that the friction along the Swellex-concrete interface was not high enough to allow elongation or tearing of the bolt.

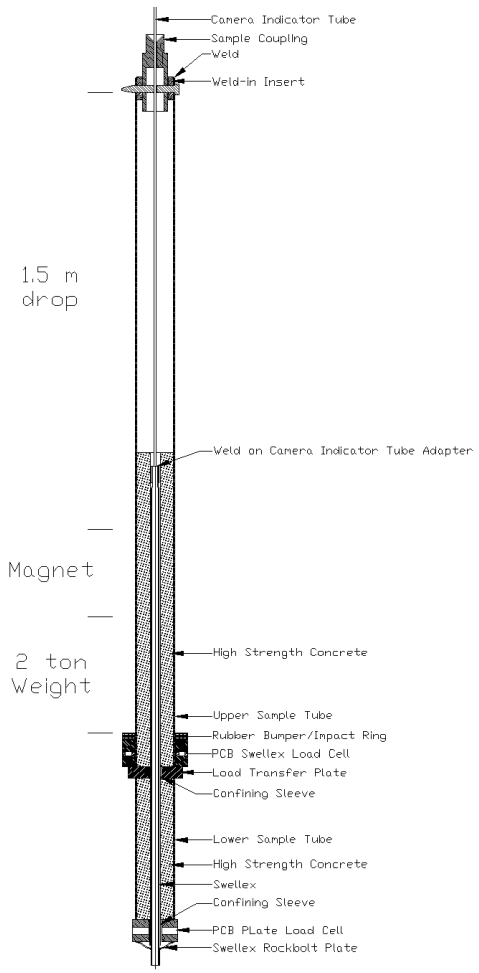

Figure 6. Schematics showing the assembly of the different parts for a dynamic test on a friction bolt

A second series of samples were prepared in which the concrete hole was reamed to clean it up. It was noticed that residues of foam and fiber used to create asperities in the simulated borehole during casting were removed during the reaming process. Reaming the boreholes is also more representative of a drilled hole. This could explain the lower coefficient of friction encountered during the testing of the first two samples. For the second series, elongation values of 134 and 61 mm were determined before the sample reached the floor. With an embedded length of 1 325 mm in the upper part of the sample (using energy levels around 6.5 kJ), these values represent an elongation of about 10% and 5%, respectively.

These elongation values are far from the theoretical 30% value. However, they show that reaming the concrete borehole improved the coefficient of friction along the bolt-concrete interface.

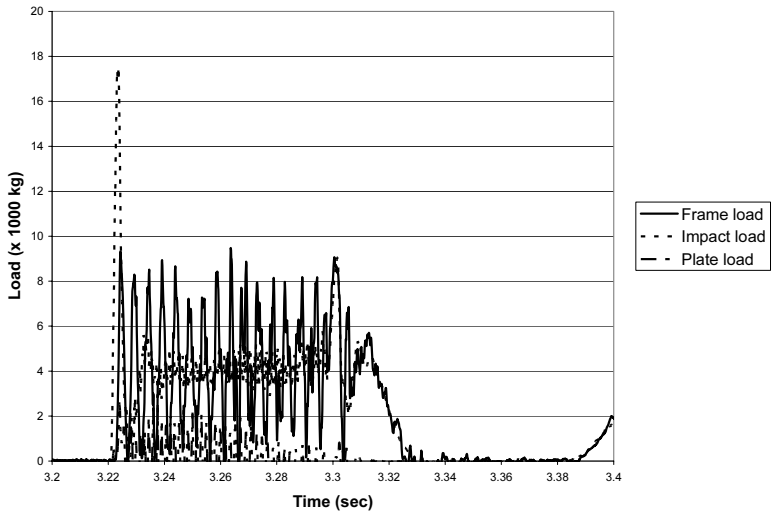

Figure 7. Load – time graph showing the values recorded by the frame, impact and plate load cells ring

It was recommended that further tests be conducted using the same concrete but with additional work on improving borehole roughness and the bolt-concrete interface, as higher energy drops must be performed. Further tests, similar to the ones performed by Ortlepp and Stacey (1998) with weights dropping on the head bushings, but conducted using this new high-strength concrete, are also recommended.

7 Future research

Presently, the CANMET-MMSL dynamic testing rig is being used for individual reinforcement units that have a length up to 2.1 m. In the near future, research will include modifications in order to test all types of tendons and to evaluate the contact zone between tendons and surface support.

A recent report to the Deep Mining Research Consortium [Hadjigeorgiou and Potvin (2005)] mentioned the need to establish standardized procedures on laboratory dynamic testing of tendons and support systems. As a result, CANMET-MMSL testing protocols are currently being assessed by the American Society of Testing Materials Inc. It is hoped that a standard test procedure will be approved during 2008.

In collaboration with their partners (suppliers, mining community, R&D organizations and academia), CANMET-MMSL will continue to participate in the development and the dissemination of knowledge in the field of dynamic behaviour of tendons. This knowledge is extremely valuable in helping mining engineers in designing and optimizing their support

systems, thus improving the stability of the underground openings and the safety of the workers.

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9 References

Andrieux, P., Turichshev, A., O'Connor, P., Brummer, R.K., 2005. Dynamic testing with explosive charges of rockburst-resistant ground support systems at the Fraser Nickel Mine. Itasca Consulting Canada - Report to Falconbridge Limited Mine Technical Services; Final Version, September 2005, Sudbury Canada.

Ansell, A., 2005. Laboratory testing of a new type of energy absorbing rock bolt, Tunnelling and Underground Space Technology 20, pp. 291-300.

Ansell, A., 2006. Dynamic testing of steel for a new type of energy absorbing rock bolt, Journal of Constructional Steel Research 62, pp. 501-512

Archibald, J.F., Baidoe, J.P. and Katsabanis, P.T., 2003. Rockburst damage mitigation benefits deriving from use of spray-on rock linings. Third International Seminar on Surface Support Liners: Thin Spray-on Liners, Shotcrete and Mesh, Quebec City, Canada, August 2003, Section 19.

Charette, F., 2004. Performance of Swellex rock bolts under dynamic loading conditions, Second International Seminar on Deep and High Stress Mining, The South African Institute of Mining and Metallurgy, p. 95-106.

Charette, F., 2007, *pers. comm*.

Delagrave, Y., Dallaire, É., Aïtcin, P.-C. and Lachemi, M., 1998. Une première mondiale : une passerelle de 350 MPa, un béton de poudres réactives, Routes et Transports, vol. 27, n° 4, p. 25-27.

Falmagne, V. and Simser, B.P., 2004. Performance of Rockburst Support Systems in Canadian Mines. Ground Support in Mining and Underground Construction. Villaescusa and Potvin (eds). pp. 313-318.

Gaudreau, D., Aubertin, M. and Simon. R., 2004. Performance of tendon support systems submitted to dynamic loading. Ground Support in Mining and Underground Construction. Villaescusa and Potvin (eds). pp. 299-312.

Güler, G., Kuijpers, J.S., Wojno, L., Milev, A. and Haile, A., 2001. Determine the effect of repeated dynamic loading on the performance of tunnel support systems. SIMRAC, GAP 616.

Hadjigeorgiou, J. and Potvin, Y., 2005. Critical Review of Dynamic Testing of Support Systems. Report to the Deep Mining Research Consortium, 63 p.

Hagan, T.O., Milev, A.M., Spottiswoode, S.M., Hildyard, M.W., Grodner, M., Rorke, A.J., Finnie, G.J., Reddy, N., Haile, A.T., Le Bron, K.B. and Grave, D.M., 2001. Simulated rockburst experiment – an overview. The Journal of The South African Institute of Mining and Metallurgy, August 2001, pp. 217-222.

Heal, D., 2005. Ground support for rockbursting conditions. Australian Centre for Geomechanics Course No.0505; Advanced Geomechanics, Section 8, Perth.

Kaiser, P.K., Tannant, D.D. and McCreath, D.R., 1996, Drift support in burst-prone ground, CIM Bulletin, vol. 89, n° 990, March 1996, p. 131-138.

Malier, Y., Richard, P., Cheyrezy, M., Maret, V., Frouin, L., Dugat, J., Roux, N., Bernier, G., Behloul, M., Barrancon, M., Andrade, C. and Sanjuan, M.-A., 1995. Les Bétons de poudres réactives (BPR) à ultra haute résistance (200 à 800 MPa), Annales de l'Institut Technique du Bâtiment et de Travaux Publics, n° 532, p. 83-143.

McDowell, G.M. and Tannant, D.D., 1995. Monitoring particle velocities in steel-fibre reinforced shotcrete at Stobie Mine. GRC internal report.

Moreau, L., Espley S., Dunbar, W.S., 2003. Recent investigations into thin spray-on liner support systems at Inco. Third International Seminar on Surface Support in Mines, Quebec City, August 2003.

Ortlepp W.D., 2001. Performance testing of dynamic stope support test facility at Savuka. SIMRAC Report GAP 611.

Ortlepp, W.D. and Swart, A.H., 2002. Extended use of the Savuka dynamic test facility to improve material and analytical technology in deep-level stope support. SIMRAC Report GAP 818.

Ortlepp, W.D. and Stacey, T.R., 1997. Testing of tunnel support: dynamic load testing of rock support containment systems. SIMRAC GAP Project 221.

Ortlepp, W.D. and Stacey, T.R., 1998. Testing of tunnel support: dynamic load testing of rockbolt elements to provide data for safer support design. SIMRAC GAP Project 423.

Player, J.R., Villaescusa, E. and Thompson, A.G., 2004. Dynamic testing of rock reinforcement using the momentum transfer concept. Ground Support in Mining and Underground Construction. Villaescusa and Potvin (eds), pp. 327-339.

Plouffe, M., Anderson, T. and Judge, K., 2007a. Dynamic and Static Testing of Tendons: Part A – Testing of Modified Cone Bolts, Natural Resources Canada, CANMET-MMSL report 06-033-A(CR), 37 p plus Appendices.

Plouffe, M., Anderson, T. and Judge, K., 2007b. Dynamic and Static Testing of Tendons: Part B – Development of a Testing Protocol for Friction Bolts, Natural Resources Canada, CANMET-MMSL report 06-033-B(CR), 22 p. plus Appendices.

Saint-Pierre, L., Hassani, F., Radziszewski, P, Ouellet, J. and Plouffe, M., 2007. Testing and analyzing the testing responses of rock support elements. Aachen International Mining Symposia, May 2007, pp. 353-368.

Tannant, D.D. and McDowell, G.M., 1992. Rockbolt response to mining-induced seismicity. Report to the Mining Research Directorate.

Tannant, D.D., McDowell, G.M. and Kaiser, P.K., 1992a. Support monitoring and field trials (task 3). Technical Progress Report to the Mining Research Directorate.

Tannant, D.D., Kaiser, P.K. and McDowell, G., 1992b. Dynamic support monitoring. International Symposium on Rock Support, Sudbury Ontario, pp. 657-664.

Thompson, A.G., Player, J.R. and Villaescusa, E, 2004. Simulation and analysis of dynamically loaded reinforcement systems, Ground Support in Mining and Underground Construction. Villaescusa and Potvin (eds), pp. 341-355