GeoScience Engineering
Volume LIII (2007), No.1, p. 15-24, ISSN 1802-5420

Pavel PROKOP*

THE QUESTION OF RELIABILITY OF CLOSING SEALS IN THE COAL MINES IN THE USA

OTÁZKA UZAVÍRACÍCH HRÁZÍ V DOLECH USA

Abstract

The paper deals with the problem of closing seals in coal mines. After several accidents in Sago, Darby and other mines in the USA the explosion destructed the seals completely. This raised a question of what resistance is necessary for their construction. I would like to express my opinion that the request of federal safety regulation to achieve the resistance of seal of 20 pounds per square inch, which corresponds to the European 0,138 MPa (MegaPascal) is dangerous. If the temperature in the area before explosion is for example 15°C, then after the explosion it can reach up to 2 650°C. After recalculation the absolute temperature of mixture before and after the explosion can be 288 K to 2 923 K. Gases then increase during explosion in volume more than 10 times. According to Mariott law, the original pressure of 0.1 MPa must increase 10 times as much, up to 1 MPa. The seals should be designed, as the prevailing opinions claim, to this pressure value.

Abstrakt

Příspěvek se zabývá problémem uzavíracích hrázi v hlubinných uhelných dolech. Po haváriích na Dole Sago a Darby v USA, byly výbuchem tyto hráze rozmetány. To vyvolalo otázku, jaký odpor je nutný k jejich dimenzování. Předem bych chtěl vyslovit názor, že požadavek bezpečnostních federálních předpisů v USA, aby hráze byly konstruovány na odpor 20 psi (tj. 0,138 MPa) je nebezpečný. Pokud je v uzavřené oblasti teplota například 15 °C, pak po výbuchu může dosáhnout 2 650 °C . Po přepočtu to je z 288 K na 2 923 K. Podle Mariottova zákona tak musí původní tlak 0,1 MPa vzrůst přibližně l0x, tj. na 1 MPa. A na tento tlak by měly být, podle dosavadních převládajících názorů, hráze dimenzovány.

Key words: Mining, closing seal, explosion

1 INTRODUCTION

On 2nd January 2006 there was a methane explosion behind the seals in the enclosed area of Sago mine in Western Virginia. The explosion destroyed the closing seals and 12 miners died in the originated semi-explosive residues. On 20th May 2006

* Prof. Ing. CSc., VSB-Technical University of Ostrava, Faculty of Geology and Mining, Mining Engineering and Safety Institute 17. listopadu 15, Ostrava-Poruba, Czech Republic

another explosion occurred in Darby Mine no. 1 in Harlan County, Kentucky, which disturbed the seals as well. This event ended up with 5 fatalities.

In both cases, the seals were of Omega type made from reinforced concrete blocks by the Burrell Mining Products in New Kensington, Kansas. These seals have been reportedly used in the USA for 15 years, but we have no detailed information about their design.

The Mine Safety and Health Administration (MSHA) allowed installation of these blocks without traditional kirvings. It is a method consisting in break on the roadway perimeter up to the undisturbed rock, which is supposed to ensure a reliable seal-rock contact. The approval was granted when the such-free seals withstood testing explosion waves of 20 psi (i.e. 0,138MPa).

The aforesaid events and other accidents aroused a wave of emotions in the USA. They were reported in closer details by [1, 2, 3]. The mining industry in the USA must definitely be considered very advanced. Therefore, these cases involved our interest and we try to gather knowledge associated with them also for our practice.

A series of experimental research studies is currently conducted in the USA to clarify the case. It also includes practical verifications in a testing mine.

The researchers constructed three separate seals in Lake Lynn experimental Mine in Fayette County to re-enact the explosion in the Sago Mine. One seal was made of a cement block, the second of high-density foam similar to those that were used in Sago Mine and the third experimental seal was of a hybrid structure. These seals were subsequently exposed to an air blast wave impact of 20 psi (i.e 20 pounds per square inch, i.e lb/sq.in, which is approximately 138 kPa), an overpressure that we consider to be a hazardously low limit here. I have to underline that it is a value given the USA Code of Federal Regulation as the limit for defining explosion resistance of the seals.

The seals withstood the overpressure and according to the opinion of one of the parties concerned, they were not disturbed by the explosion at all, whereas in Sago Mine they were destructed by the explosion.

The information [2] state that this finding leads the researchers towards two opinions:

Either the seals in Sago Mine were not made in sufficient quality, or the explosion behind the seals on 2nd January 2006 was stronger than could be expected.

Further is was discovered that during the Sago Mine explosion a container filling device with a weight of 1 200 lb (≅ 544 kg) was thrown in a distance of 150 ft (≅ 45 m). During the experiment on 15th April 2006 similar device, which was equally positioned, was thrown only to a distance of 15 ft (≅ 4,5 m).

When there was another destructive explosion on 20th May 2006, Mr. David Dye, the then MSHA executive administrator expressed his significant concern, when the Omega Block seals tailed to resist the explosion for the second time.

Recent information published by US Mining Rescue Association (USMRA) [3] implies that the use of the Omega Block seals is forbidden until complete investigation of the cases.

In connection with the second case on May 2006 the USMRA disclosed that the resistance of the seal to 20 psi is less then a half compared to the Australian regulations, according to which the seal should be able to resist the pressure of 50 psi. European regulations reportedly require the seals to withstand the pressure of 72 psi. We do not know from where [3| the above quoted was taken, but it is rather simplified and distorting. Most probably USMRA imprecisely used data from German practice.

Opinions on the pressure wave value during explosion

It is definitely interesting that Czech safety regulations are more stringent than the American ones.

It is due to the fact that traditionally they are based on the values recommended at the end of the 19th century with the use of state equation, where according to the Boyle-Mariott law the originated pressure must correspond to the change in volume of gas, which is the energy of explosion in consequence of the combustion residues heating. For the ideal mixture and heating from 288 K to 2 923 K the gases increase in volume almost ten times, which resulted in the opinion that the pressure originated during the explosion of the methane-air mixture can achieve a tenfold of the original pressure in the point of explosion. This does not necessarily have to be so, as claimed by the VSB professors K. Voralek and A. Riman in the fiftieths of last century. They were aware of the fact that in the mine environment there are significantly different conditions in the 1D waveguide dimension, given by the mine works geometry and many local resistances on one side ant waveguide wall roughness on the other.

This question is tackled by [5], which can be considered one of the newer sources. In free areas and in the extreme case they assume turbulences forming a mixture with sufficient energy to shifting from deflagration to detonation. This way of flame expansion is associated with expansion speed exceeding the speed of sound (double to quintuple of the sonic speed) and maximum overpressure around 1.8 MPa. If detonation already occurs, the turbulence is not necessary to maintain the expansion speed. However, it is necessary to mention that the detonation expansion requires the burning part of the cloud to be homogeneously be mixed. However, as such homogeneous areas occur only rarely, the cloud detonations are extremely improbable. Our authors in their conclusions draw, apart from others, on the works of scientists in the USA.

Whether a deflagration or detonation occurs is influenced also by the available initiation energy. Deflagrations of mixtures of common hydrocarbons with air require initiation energy of approximately 10^{-4} J. On the other hand, direct initiation of detonation of these mixtures requires initiation energy of approximately 10^{6} J, which is a value comparable to energy generated by a blast charge of a condensed explosive. Direct initiation of detonation is therefore also very improbable in case of accident, but it is possible, if generated by a preceding smaller explosion.

The air blast wave intensity is in principle expressed by two values, i.e. maximum pressure. which is usually identical with the pressure in front of the air blast wave (p_f, *)* and impulse of the overpressure part of the air blast wave (I+).

For ordinary calculations and evaluation of the air blast wave procedure underground we monitor, as the necessary parameters, mainly overpressure in front of the air blast wave (Δp_f) and speed of the expansion of the front of air blast wave in the compression range. Generally, the speed of progress of an air blast wave is proportional to the air blast wave pressure and the values of these parameters decrease with increasing distance from the source. In real mine environment these values are different and considerably lower, because the mixture in the explosive system is not completely homogeneous and is subject to many inhibiting factors of technical nature. On top of that, the methods of measuring overpressure in experimental tanks, shock tubes, testing roadways and mines are varied, relatively imprecise and imperfect.

Dimensioning of seals in the Czech Republic and in other countries

For our conditions, the valid value of calculation results from the assumption of initiation of pressure wave with a value of 1 MPa, which is used in amended form also by valid mining authority decree no. 4/1994 of coll. This value of calculation defines requirements for design and construction of objects and devices for distribution and isolation of airs and closing of mine works, as amended by the decree of the Czech Mining Authority no. 90/2003 of Coll.. whose § 14 stipulates the following:

Seal object explosion-resistance

1) Explosion resistant object is designed for explosion pressure $P_v = 0{,}5 MPa$. The following safety coefficient values must be chosen:

a) k = 1 for an object of dam door designed for isolation of air currents inside the air area and for closing seal intended for closing of abandoned mine works and gobs without the risk of spontaneous combustion of coal;

b) k = 2 for an object of dam door designed for isolation of the individual air areas and for closing seal intended for closing of abandoned mine works and gobs with the risk of spontaneous combustion of coal and for dam object, which is to be allowed by the local mining authority during the approval of mining activity.

2) The lowest thickness of the seal L in meters is defined by the following formula:

$$L = 0{,}9 \cdot b_{\max} \cdot \left[\frac{P_v \cdot k}{\sigma_d} \right]^{\frac{1}{2}} \qquad (1)$$

where

k and P_v - is defined according to paragraph 1

σ_d - the lowest compressive strength of the used construction material in MPa;

$b_{\max}$ - the largest from the dimensions of gross cross-section of the work (height or width) in meters.

The equation (1) implies that for the given example of closing seals that should have been constructed in the case of the above accidents, according to our regulations, 1 b coefficient should have been chosen, i.e. they should have been designed for the pressure of 1 MPa. In order to have the full picture of the complex issue of pressure value in the moment of explosion and subsequent dynamic action (impact and backlash of the pressure wave), I mention findings from other countries with advanced mining.

The main parameter in Germany is the value of explosion resistance limit, which is 0,5 MPa (this might be the source for the quote in the USMRA information) [3].

Similarly to our conditions the construction of explosion-proof seals is solved in Slovakia and Poland (where the instructions for building seals is considerably simpler). The seals in Ukraine and Russia are built in so called safe distance from the seat of explosion, which is calculated from the estimated value of overpressure in front of the air blast wave in problematically specified limit of detonation wave $\Delta p_f = 2{,}8 MPa$ (according to A. M. Cechovskich), with estmation of exponential drop of overpressure on its further way through mine works. Its definition is commonly accepted in general equation:

$$\Delta p_x = \Delta p_f \cdot e^{-kx} \tag{2}$$

where

Δp_x - is the overpressure in front of the air blast wave in the distance x from the explosion zone boundary;

Δp_f - is the overpressure in front of the formed air blast wave on the explosion zone boundary;

k - is dimension-less coefficient of the air blast wave attenuation depending mainly on the resistance of mine works and many other factors and generally ranges from 0,001 to 0,01;

x - is the distance of the surveyed spot from the explosion zone boundary. Interesting data comes from the Emergency Preparedness and Mines Rescue in Australia. New South Wales, where they claim that the experimental explosions of coal dust brought about a result of maximum pressure of 100 psi ($\cong$ 0,69 MPa), but the majority of experts considers this overpressure in the underground conditions very improbable and the explosion-resistance sealing should probably deal with the limit value of 50 psi ($\cong$ 345 kPa). The ministry for minerals and rescue work in Australian Queensland issued directives defining the seal resistance, which specify the limit value of 5 psi ($\cong$ 35 kPa) for use in mines, where the level of natural occurrence of flammable gases is not able to achieve the lower limit explosiveness under no circumstances, 50 psi ($\cong$ 345 kPa) where people stay underground and where combustible mixture can accumulate in an enclosed area and where there is a risk of spontaneous combustion, or the risk of mixture combustion, and finally 20 psi ($\cong$ 138 kPa) in other cases not specified above.

The technology of building seals known in Europe is not commonly used in the Australian mines, because their length is according to the known data hardly realizable in the mining conditions of the New South Wales. Despite this fact, the thickness of definitive seals is reported with the dimensions from 1 to 4 meters depending on the roadway profile and seal equipment.

The Canadian Handbook of Training in Mine Rescue and Recovery Operations 2001 issued by MSHA, Canada describes the temporary closing seals as well as “barricade seals", but the values of their resistance against action of air blast waves are not reported. According to the figures and building instructions it is possible to assume that their design approximates rather the German seal parameters than the American ones.

Discussion on the reliability of seals

According to the last information [4] the standpoint of the federal institution has already been issued. It stipulates that the new closing seals must withstand a resistance of 50 psi (≅ 345 kPa). The previous federal standard of 20 psi (≅ 138 kPa) is thus questioned. The standpoint of the federal body holds that the Omega block seals used for the test explosion in the Lake Lynn Laboratory experimental mine in Fayette County, which was of the same construction like in the Sago mine, showed only hair-line cracks on the perimeter. Also the data on the explosive strength was specified, achieving the vale of 22.5 psi (≅ 155 kPa).

Mr. James M. Dean, who was in charge of the management of the West Virginia's Office of Miners Health, Safety and Training, according to [4] states that he does not understand, why the research specified the standard of 50 psi (≅ 345 kPa). In his opinion this value should be higher. For the sake of completeness, Mr. James M. Dean is the head teacher of the mining post-graduate study program of West Virginia University in Morgantown.

The discussed issue of the reliability of the closing seats has two aspects: The first one – the safety of crew - which results from the above cases in the American mines, now becomes a serious issue. Another aspect is the economics of the construction of these objects. If there was a possibility to reduce the seal dimensions (mainly its thickness) without reducing the reliability of the seal, it would result in a considerable cost saving. The dimensions of the seal is naturally associated with the blast wave pressure, therefore the specification of this value constitutes a crucial factor. It is interesting that this possibility was a subject of a series of important tasks. When assessing the problems associated with seals, not only their dimensions and used material characteristics are important.

A very important factor is mainly the execution of seal and its connection with the adjacent rock. The integration of the entire seal structure within the undisturbed rock mass by means of executing sufficiently deep cutting, or the anchoring is of significant importance.

The research effort should be focused also in this particular direction and should try to look for solutions for a reliable contact of the seal with the adjacent rock.

Example of a seal construction in the Czech Republic

An example of suitable seal structure, which has recently been used in the Czech Republic, is shown in fig. 1. It is one of the designs compliant with Czech Mining Authority regulation no. 4/1994 Coll.

According to §§ 16, 17 of the regulation it makes use of a mixture of fly ash and water with cement with a weight ratio 4 : 1 to 1 : 1. The depth of cutting in solid rock must be at least 50 cm. The material strength in simple tension after 28 days of solidification is decisive for the calculation of

the seal dimensions. The "L" value (minimum thickness) is defined by the formula (1):

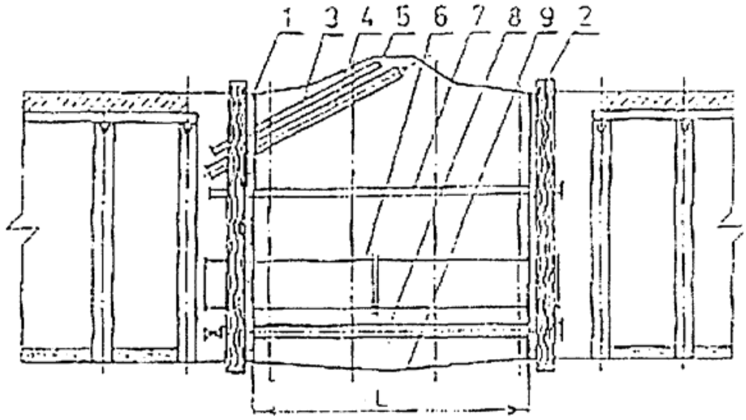

Fig. 1. Example of a cement-ash seal in the roadway supported with steel arches

1	Front brattice stopping	6	Manhole
2	Back brattice stopping	7	Off-take piping
3	Checking piping	8	Drain piping
4	Float piping	9	Hitching on the mine work perimeter
5	Roof break		

2 CONCLUSIONS

If I were to express my opinion and conclusion on the above issues. I would recommend designing the seals according to our existing legislation, which should apply also in countries. which are subject to other regulations. Furthermore, it would be purposeful to acquire means for a research task on the influence of rock-seal contact in terms of reliability of the seal. International cooperation would also be suitable in this matter.

3 SUMMARY

After explosion on Sago mine No. 1 in Upshur County, West Virginia at 2nd January 2006 together 13 miners waned. Twelve miners died from carbon monoxide poisoning and one was left brain damaged after the event. The further explosion on the Darby mine No. 1 in Harlam County, Ky. occurred at 20. May 2006 and required 5 victim on life. The closing seals were destroyed in the both incidents. The seals were constructed from Omega Block, a cement-and-fiber foam block favored by many mine operators because they are lighter than the traditional cement blocks used to seal abandoned areas of mines. The material for producing of these seals was manufactured by Burrell Mining products New Kengsington Westmoreland County. These seals are in USA 15 years in use at least.

The Mine Safety and Health Administration (MSHA) first approved the blocks for use nearly a decade ago, but more recently allowed the installation of the blocks without the traditional "cutting" — the practice of digging a notch into the mine wall and ceiling to secure the seal.

Unhitched Omega Block walls were approved after one such wall withstood the minimum 20 pounds per square inch blast pressure during a test of seals meant to be erected during mine emergencies. Unite State Mining Rescue Association (USMRA) has published after second blast in the colliery this information [3]:

The counteraction of 20 pounds per square inch (psi) is one half of requirement withstood according to Australian safety rules only. In Australian the requirement withstood of seal is 50 psi (345 kPa). The safety regulations in Europe expectant the resistance of seal 72 psi (517 kPa).

I do not know from where [3] the quoted statement assumed but is somewhat simplified and misrepresenting. Probably it uses not correctly the data from Germany rules. According to our information experimental blasts of coal dust in Australian fetch result of maximum pressure 690 kPa (0, 69 MPa) = (100 psi). (1 psi = 0,0069MPa.). These events and further accidents developed in USA undulation of emotion. The more detailed information is in [1, 2, 3]. The mining industry in USA we must definitely account very mature a that is why us these cases interest and we try from themselves obtain piece of knowledge for our practice also. To clear up these case are provided series of experimentally-investigative solution. A test blast in an experimental Lake Lynn mine in Fayette County is one of the important. Test blast raises specter of bigger Sago explosion than thought.

The test result apparently leaves researchers with two possibilities: that the seals were not constructed properly, or that the Jan. 2. 2006 Sago explosions were more powerful than **investigators thought.**

During the experiment researchers had constructed three separate seals — one made of concrete blocks another of high-density foam blocks like those used at the Sago mine and a third of a hybrid construction — then hit them with a force of 20 pounds per square inch (138 kPa), the federal standard (Code of Federal Regulation), that mine seals are supposed to withstand.

According to information briefed on the experiment at the Lake Lynn mine, near Fairchance: "The seals are completely intact." By contrast, the force of the methane explosion at Sago Mine No. 1 in Upshur County, W.Va.. destroyed the walls that were erected to close off an abandoned section of the mine.

In addition, the blast hurled a nearby 1,200-pound (543 kg) filling machine of the storage tank 150 feet (45 m). In experimental blast, the same filling machine of the storage tank was similarly placed but the force moved it only about 15 feet. (4,5 m).

Official released transcripts of testimony by Sago miners indicate that investigators are keenly interested in how crews built the concrete-and-fiberglass foam Omega block seals and whether they were installed according to specifications.

In a statement released later, a spokesman for the federal Mine Safety and Health Administration (MSHA) said the agency will be conducting additional tests for the investigation.

From last information of (USMRA) [3] follows that using of seal type Omega block is until investigation case off limits.

REFERENCES

[1] Lát, J., Faster, P., Informace o haváriích na dole Sago a Darby v USA. (Information on Accidents in Sago and Darby Mines, in USA. Casopis Zachranar c. (Rescuer Magazine no.) 1/2006, 2/2006 and 3/2006. Vydává (Published by) OKD, HBZS, a.s. Ostrava Radvanice.

[2] Internetový server (Internet server) US Mining Rescue Association (USMRA), (20. duben 2006). (20th April 2006) www.usmra.com.

[3] Internetový server (Internet server) USMRA pan (Mr.) Steve Twedt (Pittsburgh Post-Gazette, (May 23, 2006). www.usmra.com.

[4] Internetový server USMRA pana Steve Twedt (Pittsburgh Post-Gazette. (www.usmra.com. August 31. 2006). www.usmra.com.

[5] B. Janovský and M. Krupka Univerzita Pardubice (University of Pardubice), K'T'TV: 2003. Závěrečná zpráva řešení projektu č. 10/2001 ČBU „Zdolávání závažných provozních nehod" (Final Report on Solution of Project no. 10/2001 of the Czech Mining Authority "Serious Operation Accident Management".)

RESUMÉ

Po výbuchu na dole Sago c. 1 v Upshur County v Západní Virginii 2. ledna 2006 zahynulo celkem 13 horníků. Dvanáct horníků zemřelo na otravu oxidem uhelnatým a jeden na mozková poranění bezprostředně po události. K. dalšímu výbuchu v dole Darby c. 1 v Harlam County v Kentucky došlo 20. května 2006 a vyžádal si 5 lidských obětí. Při obou výbuších byly zničeny uzavírací hráze. Hráze byly postaveny z cementových pěnových bloků typu Omega Block, kterým mnoho těžařů dává přednost, protože jsou lehčí, než tradiční cementové bloky používané v důlních stařinách. Materiál pro tyto hráze byl vyroben společností Burrell Mining products z New Kengsington Westmoreland County. Tyto hráze se v USA používají nejméně 15 let. Úřad Mine Safety and Health Administration (MSHA, což je obdoba naší Báňské Správy) poprvé schválil tyto bloky skoro před deseti lety, ale nověji povolil instalaci těchto bloků bez tradičního "záseku" - vytvoření zářezu do stěny důlního díla a jeho stropu za účelem zajištění hráze. Bezzásekové stěny z bloku Omega byly schváleny poté, co taková stěna odolala minimálnímu tlaku 20 liber na čtverečný palec při testování hrázi, které měly být budovány v nouzových situacích v dole. Americká Báňská Správa Unite State Mining Rescue Association (USMRA) zveřejnila po druhém důlním výbuchu následující informaci [3]: Odpor 20 liber na čtvereční palec (psi) je pouze polovina hodnoty požadované australskými předpisy. Požadovaná hodnota odporu v Austrálii je 50 psi (345 kPa). Bezpečnostní předpisy v Evropě předpokládají odpor hráze v hodnotě 72 psi (517 kPa). Nevím, odkud |3| uvedené tvrzení pramení, ale je poněkud zjednodušené a zavádějící. Pravděpodobně nesprávně interpretuje údaje Německých norem. Podle

našich informací poskytly experimentální výbuchy uhelného prachu v Austrálii výsledný maximální tlak 690 kPa (0, 69 MPa) = (100 psi). (1 psi = 0,0069MPa.). Zmíněné události a další havárie vyvolaly v USA vlnu emocí. Blíže o nich informovaly [1.2.3]. Hornictví USA musíme rozhodně považovat za velmi vyspělé, a proto nás tyto případy také zaujaly a snažíme se z nich získat poznatky i pro naši praxi. K osvětlení případu je v USA prováděna řada experimentálně-výzkumných prací. Patří mezi ně i praktické ověření na zkušebním dole Lake Lynn v Fayette County. Zkušební výbuch vzbudil domněnku, že výbuch v dole Sago byl silnější, než se předpokládalo. Výsledek zkoušky vede výzkumníky ke dvěma názorům: Buď nebyly hráze na Dole Sago zhotoveny kvalitně, nebo byla exploze za hrázemi dne 2. ledna 2006 v dole Sago silnější, než výzkumníci předpokládali. Při pokusu výzkumníci zkonstruovali tři samostatné hráze. Jednu z cementového bloku, druhou z bloku z vysokohustotní pěny, obdobnou těm, které byly použity na Dole Sago a třetí pokusná hráz byla hybridní konstrukce. Potom je vystavili nárazu vzdušné rázové vlny (VRV) o přetlaku 20 psi (což je přibližně 138 kPa), což je hodnota dána v USA báňskými předpisy, které důlní hráze mají odolat. Podle informací získaných z pokusu v dole Lake Lynn v blízkosti Fairchance zůstaly tyto hráze zcela netknuty. Naproti tomu síla výbuchu metanu na dole Sago č. 1 v Upshur County v Zapadni Virginii zničila stěny, které byly vystaveny za účelem uzavřít opuštěnou část dolu. Kromě toho při výbuchu na Dole Sago došlo k odvržení plnícího zařízení zásobníku o hmotnosti 1 200 lb (544 kg) vzdálenosti 150 ft (45 m). Při experimentu 15. dubna 2006 bylo obdobně zařízení umístěno stejným způsobem, ale síla výbuchu jím pohnula pouze do vzdálenosti 15 ft. (4,5 m). Oficiálně zveřejněné přepisy svědectví horníků z dolu Sago naznačují, že vyšetřovatelé se živě zajímají o to, jak osádka hráze z betonových a sklolaminatových bloků Omega vystavěla a zda byly instalovány v souladu se specifikacemi. V následné uveřejněném prohlášení mluvčí federální Báňské Správy uvedl, že úřad provede dodatečné zkoušky pro účely vyšetřování. Z posledních informací US Mining Rescue Association (USMRA) [3] vyplývá, že používání hrází typu Omega Block je až do vyšetření případu zakázáno.

Reviewer: Ing. Antonín Taufer – Český báňský úřad

Ing. Petr Schreiber, CSc.